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# Factors conditioning the distribution of fresh water pulmonates, *Biomphalaria* spp., *Bulinus* spp., and *Lymnea* spp., in Babati District, Tanzania.

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## **Abstract and key words**

The aim of this essay was to investigate if different variables affected the distribution of fresh water pulmonate in Babati District, Tanzania. Can the absence of intermediate host be explained by basic vegetation evaluation, pH, conductivity and temperature? Or can it be explained by other factors as animals and vegetation in the surrounding? The study was carried out in Babati District, in Lake Babati, Kiongozi/Farahani River and the irrigation schemes in Matufa and Gichamedia from the 23<sup>rd</sup> of February until 7<sup>th</sup> of March, 2009. The species found during the survey were *Biomphalaria*, *Bulinus*, and *Lymnea*. Only *Biomphalaria pfeifferi* were present in the genus *Biomphalaria*. In *Bulinus* spp., *B. globosus*, *B. forskalii*, and *B. africanus* were present. *Lymnea* spp. was represented by *L. natalensis*.

Statistical tests were carried out with logistic models. The results of the statistical analysis revealed different significant results for the different snail species present. *L. natalensis* showed a significantly positive effect of the water temperature and was distributed in water temperatures ranging from 20.9°C to 24.3°C, which is in the lower range in this study. *Biomphalaria pfeifferi* and *Bulinus* spp. were significantly affected to an increase in conductivity. *L. natalensis* did show a significant effect of the type of bottom in the water body, and found muddy bottoms more suitable. Animal activity (livestock) did show a significant effect on the distribution of *L. natalensis* which found habitats without animals more suitable. Both *B. pfeifferi* and *L. natalensis* were significantly affected by vegetation in the surrounding and found habitats with grass, shrubs and trees more favourable before cultivated areas and forests.

The statistical analysis made on the data collected in Babati District showed that temperature, conductivity, bottom in water body and vegetation in the surrounding, in general, significantly affected the fresh water pulmonate. Several variables as pH, water flow, canopy cover, vegetation in the water, however, were not significantly affecting the distribution of the snails. Further investigations of interactive effects of variables, however, are necessary to prevent high infection rates of trematodes infecting the pulmonate present in Babati District, Tanzania.

**Keywords:** snail distribution, Pulmonata, chemical factors, biological factors, Babati, Tanzania

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## **Introduction**

The focus in this research is to bring knowledge about the distribution of veterinary important snails like *Biomphalaria* spp., *Bulinus* spp., and *Lymnea* spp. As been described in other studies, different factors are conditioning the distribution of the fresh water pulmonates in East Africa. These are the physiological features of the water, aquatic vegetation, rainfall, season and activities around the water source (Abdel Malek 1958, Madsen 1985a), but also the food available, growth of aquatic weeds, oxygen content of the water, sunlight, strength of the current, nature of substratum, ionic composition of the water and presence or absence of predator and parasites. According to Abdel Malek (1958) these factors are interdependent.

Several other studies have been carried out through the years to show place specific factors in other parts of Tanzania, but not in Babati District. The aim is to investigate whether temperature, pH, conductivity or other more vegetation and habitat describing factors could give an answer to the presence of the fresh water pulmonates of veterinarian and human interests.

### ***General science of snails – Phylum Mollusca, class Gastropoda***

Phylum Mollusca is one kind of an invertebrate (i.e. animals that lack a back bone) (Campbell & Reece 2005). The Mollusca consists of snails and slugs, oysters and clams, octopuses, and squids. Most of the molluscs are living in marine habitats; however, some of them inhabit fresh land and waters. They have a soft body and most of them are protected by a hard shell. Some of them, though, have lost their shells through years of evolution (Campbell & Reece 2005). The mollusca body has three main parts; a muscular foot for moving around, a visceral mass that contains most of their organs, and they also have a mantle. Molluscs in general have separate sexes, but snails, however, are hermaphroditic (Campbell & Reece 2005).

One of the eight classes of the phylum Mollusca is Gastropoda which contains snails and slugs. Gastropoda are either marine, fresh water or terrestrial living organisms. They have an asymmetric body usually with a coiled shell, if a shell is present, and a foot for locomotion and a radula (Campbell & Reece 2005). Several of the different Gastropods have a single, spiral shell which often is conical but sometimes even flat. They have a rippling motion of their foot to by means of cilia. Most of the gastropods graze on algae or plants with their radula, and most of marine living gastropods have gills (Campbell & Reece 2005), except the Pulmonata, who has developed a pallial lung and can breathe air (Madsen 1985a).

The class Gastropoda comprises about three quarters of all Molluscs, and includes several subclasses including Pulmonata (Madsen 1985b). All of the investigated snails are Pulmonates, which is a genera of Gastropoda. The families which are investigated are Planorbidae and Lymnaeidae.

### ***Chemical factors***

Chemical factors conditioning the prevalence of fresh water snails have been described in several studies during the last 60 years, and these are conductivity, dissolved gases in water, pH and temperature (Madsen 1985a, 1985b, Abdel Malek 1958, Mapinda 2006). Attempts to explain the distribution of African fresh water snails in terms of chemical factors, however, have rarely been done (Mapinda unpubl.). Both Madsen (1985a) and Abdel Malek (1958) describe different chemical factors of more or less importance. One of these is the dionic reading, e.g. the electrical conductivity which is a measure of the total amount solids present in the water (Madsen 1985a, Abdel Malek 1958). The electrical conductivity of the water is considered as a better indicator of the toxicity of the water than the concentration of only salt present (Madsen 1985a, Abdel Malek 1958). The conductivity measures the total amount solved salts (mg/l or ppm) and the total salt is calculated like the conductivity ( $\mu\text{Siemens/cm}$ ) multiplied with 0.6 (0.5-0.7) at 25°C (Anderson & Cummings 1999). This gives that the higher the conductivity reading, the higher the salinity (Madsen 1985a, Abdel Malek 1958). Usefulness of water is depending on the electrical conductivity. Good drinking water for humans has an EC ( $\mu\text{S/cm}$ ) range between 0-800. This kind of water is also suitable for all livestock and is generally good for irrigation. In the range between 800-2500, the water can be consumed by humans although the lower range is preferable. This range is also suitable for livestock. If this water is used for irrigation, drainage and salt tolerance for the plants is important (Anderson & Cummings 1999).

The concentration of hydrogen ions is rarely a factor conditioning the presence and distribution of the snails. Investigations have shown that the pH can fluctuate in the same habitat. The pH is of importance, but not as a limiting factor because the snails can tolerate a wide range of Ph, and the snails have been found by some authors to exist in water bodies with a pH as low as 5.8 or even 4.0 up to 9.2 (Abdel Malek 1958, Teesdale 1962). The importance of pH has been argued because of its ecological and biological implications, but also because it is easy to measure in field (Abdel Malek 1958). Other factors correlated with pH as alkali reserve, carbon dioxide content, sunlight photosynthesis and the character of the substratum availability to live in the water bodies are more important than pH alone (Abdel Malek 1958).

### ***Physical and biological factors***

Physical and biological factors conditioning the presence as described by Madsen (1985b) include food availability, localization, quantity and quality of food sources. Other typical features of biological factors of importance are the fluctuation of total water in the water body, rain and dry seasons but also the water flow. The current should not be strong because of the difficulties for the snail colony to be established. They are normally not found at falls, on exposed shores of a lake or in irrigations schemes with very swift flow (Abdel Malek 1958). There are differences within the different species, however, *Bulinus* is better to withstand currents than *Biomphalaria* according to Abdel Malek (1958).

The effect of temperature on the vectors of bilharzia, are shown to have a high effect, but investigations also shows that it principally just have a big influence of the reproduction of the vectors. The higher temperature in the warm seasons are needed to maintain the vectors number, and is not just favourable for the reproduction, but it is also important because of the food availability and the availability of aquatic weeds. The aquatic weeds are a suitable surface on which the snails can use for shelter, not just for themselves but also for egg masses (Abdel Malek 1958).

Charbonnel *et al.* (2002) discusses spatial and temporal activities affecting population ecology in *Biomphalaria pfeifferi*. They argue that habitat openness (open vs. close) and season (end of dry vs. rainy season) are factors that affect the snail in population size, migration and mode of colonization. Extreme contraction of the habitat especially under dry season might lead to patchy extinctions or even total extinction. Recolonization might occur following flooding or rainy seasons.

Vectors of bilharziasis, *Biomphalaria* spp., and *Bulinus* spp. occurs over a wide range of altitude, ranging from the coast up to 2012 meters in the highlands in Ethiopia and Yemen. As been described in different investigations, the altitude itself is not a limiting factor but the collected action of different factors at the specific altitude might influence the distribution of the vectors (Abdel Malek 1958). One of the more important features, associated with the altitude, is the substratum which is viewed as part of the physical environment that influences the plants and animals present in the different water bodies. The bottom soil provides the water with different dissolved elements, different ones regarding on the type of substratum. Soils always associated with the *Biomphalaria*, *Bulinus* and *Lymnea* snails are the organic rich black cotton soils which are rich in decaying organic materials and dissolved elements particularly calcium and magnesium (Abdel Malek 1958).

The importance of sunlight has also been investigated in earlier studies (Abdel Malek 1958). The sunlight enables the macrophytic aquatic weeds and the microflora to make use of the carbon dioxide, produce carbohydrates and releasing oxygen. The sunlight itself also increases the decomposition of animal and plant remains on the bottom (Abdel Malek 1958).

To be suitable, the snail habitat should not be subject to sudden fluctuations in the water level. A small fluctuation, however, is manageable for the snails because of them being able to survive dry months by aestivating in sheltered spots, under vegetation or in the mud. In an investigation from Gaizra, Sudan, it was showed that 10% of the *Biomphalaria* and 7% of *Bulinus* were able to survive a drought (Abdel Malek 1958). Pollution is also an important feature. Industrially polluted sites, however, in where snails are absent because of the factories polluting with oils, acids and which also has a high mineral content, makes these habitats unsuitable for the snails. However, polluted sites which are used by humans for bathing and washing clothes may also be unfavourable for the snails because of the chemical contents in the detergent and soap (Abdel Malek 1958). Dr AE Makundi (pers. comm. 2009), however, suggests that these sites have a high snail abundance because of the human excrement presence. This is supported by Abdel Malek (1958) who later concludes that the snails are more present near human habitations without pollution from cleaning agents but with other contacts with humans.

### ***Schistomiasis, liver fluke and veterinary importance***

In the study area, a number of irrigation schemes are present. Irrigation schemes are used in the area to increase crop production because of unpredictable climates and the irrigations schemes are almost the only way to produce crops in some parts in Babati District (Mapinda unpubl.). Different studies in Africa have revealed that the projects with irrigation schemes in Africa have led to the increase of morbidity of human Schistomiasis (Bilharzias) because of the new habitats created for the intermediate hosts of *Schistosoma* (Hickman & Roberts 1996, Utzinger & Tanner 2000). In two different irrigation schemes the prevalence of schistosomiosis had increased seven folds, from 2-11% to 44-75% in irrigation schemes in Sudan and Mali (Talla *et al.* 1990, Oomn *et al.* 1998).

In Tanzania a number of successful water resource development programs have evolved during the years such as the lower Moshi irrigation project on River Pangan, Ikwiriri on River Rufiji, Ruaha, and Mbuyini, Bawage, and Usangu plains on Ruaha River (Mapinda unpubl.). There are also a number of small scale irrigation schemes in Tanzania, and even though only a limited environmental impact assessment has been done, studies have revealed that, example, in the lower Moshi rice project schistomiasis is a big problem. But also in other parts of Tanzania the building of new irrigation

schemes has lead to more suitable habitats for the freshwater snails acting as the intermediate host of the different trematodes infecting both human and animals (Mapinda unpubl.).

Fresh water pulmonates as *Biomphalaria* spp. and *Bulinus* spp. act as intermediate hosts for different trematodes of the genus *Schistosoma*. Schistosomiasis is an important disease of various mammals including human and some wild animals like buffaloes, zebras, (Mapinda, unpubl.) and common chimpanzee (Dr AE Makundi, pers. comm.). The different trematodes of the genus *Schistosoma* infecting mammals in East Africa are *Schistosoma mansoni*, *S. haematobium*, and *S. matheei*. The *S. mansoni* infects the planorbids of the genus *Biomphalaria* and causes common signs of colitis with bloody diarrhoea and cramps when the spined eggs penetrate through the surrounding tissues and vein walls in the definitive host (Christensen Ørnberg 1985). *Schistosoma haematobium*, which infects *Bulinus*, causes haematuria and dysuria in human. The genus *Bulinus* (e.g. *B. africanus*, *F. forskalii*, *B. nasatus* and *B. globosus*) acts as an intermediate hosts for the *S. matheei* (Christensen Ørnberg 1985).

The genus *Lymnea*, which also was present at the survey in the Babati District, 2009, acts as an intermediate host for all known species of *Fasciola* (e.g. *F. gigantica* and *F. hepatica*). Fasciolosis is a disease that infects ruminant animals like cows and goats when they ingest vegetation that carries encysted metaceariae (Dr AE Makundi pers. comm.). The adult liver fluke lives in bile ducts and bladder of the grazing animals (Mapinda unpubl.). *F. gigantica*, which is distributed in several Districts of Tanzania, has *Lymnea natalensis* as its intermediate host. *L. natalensis* is distributed all over the Babati District and its prevalence also indicated that *F. gigantica* is prevalent. These findings are also supported by data from Babati Town council, 2006, were all (100%) of Fasciolosis cases are due to *F. gigantica* (Mapinda unpubl.).

Density of snails fluctuates according to the different habitats. In a stable environment the carrying capacity will be a limiting factor by itself while in a unstable habitat, the high mortalities is caused by periodical unfavourable conditions (Madsen 1985b).

## **Methodology**

### ***Study area***

The study areas were Lake Babati, Kiongozi River/Farahani River, and the irrigation schemes in Matufa, Mawemairo and Gichamedia. All areas are located in Babati Districts in the northern part of Tanzania. Babati District and four other Districts, Mbulu, Hanang, Simanjiro and Kiteto make the

Manyara region. The District lays immediate south of Lake Manyara to the north border of the Kondo District.

The study area was the District of Babati with starting point from Lake Babati (fig. 1, appendix 1). Measurements were also taken following the Kiongozi/Farahani-river downstream, from Darajani to the Matufa/Gichamedia irrigation scheme. The time of the field research was carried out from the 23<sup>rd</sup> of February until 7<sup>th</sup> of March, 2009. During the time of research there were no significant amounts of rain fall and the small rain period before the long rains had not been that rainy. The bimodal rain season in Babati District reaches from November to May with one long and one short rain (Sandström 1995).



**Figure 1** Picture from Google Earth, search word: Babati. The picture describes the area of Lake Babati and its surroundings. Measurements were carried out along the shore (pointed at with an arrow)

The habitat was very dry at the time, the area is arid or semi arid with small seasonal variations in temperature (Sandström 1995) and the total annual rainfall range between 600-1000 mm giving an average of 800 mm annual rainfall (Mapinda unpubl.). The soils are dark and characterized by flats of lava and tuff, making the area extremely vulnerable to erosion. In the flat lands, a light coloured sand soil is present and in the valleys a more black nutrient rich soil is present (Mapinda unpubl.). The altitude in Babati District varies between 950 meters and 2450 meters above sea level (Sandström 1995). In Babati District, four main types of vegetation is present, these are open grasslands, miombo woodlands, acacia woodlands, and mountainous rain forests (Sandström 1995).

The aim was to investigate as many possible suitable habitats within the Babati District. The habitats were almost all sites where human water contact is more or less common. However, a few sites with no human contact were also included and examined.

## **Lake Babati**

Lake Babati is a fresh water lake located in the eastern part of the East Rift Valley, 168 km from Arusha at an elevation of 1,346 m on longitude 35° 45' E and latitude 4° 15' S, (Google Earth, 2009) (fig. 1) and is used by people as a source of income, primarily fishing, but also for watering animals. The typical feature of the lake is given by the gradually widening of the Rift Valley during the last million years and the lake floor might rise or fall relatively or absolutely because of this (Gerdén *et al.* 1992). The lake is a low point in the valley, and with constantly fluctuating water levels. This is primary because of the trends in the annual rainfalls in the Highlands, and with that some over flooding has occurred (Gerdén *et al.* 1992). Siltation in the lake is quite high and during the last couple of years the depth in the lake has decreased with several meters and is now about five meters as most (Nhwani, pers. comm.). The area of the lake has also fluctuated during the last couple of years, from 5 km<sup>2</sup> to 18 km<sup>2</sup> in 1990. The outlet of Lake Babati is in the Kiongozi/Farahani River (Gerdén *et al.* 1992).

Lake Babati was divided into ten different sections and in each section three different locals were studied (appendix 1).

## **Kiongozi/Farahani River**

Most of the different rivers and streams in the Babati District originates from the mountain/high altitudes and drain into Lakes but River Kiongozi/Farahani originates in Lake Babati as an overflow drain channel which in case of over flood leads the water to the Mrara bridge where the Kiongozi River starts (Mapinda unpubl.). All along the Kiongozi River there are several sites with daily human contact, where people bath, clean and water their animals. The habitat surrounding the river is diverse, from high diverse forests with mainly big *Ficus spp.* and different shrubs and a rich bird and animal life to cultivated land or sedge rich areas. Eight different places after the Kiongozi/Farahani River were studied (appendix 1).

## **Matufa and Gichamedia Irrigation Scheme**

The small scale irrigation schemes in Matufa and Gichamedia have their inflow either from natural perennial streams or rivers from which the watering of the fields is direct or through channels. Most of the fields connected to the irrigation scheme are used for paddy production (rice) in the rainy period while the main crops in the dry period are maize and other food and money crops. The areas near the irrigation schemes are also used for a sole grazing area for both domestic and wild herbivores during the period when other sources of pastures have been completely dried of (Mapinda unpubl.).

13 different localities were studied in the different irrigation schemes in Matufa and Gichamedia (appendix 1).

### ***Study species***

All of the study species are of high veterinary and medical importance because they are vectors of important trematodes infecting humans and animals; these are Schistosomiasis and Fasciolosis (Mapinda unpubl., Madsen 1985b, Christensen Ørnberg, 1985). The snails were identified using “A field Guide To African freshwater snails, East African species, 2<sup>nd</sup> edition” (1987). Study species for the field work was three different pulmonates, fresh water species, holimnic ones, who spend all their life in fresh water (Mandal-Barth 1965). The distinguished differences between the prosobranchs and the fresh water pulmonates are the absence of an operculum and by the radula in the pulmonates. Freshwater pulmonates have more delicate shells (Kristensen 1987). The three different genera present in the survey were *Bulinus*, *Biomphalaria* and *Lymnea*. They are split up into more or less different populations regarding to the nature of their fresh water habitats (Mandahl-Barth 1965). Given optimal conditions, these snails has a very high reproductive capacity, but however, under field conditions the maturation period, egg laying period and intensity is lower, which has a high influence on the distribution (Madsen 1985a).

### ***Biomphalaria spp.***

*Biomphalaria* spp. are freshwater snails and are distributed all over the Sub-Saharan area but also recently over Madagascar, probably due to human activity. Spatial distribution, recruitment, and migration of *Biomphalaria pfeifferi* is highly influenced by the rainy/dry periods of the season (Charbonnell *et al.* 2002). As all of the snails studied, *B. pfeifferi* is a hermaphroditic snail which most often fertilizes itself. It has a generation range between 39 days (at 32°) and 147 days (at 17°) under laboratory conditions. It has a small migration distance and this through active dispersal, against or following water flow. Long distance migration is possible but then through other animals, like birds, or through human activities (Charbonnell *et al.* 2002).

### ***Bulinus spp.***

The genus *Bulinus* is naturally divided into two different subgenera: *Physopsis* and *Bulinus* spp. which also includes the old subgenus *Pyrgophysa* (Mandal-Barth 1965).

### ***Lymnea spp.***

*Lymnea*, family *Lymnaeidae*, is a fresh water snail with a thin dextral (right) opening shell and in Africa, only one genus is present, the *Lymnea*. *Lymnaeidae* is up to 23x15 mm but are usually smaller. It has a

shell without spiral lines and about 4 whorls. The spire itself is much shorter than aperture (Kristensen 1987).

### ***Presence or absence***

If snails were present in the sample, they were caught and counted. “A field Guide to African freshwater Snails – East African species” from the Danish Bilharziasis Laboratory (1987) was used to identify the present species *Biomphalaria spp.*, *Bulinus spp.*, and *Lymnea spp.* The snails were recorded as the total number of snails and species obtained in each case. A colander put on a stick was scooped in the water 5 times, along a longitudinal transect, at each case of investigation (following Danish Bilharziasis Laboratory), this is a well known way of fetching snails in African habitats due to the risks with water contact. In each case 15 scoops were done.

### ***Patch variables***

First a brief overlook of the area was done, pictures of the different plots were taken and different key variables around the chose area were noticed and written down. There were different kinds of habitats present at the different plots, lake shore with submerge and emergent water vegetation, irrigation schemes with nearby vegetation like trees, shrubs and grass but also rocky water bodies with no clear vegetation around.

A map over the area, with certain interesting plots recommended by Dr A.E Makundi (pers. comm.2009), were drawn down and then used as a foundation for the following investigation. Type of water body (WB), water body bottom (BIL) water flow (FL), isolation (IS)<sup>1</sup>, vegetation around and in the water (WH, TW and VEG), activity (ACT and AN) (both human and domestic animals) were noticed and written down (table 1). At each plot the number of fetched snails, and which kind of snail that were found, were also noticed.

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<sup>1</sup> The variable “IS” (Isolation) was later taken away from the study because all of the habitats investigated were open habitats.

**Table 1 Different variables used in field.**

<b>Water temperature</b>	Temperature °C		<b>FL</b>	Water flow
<b>Conductivity</b>	Conductivity $\mu\text{S/cm}$ (mg/l)		<b>IS</b>	Isolation
<b>pH</b>	-		<b>WH</b>	Water Habitat vegetation
<b>WB</b>	Type of water body		<b>TW</b>	Type of aquatic vegetation
<b>BIW</b>	Bottom in water body		<b>ACT</b>	Activity near water
<b>AN</b>	Animals present near water		<b>BIO</b>	<i>Biomphalaria</i> spp.
<b>VEG</b>	Vegetation in surroundings		<b>BUL</b>	<i>Bulinus</i> spp.
<b>CAN</b>	Canopy cover		<b>LYM</b>	<i>Lymnea</i> spp.

Type of water body was decided and the given variables were: concrete dam/pond, ponds, natural dams, lake or water hole. The canopy cover was measured using a method by which a circle of 1.6 meters was used. The overall coverage was divided into five steps from 0 to 100 %. Notes were also taken about human and domestic animal activity around the area with variables from “no clear activity” to specific activities. Water flow and vegetation in the surroundings were briefly noticed, where a slow flowing water body was a lake and moderate to fast flow were noticed in rivers and irrigation schemes.

Water temperature, conductivity and pH were measured with a Cyberscan PC 10.

### **Statistic analysis**

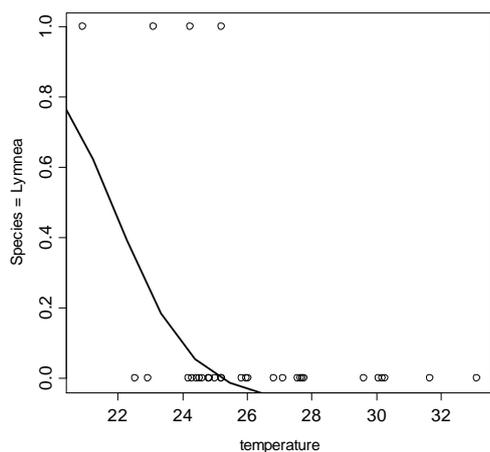
To analyze data fetched in field, the different variables were compared in Excel and then further analyzed in R using a generalized linear model with logit link. Statistical tests were carried out with the menu choice Models – Hypothesis tests – ANOVA table in R Commander’.

## **Results**

There were three different genus present in this study; *Biomphalaria*, *Bulinus*, and *Lymnea*. Only *Biomphalaria pfeifferi* were present in the genus *Biomphalaria*. In *Bulinus* spp., *B. globosus*, *B. forskalii*, and *B. africanus* were present. *Lymnea* spp. was only represented by *L. natalensis* (table 2, table 3).

### **Temperature**

The temperature in the different types of water bodies ranged from 20.9°C in the Kiongozi/Farahani River to 33.1°C, in the Matufa irrigation scheme (table 2). Only *L. natalensis* showed significant effect ( $\chi^2= 7.42$   $df= 1$   $p=0.006$ ) (fig. 2) of the water temperature and was distributed in water temperatures ranging from 20.9°C to 24.3°C which is in the lower range of the temperatures measured. *Biomphalaria pfeifferi*, and *Bulinus* spp. were found in temperatures ranging from 20.9°C up to 30.1°C (table 3) and did not show any significant effect of temperature (Table 3).



**Figure 2** Figure showing the relationship between *L. natalensis* (0: no *L. natalensis* present 1=*L. natalensis* present. and temperature.

### **pH**

The pH in the different waters ranged from 7.4 pH to 9.1 pH (Appendix 1). None of the snails showed any effect of the pH in the statistical analysis (table 3). *B. pfeifferi* was found in water with pH ranging from 7.2 to 8.8, *Bulinus* spp. in water with pH ranging from 7.6 to 8.6, and *Lymnaea* spp. in water with a pH from 7.6 to 8.8 (Appendix 1, table 3).

### **Conductivity**

The conductivity ( $\mu$ Siemens/cm) ranged from 60.9  $\mu$ S/cm to 1079  $\mu$ S/cm (Appendix 1). *Biomphalaria pfeifferi*, and *Bulinus* spp., did both show significant p-values to the conductivity ( $(\chi^2= 5.35$   $df= 1$   $p=0.021)$  ;  $(\chi^2= 4.09$   $df= 1$   $p=0.043)$ ) (Table 3). *B. pfeifferi* was present in water with a conductivity ranging from 652  $\mu$ S/cm up to 1079  $\mu$ S/cm (App. 1, table 3, fig 3), while *Bulinus* spp., was present in water with a conductivity ranging between 665  $\mu$ S/cm and 1079  $\mu$ S/cm, which is in the higher range of the conductivities. *L. natalensis* did not show a significant effect on the conductivity in the different habitats and was present in habitats with a conductivity ranging from 652  $\mu$ S/cm to 768  $\mu$ S/cm.

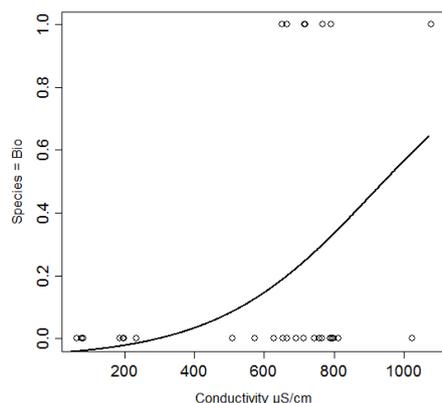


Figure 3 Figure showing the relationship between snail's species *Biomphalaria* spp. and conductivity. 0=no *Biomphalaria pfeifferi* present, 1=*B. pfeifferi* present.

Table 2 This table show the different temperature, pH and conductivities in which *Biomphalaria pfeifferi*, *Bulinus* spp., and *Lymnea natalensis*, were present.

	<i>Biomphalaria pfeifferi</i>	<i>Bulinus</i> spp.	<i>Lymnea natalensis</i>
Water temperature °C	25.2, 29.6, <b>30.1</b> , 26.8, 22.3, <b>20.9</b> , 26.4	<b>8.8</b> , <b>7.2</b> , 8.5, 8.6, 7.6, 8.3, 8.3	<b>652</b> , 715, <b>1079</b> , 665, 718, 793
pH	<b>30.1</b> , 26.8, 22.3, <b>20.9</b>	8.5, <b>8.6</b> , <b>7.6</b> , 8.3	<b>1079</b> , <b>665</b> , 768, 718
Conductivity µS/cm	<b>25.2</b> , 24.3, <b>20.9</b> , 23.1	<b>8.8</b> , <b>7.6</b> , 8.3, 8.2	<b>652</b> , <b>768</b> , 718, 714

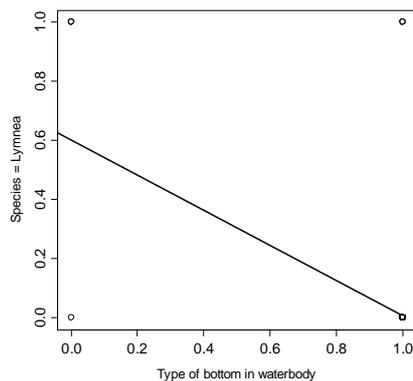
Notes: The numbers written in **bold** shows the lowest and the highest value of the different variables.

### Water body

The different families were found in either lake habitats or in rivers. No snails were found in the irrigation schemes. The distribution of the *Biomphalaria pfeifferi*, and *Bulinus* spp. and *Lymnea natalensis* did not show any significant effect depending on the water body (Lake, river or irrigation scheme) (Table 3).

### Bottom in water body

All of the snails were found in habitats with either muddy or bare ground/stone bottoms but only the *L. natalensis* did show a significant p-value ( $\chi^2= 5.61$   $df= 1$   $p=0.018$ ). *L. natalensis* was significantly positively associated with muddy bottoms (fig 4).



**Figure 4** This figure shows the relationship between *Lymnea* spp. and type of bottom in the water bodies, where x-label 0=no clear vegetation/stone/rock and 1=Muddy

### ***Water flow***

The water flow in the different habitats was very different from each other. In Lake Babati, water flow were silent (stagnant) or slowly moving while in the River Kiongozi/Farahani and Matufa, and Gichamedia irrigation scheme, the flow differed from silent water up to fast flow. All of the snails were found in habitats with either silent to slow, or slowly to moderate flow. Water flow did not have a significant effect on snail occurrence, but no snails were found where a fast flow was noticed.

### ***Aquatic vegetation***

*Biomphalaria pfeifferi* was found in all different habitats with either no vegetation, floating or submerge vegetation (included water lilies) and in habitats with emergent and submerge vegetation (sedge and other emergent/submerge vegetation). *Bulinus* spp. and *Lymnea natalensis* were found in habitats with vegetation but was absence in the habitats without any clear vegetation in the water. None of the different snail species showed any significant effects on the aquatic vegetation or type of aquatic vegetation (Table 3).

### ***Activity in the surroundings***

All of the studied snails were present in habitats with both a non clear activity in the surroundings and with clear activity in the question of human activity. The human activities in the surroundings included fishermen, people washing and bathing, but also other, not identified, activities. However, none of the snail species, *Biomphalaria pfeifferi*, *Bulinus* spp., and *Lymnea natalensis*, did have a significant p-value in the question of human activity or tadpoles present, in the surroundings (Table 3). Further notice of animal activity was also taken. Each case was given variables of animals present or not. *Lymnea natalensis* showed a significant p-value regarding the animal activity and was also the only species not

present in the habitats with animal activity ( $\chi^2= 3.39$   $df= 1$   $p=0.065$ ). *Biomphalaria pfeifferi* and *Bulinus* spp. were present in both cases (Table 3).

### Vegetation in the surroundings

The vegetation in the surroundings consisted of several different types of variables ranging from no clear vegetation (bare ground, rocks or cement) and swampy areas to cultivated areas, and bush or forest like areas. *Biomphalaria pfeifferi* and *Lymnea natalensis* were found in areas containing either no clear vegetation, areas which included grass, bushes and trees, or swampy areas. *Bulinus* spp., however, was not found in areas with grass, bushes and trees in the surroundings. Both *B. pfeifferi* and *L. natalensis* were significantly affected by the different vegetation ( $(\chi^2= 3.24$   $df= 1$   $p=0.072)$  ;  $(\chi^2= 2.84$   $df= 1$   $p=0.092)$ ) (Table 3).

### Canopy cover

The different variables regarding canopy cover ranged between 0% cover up to 100% cover in the different habitats. All of the snails were distributed in the range of 0-80% canopy cover and none of them were significantly affected by the canopy cover (Table 3).

The logistic models shows that the highest significance value of *B. pfeifferi* and *Bulinus* spp. was the effect of the conductivity, while *L. natalensis* was most affected of the temperature in the water.

**Table 3 Table showing the results of ANOVA-analyze done of generalized linear models**

	<i>B. pfeifferi</i>	<i>Bulinus</i> spp.	<i>L. natalensis</i>
	$\chi^2 =*$ $df =*$ , $p =*$	$\chi^2 =*$ $df =*$ , $p =*$	$\chi^2 =*$ $df =*$ , $p =*$
temperature	0.014589 1 0.9039	0.33541 1 0.5625	<b>7.4212 1 0.006446 **</b>
pH	0.43197 1 0.511	0.18520 1 0.667	0.05373 1 0.8167
Conductivity $\mu$ S/cm	<b>5.3515 1 0.02070 *</b>	<b>4.0946 1 0.04302 *</b>	1.2697 1 0.2598
Water Body	2.2562 1 0.1331	2.2919 1 0.1301	1.3446 1 0.2462
Bottom in Water body	0.20233 1 0.6529	0.95459 1 0.3286	<b>5.6127 1 0.01783 *</b>
Water flow	2.5159 1 0.1127	0.88612 1 0.3465	0.88612 1 0.3465
Water habitat vegetation	0.68719 1 0.4071	2.5880 1 0.1077	2.5880 1 0.1077
Type of water veg.	0.2256 1 0.6348	1.4454 1 0.2293	1.4454 1 0.2293
Activities in surrounding	0.11108 1 0.7389	1.0513 1 0.3052	1.0513 1 0.3052
Animals present	0.057108 1 0.8111	0.11512 1 0.7344	<b>3.3913 1 0.06554 .</b>
Veg. in surroundings	<b>3.2448 1 0.07165 .</b>	0.70992 1 0.3995	<b>2.8438 1 0.09173 .</b>
Tadpoles present	0.20233 1 0.6529	0.87515 1 0.3495	0.87515 1 0.3495
Canopy cover	0.18767 1 0.6649	0.14959 1 0.6989	0.14959 1 0.6989

Note: Different p-values of logistic models for the different species present in the survey. As noticed, the results varied among the species and all of the variables did not seem to have any importance when to describe the incidence of these fresh water snails.  $\chi^2 =*$   $df =*$ ,  $p =*$  The different values are separated with blank-step. Significant values are written in **bold**.

## Discussion

During the research time, the climate in Babati District was dry, with small amount of rains even though the time of research was accomplished during the short rain. The temperatures measured ranged from 20.9°C up to 33.1°C. Snails collected during the survey were *Biomphalaria pfeifferi*, *Bulinus africanus*, *B. globosus*, *B. forskalii*, and *Lymnea natalensis*. These findings were also supported by the data collected by Mapinda (unpubl.) during his study 2006. The effect of different variables on the distribution of three Pulmonata molluscs, *Biomphalaria*, *Bulinus* and *Lymnea* were analyzed using logistic models and revealed several similarities but also dissimilarities from other research done in the subject during the years.

This study revealed that the temperature, as a limiting factor did not have any influence on two of the snail genera's *Biomphalaria* and *Bulinus* spp., but did show high significance in the distribution of *Lymnea natalensis* which found habitats with temperatures ranging from 20.9 to 24.3°C more suitable. According to Madsen (1985a) the temperature has a very important effect on the life cycle of *Biomphalaria*, *Bulinus* and *Lymnea* spp. The hatching time is as lowest at 25-28°C and with a higher temperature, the hatching rate and the survival decreases. In *Biomphalaria* species, the egg production may be reduced at temperatures above 30°C due to pathological changes in their reproductive system (Madsen 1985b). This is also stated by Abdel Malek (1958) and Teesdale (1962) which investigations shows that in small water bodies, a constant high temperature can reduce the population, and this through the reduction of dissolved oxygen and volume of the water. Abundance of *B. pfeifferi* tends to be highly influenced by time and space, but also of chemical and physical features (Abdel Malek 1958, Teesdale 1962).

Woolhouse (1992) describes that in Zimbabwe, juvenile growth rate and the survival decreases over 25°C, which also is supported by laboratory findings made by the same author. Also in a literature review made by Utzinger and Tanner (2000), it was presented that water temperature in stagnant waters and the current velocity in flowing waters are key factors that determine distribution of *B. pfeifferi*. Teesdale (1962) do argue that the effect of temperature as one lonely limiting factor is not that clear on the *Biomphalaria* spp., *Bulinus* spp., and *Lymnea* spp. and continue with explaining that the general temperature curves follow the bimodal seasons with rain and dry periods with high and low temperatures. However, it has been described by Abdel Malek (1958) that vectors of schistosoma (*Biomphalaria* spp. and *Bulinus* spp.) are more tolerant to low temperatures than high ones, but can tolerate a seasonal and diurnal variation of 18 degrees in a monthly average in the different habitats. In this study, however, the findings point to the fact that in habitats in Babati District, the temperatures

does not have a limiting factor of the distribution of the two genera *Biomphalaria* and *Bulinus*, but do influence *Lymnea natalensis*. Canopy cover in the different habitats, which supplies the snails with shade and shelter, but also lower temperatures, did not either, however, show a significant effect on the distribution of the snails.

In the study area in Babati District the pH ranged from 7.4 to 9.1 pH. *B. pfeifferi* was found in water with pH ranging from 7.2 to 8.8, *Bulinus* spp. in water with pH ranging from 7.6 to 8.6, and *Lymnea* spp. in water with a pH from 7.6 to 8.8. The analysis done with the logistic models shows that the pH don't have any influence on the distribution of the Pulmonate snails present in Babati District. However, several studies have revealed facts about pH as an important and limiting factor of the distribution of fresh water pulmonate snails (Madsen 1985a, 1985b, Teesdale 1962, Abdel Malek, 1958). In other studies, the Pulmonate snails present in this survey, have been found in water with a pH ranging from as low as 5.8 or even 4.0 up to 9.2 (Abdel Malek 1958, Teesdale 1962) and the authors also argue that the different habitats contains microhabitat which the snails might find more suitable. According to several authors (Abdel Malek 1958, Teesdale 1962, Madsen 1985a) the pH itself is not a limiting factor. But the correlation to other more important factors, as the availability to substratum, sunlight, and the photosynthesis (availability of carbon dioxide) has more influence on the distribution. However, in this study, no further analysis about the pH and how it affects other variables have been done.

One factor that significantly affected the snail species *Biomphalaria pfeifferi* and *Bulinus* spp. was conductivity. Conductivity is a measure of the total amount solids present in the water. The conductivity in the studied area ranged from 60.9  $\mu\text{S}/\text{cm}$  to 1079  $\mu\text{S}/\text{cm}$ , with different values regarding the kind of water body. No analysis of interactive effects of conductivity and kind of water body were done. However, in Abdel Malek (1958) literature study, the highest dionic reading was 350  $\mu\text{S}/\text{cm}$  in *Biomphalaria* spp. and *Bulinus* spp. This study revealed that *B. pfeifferi* and *Bulinus* spp. were present in water bodies with a pH ranging from 652  $\mu\text{S}/\text{cm}$  up to 1079  $\mu\text{S}/\text{cm}$  respective 665  $\mu\text{S}/\text{cm}$  to 1079  $\mu\text{S}/\text{cm}$  and also showed a significant value, where they found habitats with a higher conductivity (higher salinity) more suitable. Anderson and Cummings (1999) describes that suitable drinking water for humans and livestock have a conductivity range ( $\mu\text{S}/\text{cm}$ ) between 0-2500  $\mu\text{S}/\text{cm}$ , with a preferable value between 0-800 and the lower range between 800-2500  $\mu\text{S}/\text{cm}$ . However, none of the measured values of conductivity falls in the range of non suitable drinking water, but it is interesting that the highest value (where both *Biomphalaria pfeifferi* and *Bulinus* spp. were present) is approximately two to three times higher than the values introduced by Abdel Malek in 1958.

In the studied area rivers, lakes, and irrigation schemes were studied. No effect of the different water bodies could be found with the results of the logistic models. This is supported by studies done by Abdel Malek (1958), Teesdale (1962) and Mandal-Barth (1965), and Madsen (1985a), however, in a literature review made by Teesdale (1962) he argued that that in hand made cement irrigation schemes, the snails were heavily distributed. However, the importance of the different water bodies is not the most important thing, which also the authors reports (Abdel Malek 1958, Mandal-Barth 1965, Madsen 1985a).

The distribution of Pulmonata snails are more complex than that, and water bodies in correlation with other factors might give another out fall, because of the different variables affecting each others (Abdel Malek 1958, Mandal-Barth 1965, Madsen 1985a). The kind of water bodies in this survey was Lake Babati, River Kiongozi/Farahani and the irrigation schemes in Matufa and Gichamedia. These different water habitats showed similarities with each other regarding water flow, human and animal activity, vegetation in the surroundings and chemical features. Further investigation regarding water body and its correlation with other factors should be of high interest because of the high distribution of snails found in irrigation schemes by Mapinda (unpubl.) in earlier years. Woolhouse (1992) also mention that the total distribution of the *B. pfeifferi* is higher during the rainy season in December and January, but decreases during the drier parts of the seasons. However, the results from this study can only be implemented in a specific time during dry periods in the time of the short Rain in Babati District, and this is why further investigations is important because of the prevalence of veterinary important diseases in the area. The unclear relationship between the different Pulmonata and its distribution within Babati District's water bodies is of highly importance in the prevention of infection.

The water flow varied from each other, but did have similarities between the sites. In Lake Babati, water flow were silent or slowly moving while in the River Kiongozi/Farahani and Matufa, and Gichamedia irrigation scheme, the flow differed from silent water up to fast flow. All of the snails were found in habitats with either silent to slow, or slowly to moderate flow. No snails were found where fast flow was noticed, and none of the snails were significantly affected by the water flow. The water flows effect is very hard to measure in snail specific places because of the micro habitats in which the snails can inhabit even if there is fast flowing water. As Abdel Malek describes, the most important feature of the water is the availability of food and substratum for the snails, and the water aquatic weeds availability to grow within the water body. However, the effect of water flow has been described as important (Abdel Malek 1958, Madsen 1985b), and in this study, the distribution of the snails are not influences by the effect of water flow.

All of the snails present in the study were found in habitats with both clear ground/rocky bottoms, but also in habitats with mud covering the bottom. However, the importance of the substratum in the water bodies is suggested to be limiting and has also been emphasized by different investigators which Abdel Malek (1958) presents. The author states that a mud rich in decaying organic material appears to be usual in the habitats of *Bulinus* in Iraq, and in Congo, *Biomphalaria* and *Bulinus* prefer shallow ponds in a savannah country rich in aquatic plants and with a bottom rich in decaying vegetable matter (Abdel Malek 1958). This is not, however, supported in this research where the snails of *Biomphalaria* and *Bulinus* did not show any significant results on the effect of the bottom layer in the water bodies. However, type of bottom seems to have a significant effect on the distribution of *Lymnea natalensis*, but not on the other pulmonates. *L. natalensis* found muddy bottoms more suitable.

The aquatic vegetation and other vegetation have been described as an important feature because of the availability of food sources for the snails (Madsen 1985a, Abdel Malek 1958). *Biomphalaria pfeifferi* was found in all kind of vegetation types but also in habitats without any clear aquatic vegetation. *Bulinus* spp. and *Lymnea natalensis* was only found in habitats with vegetation. The results presented in this study shows that there were no significant effect of the present of aquatic vegetation or by which type of vegetation present. The different type of aquatic vegetation in the studied area were divided in to floating or submerge vegetation (including water lilies) or emergent and submerge vegetation (Sedge and other emergent/submerge vegetation). This indicates that the food availability and the effect of vegetation of other variables which might influence the distribution of the snail do not have any influence of the snail distribution in Babati District.

In Babati District, most of the reachable habitats are used for either human activities as bathing, fishing and washing clothes or for watering animals. In this study, both habitats with clear activities in the surroundings and unclear or habitats not used by humans were examined. All of the snails were found in habitats with or without activity. The human activity did not show any significant effect of the distribution of the snails, they were not just present in habitats with human contact or the other way. In a recent study made by Mapinda in 2006, they found high prevalence of snails in habitats with human contact. This study was carried out from November to December. However, the data in this study does not indicate an impact of human activities regarding the distribution of *B. pfeifferi*, *Bulinus* spp., and *Lymnea natalensis*. The influence on this type of variable can be discussed further and need to be investigated during a long time because of the veterinary importance of the snails.

However, the impact of animal activities did show significant effect on the *L. natalensis*. *L. natalensis* was found to favour habitats with no animals present. This might be of highly importance because found prevalence of Fasciola infected livestock in the area where large populations of *Biomphalaria*, *Bulinus* and *Lymnea* sp, was found to be directly associated with human and domestic animals contacts sites in a survey done in November to December 2006 (Mapinda unpubl.). The study made by Mapinda in 2006, contains information from Babati Town abattoir, who concludes prevalence of infected livestock, they also concludes that the infected animals might come from other areas in Babati District than those near the sampling area. If this is the case, there is of high importance that habitats free from animals should stay free to prevent animals from getting infected with the Fasciola. It is also of highly importance that suspicious infected livestock not be introduced to habitats where *L. natalensis* might be present. Further investigations regarding the correlation of animals and *L. natalensis* are of highly importance for Babati District and should be carried out through a longer period to include seasonal and yearly fluctuations in the distribution of the *L. natalensis*.

As stated earlier in this study, the different type of vegetation in habitats nearest surroundings varied between no clear vegetation clear vegetation (bare ground, rocks or cement) and swampy areas to cultivated areas, and bush or forest like areas. *B. pfeifferi* and *Lymnea natalensis* were found in habitats containing no clear vegetation, areas with grass, bushes and trees or swampy areas. *Bulinus*, however, was not found in the areas containing a variable of grass, bushes and trees. It seems, with this data collected in this study, that the different vegetation types in the surrounded areas did have a significant effect on the distribution of *B. pfeifferi* and *Lymnea natalensis*. Organic rich soils, which also are present in the areas which might, in other cases, be unsuitable for cultivation, are also favourable for natural habitats of grass, bushes and trees. The soils are rich in decaying organic materials and contain both calcium and magnesium which are of importance for the snails (Abdel Malek 1958). Those kinds of habitats also provides a relatively stable environment for the snails, the habitats which have natural vegetation are more inclined to supply surrounding areas with shelter, organic material (used for snails as food) or relatively stable temperatures.

Utzing and Tanner (2000) argues that *B. pfeifferi* cannot withstand a habitat that dries out in the same extent that *Bulinus* and *Lymnea* species, this can support these findings because of the stable environment the present of vegetation in the surroundings gives. Utzing and Tanner (2000) also describes the spatial distribution of *B. pfeifferi* and *L. natalensis* as uneven within habitats but that they tend to prefer similar habitats, including those close to the shore line. This supports the findings regarding the similarities in the distribution. The importance of surrounding areas vegetation has not

been described, as far as I know, in studies of *Biomphalaria* spp., *Bulinus* spp., and *Lymnea* spp. This study, however, shows a significant effect of the surrounding vegetation as one explaining factor of the distribution of *B. pfeifferi* and *L. natalensis*. Further investigations, however, to divide the habitats into more explaining factors are of highly interest.

In Babati District, further investigations have to be done regarding the different variables interactive effects. However, the significant effect of the absence of animals, bottom in the water body and of temperature on *L. natalensis* and also surrounding vegetation effect on *B. pfeifferi* and *L. natalensis* might lead to new information about the distribution of these snails in Babati District. Conductivity, however, is also a highly interesting variable which showed significant results on the distribution of *B. pfeifferi* and *Bulinus* spp.

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Internet sites:

Google Earth, <http://earth.google.com/> Google Earth version 5.0, 2009-05-02 search word: Babati

## Appendix 1

Name of place	Water temperature °C	pH	Conductivity µS/cm	Biomphalaria pfeifferi	Bulinus spp.	Lymnaea natalensis
Lake Babati-Royal Beach Hotel	25,2	8,82	652	found	-	found
Lake Babati-Royal Beach Hotel	25,2	8,79	666	-	-	-
Lake Babati-Singe	30,3	8,26	691	-	-	-
Lake Babati-Mbutu	29,6	7,72	715	found	-	-
Lake Babati-Managhat	30,1	8,54	1079	found	found	-
Lake Babati-Himiti	24,3	7,83	1025	-	-	-
Lake Babati-Dipuni	27,6	8,68	758	-	-	-
Lake Babati-Kipara	26,8	8,64	665	found	found	-
Lake Babati-Nakwa (forodha la Kuryweshea)	27,1	8,91	743	-	-	-
Lake Babati-Nakwa (Forodha mzamio)	24,2	7,64	768	found	found	found
Kiongozi-Darajani near bridge	20,9	8,28	718	found	found	found
Kiongozi - Darajani 3-- m from bridge	23,1	8,21	714	-	-	found
Kiongozi River-Kiongozi Village Paeli	23,1	8,40	766	-	-	-
Kiongozi River- Kiongozi 1-- m east of bridge	24,4	8,37	789	-	-	-
Kiongozi River-west of bridge 5-- m	24,2	8,36	798	-	-	-
Kiongozi River-west of bridge 15-- m	24,8	8,21	812	-	-	-
Kiongozi River-direct east of dam	26,0	8,34	793	found	-	-
Kiongozi River-direct west of dam	26,0	8,41	793	-	-	-
Matufa-Catchment-Dam-irrigation scheme	25	8,04	195	-	-	-
Matufa-Irrigation-Scheme-1 km from dam downstream	24,6	8,10	198	-	-	-
Matufa-Kiongozi river-near bridge in 2-.1-5	25,8	8,13	186	-	-	-
Mawemairo-Matufa-irrigation Creek after bridge	22,5	8,12	195	-	-	-
Matufa-end irrigation scheme (after the road, big isolated pond)	33,1	9,02	509	-	-	-
Gichamedia-Cattle watering area	27,8	8,04	655	-	-	-
Gichamedia-Bridge about 1-- m upstream Kiongozi-branch	27,7	7,39	628	-	-	-
Gichamedia-In take-Catchment area	24,8	7,99	81	-	-	-
Gichamedia-Irrigation-channel, start	24,5	7,82	77	-	-	-
Gichamedia, irrigation channel, near footbridge	25,2	7,84	76	-	-	-
Gichamedia-Irrigation-channel near bigger bridge	30,2	7,78	574	-	-	-
Gichamedia-IFAD Bridge	31,7	7,74	61	-	-	-
Gichamedia-Madibira	27,6	7,64	233	-	-	-

Appendix 1 Table showing temperature, pH, and conductivity in each of the places investigated during the survey. The table also includes where the different snails were found.