A WATER QUALITY-BASED PREDICTIVE TOOL FOR DISASTER MANAGEMENT OF WATERBORNE INFECTIONS DURING DROUGHT EVENTS

WORK PACKAGE 1: INTEGRATED ECOLOGICAL ASSESSMENT OF VEGETATION, PHYSICO-CHEMICAL PROPERTIES, AND SCHISTOSOMIASIS INTERMEDIATE HOST SNAIL DISTRIBUTION IN FRESHWATER BODIES

Final Report to the
Water Research Commission

by

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- Overview of work packages (WRC report no. 3229/1/25)
- Work package 2: Prevalence, associated risk factors and diagnostic biomarkers of schistosomiasis among school-going children in Nelson Mandela Bay Municipality (WRC report no. 3229/3/25)
- Work package 3: Bacteriological assessment of water sources and retrospective analysis of diarrhoeal prevalence in Nelson Mandela Bay (WRC report no. 3229/4/25)
- Work package 4: Pre- and post-intervention assessment of an educational program on hygiene knowledge and practices among municipal waste and sanitation workers in Nelson Mandela Bay (WRC report no. 3229/5/25)

EXECUTIVE SUMMARY

BACKGROUND

Schistosomiasis, a parasitic waterborne disease caused by Schistosoma flatworms, is transmitted through skin contact with freshwater harbouring infective cercariae. Freshwater snails (*Bulinus* and *Biomphalaria genera*) act as intermediate hosts, with their distribution and abundance influenced by ecological factors, such as temperature, pH, salinity, aquatic vegetation, and human activities (e.g., waste disposal). In South Africa, over 4 million cases are reported, primarily in KwaZulu-Natal, Limpopo, Mpumalanga, and the Eastern Cape. Key snail hosts include *B. globosus* (for *S. haematobium*, causing urogenital schistosomiasis) and *B. pfeifferi* (for *S. mansoni*, intestinal schistosomiasis), distinguishable by shell morphology and habitat preferences. These snails thrive in shallow, vegetated waters and are rarely found in fast-flowing systems.

Recent studies in Nelson Mandela Bay (NMB) confirmed the presence of these snails, raising concerns as closed community swimming pools may drive residents to natural water sources, increasing exposure risks. This study investigates how vegetation types, physico-chemical properties (e.g., pH, turbidity) influence snail distribution in Kwa Nobuhle and Kariega areas with reported schistosomiasis. Findings aim to inform targeted interventions to disrupt transmission cycles by addressing ecological drivers and human behavioural factors.

AIMS

The aims of the project - work package 1 (WP1):

1. Assess natural water bodies to determine vegetation type, and water physico-chemical properties in each sampling site, and the impact on schistosomiasis intermediate host (snail) distribution.
2. Assess natural water bodies in the study area to determine the presence of snail intermediate host (potential transmission sites) and infected snails (transmission sites).

METHODOLOGY

A quantitative cross-sectional research design approach was employed in this study. Data for the water physicochemical properties was collected over different seasons over a 9-month period. Eight sampling sites were selected based on their proximity to residential areas. A simple dip method was used for surface water samples and measurements were done using a Bante 900P multiparameter meter, Macherey Nagel PF-12 plus, and a hardness meter. A 300 µm mesh scoop net on a metal frame was used to capture snails. At each sample site, the predominant plant species were gathered and transported to experts in the Botany Department at Nelson Mandela University for identification. The composition and percentage cover of vegetation were visually estimated and documented. Data was analysed using R software (version 4.3.1) and Microsoft Office Excel 365 (2019 version).

RESULTS AND DISCUSSION

In the current study, 844 snails were collected, with *Physa* genera accounting for 95.9% of the total number of snails. *Bulinus* and *Biomphalaria* snails accounted for 0.9% and 0.6%, respectively. Most snails were collected during the dry season. This could be due to less precipitation, a characteristic that frequently disrupts snail habits by removing the flora to which the snails attach. The abundance of *Physa* snails may be explained by their ability to endure difficult conditions, such as the NMB's severe drought. The low abundance of schistosomiasis snail hosts in the area likely contributed to the reduced transmission rate, though predation, competition with *Physa* snails, or environmental factors may also explain this scarcity. Furthermore, the discovery of these intermediate host snails was confined to rivers, which is consistent with other study findings.

It was observed that the physico-chemical properties were, on average, higher during the wet season in comparison to the dry season with the exception of the EC, salinity and TDS properties, which were higher during the dry season. Moreover, a substantial difference was observed in the temperature measurements acquired throughout the wet and dry seasons. However, the remaining seven physicochemical properties of the water bodies did not change significantly during the wet and dry seasons. Research findings indicated that a negative and weak relationship existed between the number of snails and: EC (r=-0.240), DO (r=-0.185), hardness (r=-0.210), pH (r=-0.235), salinity (r=-0.242), temperature (r=-0.273), and TDS (r=-0.236). This suggests that a slight decrease in snail abundance can be expected as physicochemical property concentrations increase. However, snails were shown to be unaffected by turbidity at both high and low concentrations, as indicated by the lack of correlation between snails and turbidity in the research data (r=-0.070).

Comparing the dry and wet seasons, research revealed that vegetation cover was significantly greater in all water bodies during the wet season. This could be because precipitation promotes plant development in comparison to hot, dry temperatures. Grass, reeds, sedges, and rushes were among the emergent vegetation that was identified. Most water bodies included *Typha capensis* (bulrush), which is indicative of nutrient-rich, contaminated conditions. The presence of floating vegetation, including water hyacinth (*Eichhornia crassipes*), an invasive alien aquatic species that signifies polluted and disturbed conditions, was seen exclusively at one location. Submerged vegetation was observed exclusively at two locations, both of which were distinct tributaries of the Swartkops River. Moreover, findings revealed a weak and negative correlation between snails and vegetation coverage (r=-0.127), indicating that regions with little vegetative cover harboured the greatest number of the snails.

GENERAL

The aims of WP1 have been completed. Recommendations derived from the data findings can be distributed to healthcare professionals and other stakeholders, where they can be utilised to raise awareness on schistosomiasis. Additionally, they can be used to implement preventive and control strategies aimed at eliminating the disease from both the study area and other regions where it is endemic

CONCLUSIONS

Findings indicate that most of the water bodies studied provided snails with every necessary attribute for survival. *Biomphalaria* snails, which are members of the Pulmonata order, have an enhanced capacity to endure more severe environmental circumstances due to their vascularized mantle chamber for air absorption. However, they were not found in abundance in the current study, regardless of this ability. The decline in the populations of *Bulinus* and *Biomphalaria* snails could also be linked to additional factors, including competition among the snails. The abundance of snails belonging to the *Physa* genus can be attributed to their remarkable resilience in challenging environments. Since they outcompete other snails and have little medical or veterinary significance, *Physa* snails can be utilized as a biological control measure in endemic regions in South Africa and this was already seen in Mozambique.

RECOMMENDATIONS

Environmental Health Practitioners should monitor waterbodies and intermediate host snails. *Physa* snails' adaptability and environmental resilience can be studied, notably their potential as biological control agents in schistosomiasis-endemic areas. More research is needed on how physical properties (e.g., pH, turbidity) and plant types affect snail abundance in water bodies. Other research can examine plant-based prevention and understudied variables such as water depth, calcium, alkalinity, BOD, pesticide impacts, and industrial/municipal effluent pollution on snail ecology. See the conclusions and recommendations in Chapter 4 below for more details.

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ACRONYMS & ABBREVIATIONS

Ca	Calcium
Cl	Chloride
DO	Dissolved Oxygen
EC	Electrical Conductivity
EHP	Environmental Health Practitioner
F	Fluoride
FAU	Formazine Attenuation Unit
QGIS	Quantum Geographic Information System
GPS	Global Positioning System
MDA	Mass Drug Administration
Mg	Magnesium
Mg/L	Milligram Per Litre
Ms/M	Milli siemens Per Metre
NMB	Nelson Mandela Bay
NTD	Neglected Tropical Disease
NTU	Nephelometric Turbidity Units
pH	Potential of Hydrogen
PPT	Parts Per Thousand
PPM	Parts Per Million
PSU	Practical Salinity Unit
PZQ	Praziquantel
SSA	sub-Saharan Africa
TDS	Total Dissolved Solids
WASH	Water, Sanitation and Hygiene
WHO	World Health Organisation

GLOSSARY

Schistosomiasis: A waterborne parasitic disease caused by *Schistosoma* flatworms, transmitted through skin contact with freshwater infested with infectious cercariae. It has significant public health and veterinary impacts.

***Schistosoma* flatworms**: Parasitic worms responsible for schistosomiasis. Key species include *S. haematobium* (urogenital schistosomiasis) and *S. mansoni* (intestinal schistosomiasis).

Cercariae: Free-swimming larval stage of *Schistosoma* parasites released by infected snails; infects humans via skin penetration.

Intermediate hosts: Freshwater snails (e.g., *Bulinus* for *S. haematobium*; *Biomphalaria* for *S. mansoni*) that harbour schistosome larvae, enabling their development into cercariae.

Physicochemical properties: Abiotic factors (e.g., temperature, pH, conductivity, turbidity, salinity) influencing snail survival, distribution, and schistosome transmission in freshwater ecosystems.

Haemolymph: Fluid in snails analogous to blood, which schistosomes feed on during their larval development.

KAP (Knowledge, Attitudes, Practices): A framework used to assess community understanding and behaviours related to disease prevention (e.g., schistosomiasis).

Urogenital schistosomiasis: A form of schistosomiasis caused by *S. haematobium*, affecting the urinary tract and genital organs.

Intestinal schistosomiasis: A form caused by *S. mansoni*, damaging the intestines and liver.

Trematodes: Parasitic flatworms (flukes) that include schistosomes; they rely on snails as intermediate hosts.

Detritus: Decomposing organic matter (e.g., aquatic vegetation) serving as a primary food source for snails.

Periphyton: Complex mixture of algae, bacteria, and detritus growing on submerged surfaces; a food source for snails.

Columella: Central axis of a snail’s shell; the presence of a notch here aids in identifying *Bulinus* species.

Non-native species: Organisms introduced to an ecosystem outside their natural range (e.g., *Helisoma duryi* in South Africa).

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

Schistosomiasis, an infectious waterborne disease, is a parasitic disease that holds substantial medical and veterinary importance. It is transmitted by Schistosoma flatworms (Ntajal et al., 2021). Human infection with the parasite occurs via skin penetration subsequent to exposure to water infested with schistosome cercariae (Takeuchi et al., 2019). Freshwater snails from the *Bulinus* and *Biomphalaria* genera serve as intermediate hosts for the parasite. In light of the water-based mode of transmission for schistosomiasis, it is critical to prevent the contamination of water bodies by *Schistosoma* eggs in order to disrupt the aquatic life cycle (Mulopo & Chimbari, 2021). The estimated prevalence of schistosomiasis infection in South Africa exceeds 4 million individuals. The provinces in which the disease is endemic include KZN, Limpopo, Mpumalanga, and the Eastern Cape (Magaisa et al., 2015; de Boni et al., 2021; Nwoko et al., 2023a).

Freshwater snails are found in a variety of habitats and freshwater environments, including wetlands, dams, rivers, ponds, and other humid regions with open water, aquatic vegetation, and/or submerged grass (Wepnje et al., 2023). The abundance, density, and distribution of intermediate host freshwater snails are significantly impacted by numerous ecological conditions, both biotic and abiotic (Peletu et al., 2023). The abiotic factors that exert the greatest influence on the survival, bionomics, distribution, infection rates, and density fluctuations of snail host species are the physicochemical properties of freshwater environments (Peletu et al., 2023). Temperature, pH, alkalinity, EC, turbidity, salinity, and hardness are among the physicochemical properties that are encompassed within this category. The snail vector’s biology is highly dependent on aquatic vegetation. Rich microflora, in conjunction with decomposing aquatic vegetation, constitute the primary food source for snails in the majority of aquatic settings (Ezeugwu, 2006). Schistosomes, which feed on snail haemolymph, and snails, which ingest detritus, bacteria and periphyton, both increase in number and per-snail productivity of human-infectious cercariae with high resource quantity or quality in response to resource availability (Halstead et al., 2018; Desautels et al., 2022). According to reports, human activities such as waste disposal are closely associated with the occurrence of snail species in extensively disturbed water bodies, owing to the quantity of dissolved ions and organic matter that are vital to snail survival and distribution (Wepnje et al., 2023; Yigezu et al., 2018). More than 350 species of freshwater snails serve as intermediate hosts for flukes (trematodes) that may have clinical or veterinary significance (Urude et al., 2021). In South Africa, the intermediate host snails for *S. haematobium*, which causes urogenital schistosomiasis, and *S. mansoni*, which causes intestinal schistosomiasis, are *B. pfeifferi* and *B. globosus*, respectively (Nwoko et al., 2023a). The species can be recognised by the shape of their outer shells, and they are found in a variety of habitats due to their adaptability to a wide variety of environmental conditions (Fisheries, Tamu, 2013). Snails are classified into two major groups: aquatic snails that live beneath the surface of the water and are unable to survive anywhere else (*Bulinus, Biomphalaria*) and amphibious snails that are adapted to living both inside and outside of water, such as *Oncomelania* (Fisheries, Tamu, 2013).

Each schistosome species has a narrow range of suitable snail hosts, and thus, their distribution is distinguished by the habitat range of their host snails. A solitary infected snail can shed thousands of cercariae per day for several months. Adult schistosomes have an average lifespan of three to five years, but they can live up to thirty years (Adenowo et al., 2015). *S. haematobium* and *S. mansoni* use freshwater snails found throughout South Africa's eastern half, and because they obtain their oxygen from the atmosphere rather than the water, they prefer shallow water with vegetation. Even at water flow speeds of 0.3 m/s, they are extremely rare. With a matte texture and never bright, their shells come in all sorts of brown shades. Filamentous green algae, as well as other encrustations on the shells, can obscure diagnostic features (Appleton et al., 2015).

Morphologically, *B. globosus* and *B. africanus* snail species are ovate, both have sinistral shells that are smooth except for growth lines, and range in colour from dark brown to pale brown. After reaching maturity, they resemble an orange in size. The basal whorl is typically large, the spire is usually short and round, and the first few whorls are regularly stripped away, particularly in large specimens. On the basal margin of the columella, there is a notable notch or truncation. This notch is important in the diagnosis of all *B. africanus* species found in South Africa (Appleton et al., 2015). However, *B. pfeifferi*, has a flat discoid shell that measures up to 5 x 17 mm in diameter and features uniformly rounded shoulders. It is typically sleek and faint brown, though some specimens may be darker. *Helisoma duryi*, an introduced North American snail, seems to be the only species that can be confused with *B. pfeifferi. H. duryi* has a brown, matt textured shell, and orange-coloured soft sections, which makes it popular with aquarists. It differs from *B. pfeifferi* in size and appearance. It expands to a length of 12 x 25 mm. Notably, *H. duryi* is uncommon in natural water bodies but is found mainly in man-made water bodies, such as decorative ponds and aquaria, habitats where B. pfeifferi is uncommon (Appleton et al., 2015).

The presence of snails belonging to the genera *Biomphalaria* and *Bulinus* in NMB was verified in an NMB-based study undertaken by Getse (2022). Furthermore, due to persistent drought and effort to conserve water, the municipality decided to close all community swimming pool facilities in the NMB. As a result, people of the community may be compelled to seek different water sources for recreational purposes, such as swimming, thus resulting in frequent direct contact with water bodies that may be harbouring these intermediate host snails. In light of this, the present study aimed to determine the extent to which variables, including vegetation type, physicochemical properties, community knowledge, attitude, and practices, influence the distribution and habitat preference of intermediate host snails in Kwa Nobuhle and Kariega areas, where schistosomiasis has been reported.

1.2 PROJECT AIMS

The following were the aims of the project:

1. Assessment of natural water bodies to determine vegetation type, and water physico-chemical properties in each sampling site, and the impact on schistosomiasis intermediate host (snail) distribution.

2. Assessment of natural water bodies in the study area to determine the presence of snail intermediate host (potential transmission sites) and infected snails (transmission sites).

1.3 SCOPE AND LIMITATIONS

The study demonstrated methodological rigor through longitudinal data collection spanning nine months, enabling comprehensive analysis of seasonal variations (rainy and dry seasons) in water body conditions. Exposure assessment was strengthened by employing validated, peer-reviewed protocols for snail sampling and surface water analysis, ensuring methodological validity and reliability.

A notable limitation arose during site selection: while the original sampling framework included ten water bodies, municipal access restrictions at two fenced sites introduced logistical constraints, reducing the final sample size to eight. This limitation may affect the generalisability of findings to excluded habitats and underscores potential biases in geographic representation.

CHAPTER 2: METHODOLOGY

2.1 STUDY SETTING

The study was carried out in two areas, namely Kariega, formerly known as Uitenhage and Kwa Nobuhle, which is located on the outskirts of Kariega. Both Kariega and Kwa Nobuhle fall within NMB and eight sites (water bodies) from these areas were sampled. South Africa was confronted with prolonged drought conditions from 2014 to 2019, culminating in the official designation of the drought as a national disaster in March 2018 (Botai et al., 2020). Port Elizabeth, situated in close proximity to the study regions, came close to entering a 'day-zero' state. **Figure 2.1** shows the map of the study area.

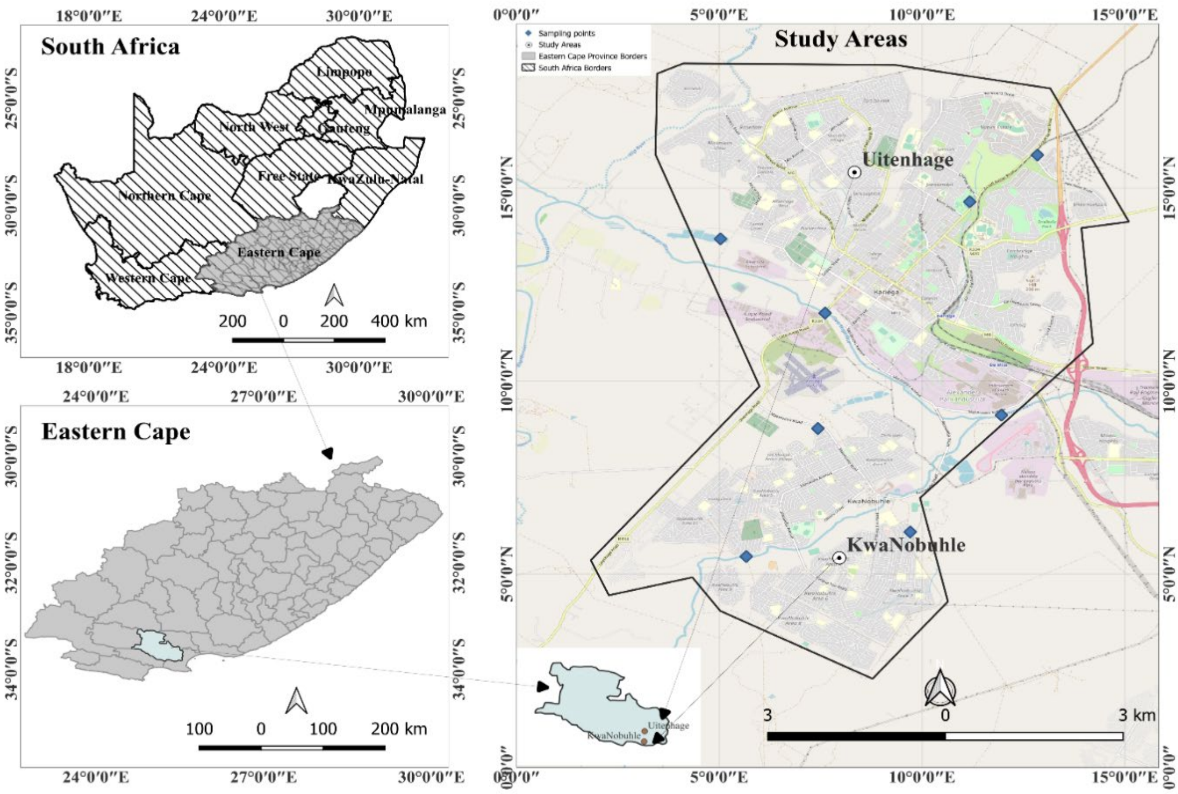

Figure 2. 1: Map of study area.

2.2 STUDY DESIGN

A quantitative cross-sectional research design approach was used to determine the water physicochemical properties and type of vegetation preferred by schistosomiasis intermediate host snails, as well as their distribution and habitat preference. Sampling sites were purposively selected based on their proximity to residential areas and their likelihood of being used by community members for activities such as recreational, religious, and domestic.

2.3 DATA COLLECTION

Data was collected over a nine-month period, with sampling taking place once a month from March to November 2023. This period allowed the study to factor in both the wet and dry seasons. Data collection took place between 08:00 a.m. and 15:30 p.m. to allow sufficient time to collect samples in eight different water bodies while spending approximately 45 minutes per water body. Fifteen minutes for water sampling and the taking of vegetation images, and 30 minutes for the collection of snails. A smartphone was used as a portable global positioning system (GPS) device to capture and store geographical coordinate measurements at every sampling site.

2.3.1 Determination of physicochemical properties

Grab surface water samples were collected using 1 L plastic containers using a simple dip method (Marie et al., 2015). At each water body, the physicochemical properties of water bodies that were measured are temperature, pH, salinity, total dissolved solids (TDS), turbidity, electrical conductivity (EC), hardness, and dissolved oxygen (DO). Some were measured using a handheld Bante 900P multiparameter meter and the Macherey Nagel PF-12 plus was used to measure turbidity, while water hardness was measured using a hardness meter. The researcher calibrated the equipment and tested it against standards (known values) to ensure that the readings were accurate. To ensure consistency and reliability, samples were taken by the same person throughout the study.

2.3.2 Aquatic macrophytes

Dominant species of vegetation at each sampling site were collected and taken to experts in the Botany Department at Nelson Mandela University for the identification process. The percentage of aquatic vegetation cover (submerged, floating and emergent) was visually evaluated using a simple estimation of the amount of the site covered by aquatic vegetation within a 500 m distance with the sampling site as the centre (Olkeba *et al*., 2020). Furthermore, images were captured from a single vantage point throughout the sampling period and verified visually by experts in the field of botany. Vegetation composition and percentage cover were recorded at each sampling point. Areas with vegetation cover < 10% were classified as ‘bare ground’; areas where vegetation cover is > 10% were classified as ‘vegetated’, and areas where the cover of dead plant material exceeded that of living plants were classified as “dead vegetation” (Olkeba *et al*., 2020).

2.3.3 Determination and identification of freshwater snails

Snails were caught with a standard 300 µm mesh scoop net on a metal frame (Opisa *et al*., 2011; Olkeba *et al*., 2020). Each sweep lasted for thirty seconds, and all substrates at the site were thoroughly searched to collect snails. A fixed sampling time of 30 minutes per site was adhered to (Olkeba *et al*., 2020). The sampling area per site was fixed at approximately 5 m^2. Snails collected from each waterbody were stored in bottles containing water from that specific waterbody and the Danish Bilharziasis Laboratories manual was subsequently utilised to identify them to species level based on their shell morphology and further verification by a malacologist. The number of snail species gathered per water body was counted. Since there were no bilharzia prophylactics, rubber gloves and protective footwear were worn when collecting the snails on-site for protection and to avoid potential disease transmission.

2.4 STATISTICAL ANALYSIS

Descriptive statistics and inferential statistics were used to analyse and describe the data, including Pearson's correlation calculated to examine the relationships among the water physicochemical properties of select water bodies in NMB. A correlation value higher than ±0.75 was considered a strong relationship. In addition, the Student's t-test for independent samples was performed to compare the difference between the obtained physicochemical properties levels in the wet season and dry season in this study, with a *p-value* < 0.05 considered significant. All statistical data analyses were done using the R software (version 4.3.1) and Microsoft Office 365 (2019 version).

2.5 ETHICAL CONSIDERATIONS

Permission was sought from the community leaders of the study area before proceeding with the research and the study also received ethical clearance from the Nelson Mandela University (NMU) Research Ethics Committee: Human (REC-H) H22-HEA-ENV-009.

CHAPTER 3: RESULTS AND DISCUSSION

3.1 PHYSICOCHEMICAL PROPERTIES OF FRESHWATER BODIES

A total of 72 visits to sampling sites were carried out in this study, of which 32 were done during the wet season (March, April, October, and November), while 40 were done during the dry season (May, June, July, August, and September). A total of eight water bodies were visited per month during both the wet and dry seasons. These were Willow Park (Dam), Mel Brooks (River), Doornhoek (Watershed), Winterhoek (Pond), Cuyler (River), Godolozi (Dam), Matanzima (Marsh Wetland) and Sangcaphe (River). At each water body, eight water physicochemical properties were measured, and these included the pH, Temperature (°C), EC (mS), Salinity (psu), TDS (ppt), DO (mg/L), Turbidity (FAU) and Hardness (mg/L).

Table 3.1 shows the overall mean and standard deviation values obtained per water physicochemical property across the eight water bodies during both the wet and dry seasons. On average, the temperature during the wet season had the highest mean measurement of 23.4 °C ($\pm$2.8), while the highest mean measurement during the dry season was observed for hardness (17.1 mg/L $\pm$ 6.1), followed by temperature (16.7° C $\pm$ 3.5). In addition, the wet season was observed to have a higher physicochemical property measurement overall, when compared to the dry season on average, with the exception of the EC, salinity, and TDS properties, which were higher during the dry season.

Table 3.1: Overall mean and standard deviation values for the water physicochemical properties

	Wet		**Dry**	
	Mean	Standard deviation	Mean	Standard deviation
pH	8	1	8.2	0.6
Temperature (°C)	23.4	2.8	16.7	3.5
Conductivity (mS)	5.6	5	7.5	7.3
Salinity (psu)	3.1	3	4.3	4.4
Total Dissolved Solids (ppt)	2.8	2.5	3.8	3.7
Dissolved Oxygen (mg/L)	5.3	4.9	4.5	4.4
Turbidity (FAU)	10	8.6	8.6	6.5
Hardness (mg/L)	17.1	6.1	17.1	6.1

3.1.1 Temperature

In the current study wet season had the highest average temperature among all sites investigated, with 23.4°C, whereas for the dry season it was 16.7 °C. It has been discovered that cold and dry seasons, as well as the period following a rainy season, provide favourable environments for *B. globosus* and *B. pfeifferi*. However, the abundance of snails is reduced during hot, dry seasons owing to ponds and rivers drying up (Nwoko *et al*., 2023a). According to a study by Kalinda *et al*. (2017), snails have the ability to endure temperatures as low as 15.5°C during cold seasons. However, when temperatures rise, snail growth increases, leading to a higher occurrence of diseases. The effect of small temperature increases in regions endemic to schistosomiasis will be dependent upon the snail species serving as an intermediate host, according to mathematical modelling. The temperature range within which simulated populations of *B. alexandrina* could survive was 12.5–29.5°C, whereas populations of *B. pfeifferi* required 14–31.5°C to survive. In regions where *B. alexandrina* is the prevailing host, a 2°C rise in temperature can raise the likelihood of *S. mansoni* infection by more than double

(McCreesh *et al*., 2015; El-Khayat *et al*., 2022). This indicates that the temperature reported during the study was within the optimal range for snail development and growth.

Summers that are warm and humid have been seen to be conducive to the growth of both *B. globosus and B. pfeifferi.* Additionally, when the snails grow more active, these warm temperatures facilitate their life cycle, beginning with egg laying and continuing through hatching and larval development (Nandy & Aditya, 2022). According to Oso & Odaibo, (2021) snail habitat suitability is influenced by temperature due to its impact on vegetation growth, oxygen levels, and water availability.

3.1.2 pH

The average pH was slightly alkaline range of 8.2 during the dry season and dropped to 8 in the wet season. According to the findings of Urude *et al*. (2021). The majority of *Bulinus* snails appeared to favour alkaline water bodies with a pH above 8. However, they discovered no significant relationship (p>0.05) between pH and snail distribution. On the contrary, a study carried out in Egypt by El-Khayat *et al*. (2022) revealed that the pH of the water remained neutral across all the sites investigated during different seasons. Snail production decreases by roughly 1.35% and 13.28%, respectively, in response to pH fluctuations below or above 7 and 9 (Adekiya *et al*., 2020). Thus, the pH value documented in the present investigation was conducive to the survival of freshwater snails.

3.1.3 Dissolved oxygen (DO)

Dissolved oxygen concentration has been suggested as a potential indicator of organic contamination in water, and its impact on aquatic organisms is profound (Mereta *et al*., 2019). As part of their metabolic processes, Pulmonate freshwater snails breathe by taking DO from the water via their lungs. Therefore, high levels of DO are essential for life and reproduction (Nwoko *et al*., 2023c). In the current study, the recorded mean DO value was high during the wet (5.3 mg/L) compared to the dry season (4.5 mg/L). Similarly, a study by Joseph *et al*. (2023) discovered that the average concentration of dissolved oxygen in all the sample points was around 4.93 mg/L. This indicates that DO levels recorded in the current study were conducive to snails. However, in a study by Usman *et al*. (2017) snails were detected at DO concentrations between 7 and 8.3 mg/L. Nevertheless, the majority of snails were found at concentrations ranging from 7.7-8.3 mg/L, while they were negligible or non-existent at levels below 7.7 mg/L. Water quality degradation caused by organic and anthropogenic pollution is indicated by low levels of DO. In addition, the development of intermediate host snails is impacted by low oxygen levels in water, resulting in differences in egg size, snail number, and form (Oso & Odaibo, 2021). This deficiency in oxygen further accelerates the decomposition of active organic matter in the sediments, causing freshwater snails to suffocate and perish.

3.1.4 Turbidity

Turbidity is a characteristic shared by all natural water bodies, and it can be caused by a variety of factors, like flooding, high planktonic volume or sediments deposited due to soil erosion (Akande & Odetol, 2013). In the current study, the mean turbidity was high during the wet (10 FAU) season compared to the dry season (8.6 FAU). Snails were collected in turbidity levels ranging from 2.8 - 247 NTU during the tropical rainy season, and 1.8 - 159 NTU during the warm temperate rainy climate (Olkeba *et al*., 2020). Snail populations are negatively affected by murky water, according to a number of studies (Ngassam *et al*., 2014; Amoah *et al*., 2017; Olkeba *et al*., 2020). As the mean turbidity levels assessed in this investigation were low, it is probable that the freshwater snails were not affected by it.

3.1.5 Total dissolved solids (TDS)

The mean TDS was higher during the dry (3.8 ppt) compared to the wet (2.8 ppt) season. Snails belonging to the genus *Biomphalaria* were discovered in breeding sites containing TDS values ranging from 0.2 to 0.7 ppt (Barbosa *et al*., 2017). Asphyxiation in aquatic ecosystems and a drop in snail populations may result from oxygen deprivation caused by elevated TDS levels (Amoah *et al*., 2017).

3.1.6 Electrical conductivity (EC)

The EC of water is a property that quantifies the ionic strength of dissolved minerals, such as magnesium and calcium. This property could potentially indicate the existence of dissolved ions (e.g., calcium), which promote the development of shells in snail species (Tabo *et al*., 2022). Nevertheless, EC, which is a multifaceted element comprising various chemical components, has been recognized as a predictor of *Bulinus* mortality and so presents a significant constraint to its prevalence (Marie *et al*., 2015; Tabo *et al*., 2022). EC was high during dry season (7.5 mS) compared to the wet season (5.6 mS) in the current study. The average EC value recorded in a study conducted by Fuss *et al*. (2020) was 0.41 mS. In contrast, prior studies have demonstrated a correlation between low snail abundance and EC values below 50 mS (Dida *et al*., 2014; Marie *et al*., 2015). According to research by Al-Jubury *et al*. (2021) snails may endure in water bodies with an EC ranging from 10 to 80 mS. This suggests that the EC levels measured in the current investigation remained conducive to the growth of snails.

3.1.7 Salinity

Since intermediate host snails are less resistant to salinity (Amoah *et al*., 2017) the salinity of aquatic habitats influences their survival and abundance (Akande & Odetol, 2013). Urude *et al*. (2021) provided further evidence for this notion, proposing that salinity might significantly restrict the range of freshwater snails within a certain geographic area. On average, the study recorded relatively higher salinity values during the dry (4.3 psu) compared to the wet (3.1 psu) season. Snails were collected in salinity levels ranging from 0.06 - 13.12 psu in a study conducted by Nwoko *et al*. (2022). According to a study by Urude *et al*. (2021) the salinity of the water varied between 25 and 70 ppt, with the majority of snails surviving in the range of 30 to 60 ppt. In the current study, the sites had relatively low salinity levels; however, freshwater snails were still present, which shows that the snail species in the study area were not affected by low concentrations of salinity.

3.1.8 Hardness

The aquatic environment and its surrounding elements, including water chemistry, have a significant influence on the developmental and infectious stages of snail vectors and schistosome parasites, respectively (Ezeugwu, 2006). Water hardness, as measured by calcium hardness, magnesium hardness, or total hardness, is a significant determinant of snail distribution. In the current study, the mean hardness value (17.1 mg/L) was constant in both seasons. According to a study conducted in Nigeria by Oloyede *et al*. (2017) the total hardness measurements ranged from 2.37 to 65 mg/L. This indicates that the recorded hardness levels were within the range conducive to snails. **Figure 3.1** shows the highest recorded mean values for each water physicochemical property in relation to seasons.

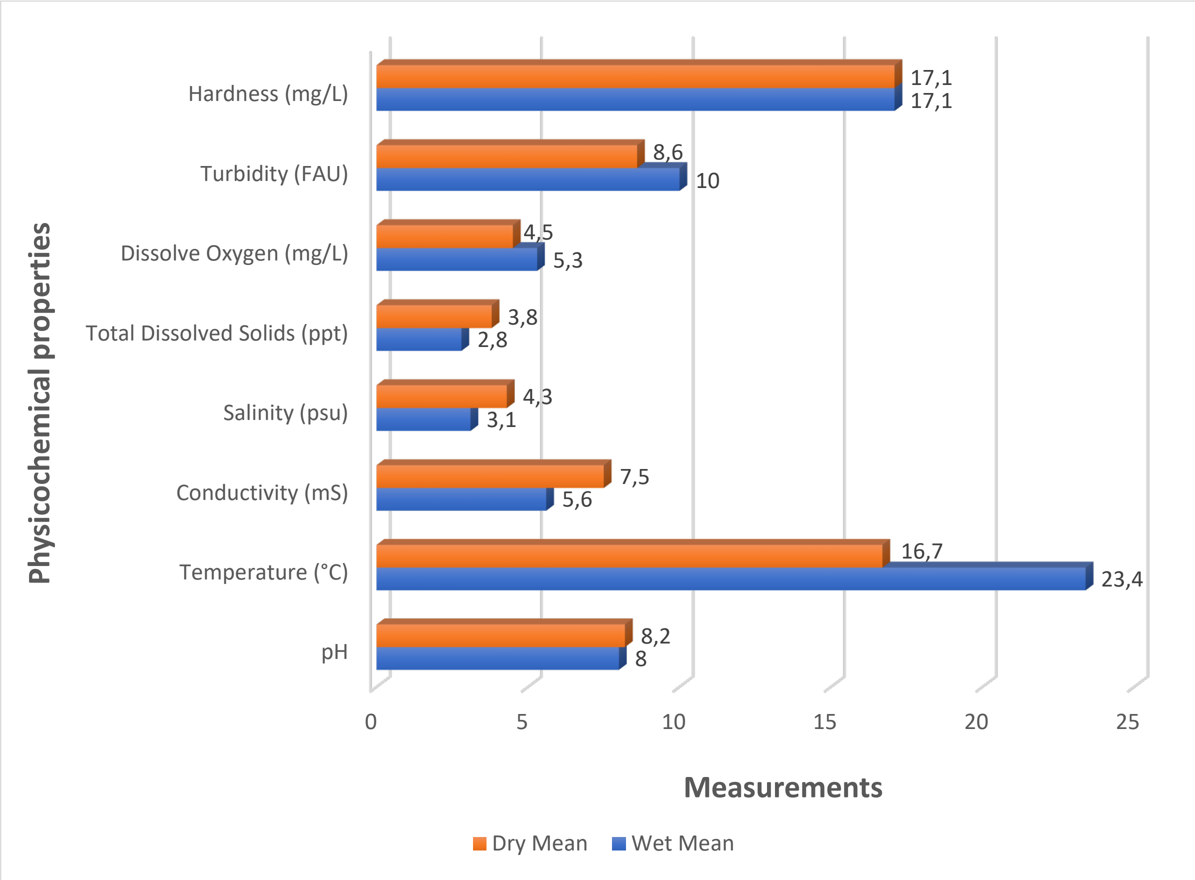

Figure 3.1: Overall mean values for the water physicochemical properties

Moreover, looking at the estimated Pearson's correlation values shown in **Table 3.2**, it can be observed that a positive and fair relationship exists between pH and DO (r=0.514), also between temperature and TDS (r=0.496), EC (r=0.494) and salinity (r=0.484). Likewise, a positive and strong relationship can be observed between EC and salinity (r=0.999) and TDS (r=0.998), as well as between salinity and TDS (r=0.995). Similarly, Wepnje *et al*. (2023) found a positive correlation between pH and TDS (r=0.35), also between temperature and EC (r=0.6), TDS (r=0.31). A previous study conducted in Nigeria by Oladejo *et al*. (2021) discovered a positive correlation between various physiochemical properties, such as pH and turbidity (r=0.442, p<0.011), and water temperature and turbidity (r=0.535, p<0.002). Moreover, a negative and weak relationship can be observed between temperature and turbidity (r=-0.019), between EC and turbidity (r=-0.106) and hardness (r=-0.073), also between salinity and turbidity (r=-0.121) and hardness (r=-0.081), and between TDS and turbidity (r=-0.094) and hardness (r=-0.064).

Table 3.2: Estimated Pearson's correlation values

	pH	Temperature (°C)	Electrical Conductivity (mS)	Salinity (psu)	Total Dissolved Solids (ppt)	Dissolve Oxygen (mg/L)	Turbidity (FAU)	Hardness (mg/L)
pH	1.000							
Temperature (°C)	0.352	1.000						
Electrical Conductivity (mS)	0.302	0.494	1.000					
Salinity (psu)	0.285	0.484	0.999	1.000				
Total Dissolved Solids (ppt)	0.319	0.496	0.998	0.995	1.000			
Dissolve Oxygen (mg/L)	0.514	0.166	0.282	0.272	0.285	1.000		
Turbidity (FAU)	0.187	-0.019	-0.106	-0.121	-0.094	0.064	1.000	
Hardness (mg/L)	0.276	0.057	-0.073	-0.081	-0.064	0.078	0.194	1.000

From the performed t-tests, at a 5% level of significance, it can be concluded that significant difference existed between the temperature values obtained in the wet and dry seasons (t-stat=8.77, $p<0.001$) as shown in **Table 3.3.** However, there were no significant differences between the wet and dry seasons of the remaining water physicochemical properties. In a study conducted in China, Min *et al*. (2022) discovered that there were notable differences in physical habitat properties, including water temperature, river depth, and water velocity, when comparing the wet and dry seasons. Furthermore, Amoah *et al*. (2017) discovered that all physico-chemical properties varied seasonally and monthly across the two seasons (wet and dry), with the exception of salinity levels, which remained constant during the whole sample period. The notable difference in temperature between the two seasons in the current study could perhaps be attributed to precipitation, as rainfall has the effect of reducing surface water temperatures by cooling the air. Throughout the sampling period, specific months had precipitation, perhaps resulting in a significant reduction in temperature. Conversely, months devoid of rainfall might have witnessed a rise in temperatures.

Table 3.3: Wet and dry season mean comparison of water physicochemical properties

	Mean	n	Degree of freedom	t-statistics	*p-value*
Wet: pH	7.98	32	70	-0.98	0.332
Dry: pH	8.17	40			
Wet: Temperature (°C)	23.38	32	70	8.77	<0.001*
Dry: Temperature (°C)	16.75	40			
Wet: Electrical conductivity (mS)	5.59	32	70	-1.29	0.202
Dry: Electrical conductivity (mS)	7.54	40			
Wet: Salinity (psu)	3.12	32	70	-1.24	0.221
Dry: Salinity (psu)	4.25	40			
Wet: Total Dissolved Solids (ppt)	2.76	32	70	-1.33	0.187
Dry: Total Dissolved Solids (ppt)	3.77	40			
Wet: Dissolve Oxygen (mg/L)	5.28	32	70	0.69	0.495
Dry: Dissolve Oxygen (mg/L)	4.53	40			
Wet: Turbidity (FAU)	9.98	32	70	0.80	0.429
Dry: Turbidity (FAU)	8.56	40			
Wet: Hardness (mg/L)	17.09	32	70	0.00	0.999
Dry: Hardness (mg/L)	17.09	40			

*Significant at a 5% level of significance

3.2 SNAIL SAMPLING OF FRESHWATER BODIES

A total of 844 snails were collected in this study, out of which 298 (35.3%) were collected during the wet season and 546 (64.7%) were collected during the dry season. Sampled snails belonged to 5 genera, and among all, *Physa* snails (n=809) were the predominant genus, accounting for 95.9% of the total number of snails, and were encountered in 87.5% of the sampling sites **(Figure 3.2).** Snails from the *Lymnaea* genus (n=18) were the second most common, accounting for 2.1% of collected snails and occurring in 62.5% of the sampled sites. *Melanoide* snails (n=4, 0.5%) were the least collected. Schistosomiasis intermediate host snails were not abundant in the sampled sites and snails from the *Bulinus* genus (n=8, 0.9%) were the most common, with *Biomphalaria* snails (n=5, 0.6%) being the least. Freshwater snails from genera such as *Physa* and *Melanoide* have no notable medical or veterinary relevance **(Figure 3.3).**

The abundance of *Physa* snails may have contributed to the low abundance of *Bulinus* and *Biomphalaria* snails in the study area. Nwoko *et al*. (2023b) discovered that an inverse correlation existed between the abundance of *Physa acuta* and that of *B. pfeifferi* and *B. globosus*. However, only *P. acuta* and *B. pfeifferi* exhibited this negative correlation significantly (*p-value* < 0.05). This phenomenon may be due to the rapid generation period and high reproduction rate exhibited by *P. acuta*, which result in a population increase that surpasses that of *B. pfeifferi*. Moreover, *P. acuta* has the ability to displace snail species belonging to the genera *Bulinus spp*. and *Biomphalaria spp*., which are known to be carriers of urogenital and intestinal schistosomiasis (Lawton *et al*., 2018). Additionally, there is speculation that *P. acuta* may secrete chemical inhibitors in the presence of *B. pfeifferi*, given the observed drop in egg production and development rates of *B. pfeifferi* (Lawton *et al*., 2018). Additionally, it has been demonstrated that *P. acuta* exhibits superior fecundity, a shorter hatching period, increased tolerance to salinity and temperature, and can withstand fast current velocities of up to 0.6 m/s in comparison to other Pulmonates that are not detected in water exceeding 0.3 m/s (Wepnje *et al*., 2023).

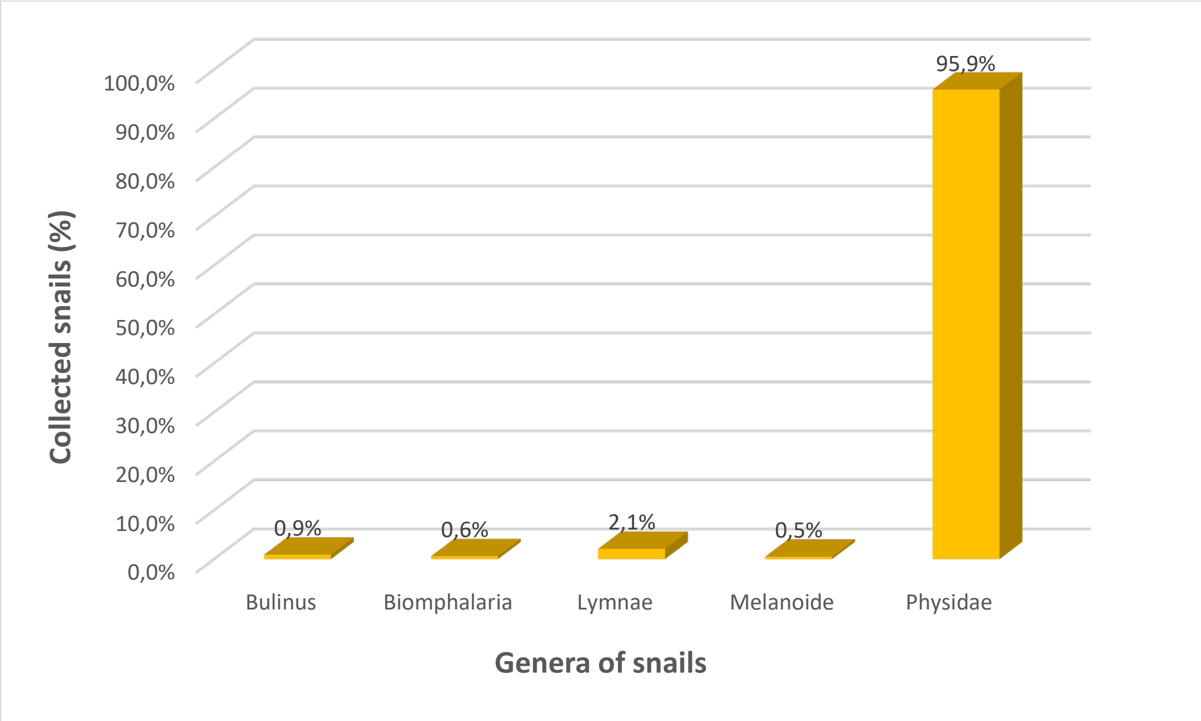

Figure 3.2: Snails collected from eight different water bodies.

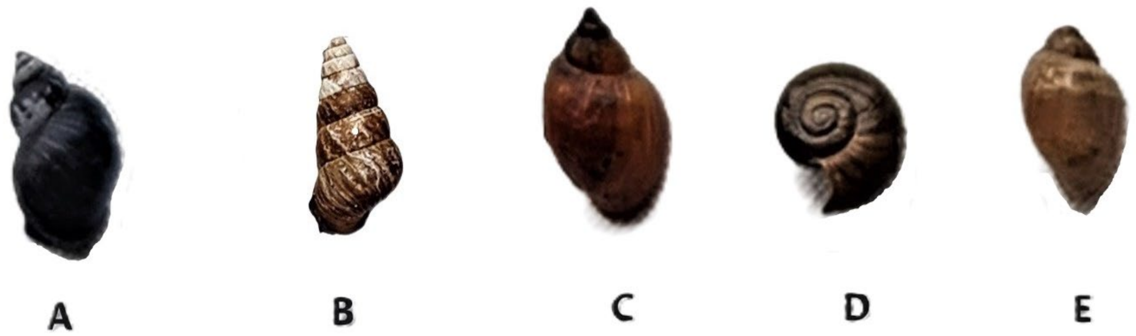

Figure 3.3: Picture showing the different genera of snails collected (Abapertural view). A – *Lymnaea*. B – *Melanoide*. C – Physa. D – *Biomphalaria*. E – *Bulinus*. (Source: The image was captured and edited by the researcher)

Moreover, looking at the distribution of the types of snails collected from across the water bodies regardless of the season **(Table 3.4)**. A high number of snails were collected from Matanzima (n=233, 28%), followed by Mel Brooks (n=156, 19%) and then Sangcaphe (n=154, 18%). The least number of snails were collected from Winterhoek (n=3, 0.4%). This may be due to the fact that Winterhoek is a sandy environment. Min *et al*. (2022) discovered that sandy areas contained fewer snails. This was primarily due to the fact that, when subjected to same water flow conditions, sand was considerably more susceptible to disturbance than gravel, pebbles, and silt, and its inadequate stability significantly disrupted the habitats of benthic invertebrates (Min *et al*., 2022).

Bulinus snails were only found in rivers viz. Mel Brooks (n=4); Cuyler (n=2) and Sangcaphe (n=2). Likewise, *Biomphalaria* snails were also found in rivers viz. Mel Brooks (n=2) and Cuyler (n=2). Mel Brooks and Cuyler are two different points of the same river with Cuyler being the upstream site, while Mel Brooks was the downstream site. Identical habitat associations were observed between *Bulinus* and *Biomphalaria* snails; however, these associations varied depending on whether water access locations were situated in a lake or river environment (Jones *et al*., 2021). In line with this, Nwoko *et al*. (2023b) found that streams contained a greater number of *B. globosus* snails than dams. This may be explained by their preference for habitats with clear water, gravel and sandy substrates as opposed to ponds and dams with muddy substrates, as well as their tolerance for moderate contamination (Hailegebriel *et al*., 2022).

The predominant habitats inhabited by *Physa* snails were logs that were freely floating, muddy substrate, and emergent and submerged plant vegetation. *Lymnaea* and *Melanoide* snails were discovered connected to dead logs that were adrift in the water along the banks. Additionally, in close proximity to the riverbank, floating logs and submerged macrophytes were observed to harbour *Biomphalaria* and *Bulinus* snails. This finding is consistent with the research conducted by Ikpeze & Obikwelu, (2016), which reported that *Bulinus* species were obtained from submerged vegetation along the shorelines of waterways, whereas the majority of *lymnaeid* snails were observed affixed to floating debris on the periphery of the water near the bank. Upon examination of all collected *Bulinus* and *Biomphalaria* snails for cercarial shedding, no evidence of *Schistosoma* infection was detected.

Table 3. 4: Distribution of the type of collected snails from water bodies

Name of site (Habitat)	**Types of snails**					
	No. of snails	*Bulinus*	*Biomphalaria*	*Lymnaea*	*Melanoide*	*Physidae*
	n=844	8 (0.9%)	5 (0.6%)	18 (2.1%)	4 (0.5%)	809 (95.9%)
Willow Park (Dam)	16 (1.9%)	0	0	2	0	14
Mel Brooks (River)	156 (18.5%)	4	2	9	0	141
Doornhoek (Watershed)	25 (3%)	0	0	0	0	25
Winterhoek (Pond)	3 (0.4%)	0	0	0	3	0
Cuyler (River)	116 (13.7%)	2	2	4	1	107
Godolozi (Dam)	141 (16.7%)	0	0	2	0	139
Matanzima (Wetland)	233 (27.6%)	0	0	1	0	232
Sangcaphe (River)	154 (18.2%)	2	1	0	0	151

Of the 844 snails collected in this study, 298 (35.3%) were collected during the wet season and 546 (64.7%) collected during the dry season as shown in Table 4.5. This is in accordance with the findings of Ikpeze & Obikwelu, (2016) and Wepnje *et al*. (2023), who discovered that seasonality had a significant effect on the abundance of all freshwater snails investigated, with abundances being greatest during the dry season and lowest during the wet season. Elevated rates of biological activity and a greater prevalence of snails have been seen during the dry season (Ikpeze & Obikwelu, 2016). Snail populations are considered to be more acclimatized to the ecological conditions that prevail during the dry season as opposed to the wet season (Ikpeze & Obikwelu, 2016). Of the 298 snails collected during the wet season, 45 (15.1%) were collected in March, 61 (20.5%) in April, 100 (33.6%) in October and 92 (30.9%) in November. Furthermore, out of the 546 snails collected during the dry season, 91 (16.7%) were collected in May, 59 (10.8%) in June, 96 (17.6%) in July, 190 (34.8%) in August and 110 (20.1%) in September (Table 4.5). Thus, it can be concluded that a high number of snails were present in the water bodies in October (wet season), while a high number of snails were present in the water bodies in August (dry season).

In addition, majority of the collected snails were found in the waterbody at Matanzima (n=18, 6%) in March, Godolozi (n=24, 8.1%) in April, Mel Brooks (n=51, 17.1%) in October, and Cuyler (n=32, 10.7%) in November for the wet season. Whereas, during the dry season, majority of the snails were collected at Matanzima (n=27, 4.9%) in May, Matanzima (n=40, 7.3%) in June, Matanzima (n=28, 5.1%) in July, Cuyler (n=54, 9.9%) in August, and Sangcaphe (n=38, 7%) in September **(Table 3.5)**.

Table 3.5: Distribution of collected snails from water bodies across wet and dry seasons

Wet season (n=298)			**Dry season (n=546)**		
Name of site (Habitat)	**No. of snails**	**%**	**Name of site (Habitat)**	**No. of snails**	**%**
March (n=45)			**May (n=91)**		
Willow Park (Dam)	4	1.3	Willow Park (Dam)	3	0.5
Mel Brooks (River)	0	0	Mel Brooks (River)	7	1.3
Doornhoek (Watershed)	4	1.3	Doornhoek (Watershed)	4	0.7
Winterhoek (Pond)	0	0	Winterhoek (Pond)	1	0.2
Cuyler (River)	2	0.7	Cuyler (River)	5	0.9
Godolozi (Dam)	6	2	Godolozi (Dam)	25	4.6
Matanzima (Wetland)	18	6	Matanzima (Wetland)	27	4.9
Sangcaphe (River)	11	3.7	Sangcaphe (River)	19	3.5
April (n=61)			**June (n=59)**		
Willow Park (Dam)	2	0.7	Willow Park (Dam)	1	0.2
Mel Brooks (River)	7	2.3	Mel Brooks (River)	1	0.2
Doornhoek (Watershed)	5	1.7	Doornhoek (Watershed)	2	0.4
Winterhoek (Pond)	2	0.7	Winterhoek (Pond)	0	0
Cuyler St (River)	4	1.3	Cuyler (River)	3	0.5
Godolozi St (Dam)	24	8.1	Godolozi (Dam)	4	0.7
Matanzima (Wetland)	5	1.7	Matanzima (Wetland)	40	7.3
Sangcaphe (River)	12	4	Sangcaphe (River)	8	1.5
October (n=100)			**July (n=96)**		
Willow Park (Dam)	0	0.0	Willow Park (Dam)	2	0.4
Mel Brooks (River)	51	17.1	Mel Brooks (River)	25	4.6
Doornhoek (Watershed)	0	0	Doornhoek (Watershed)	8	1.5
Winterhoek (Pond)	0	0	Winterhoek (Pond)	0	0
Cuyler (River)	5	1.7	Cuyler (River)	3	0.5
Godolozi (Dam)	10	3.4	Godolozi (Dam)	14	2.6
Matanzima (Wetland)	33	11.1	Matanzima (Wetland)	28	5.1
Sangcaphe (River)	1	0.3	Sangcaphe (River)	16	2.9
November (n=92)			**August (n=190)**		
Willow Park (Dam)	0	0.0	Willow Park (Dam)	2	0.4
Mel Brooks (River)	13	4.4	Mel Brooks (River)	43	7.9
Doornhoek (Watershed)	0	0	Doornhoek (Watershed)	2	0.4
Winterhoek (Pond)	0	0	Winterhoek (Pond)	0	0
Cuyler (River)	32	10.7	Cuyler (River)	54	9.9
Godolozi (Dam)	21	7.0	Godolozi (Dam)	20	3.7
Matanzima (Wetland)	11	3.7	Matanzima (Wetland)	35	6.4
Sangcaphe (River)	15	5.0	Sangcaphe (River)	34	6.2

September (n=110)		
Willow Park (Dam)	2	0.4
Mel Brooks (River)	9	1.6
Doornhoek (Watershed)	0	0
Winterhoek (Pond)	0	0
Cuyler (River)	8	1.5
Godolozi (Dam)	17	3.1
Matanzima (Wetland)	36	6.6
Sangcaphe (River)	38	7.0

3.3 VEGETATION IDENTIFICATION IN FRESHWATER BODIES

Areas where vegetation cover is > 10% were classified as ‘vegetated, whereas areas with vegetation cover < 10% were classified as ‘bare ground'. Moreover, areas where the cover of dead plant material exceeded that of living plants were classified as “dead vegetation”.

3.3.1 Description of vegetation at sites

Another significant determinant influencing the distribution of freshwater snails was the cover of aquatic macrophytes (Tietze & de Francesco, 2010). In the current study, vegetation cover was recorded for 9 months, and it varied between 5 and 85% cover **(Table 3.6)**. The highest vegetation cover recorded was at Willow Park (85%) in November, followed by Mel Brooks (65%) in April, whereas as the least vegetation cover recorded was at Doornhoek (5%) from June-November. On average, Winterhoek had the highest vegetation cover (36%), followed by Willow Park and Matanzima with a 20% coverage respectively. In terms of monthly vegetation cover, November (32%) had the highest, followed by April (31%) and both months fall within the wet season. The least vegetation cover was recorded in July and September with both months having 13% coverage. These months fall within the dry season.

Table 3.6: Mean vegetation cover at specific sites from March to November 2023

		(%) Wet season				(%) Dry season				
Name of site	**Site cover (mean %)**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
Willow Park (Dam)	20 ± 25	10	15	10	10	10	10	10	20	85
Mel Brooks (River)	18 ± 19	30	65	20	10	10	10	5	5	10
Doornhoek	7 ± 3	10	10	10	5	5	5	5	5	5
Winterhoek (Pond)	36 ± 10	40	50	25	25	25	35	35	45	45
Cuyler (River)	16 ± 13	30	45	10	10	10	10	5	5	15
Godolozi (Dam)	18 ± 18	10	10	10	10	10	10	10	25	65
Matanzima (Wetland)	20 ± 0	20	20	20	20	20	20	20	20	20
Sangcaphe (River)	19 ± 9	30	35	20	20	15	15	15	10	10
Monthly cover (mean)		23	31	16	14	13	14	13	17	32

Looking at the mean seasonal vegetation cover for both dry and wet seasons, findings show that all water bodies had a high vegetation cover during wet season, except for Matanzima which had a constant vegetation cover in both seasons. The highest vegetation cover recorded during the wet season was in Winterhoek (45% ± 4%), followed by Willow Park (33% ± 35%), whereas the least recorded was in Doornhoek (8% ± 3%). Moreover, during the dry season, Winterhoek (29% ± 5%) had the highest vegetation cover, followed by Matanzima (20% ± 0%), while Doornhoek (6% ± 2%) recorded the least. This shows that Winterhoek had the highest vegetation cover in both seasons and Doornhoek had the lowest vegetation cover in both seasons **(Figure 3.4)**.

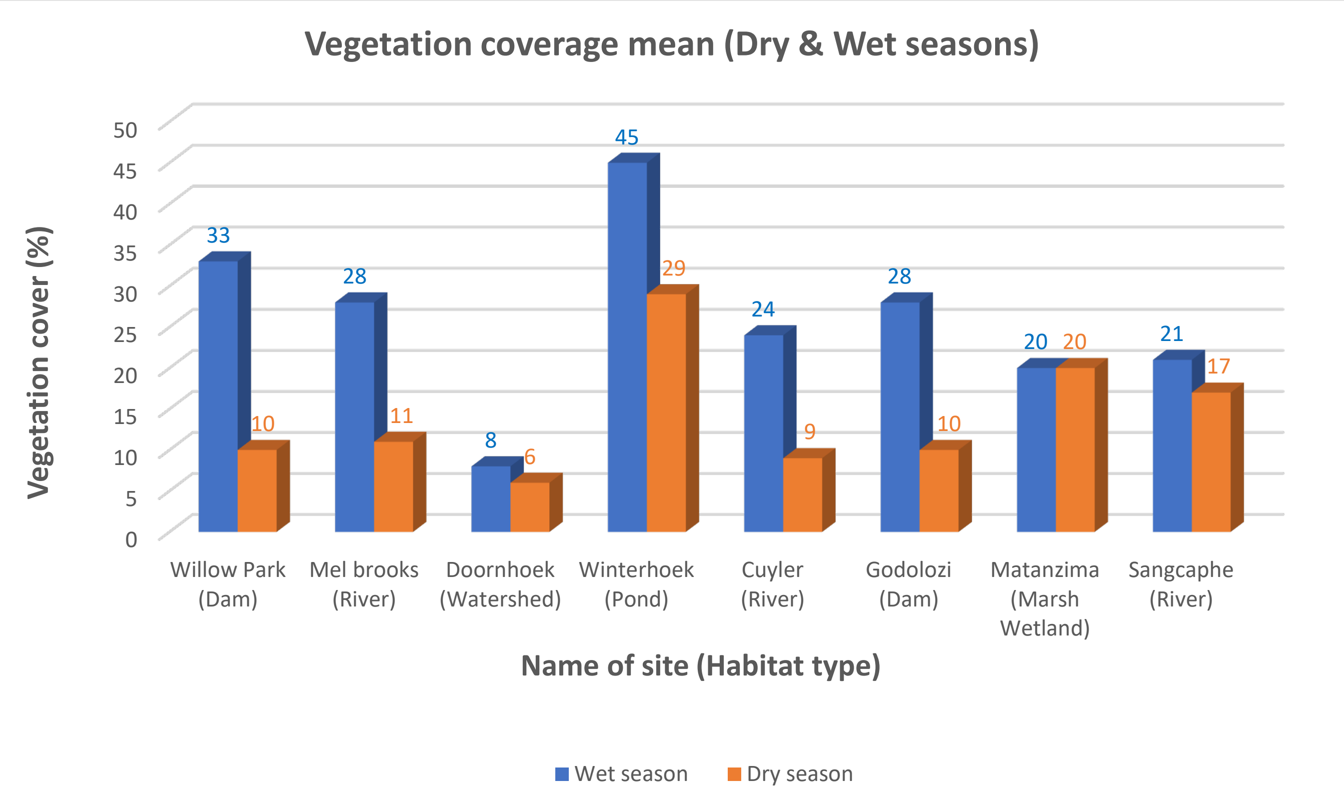

Figure 3.4: Mean vegetation coverage (%) per season

While snails do not ingest living macrophytes, it is widely acknowledged that plants can provide crucial environments for the development of edible algae and microorganisms, as well as shelter from predators (Haggerty *et al*., 2020; Desautels *et al*., 2022). In the current study, most sites were disturbed, manmade water bodies and the vegetation present reflected this.

Emergent plants that were identified consisted of reeds, sedges, rushes, and grasses **(Table 3.7)**. Emergent vegetation inhabits areas next to water bodies, including riverbanks. Roots and rhizomes of these vascular plants are frequently found in the sediment, while stems and leaves are occasionally submerged but predominantly elevated above the water. Additionally, they provide vital habitat for aquatic-dwelling insects, birds, snails, and other species (Extension USU, 2023). *Typha capensis* (bulrush) indicative of nutrient rich polluted conditions was found at Sangcaphe (river), Doornhoek (watershed), Willow park (dam), Cuyler (river) and Mel Brooks (river). Other emergent plants identified in the sampled water bodies included *Schoenoplectus scirpoides* (spikerushers), *Persicaria madagascariensis* (bristly snakeroot), *Rumex conglomeratus*, *Cyperus* spp. and *Nasturtium officinale.*

Floating vegetation leaves float on the surface of the water. Their roots may be embedded in the substrate or float freely in the water column. Floating plants such as the invasive alien aquatic *Eichhornia crassipes*, commonly known as water hyacinth were found only at Mel Brooks throughout the data collection period. This plant indicates polluted disturbed conditions. Many schistosome-endemic sites are infested with invasive aquatic plants that are inedible to snail intermediate hosts. These plants, including water lettuce, duckweed, soft hornwort, and water hyacinth (*Eichhornia crassipes*), disrupt water-use patterns for local communities that rely on the water for economic and consumption purposes (Desautels *et al*., 2022). Although these plants might affect the density of snail hosts, definitive experiments are required (Haggerty *et al*., 2020; Desautels *et al*., 2022). Snail development, reproduction, and cercariae production were all significantly impaired when snails consumed water hyacinth, according to El-Khayat *et al*. (2022). This may be due to the fibrous and waxy cuticle of the plant. On the other hand, Ofulla *et al*. (2013) discovered in a study conducted in Kenya that numerous schistosomiasis host snails were linked to water hyacinth, with hippo grass (*Echinochloa stagnina*) being the next most frequent host. Floating macroalgae was also observed in the water bodies sampled in the current study.

Submerged macrophytes have their roots in the sediment and leaves in the water column. As a result, depending on the clarity of the water, they may grow to deeper depths than emergent and floating plants. In addition to providing food for ducks and aquatic mammals, submerged macrophytes establish a habitat that is beneficial for fish and small invertebrates like snails. Significant fluctuations in DO and pH can result when their abundance becomes excessive (Extension USU, 2023). Submerged plants were only found in two sites which were actually different points of the Swartkops river namely, Mel Brooks and Cuyler. *Stuckenia pectinata*, generally known as pondweed was the common submerged plant, and their growth is influenced by water turbidity. These plants do not occur in highly turbid water bodies or those where there are extreme water level fluctuations. According to Haggerty *et al*. (2020), an increase in periphyton, which serves as the food source for *Bulinus* and *Biomphalaria* snails, could be facilitated by submerged aquatic macrophytes.

During wet conditions vegetation was greener and thicker, however, species composition did not change. An ideal snail habitat is characterized by a reasonable amount of green vegetation cover, particularly aquatic weeds, which serve as a food source for the snails (Nwoko *et al*., 2023c). Snails might have access to adequate food and spawning grounds if macrophytes were abundant. The development rate of numerous omnivorous snail species, which are capable of consuming substantial quantities of aquatic plants, is proportional to the number of plants that they consume (Min *et al*., 2022). Moreover, macrophytes may provide snails with a shelter from the detrimental effects of the current and wind, and protection from predation by fish and other large animals (Min *et al*., 2022). Secondly, by producing DO via photosynthesis, macrophytes have the potential to improve conditions for aquatic macroinvertebrates.

In a study conducted in Senegal by Liu *et al*. (2022) using deep learning segmentation approach to automatically identify the aquatic vegetation associated with schistosomiasis intermediate host snails. It was found that the percentage of areas covered by suitable snail habitat (i.e., floating, non-emergent vegetation) was a better indicator of schistosomiasis infections in humans. On the other hand, a study conducted by Jones *et al*. (2021) demonstrated that *Bulinus* snail numbers were minimal in non-emergent vegetation situated near water access points.

Table 3.7: Dominant vegetation found in the sites and their growth form

Name of site (Habitat type)	Dominant Vegetation type / growth form	Floating vegetation
Willow Park (Dam)	Emergent sedges, reeds, and rushes	Present
Mel Brooks (River)	Floating macrophytes	Present
Doornhoek (Watershed)	Emergent & bare areas	Absent
Winterhoek (Pond)	Emergent & floating macroalgae	Present
Cuyler (River)	Floating macrophytes & emergent rushes (*Typha capensis*)	Present
Godolozi (Dam)	Emergent	Present
Matanzima (Marsh Wetland)	Emergent grasses	Absent
Sangcaphe (River)	Emergent rushes (*Typha capensis*)	Present

3.4 MONTHLY RAINFALL DATA

Table 3.9 below shows the recorded rainfall for the study area throughout the sampling period (March to November 2023). The rainfall data was provided by the South African Weather services and represents the average monthly rainfall in Kariega which includes Kwa Nobuhle since both areas are close to one another. Monthly, daily rain (mm) data for station [0034763 X] – Kariega, measured at 08:00. The symbol "=" indicates that the average is unreliable due to missing daily values.

Findings from the rainfall data indicates that the month May experienced the highest rainfall (172.6 mm), followed by October (116.6), then September (79.8). The month which experienced the least rainfall was August (1 mm), followed by April (3 mm), then November (4.4 mm). The month July was not included since it had missing data, as reported by the weather services. According to Adekiya *et al*. (2020), a rise in precipitation facilitates the growth of snail populations by increasing the volume of runoff water directed via irrigation canals. Subsequently, this may result in elevated flow velocities, which would facilitate interaction between the parasite and its intermediate host. However, increased water levels resulting from heavy precipitation can induce water turbulence, leading to heightened water flow rates which may disrupt snail habitats and diminish the viability of cercariae (Adekiya *et al*., 2020).

Codjoe & Larbi (2016) discovered in a study done in Ghana that years with low precipitation were associated with a low incidence of schistosomiasis, but years with moderate to high precipitation were associated with a high prevalence of the parasite. However, they could not discover any statistically significant correlation between precipitation and the disease. In the current study, most snails (n=190) were collected in August which is the month that experienced the least rainfall (1 mm), followed by September (n=110) which experienced the third highest (79.8 mm) rainfall. Only 91 snails were collected in May which had the highest (172.6 mm) rainfall. This indicates that snails were consistently observed during the entire sampling period, irrespective of precipitation levels.

Furthermore, November (32%) and April (31%) were the months with the highest vegetation coverage during the same period. However, both months were among those with the least rainfall, with November (4.4 mm) and April (3 mm). May and October recorded a vegetation coverage of 16 and 17% respectively, while being the months that experienced the most rainfall. This suggests that months with less rainfall had a greater coverage of vegetation, and this occurs as a result of increased runoff during periods of heavy precipitation, which may also wash away vegetation in the water bodies.

Table 3.8: Total daily rainfall (in mm) by month in Kariega

Wet		**Dry**					**Wet**	
Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
31	3	172.6	12.2	0.6=	1	79.8	116.6	4.4

3.5 ASSOCIATIONS BETWEEN SNAILS AND PHYSICOCHEMICAL PROPERTIES

Figures 3.5-3.6 show that a negative and weak relationship exists between the number of snails and EC (r=-0.240), DO (r=-0.185), hardness (r=-0.210), pH (r=-0.235), salinity (r=-0.242), temperature (r=-0.273) and TDS (r=-0.236). This indicates that increased physicochemical concentrations were associated with a marginal decline in snail abundance. Similarly, Ebenezer & Ekwuribe (2022) discovered in a study done in Nigeria that *Biomphalaria* snails and temperature exhibited a significant (p<0.05) negative correlation (r=-0.63684). Snails become less active and their reproduction rate and metabolism slow down at colder temperatures, whereas they experience stress and vulnerability to infections and eventual mortality when exposed to elevated temperatures, typically over 30°C (McCreesh *et al*., 2015).

In contrast, Nwoko *et al*. (2023b) discovered that there was no relationship between pH and the abundance of *B. globosus* snails. Furthermore, a study by Fuss *et al*. (2020) found no statistically significant link between the abundance of snails and water temperature (p=0.8), pH (p=0.6), EC (p=0.9), or DO (p=0.8). Moreover, previous investigations have established that EC exerts an adverse effect on snails (Moser *et al*., 2014; Rowel *et al*., 2015). On the contrary, this assertion was challenged by other research investigations which reported EC's beneficial effects on the snails (Oloyede *et al*., 2017; Alhassan *et al*., 2020; Mereta *et al*., 2023). Additionally, it was discovered by Ezinna *et al*. (2023) that the crucial factors affecting snail reproduction were DO and pH levels.

Peletu *et al*. (2023) discovered that snail species were positively associated with alkalinity, conductivity, and negatively associated with air temperature. In another study conducted by Nwoko *et al*. (2023c), there was a statistically significant (p<0.05) and positive correlation between DO and the abundance of *B. globosus*. The correlation observed between the abundance of snails and DO can be attributed to the pollutant removal process facilitated by flowing water. As water purification increases, it becomes more conducive to snail survival (Nwoko *et al*., 2023c). Positive correlations were seen between turbidity and pH with all freshwater snail species, according to research conducted in Nigeria by Oladejo *et al*. (2021). However, all snail species, did not exhibit a significant correlation with temperature.

El-Khayat *et al*. (2022) identified a positive correlation between TDS and the abundance of intermediate host snails. This finding aligns with the results of several other studies that also observed a beneficial effect of TDS on snails (Abdulkadir *et al*., 2013; Alhassan *et al*., 2020). According to the research of El Deeb *et al*. (2017), a reduction in water hardness caused a decline in snail population and a thinning of snail shells. Furthermore, research indicates that salinity may in fact have a beneficial effect on the quantity of snails (Fuss *et al*., 2020; Urude *et al*., 2021).

Moreover, no correlation can be observed between snails and turbidity (r=-0.070) in the current study. This suggests that the snails were unaffected by turbidity at both high and low levels. Amoah *et al*. (2017), on the other hand, discovered a negative but significant correlation between turbidity and the quantity of living snail species. Conversely, alternative research has challenged this notion, positing that turbidity in fact enhances the abundance of snails (Obisike *et al*., 2018; Oladejo *et al*., 2021).

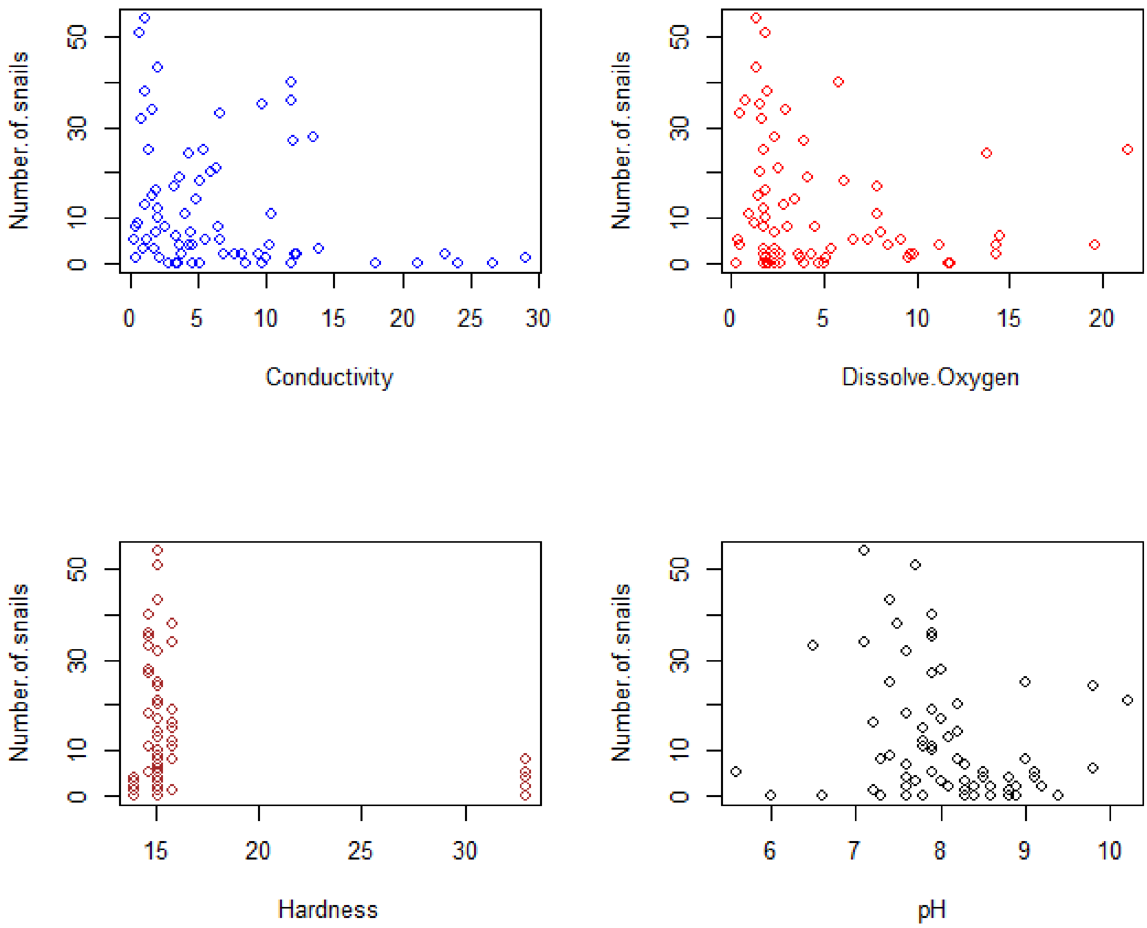

Figure 3.5: Scatterplot of the number of snails and physicochemical properties (conductivity, dissolved oxygen, hardness, and pH)

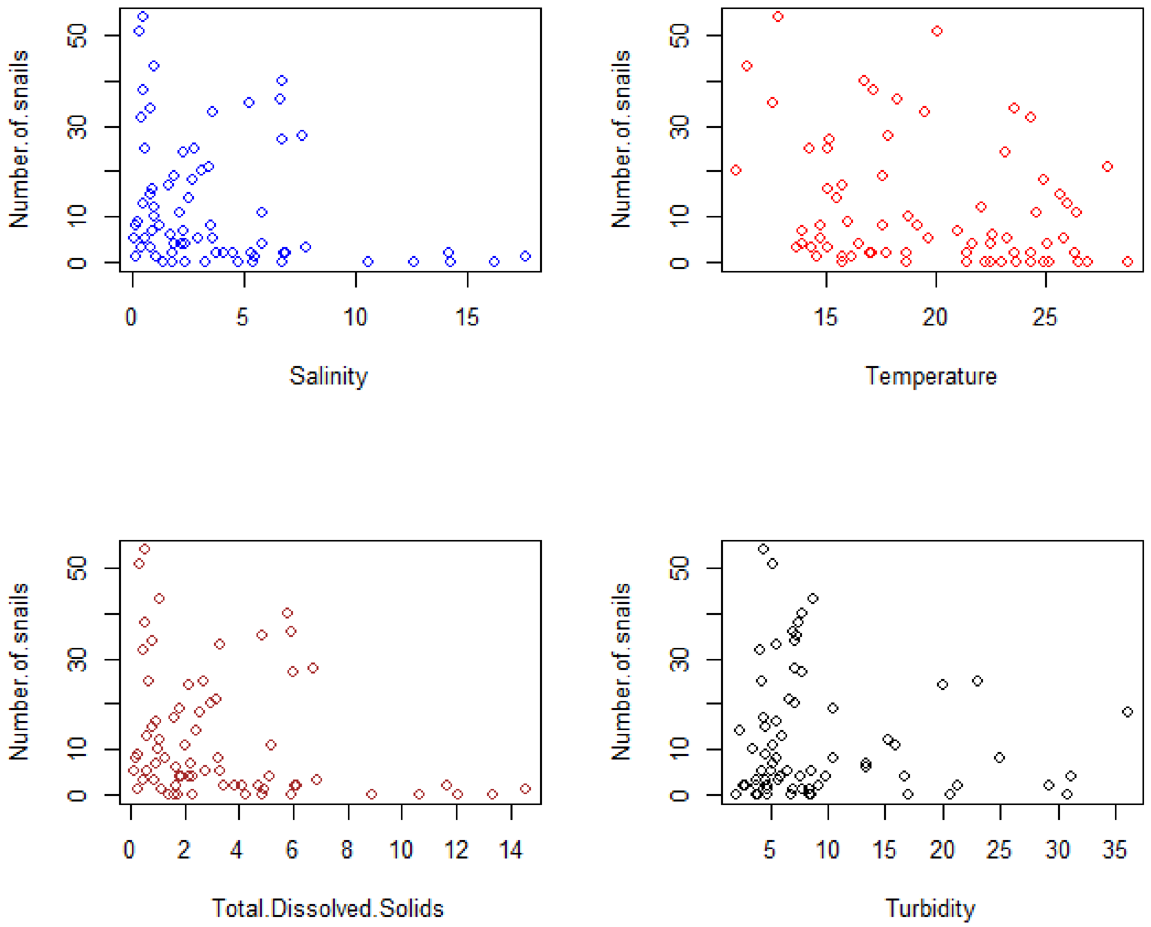

Figure 3.6: Scatterplot of the number of snails and physicochemical properties (salinity, temperature, total dissolved solids, and turbidity)

3.6 ASSOCIATIONS BETWEEN SNAILS AND VEGETATION COVERAGE

Looking at **Figure 3.7**, it can be observed that a negative and very weak relationship exists between the snails and vegetation coverage (r=-0.127). This indicates that areas with minimal vegetative cover contained the majority of the snails examined. Consistent with this discovery, an earlier investigation conducted by Min *et al*. (2022) demonstrated that *B. straminea*, an intermediate host snail for schistosomiasis, was frequently observed in areas with less emergent vegetation cover.

Nwoko *et al*. (2023c) on the other hand, discovered a positive correlation between the abundance of *B. globosus* and the Normalized Difference Vegetation Index (NDVI), suggesting that a rise in the NDVI value corresponds to a greater number of snails. NDVI reflects the quantity of vegetation present at each site; higher values imply more dense vegetation cover; this is another environmental component that influences snail abundance. Potentially, the positive correlation can be attributed to the optimal vegetation cover in the freshwater environments, which created conditions favourable for the reproduction and development of freshwater snails. Deribew *et al*. (2022) did a study in Ethiopia whereby they discovered floating macrophytes as the prevailing vegetation cover. However, no correlation was found between the abundance of snails and vegetation cover. According to the findings of Olkeba *et al*. (2020), locations characterised by emergent and submerged macrophytes had a greater abundance of *B. pfeiferi.*

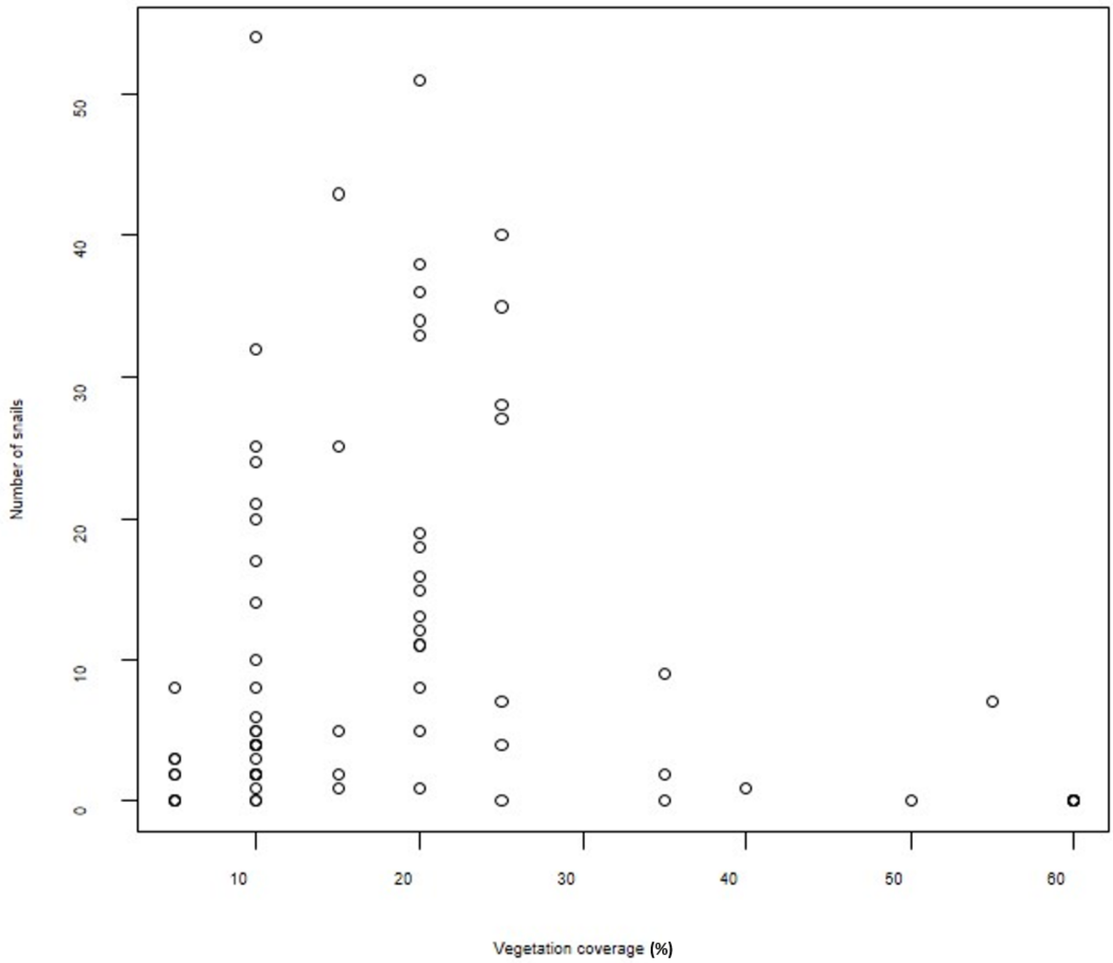

Figure 3.7: Scatterplot of the number of snails and vegetation coverage

CHAPTER 4: CONCLUSIONS & RECOMMENDATIONS

4.1 CONCLUSIONS

Most of the water bodies studied provided snails with every necessary attribute for survival. Moreover, *Biomphalaria* snails which are members of the Pulmonata order, have an enhanced capacity to endure more severe environmental circumstances due to their vascularized mantle chamber for air absorption (Habib et al., 2018; Min et al., 2022). However, they were not found in abundance in the current study, regardless of this ability. The decline in the populations of *Bulinus* (0.9%) and *Biomphalaria* (0.6%) snails could also be linked to additional factors, including competition among the snails. The study found an abundance of snails belonging to the *Physa* genus, which can be attributed to their remarkable resilience in challenging environments. Since they outcompete other snails and have little medical or veterinary significance, *Physa* snails may one day be utilized as a biological control measure in endemic regions in South Africa as this has already be done in other countries such as Mozambique. Further investigation should be undertaken in additional aquatic habitats across the NMB region, as these sites may function as potential reservoirs for intermediate snail hosts of schistosomiasis. This recommendation is supported by field observations indicating the presence of numerous additional water bodies within local communities, which could sustain snail populations critical to the parasite's transmission cycle. As a result, the outcomes of the research do not provide conclusive evidence about the absence of disease-causing snails in water bodies in NMB; rather, it is noteworthy that the snails were not found in abundance in the eight water bodies that were investigated.

4.2 RECOMMENDATIONS

EHPs

More health education programs concerning WASH as well as NTDs like schistosomiasis should be implemented by EHPs in NMB. This would serve to increase community awareness regarding these diseases and subsequently promote behavioural modifications that will interrupt disease transmission.

- In order to disseminate health education, EHPs can use alternative media sources, such as the radio, which is frequently listened to by the majority of adult community members.

- In NMB, EHPs should conduct routine monitoring of freshwater bodies and collect samples to determine the presence of intermediate host snails for schistosomiasis and other snails of medicinal and veterinary significance.

NMB municipality and Department of Education

- As NTDs and WASH are interconnected, the Department of Education should incorporate health education regarding these topics into the school curriculum. This could facilitate the dissemination of knowledge from children to parents, and subsequently, the entire community.

Environmental Health Research

- Further investigation could be undertaken about *Physa* snails, with a specific emphasis on their capacity to acclimate and withstand diverse environmental circumstances. Such research might explore the potential of these snails as a biological control agent in endemic regions and other settings.

- Further research focusing on the impact of water physico-chemical properties and vegetation type on snail abundance can be conducted in other water bodies which were not included in this current study.

- Further research may centre on the characterisation and efficacy of specific plant species that may function as a preventative measure against the intermediate host snails of schistosomiasis.

- Further studies may investigate additional physiochemical variables that have the potential to impact intermediate host snails, including water depth, calcium levels, alkalinity, bio-oxygen demand (BOD), and impact of pesticide usage as well as industrial and municipal effluents into the water bodies.

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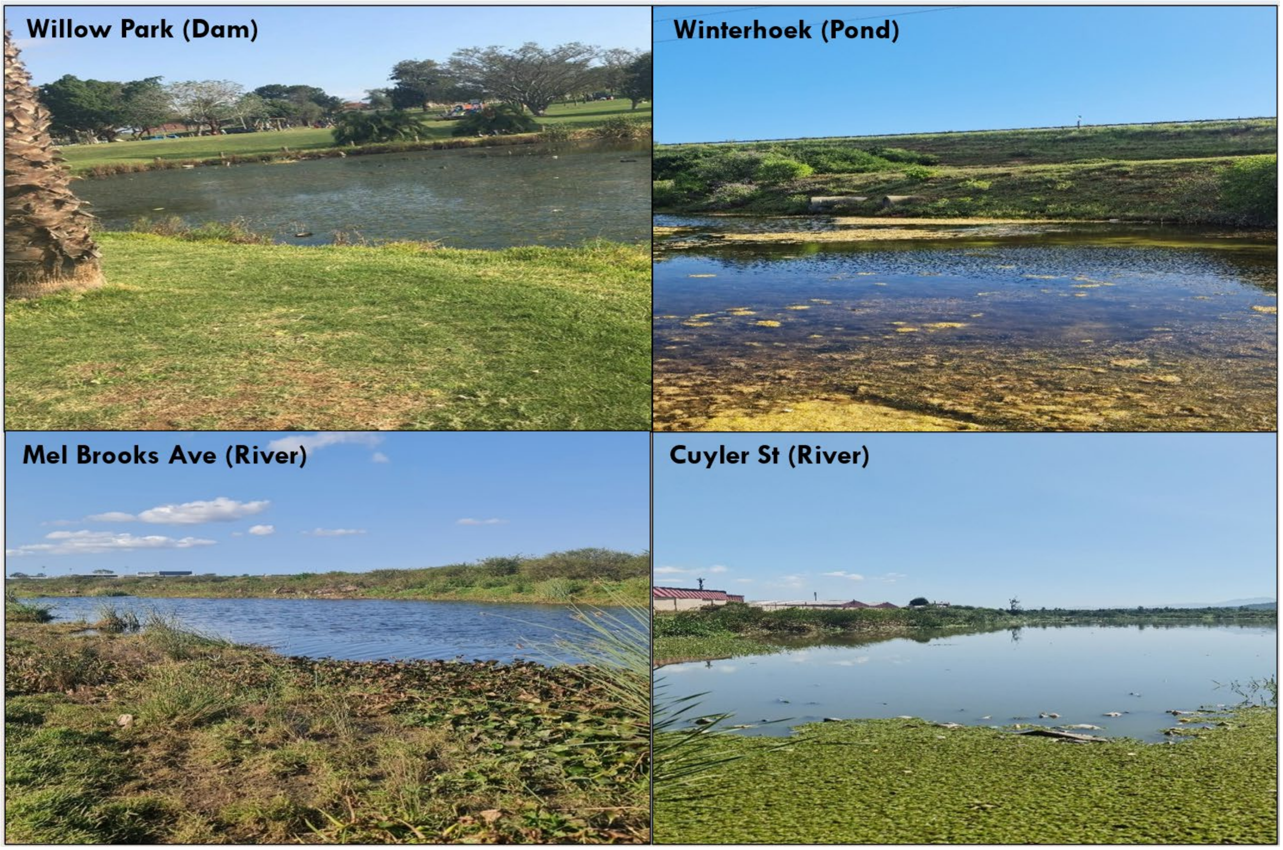
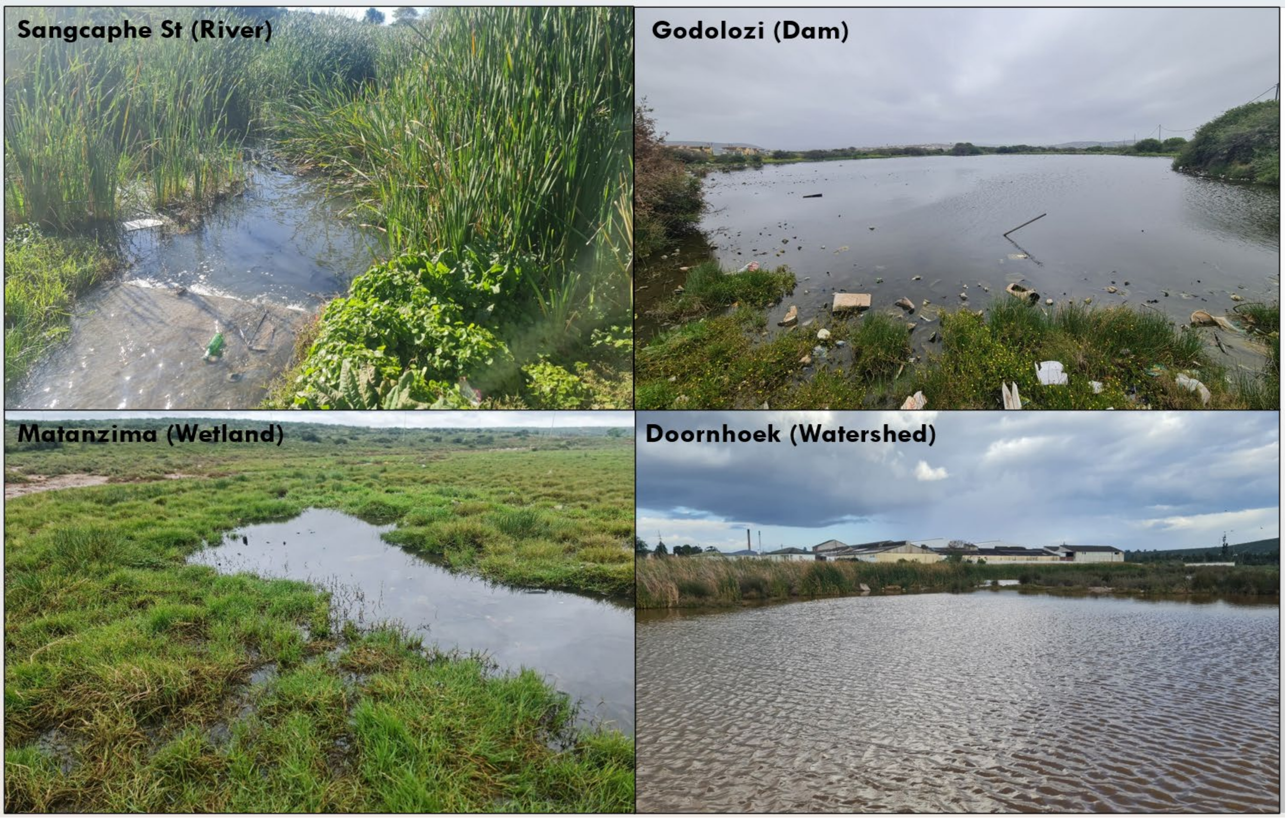
APPENDIX A: SAMPLED SITES





APPENDIX B: SAMPLING TECHNIQUES

APPENDIX C: PILOTING