PHYSIOLOGICAL RESPONSE OF NONDESCRIPT GOATS DRINKING WATER CONTAMINATED BY TAILINGS DUST IN SUBTROPICAL REGIONS

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N. W. SERAKALALA

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PHYSIOLOGICAL RESPONSE OF NONDESCRIPT GOATS DRINKING WATER CONTAMINATED BY TAILINGS DUST IN SUBTROPICAL REGIONS

by

NTSHETE WILLIAM SERAKALALA

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DECLARATION

I declare that the mini–dissertation hereby submitted to the University of Limpopo, for the degree of Master of Science in Agriculture (Animal Production) has not previously been submitted by me for a degree at this or any other university; this is my work in design and execution, and that all material contained herein has been duly acknowledged.

______________________________ ______________________________

Serakalala, NW (MR) **Date**

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DEDICATION

I dedicate this dissertation to my mother, Mantladi Dianah Serakalala. We made it!

List of acronyms

µS/cm	micro-Siemens per centimetre
ADFI	average daily feed intake
ADG	average daily gain
ADWI	average daily water intake
BCS	body condition score
BWT	body weight
cm	centimetre
Cr	chromium
Cu	copper
EC	electrical Conductivity
ES	clouding of cornea
FAMACHA	Faffa Malan Chart
GDP	gross domestic product
Kg	kilogram
LCI	lower confidence interval
Mg	magnesium
Mg/L	milligrams per litre
N	number of individuals
NS	not significant
P	probability
Pb	lead
R	Pearson correlation
SAS	statistical analysis systems
STD	standard deviation

TDS	total Dissolved Solids
TDS/L	total dissolved solids per litre
TSS	total Soluble Salts
UPI	upper confidence interval
USEPA	United States environmental protection agency
WHO	World health organisation

Abstract

Goat health and reproductive performance in poor, resource-limited communities in mining areas remain increasingly challenged by tailing dust contamination of surface water bodies. The broad objective of the study was to evaluate the effect of tailing dust contamination on surface water bodies on health status of goats. A total of 200 questionnaires were administered to resource-limited households in two villages of Ba-Phalaborwa Local Municipality to assess beliefs and attitudes of resource-limited farmers on the health status of goats drinking water polluted by tailing dusts in contaminated and uncontaminated areas. As a follow-up, the physiological response of 100 goats (n=100) from contaminated and uncontaminated areas were assessed twice during the cool-dry season. Body condition score (BCS), body weight (BWT), FAMACHA score, and corneal opacity (ES) were determined for dry non-lactating does (n=100). The area of the cornea that was extremely opaque was assessed to determine the degree of corneal opacity.

Contamination of surface drinking water by tailing dust was ranked highest during the cool-dry season. Urine colour, oedema of the eyelids and high kid mortality rates were perceived as the health indicators for goats drinking water contaminated by tailing dust. Contaminated areas were correlated ($P \leq 0.05$) with BCS, BWT, and ES in goats. Goats reared in contaminated areas had lower BCS and BWT ($P < 0.001$) than goats reared in uncontaminated areas. Goats in contaminated areas had higher ES and FAMACHA scores ($P < 0.001$) than those in uncontaminated areas. Body condition score (BCS) had a positive ($P < 0.001$) correlated relationship with ES. Physiological responses of does drinking water contaminated by tailing dust include lower BCS and BWT, in addition to higher ES and FAMACHA scores. It was concluded that the integration of BCS and ES are physiological response of does to consuming water contaminated by tailing dusts in subtropical regions. The integration of BCS and ES should be taken into consideration in goat programme strategies for assessing the health status of goats consuming water contaminated by tailing dust.

Keywords: Tailing dusts; river systems; water quality; seasonality; goat health; does; corneal opacity; subtropical regions

Chapter 1: General Introduction

1.1 Background

The goat population in South Africa is estimated at 12 million, with the majority found in rural areas (Mogala, 2017). Across the continent, around one billion people depend on goats to ensure food security, especially in households with limited resources (Matemilola, 2017). In Sub-Saharan Africa, goats contribute significantly to agricultural income, accounting for about 40% (Staal *et al*., 2009). Goats play a crucial role in providing protein for human consumption, responsible for producing one-third of the world's protein intake (Getyengana, 2021). For instance, in South Africa, goat production constitutes a substantial portion, contributing 25 to 30% of the annual agricultural output in the form of milk, meat, and live animals (Mataveia *et al*., 2021). In communities with limited resources, goats are highly valued as they serve multiple purposes, including subsistence, reflecting social status, and contributing to household food security. The global consumption of goats is on the rise due to an increasing human population (Miller and Lu, 2019). However, this growth comes with challenges, particularly the pressure on natural resources, notably water.

Mining has always been recognised as an environmentally and socially disruptive practice (Zhengfu *et al*., 2010). Be that as it may, it has been the key industry behind the economy of South Africa (Masindi *et al*., 2015). There have been several studies focusing on tailings contamination in water, most of which dealt exclusively with aquaculture and fishery management. Mine tailings in drinking water's effect on livestock has not been extensively documented. Tailings are huge volumes of mine waste generated after the extraction of valuable metals, minerals, mineral fuels, or coal from the mining resource stored in upstream dams (Mascaro *et al*., 2001). Considering that the ore is not completely processed, tailings also contain sulphides and oxides (Kan *et al*., 2021). Leakage of tailing dams, and retention wall failure as a result of the breach after an earthquake or lots of rain, poor maintenance, and inadequate drainage is an issue of great and growing concern for resource-limited households located close to mining areas. Efforts to comprehend heavy metals contamination effect from mine tailings on the surface water have, however, focused on the health of humans (Colin-Torres *et al*., 2014; Belle *et al*., 2021), and paid little attention to the health status of livestock. The accumulation of copper metal causes cellular damage, dizziness, Wilson's disease, irritation of the upper respiratory tract and nasal mucous membranes, epigastric pain, hemolytic anaemia, and death (Fashola *et al*., 2016). There is little and unclear information on the effect of copper metal on the health status of goats.

1.2 Problem statement

Goats are important livestock animals for resource-limited households in developing countries. They provide meat, milk, fibre such as mohair and cashmere, social functions, and the generation of additional household income by selling as live animals (Qokweni *et al*., 2020). Due to excessive evapotranspiration, resulting in a water cover that prevents the oxidation of sulphides and waste rocks, tailings containing toxic heavy metals get blown by the wind and contaminate surface water sources used by goats for drinking in the villages that surround the mining areas. Heavy metal toxicity such as iron and copper causes oxidative stress, while lead, aluminium, and tin are neurotoxic, and nickel, cadmium, and chromium are carcinogenic (Nolan 1983; Kim *et al*., 2019). Heavy metal toxicity causes anaemia either through the disruption of haemoglobin production (lead and cadmium), inhibition of red blood cell formation (lead, gold, copper, and arsenic), increased destruction of red blood cells or impaired iron metabolism (lead, copper, and arsenic) (Rana *et al*. 2010). This is why goats traverse extensive distances seeking less polluted water sources for hydration (Mseleku *et al*., 2020). Information on the effect of tailing dust contamination in drinking water on the physiological responses of goats is limited and not conclusive.

1.3 Justification

Extensive research has been done to assess the effect of heavy metal toxicity the physiological responses of livestock (Rana *et al*., 2010; Sardar *et al*., 2013; Miguel *et al*., 2023). Rana *et al*. (2010) reported that there are several ways that heavy metal toxicity causes anaemia: it can interfere with the production of haemoglobin (lead and cadmium), inhibit the formation of red blood cells (lead, gold, copper, and arsenic), increase the destruction of red blood cells, or impair iron metabolism (lead, copper, and arsenic). Consumption of heavy metals above the normal range causes anaemia, BWT loss, and BCS, and Opaque, as well as opaque eyes with lids partially to fully closed in the ES (Dereure, 2001; Türkdogan *et al*., 2003; McLain, 2007; Arora *et al*., 2008). However, conclusive evidence on the physiological response of goats drinking water contaminated by tailing dust high in heavy metals is limited. It is therefore, pivotal to examine the physiological responses of goats drinking water contaminated by tailing dust high in heavy metals. The findings of this study will furnish insights into the physiological responses of drinking water contaminated by tailing dust containing substantial amounts of heavy metals. The information will be beneficial in cautioning resource-limited farmers on toxins posed by tailing dust as well as the implementation of supplementary strategies to alleviate hazards to livestock health. Understanding the influence of tailing dust contamination in drinking water can help policymakers Department of Water Affairs (DWA) devise region-specific strategies to mitigate the adverse health effects of tailing dust contamination on goats' drinking water.

1.4 Aim

To evaluate the effect of tailing dust contamination in drinking water on farmer's attitudes & beliefs and physiological responses of goats.

1.5 Objectives

The objectives of the study were:

I. To investigate farmer perceptions on how drinking water with tailing dust contamination influences the health status of goats.

II. To determine the effect of tailing dust contamination in drinking water on the body condition score (BCS), body weight (BWT), corneal opacity (ES) and FAMACHA score of goats.

1.6 Hypothesis:

I. Perceptions of the effect of tailing dust contamination in drinking water on the health status of goats across locations are similar.

II. Tailing dust contamination in drinking water does not affect the body condition score (BCS), body weight (BWT), corneal opacity (ES) and FAMACHA score of goats.

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Chapter 2: Literature review

2.1 Introduction

Goats play a central role as a primary source of protein in many resource-limited areas (Mapiye *et al*., 2009). They also play a significant role in improving livelihoods and reducing poverty within African communities (Rotberg, 2013). However, goat production in Southern Africa faces numerous challenges, including water scarcity caused by drought, diseases, feed shortages, and predation (Mdladla *et al*., 2017). Among these challenges, the rise of mining industrialization has led to the dumping of discharges into river systems. This has become a global crisis affecting the entire agricultural sector, as goats from developing countries like Africa and the Middle East, where mining activities are prevalent, end up drinking water contaminated with mining tailings (Sternber *et al*., 2022a). Previous studies on mine tailings have mostly focused on aquatic management aspects (Lavoie *et al*., 2012; Gabriel *et al*., 2020), with limited consideration given to the impact on livestock health. This chapter aims to address the issue of tailing dust contamination in waterways such as rivers and lakes, specifically examining its effect on water quality concerning the health and productivity of goats under communal farming systems. Various water management strategies will be discussed, along with methods to assess the health of goats exposed to water contaminated with tailing dust.

2.2 Goat production system in resource-limited areas

Most farmers with limited resources in rural areas raise goats under an extensive production system (Masika and Mafu, 2004). An extensive production system is characterised by small inputs of labour, capital, land and water scarcity (De Sherbinin *et al*., 2008). Presently, ownership of goats in rural areas is declining as a result of many factors discouraging farmers from practicing goat farming. The situation worsens in areas close to mines due to contaminated river systems (Celozzi *et al*., 2022). Goats in extensive systems are left to look for their water and food, and commonly, in areas close to mines, they drink water contaminated with mine tailings which results in complications to their health. Although water quality is not commonly mentioned as a constraint in goat production, Mhlongo (2015) reported that water quality for prolonged periods causes goat mortality. This is worse in semi-arid and dry regions where goats are repeatedly exposed to water that is of poor quality.

2.3 Importance of goat production in resource-limited areas

Goats play an integral part of rural livelihoods as they provide meat in the form of chevon, milk, skin, mohair and manure (Haenlein and Ramirez, 2007). Furthermore, goat's skin can be transformed to mats, drums and tents (Akhtar, 2018). There are still major improvements needed to commercialize goat production in rural areas to generate capital and employment (Coetzee *et al*., 2005). Education remains the centre of commercialization because after educating rural farmers, proper strategies can be developed to improve capital output. Communal goats hold significance in traditional ceremonies (Simela and Merkel, 2008). The same authors further reported that it is believed that goats serve as a bridge between the living and the dead during traditional ceremonies. Goats are also used during marriages to solidify kinship ties. However, the present valuation methods are based on monetary criteria and frequently disregard the non-monetary contribution of goats to families, it is difficult to determine the true value of goats at the household level. Limited data exists regarding the exact contribution of goats to human food security and livelihoods (Saico and Abul, 2007).

Presently, water scarcity and quality limit goat productivity in the country, forcing goat farmers to leave goat farming (Sejian *et al*., 2021). Goat farmers, instead tend to keep a small amount which they can be able to provide freshwater for and others will be sold. Mine tailings affect the water quality for goats. However, the extent of tailing dust contamination damage to goat productivity has not been studied, and this research intends to provide documentation in that regard.

2.4 Management of indigenous goats in resource-limited areas

Most indigenous goats kept in rural areas are old goats (Rumosa Gwaze *et al*., 2009). Several authors reported that goats in rural areas are subjected to poor management systems (Rumosa Gwaze *et al*., 2009). The majority of goats in rural areas are raised under a free-range system where they are left to look for their water and food. In communities where there are rivers, goats consume water from river sources, however, their impact on goats' health is unknown. Alternatively, Mdletshe *et al*. (2018) reported that they can walk for long distances in pursuit for freshwater. Water sources commonly found in rural areas are rivers, dams, springs and groundwater (Homann *et al*., 2007). Little, if any, is acknowledged on the quality of drinking water in these water sources and how they impact goat's health. The situation becomes worse when goats are reared in areas where there are ongoing mining activities because goats end up consuming heavy metals in water and feed.

2.5 Characteristics of Indigenous Goats of Southern Africa

Table 2.1 summarises the physical traits and features exhibited by native goats in the Southern African region. These indigenous goats encompass a blend of larger breeds (such as Nguni, Tswana, and Matebele) and smaller East African breeds (like Landin, Mashona, and Malawan). They are typically recognized by their compact physique, gradual development rate, limited milk production, and relatively low carcass weight. In many resource-limited areas, the goat population is dominated by non-descript breeds characterised by a mixture of different breeds (Tshabalala *et al*., 2003).

2.6 Importance of water to livestock

Water is the most precious natural resource in South Africa. According to Progovac and Benítez-Burraco. (2019), goats can survive for approximately 60 days without food, but they can only last around seven days without water. They are exceptionally efficient when it comes to water consumption, exhibiting the lowest water turnover rates per unit of body weight as noted by Tao *et al*. (2020). In penned-meat goats, it was reported by the same author that they consume about 0.7 L of water daily. The demand for water and its usage by goats is significantly influenced by factors such as seasonal changes, variations in water quality, and the proximity to water sources, as highlighted by Umar *et al*. (2014). The agricultural sector in South Africa receives approximately 60% of the country's available total water (Maila, 2006). Freshwater availability is an increasing concern to the economy of South Africa. This threat forces municipalities to clean a large amount of water to accommodate both humans and livestock, however, it's expensive.

Tailings discharge to waterways without treatment limits the availability of freshwater for livestock. However, the extent to which tailings discharges affect water quality has not been sufficiently studied (Arif *et al*., 2021).

Table 2.1: Phenotypic characteristics of indigenous goats in Southern Africa

Breed	Adult weight (kg)		Phenotypic characteristics	Colour
	Male	Female		
Nguni (Mbuzi)	40	30	Small-medium sized ears; Horned; Compact; Small females with large males; bearded; Short hair	Multi-coloured
Northern Cape Speckled	N/A	N/A	Large frame; Well-muscled; Large dropping lob ears; Short glossy hair	Red, red-brown, or black spots
Eastern Cape Xhosa Lob Ears	32	29	Large frame; Robust; and well-muscled	Multi-coloured
Tswana	44	40	Horned; Loped sized ears; Bearded; long neck; shallow chest; Short and fine coats	Multi-coloured
Kunene-Koakoland	N/A	N/A	Medium frame; Slender; Long hanging ears; Short glossy hair coat	Multi-coloured

Source: Pieters. (2007)

2.7 Water challenges in rural communities

In most rural areas, household water plays a crucial role as an essential resource for various purposes, such as feeding goats, irrigating gardens, brewing, and making bricks (Ncube *et al*., 2018). Remarkably, water insecurity can have both direct and indirect effects on the overall household production and the opportunities to generate income. Due to climate change, water pollution, and the growing human population, freshwater remains a scarce commodity. (Abedin *et al*., 2019). Moreover, the demand for livestock products is expected to double by 2050 as a result of population growth, urbanization and rising incomes (Oosting *et al*., 2021). Lack of freshwater in resource-limited areas causes competition for freshwater between humans and livestock (McDermott *et al*., 2010).

Drought is the most common concern amongst rural resource-limited farmers (Sternber *et al*., 2022). When there is drought, rainfall and mineral precipitation iareless, thus, resulting in increased evapotranspiration. Hence, tailing dust dispersed through the air into river systems. Mavhura *et al*. (2013) discovered that tailings dust affects water quality for goats over prolonged periods. The extent of damage to water quality needs to be extensively studied.

2.8 Factors influencing water quality

2.8.1 Tailings

Ore processing activities such as mines have always been associated with high environmental contamination. Numerous authors have reported instances of tailing dust contaminating water sources (Caldwell *et al*., 2015; Zhou *et al*., 2016; Addo-Bediako and Rasifudi, 2021). The collapse of mine dams results in discharges as tailings that find their way to waterways affecting water quality. Tailings consist of non-biodegradable heavy metals which are harmful to livestock (Saxena *et al*., 2020). These heavy metals build up in water and due to their non-biodegradability, affect the quality of water for goats. During drought, tailings are carried by wind as dust to different river systems. Do Carmo *et al*. (2017) reported that the 2015 Samarco tailings dam failure in Brazil released millions of kg of tailings into the Doce River, contaminating drinking water supplies for millions of people and killing thousands of fish and livestock. However, the extent of tailings contamination and damage to goat’s organs remains unknown.

2.8.2 Salinity

Excessive salinity in drinking water can negatively affect the water quality of goats. According to a report by Mdletshe in 2015, salinity levels exceeding 5.5 g TDS/L have been observed to cause a decrease in average daily water intake (ADWI), average daily feed intake (ADFI), and reduced average daily gain (ADG) in livestock. Salinity can be measured through various indicators such as Total Dissolved Solids (TDS), Total Soluble Salts (TSS), or Electrical Conductivity (EC).

High evaporation rates contribute to the excessive salinization of available surface water (McGregor, 2004). Consequently, this elevated salinity level enhances the mobilization of heavy metals in soils. The extent of mobilization depends on factors such as the type and total amount of heavy metals present and the specific salt responsible for the salinization process. Thus, it is crucial to consider all these factors when evaluating the risk of heavy metal release from soils affected by salinization, as highlighted by (Acosta *et al*., 2011).

Cummings (2002) reported that drinking water with an EC of less than 5800 µS/cm is suitable for all livestock. EC levels between 16500 and 25000 µS/cm are deemed appropriate for dry stock, while EC levels exceeding 25000 µS/cm are not suitable for livestock.

Vincent. (2018) reported that goats generally prefer salinity content below 2000 mg/L. The same author further reported that goats can consume moderate amounts of highly saline water for a few days without harm, provided they have not been previously deprived of water. However, abrupt changes from low salinity to highly saline water can lead to more health issues compared to a gradual transition. Forbes. (2013) supported the findings of Mdletshe. (2015), stated that when goats are provided with saline water, a reduction in water intake is highly likely to be accompanied by a decrease in feed intake. Tailings contribute to water salinization, although this outcome relies on the specific types of heavy metals contained within the tailings.

2.8.3 Sedimentation

Sedimentation is a water treatment method where water remains relatively stagnant, allowing suspended solids to settle at the bottom due to gravity, forming sediment (Park and Koo, 2015). The sediment can contain various substances, including nitrogen and phosphorus concentrations, pathogens like bacteria and protozoa, and oxygen-demanding materials, all of which influence water quality. Additionally, heavy metals can bind or adsorb to the sediment particles and subsequently be transported to different locations. These pollutants may later be released back into the environment. Chahinian *et al*. (2012) reported three ways in which pollutants can be transported as sediments namely chemicals, nutrients and pathogens. While the exact magnitude of sediment contamination remains uncertain, Burton. (2002) reported that it is evident that significant amounts of sediments in industrialized countries are tainted with metal and organic chemicals at levels that present risks to both animals and humans. Niu *et al*. (2019) reported that in livestock, sedimentation primarily occurs in cattle production when there is high animal stocking density coupled with trampling brought on by ongoing overgrazing from overgrazing and soil erosion. Mulligan *et al*. (2001) reported that heavy metals constitute the highest sediments in water, however, their impact on livestock health is unknown.

2.8.4 Oxygen demanding materials.

Oxygen-demanding materials refer to the amount of oxygen that bacteria and other microorganisms consume while breaking down organic matter under specific aerobic conditions and at a particular temperature. When the tailings from mines are discharged into the environment, they introduce organic content pollution into the receiving waters. High concentrations of organic matter can lead to a depletion of dissolved oxygen levels in the water. For bacteria to survive in water, they require organic materials that come from decomposed waste, which serve as both a substrate and an energy source. Mdletshe *et al*. (2017) reported that these bacterial species create aerobic conditions by using the dissolved oxygen present in water. Thus, this results in an increased rate of oxygen depletion in water from high levels of organic waste emitted.

2.8.5 Pathogenic bacteria

Pathogen contamination such as bacteria, fungus, protozoa, and viruses in high concentration poses a severe risk to water quality. The movement of pathogens from surface water to groundwater can make groundwater more susceptible to contamination (Jin and Flury, 2002). There are pathogenic organisms that are significant biological pollutants of water which include species of Cryptosporidium and Giardia lamblia, *E. coli 0157:H7*, C. jejuni, Salmonella, and fungus (Griffin *et al*., 2004a). The above-mentioned specie’s impact has been sufficiently explored by many authors (Jin and Flury, 2002b; Griffin *et al*., 2004; Lim *et al*., 2010; Ramírez-Castillo *et al*., 2015), and found a significant impact on water quality. The most severe bacteria is *E. coli* O157:H7 of which Lim *et al*. (2010) reported that young growing goats infected with *E. coli* O157:H7 are at a higher risk of experiencing severe issues, such as kidney failure and, in some cases, fatalities.

2.9 Environmental consequences of mining on livestock production

2.9.1 Water quality

The mining industry uses large quantities of water. The failure of the catchment dam to hold tailings forces discharges to river systems, which poses a threat to water quality for livestock. Several authors have reported the toxicity of tailings to river systems (Carrizales *et al*., 2006a; Alloway, 2012a; Tang *et al*., 2020). Freshwater ecosystems are facing a serious threat due to increasing human activities (Ashton and Dabrowski, 2011). According to Zhengfu et al. (2010), the discharge of metal-containing pollutants into the environment from human activities is the main cause of heavy metal contamination in surface and groundwater. Additionally, Jabeen et al. (2012) reported that goats that drink water from polluted environments accumulate heavy metals in their bodies. The lack of proper water and wastewater treatments, along with the growing industrial activity, has resulted in a rise in heavy metal contamination in ponds, rivers, and other water sources.

2.9.2 Land disturbance

Mining can impact land use in two ways which can be directly, by altering the land surface through activities such as excavating, blasting, and dumping; and indirectly, by creating demand for infrastructure such as roads and railways, which can lead to deforestation and other changes in land use (Zhengfu *et al*., 2010). Mining disrupts livestock and crop production by destroying grazing land, polluting water supplies, and increasing the risk of soil erosion. Topography failure from mining affects landslides and sinkholes, which can damage infrastructure and displace people. Guo *et al*. (2013) reported that affected topography causes flooding of contaminants into the water systems. Soils and rivers are contaminated with tailings when acid water from a mine flows through. This can lead to several environmental problems, including the death of fish and other aquatic life, the contamination of drinking water, and the destruction of vegetation (Lin *et al*., 2010). The chemical exposure from tailing dams collapse causes erosion of land and disturbance (Gao *et al*., 2022).

2.9.3 Air quality

Mine pollutants spread more rapidly in the air than in water (Zhengfu *et al*., 2010c). In cases where mines are constructed properly, solid minerals can still be transported through the wind to water sources. This is primarily attributed to the release of solid and liquid particles, including airborne dust (particulate matter), as well as gases like methane and sulphur dioxide (Munnick *et al*., 2010). The emission of mine pollutants is linked to the processing of substantial amounts of sulphur-containing minerals (Kaonga and Kgabi, 2009). The inhalation of contaminated dust, containing droplets of heavy metals, has been linked to significant health issues in goats (Manamela, 2021). Such health problems include respiratory infections, premature mortality, and cardiovascular diseases in goats (Ventura *et al*., 2017). In most cases, these pollutants are carried as dust during droughts to different river systems used by goats as water sources.

2.10. Tailings contamination effect on human and livestock health

Table 2.3 depicts the impact of tailings on the health of both humans and livestock. The increasing amount of heavy metals in drinking water sources is becoming a growing concern. Various studies conducted in developing countries have investigated the occurrence of heavy metals in drinking water sources and their association with health hazards in humans and animals. These studies include Emmanuel et al. (2009), Rossiter et al. (2010), Holecy and Mousavi (2012), Chowdhury et al. (2016), and Rahman et al. (2017).

It is important to note that some heavy metals pose significant risks to human health. These include lead, mercury, cadmium, copper, arsenic, thallium, and selenium, as reported by Alloway in 2012. Exposure to environmental copper has been linked to decreased IQ in children and elevated blood pressure in adults, according to Carrizales et al. in 2006. Lešková et al. in 2022 found that copper can disrupt biochemical reactions, while other heavy metals can block essential biological processes such as nutrient absorption. Furthermore, heavy metals tend to accumulate in the body, resulting in toxic concentrations after prolonged exposure. It is also important to note that some heavy metals, such as arsenic, beryllium, cadmium, and

“Table 2.2: Characteristics of common heavy metals.

Heavy metals	Human and livestock health effect	Common sources	Maximum contaminant level	
			USEPA[a] (mg/L^{-1})	**WHO[b] (mg/L^{-1})**
Arsenic (As)	Skin damage	Naturally occurring	0.010	0.010
	Circulatory system issues	Electronics production		
Cadmium (Cd)	Kidney damage	Naturally occurring	0.005	0.003
	Carcinogenic	Various chemical industries		
Chromium (Cr)	Allergic dermatitis	Naturally occurring	0.1	0.05
	Diarrhea, nausea, and vomiting	Steel manufacturing		
Copper (Cu)	Gastrointestinal issues	Naturally occurring	1.3	2.0
	Liver or kidney damage	Household plumbing systems		
Lead (Pb)	Kidney damage	Lead-based products	0.0	0.01
	Reduced neural development	Household plumbing systems		
Mercury (Hg)	Kidney damage	Fossil fuel combustion	0.002	0.006
	Nervous system damage	Electronics industries		

A-values were established by the United States Environmental Protection Agency (USEPA) in 2019, while B-values were established by the World Health Organization (WHO) in 2017.“

chromium, are known carcinogens. Many authors have highlighted these risks to human health.

2.11 Strategies developed to conserve water

2.11.1 Wastewater reuse

Wastewater collected after bathing, washing and cleaning can be used as a substitute source of water for goats. The reuse of wastewater is suitable for goats' drinking due to the non-harmful chemicals contained (Bailone *et al*., 2021). Wilderer. (2004a) further reported that wastewater collected in showers and bathtubs contains sodium bicarbonate which helps buffer the rumen environment in goats which Increases water intake. Although some wastewater might be harmful depending on the soaps used, Wilderer. (2004b), however, reported that the majority of wastewater collected in resource-limited areas is not harmful to goats. The impact of goats drinking wastewater has not been extensively studied, particularly in the context of health impact to goats, however, wastewater is better compared to tailings contaminated water for goats drinking.

2.11.2 Rainwater harvesting

Rainwater harvesting entails the capture, diversion, and storage of rainwater for goats' drinking and domestic use. DeBusk. (2013) reported that throughout history, people in rural areas shared freshwater with their livestock. Harvesting of water involves direct collection of rainwater from roofs and paved courtyards to empty containers for collection. Rainwater is free which makes the strategy beneficial in resource-limited rural areas. It will be beneficial to reduce water demands on potable water systems from sharing with livestock.

2.11.3 Treatment of mining discharges

The treatment of mining discharges has been discussed to great lengths (Brown *et al*., 2002; Cravotta and Brady, 2015a). The same authors reported that the treatment of mine discharges in tailing dams' prior release to waterways is the most efficient method to control mining discharges. For this method to be effective, chemicals such as limestone and sodium hydroxide are added to the effluents in the constructed borehole to clean the water before release to the rivers (Cravotta and Brady, 2015b; Haalck *et al*., 2021). The borehole is designed as a dual-compartment sump to allow pumping in conjunction with sump cleaning. The borehole water would still be pumped into the series of ponds and then be utilized as preparation plant makeup water. This will ensure that the effluents are safe for livestock consumption to avoid health risks.

2.11.4 Boiling

Boiling water for 15-20 minutes raises its temperature to the boiling point and kills all contaminants (Somani et al., 2011). This method, however, is not practised in many rural areas due to the amount of work and time needed to boil water (Parc *et al*., 2017). McLennan. (2000) stated that boiling is a basic and simplest method of disinfection contaminated water, however, it can only be applicable on a small scale. Despite its effectiveness in disinfecting water, the applicability to remove heavy metals has not been extensively explored at a large scale and, thus, merits further investigation.

2.11.5 Solar disinfection

Several authors have reported on the germicidal effects of sunlight (Malato et al., 2016; Forbes et al., 2021). However, further research is required to fully understand the ecological implications and the practical applications of this phenomenon. Solar water disinfection is a simple and effective method for small quantities of water (up to 3 litres) (Fadhil, 2003; Mani et al., 2006). Prototype units can be designed to disinfect water using sunlight, and their effectiveness has been demonstrated over the years (Somani et al., 2011b). Solar-disinfected water is free from taste and odour, and effectively destroys contaminants. Nevertheless, this method has some limitations, such as requiring more space and uniform solar radiation throughout the day. This aligns with the criteria in resource-limited farmers as sunlight is always available with generous spacing.

2.12 Measures of assessing the health status of goat drinking water contaminated with tailings.

2.12.1 Body weight (BWT)

The productivity of goats can be measured by their body weights. Goats drink less water when contaminated with mine tailings due to the salinization of water (Attia-Ismail *et al*., 2008a). Less water intake in goats is most likely associated with low nutrient intake (Obiri-Danso *et al*., 2008). Goat’s body weights can be used as a health indicator for goats, however, the effect of tailings contamination on body weight remains under investigation.

2.12.2 Body condition score (BCS)

Goats lose their condition when they are sick or not eating. Body condition score (BCS) can serve as an indicator of goats' health. The condition of goats can be assessed on a scale of 1-5 according to the method described by Suiter. (1994) and Mahieu *et al*. (2007). The effect of tailings contamination on the condition of goats has not been extensively studied, however, it can be related to body weight. Comparison can be drawn between body weight & body condition and report that highly saline water from tailings salinization causes loss of condition as previously reported by Attia-Ismail *et al*. (2008b), depressed body weight causes loss of condition in goats.

2.12.3 Corneal opacity (ES)

Eyesight is closely related to the health of livestock (Meehan *et al*., 2015). Mdletshe *et al.* (2017b) reported to have mistakenly fed goats 50% of salt in water instead of 5%, which resulted in one of the goats losing sight in one eye. Though there is no extensive information on the effect of mine tailings to the eyes, however, Lu *et al*. (2008) stated that hearing and sight are impaired without water. Furthermore, Njoga *et al*. (2021) revealed that high concentrations of heavy metals cause metabolic, and enzymatic disorders and lower sensitivity in goats. Low sensitivity occurs as a result of damaged sensory neurons which results in vision blur. Thus, further documentation on the effect of eyesight of tailing dust contamination needs to be extensively investigated.

2.12.4 FAMACHA

The FAMACHA score is a clinical evaluation tool for anaemia. FAMACHA score system examines the severity of anaemia by observing the colour of the conjunctival mucous membrane (Van Wyk and Bath, 2002). Rana *et al*. (2010) reported that heavy metal toxicosis results in reduced red blood cell production which causes haemolytic anaemia. Furthermore, Nolan. (2003) reported that some heavy metals such as Cu causes reduced haemoglobin production causing anaemia. Although FAMACHA score does not give an accurate measure of anaemia in goats, it can be used to assess the general health status of goat’s prior blood analysis.

2.13 Summary of literature review

Contamination from tailing dust poses hazards to the ecosystem, impacting the growth and productivity of livestock. Prolonged intake of mine tailings poses severe damage to both livestock and human beings, thus, essential to document the impact in goats to develop sound management strategies to tackle the impact. Goats are particularly vulnerable to tailings contamination because of their browsing nature, which makes them likely to encounter contaminated soil and water. Industrialization is rapidly increasing, but adequate strategies for monitoring discharges have not been established. This, coupled with escalating water scarcity and contamination, leaves resource-limited farmers unable to provide their goats with freshwater. There are several ways to prevent tailings contamination including proper design and construction of tailings dams, use of tailings ponds that are lined with an impermeable material and recycling & reuse of tailings, however, this can be a complex and expensive process. Documenting the health impacts on goats resulting from tailings contamination is crucial in developing effective strategies to manage tailing discharges into waterways. The public needs to be presented with eco-friendly and cost-effective water conservation strategies to safeguard water resources. The widespread contamination of tailings due to their toxic effects have sparked heightened public and scientific interest, however, their impact on goat’s health is under investigation.

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Chapter 3: Influence of tailing dust contamination in drinking water on the health status of goats in subtropical regions

Abstract

Contamination of river systems by sediments from tailing dams remains a constraint to goat productivity under communal farming systems. A cross-sectional study was conducted to investigate how resource-limited households in subtropical regions assess the impact of tailing contamination in river systems on goat health. Two villages in Ba-Phalaborwa Local Municipality were surveyed and 400 goat farmers were interviewed. Forty-eight (48%) of the farmers were from Ga-Makhushane and 52% from Ga-Mashishimale villages. Key factors affecting goat productivity were poor water quality and shortage, and a high prevalence of diseases. The primary water sources for goat drinking were rivers, dams, and rainwater. Water contamination was highest during the hot and cool dry seasons. Freshwater was used as the primary water supplement to goats during dry seasons. Urine colour, oedema of the eyelids, and kid survival were health indicators for goats drinking water contaminated by tailing dust. Ordinal logistic regression revealed that water contamination by tailing dust was 2.96 more likely to be reported by youth compared to elderly members. Farmers who have received informal education were 37 times more likely to report water contamination by tailing dust compared to those who have received formal education. High kid mortality as a health indicator for water intoxication was 50 times less likely to be reported in uncontaminated compared to contaminated areas. Intervention strategies to reduce the negative effects of tailing contamination in river systems should focus on the general health status of goats during dry seasons.

Keywords: Mine tailings; river systems; water quality; seasonality; goat health.

3.1 Introduction

More than 60% of all goats are kept by rural households in arid and semi-arid agroecological zones, accounting for approximately 96% of the world's total goat population (Andre-Mataveia *et al*., 2021). Goats are important to resource-limited households because they provide meat, generate additional household income by selling them as live animals, produce manure, and serve social roles such as assessing status in society and performing religious and cultural beliefs (Mdletshe *et al*., 2018). Even though goats offer these benefits, one of the primary challenges to goat production is poor water quality (Mdletshe *et al*., 2017; Runa *et al*., 2019; Ndlela *et al*., 2022).

Poor water quality is an important limiting factor of goat production under communal production systems in subtropical regions. A major health problem in subtropical areas is the contamination of surface water bodies that goats utilize for drinking by tailing dust that contains potentially toxic sediments such as Arsenic (As), copper (Cu), lead (Pb), and zinc (Zn) as a result of the drying of water cover over mine tailings caused by less mineral precipitation and higher evapotranspiration (Cleaver *et al*., 2021; Bvinc, 2022; Opara *et al*., 2022). Consumption of water contaminated with heavy metals is associated with cell damage, and respiratory, gastrointestinal, central nervous system, renal, and liver disorders (Fashola *et al*., 2016) resulting in urine colour change, infection of the translucent membranes that surround the eyelids and eyeball, and excessive salivation (Odukoya, 2015). Despite the risks water contaminated with heavy metals has on birds and pets, little, if any, information is available concerning the effects of drinking surface water contaminated by tailing on goat health.

Seasonality and distance from the tailings dam both affect the levels of heavy metal contamination in surface water bodies. As a result of being exposed to toxic heavy metals in drinking water that is close to the mining regions, goats must travel long distances in search of less contaminated water (Mseleku *et al*., 2020). The influence of tailing dust contamination of surface water sources used by goats for drinking on goat productivity is limited and has an important consequence on the flock, nutritional management and general health status. Studies on the effects of river systems contaminated with mine tailings on productivity and the general health status of goats have been limited, if any, because of the emphasis on cattle and other intensively managed livestock. This is due to the perception that goats can tolerate poor water quality (Mdletshe *et al*., 2017; Ndlela *et al*., 2022).

Understanding the beliefs of households owning goats regarding tailings polluting surface water sources and their effect on goat health will assist policymakers in developing sustainable remedial plans to increase goat productivity, develop plans to reduce the negative effects of tailings, and encourage the use of safe mining methods. Therefore, the objective of the study is to determine how households perceive the effect of tailing contamination on the health status of goats. It was hypothesized that households with access to polluted and non-contaminated surface water sources would have similar household attitudes about the influence of tailing contamination on goat health.

3.2. Materials and method

3.2.1 Description of the study site

The study was conducted in two communities of Ba-Phalaborwa Local Municipality (23° 55′ 0″ S, 30° 50′ 0″ E), Limpopo Province, South Africa. Ba-Phalaborwa has a Subtropical steppe and is located at an altitude of 437 meters above sea level. The climate receives summers that are long, hot, muggy, and partly cloudy and winters that are short, cool, dry, and clear. Average annual rainfall ranges between 96 mm and 6 mm per annum, the rainy season is between November and February. The warmest months are December and January with an average temperature of 34℃ and the lowest average temperatures of 26℃ in July. Goats grazed on communal land during the day and were housed in the afternoon.

3.2.2 Water sampling

Twelve water samples in total (six from each zone) were collected using single-use polyethylene narrow-mouth bottles with screw caps. Each bottle was sterilized in the water that would be collected and kept in a cooler box with ice for testing of heavy metals at the University of Limpopo. Using inductively coupled plasma atomic emission spectrometry (ICPE-900) (ICP-MS, IRIS Advantages, USA), the amounts of chromium (Cr), copper (Cu), magnesium (Mg), and lead (Pb) were measured (Table 3.1). The findings were then used to assess and choose areas that had access to contaminated and uncontaminated surface water bodies that goats were used for drinking.

3.2.3 Compliance with Ethical Clearance

The experiment was approved by the University of Limpopo's Turfloop Research Ethics Committee (TREC/79/2023) following the university's guidelines, which adhere to SANS 10386:2008, the South African National Standards for the care and use of animals in research and teaching.

3.2.4 Household selection and data collection

Households were selected based on their proximity to the Bosveld Phosphate mine (6 and 21 km) and the investigated surroundings (Ga-Makhushane and Ga-Mashishimale villages), which had either contaminated or uncontaminated water sources used by goats for drinking. These regions represent access to surface water that goats use for drinking that may or may not have been contaminated by tailings. The target class of weaners, does, and non-lactating does was made available by giving priority to households with flocks of 20 or more goats.

A survey was conducted on households owning goats, with a total of 400 participants interviewed. Out of these, 196 were from Ga-Makhushane and 204 were from Ga-Mashishimale villages. The interviews were conducted in the presence of extension officers, an animal health technician and elderly members of each community. The accuracy of the data obtained was validated by key informants who were elderly members of the community. The survey used structured questionnaires to evaluate the farmer's perceptions of the health status of goats that drank contaminated and non-contaminated water with tailings. To ensure accuracy, five (5) enumerators were trained and interviews were conducted in Sepedi and Xitsonga vernacular. Hundred (100) interviews were conducted per day, and the study took 4 days to complete. All interviewed goat farmers answered all the questions that they were asked. Interviews with every participant were conducted at their place of residence. The questionnaire covered household demographics, goat production and productivity, access to water and quality, and goat health.

3.2.5 Statistical analysis

The Statistical Analysis Software (SAS, 2023) was used to analyze the data. To determine the relationships between household demographics and water quality, the chi-square test was employed. The effect of water quality on the composition and flock size was determined using the general linear model procedure. The chi-square

Table 3.1: Water samples' physicochemical characteristics for goat drinking places near and far from mines (min, max, mean, and standard error)

Parameters	Close to mining area			Away from the mining area			Normal
	Minimum	Maximum	Mean ± STD	Minimum	Maximum	Mean ± STD	Maximum
pH	8.21	8.22	8.22 ± 0.01	7.97	8.07	8.01 ± 0.05	6.5-8
Dissolved Oxygen (mg/l)	18.3	18.4	18.3 ± 0.06	56.4	57.2	56.87 ± 0.42	6.5-8
Conductivity (µ/cm)	1	1.039	1.03 ± 0.02	0.583	0.583	0.58 ± 0.00	0-1.5
TDS (mg/l)	0.5773	0.773	0.70 ± 0.11	0.442	0.440	0.00	0-1000
Salinity (mg/l)	0.33	0.33	0.33 ± 0.00	0.33	0.33	0.00	0-4000
Chromium (mg/L)	25.7	27.3	26.6 ± 0.82	14.8	16.6	15.93 ± 0.99	0-1
Copper (mg/L)	0.509	0.541	0.53 ± 0.02	0.342	0.355	0.35 ± 0.01	0-0.5
Magnesium (mg/L)	97	99.3	98.23 ± 1.16	52.6	53.2	52.93 ± 0.31	0-500
Lead (mg/L)	4.33	4.68	4.56 ± 0.20	2.46	2.75	2.62 ± 0.15	0-0.01

test was also used to determine the relationship between household perceptions among farmers in contaminated and uncontaminated areas. The PDIFF option was utilized to generate comparisons between the least square means. To predict the odds of households situated in proximity to or far away from the Bosveld Phosphate mine, an ordinal logistic regression (PROC LOGISTIC) was employed. The variables that were incorporated in the logit model were age and literacy level.

The model used is shown below:

$$Ln\ [P_i \div\ 1 - P_i] =\ \beta_0 +\ \beta_1 X_1 +\ \beta_2 X_2 +\ \beta_3 X_3 + .. \beta_t X_t +\ \varepsilon$$

P denotes the probability of a farmer's perceived goat health state, and [Pi / 1 – Pi] is the odds ratio of a household's perceived goat health status. β_0 represents the intercept, while β_1 to β_t are the regression coefficients for the predictors. X_1 to X_t represent the predictor variables, and ε is the random residual error. When calculating each predictor (β_1…β_t), the odds ratio for goat health status is interpreted as the proportion of households that face challenges with goat health against households that have no challenges with goat health. A similar model is used to examine farmers' evaluations of goat production methods, water accessibility, and goat health. The value of P represents the likelihood that farmers consider adding drinking water to dilute the water quality.

3.3. Results

3.3.1 Social demographic information and constraints to goat productivity

Household demographics for participants are shown in Table 3.2. Determination of water quality was associated with literacy level ($P \le 0.05$) and livestock species ($P \le 0.05$). Most of the farmers ($P \le 0.05$) in mining (49%) and non-mining areas (38%) areas had not received formal education. Cattle herd size was generally smaller in communities located close to mining ($P \le 0.05$) compared to non-mining areas. Water quality was the major constraint to goat productivity, followed by diseases, and water shortage ($P \le 0.05$) for households located close to mining compared to non-mining areas (Table 3.3).

3.3.2 Water sources for drinking, seasonal water quality, and supplementation

There was an association ($P \leq 0.05$) between water source and quality (Table 3.4). Rainwater was generally reported to be the primary water source for goats, followed by dams, and rivers. Furthermore, there was a relationship ($P \leq 0.05$) between seasons and water quality (Table 3.5). Water contamination levels were reported to be high in the hot-dry season, followed by cool-dry, and rainy seasons when compared to their counterparts.

3.3.3 Seasonal water supplementation for goats

There was an association ($P \leq 0.05$) between water supplementation and seasonality (Table 3.6). Freshwater (used as drinking water for humans) was reported to be the primary source of water supplementation, followed by dams/ponds, and rivers in contaminated areas compared to their counterparts. The contribution of freshwater as the main water supplement for goats was a more important water source for goats ($P \leq 0.05$) in both rainy and hot-dry seasons, followed by greywater and boreholes.

3.3.4 Seasonal water quality and the health of goats

There was an association ($P \leq 0.05$) between seasonality and health of goats (Table 3.7). Urine colour was generally ranked as the major health constraint in both rainy and hot-dry seasons, in contaminated areas compared to uncontaminated areas. In areas where water is contaminated, urine colour was the most recognised health indicator in goats across both seasons ($P \leq 0.0001$). However, in uncontaminated areas urine colour was ranked higher ($P \leq 0.0001$) in rainy season as compared to hot-dry season. Duration of urination was ranked similar across both areas and seasons ($P \geq 0.05$). In areas where water is uncontaminated, kid's survival was higher compared to contaminated areas ($P \leq 0.0001$) across both rainy and hot-dry seasons. Vaccination was generally ranked as the least major health factor across both areas in rainy and hot-dry seasons ($P \leq 0.0001$).

3.3.5 Water contamination on the general health status of goats

Water contamination was associated ($P \leq 0.0001$) with indicators for the general health status of goats (Table 3.8). Urine colour was the primary health indicator followed by oedema of the eyelids, and kid mortality in areas with contaminated surface drinking water sources compared to their counterparts.

Table 3.2: Socio-economic status of farmers participating in the study, and least square means (± SE) for herd/flock sizes of different livestock species kept per household.

Parameters	Contaminated Water	Non-contaminated water	X^2	Significance
Gender				
Male	51	50	0.89	NS
Female	49	50		
Age (%)				
<18	4	2	0.41	NS
18-30	20	14		
30-50	37	35		
>50	39	49		
Education (%)				
No education	49	38	<0.001	*
Primary	18	15		
Secondary	32	26		
Tertiary	1	21		
Training (%)				
Yes	2	0	0.16	NS
No	98	100		
Livestock Species				
Cattle	(1)1.11 ± 0.11[a]	(2) 1.75±0.10[b]		*
Goat	(2) 1.48 ± 0.07	(1) 1.50±0.01		NS
Sheep	(3) 2.39 ± 0.22	(3) 1.94 ± 0.15		NS
Chicken	(4) 2.45 ± 0.13	(4) 2.44 ± 0.17		NS
Pigs	(5) 3.13 ± 0.26	(5) 2.50 ± 0.51		NS

The lower the mean ranked score (rank), the greater its importance.

Values in parentheses indicate means for ranks.

*P ≥ 0.05; NS: Not significant (P ≤ 0.05)

Table 3.3 Constraints to goat productivity

Variables	Contaminated	Non-contaminated	Significance
Water quality	1 (2.14)	6 (6.13)	*
Diseases	2 (2.43)	2 (1.92)	*
Water shortage	3 (2.94)	5 (5.49)	*
Theft	4 (4.51)	1 (1.67)	*
Parasites	5 (4.54)	3 (2.93)	*
Predators	6 (5.50)	4 (4.47)	*

The lower the mean ranked score (rank) of a species, the greater the constraint to goat productivity.

Values in parenthesis indicate means for ranks.

*$P \geq 0.05$; NS: Not significant ($P \leq 0.05$)

Table 3.4: Ranks for drinking water sources in goats.

Variables	Contaminated	Non-contaminated	Significance
Water sources			
River	1 (1.16)	1 (1.00)	*
Dam/pond	2 (2.31)	2 (1.01)	*
Rainwater	3 (2.55)	3 (1.99)	*

Values in parenthesis indicate means for ranks. The lower the mean ranked score (rank) of a source, the more used the water source.

*$P \leq 0.05$; NS: Not significant ($P \geq 0.05$)

Table 3.5: Ranks for seasonal water quality challenges in goats.

Variables	Contaminated	Non-contaminated	Significance
Seasons			
Hot-dry	1 (1.42)	2 (1.73)	*
Cool-dry	2 (1.91)	1 (1.27)	*
Post-rainy	3 (2.95)	3 (3.04)	NS
Rainy	4 (3.72)	4 (3.93)	*

Values in parenthesis indicate means for ranks. The lower the mean ranked score (rank) of a season, the greater the water quality challenges.

*$P \leq 0.05$; NS: Not significant ($P \geq 0.05$)

Table 3.6: Ranks of seasonal water supplementation for goats.

Water sources	Rainy season		Hot-dry season		Significance level
	Contaminated	Non-contaminated	Contaminated	Non-contaminated	
Freshwater	1 (1.27)	1 (1.18)	1 (1.25)	1 (1.02)	*
Greywater	2 (1.90)	3 (3.08)	2 (1.97)	3 (3.05)	****
Borehole	3 (2.83)	2 (1.68)	3 (2.84)	2 (1.73)	****

Values in parenthesis indicate means for ranks.

NS not significant ($P \geq 0.05$)

The lower the rank (mean rank score), the greater its importance (supplement use).

*$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$, ****$P \leq 0.0001$

3.3.6 Odds ratio estimates for farmer's demographics, contamination of river systems, and health indicators for water intoxication in goats.

Table 3.9 shows the probabilities of reporting water contamination for goat consumption. Male farmers were 1.2 times more likely to indicate tailings sediments to pollute river systems used by goats for drinking ($P \leq 0.05$) than female farmers. When comparing farmers who received formal education, those with informal education were 37 times more likely to indicate that tailings had contaminated river systems used by goats for drinking. High kid mortality as a health indicator that goats are drinking toxic water was 50 times less likely to occur in areas located away from the mines.

3.4. Discussion

Understanding the beliefs of goat farmers regarding tailings polluting river systems and their effect on goat health will assist policymakers in developing sustainable remedial plans to increase goat productivity, develop plans to reduce the negative effects of tailings, and encourage the use of safe mining methods. It was hypothesized that households with access to polluted and non-contaminated river systems would have similar farmer attitudes about the influence of tailing contamination on goat health. Findings that education level influenced the understanding and awareness of the effect that tailing dust contamination possess agrees with that of Khapayi and Celliers. (2016), who observed that farmers' knowledge of agricultural dynamics is limited by a lack of formal education.

The findings that flock size for goats were higher compared to other livestock species kept by farmers close to mining areas could be associated with their tolerance to poor water quality and efficient use of water (Silanikove, 2000). These results are consistent with the findings reported by Mdletshe *et al*. (2017b), who observed no difference between goats provided high- and low-salinity water regarding feed conversion efficiency, rectal temperature, and respiration rate. Further research must be done to determine how heavy metal contamination from tailings in river systems affects goat health.

Table 3.7: Ranks between seasons and health indicators for goats.

Health indicators	Rainy season		Hot-dry season		Significance level
	Contaminated	Non-contaminated	Contaminated	Non-contaminated	
Urine colour	1 (1.24)	3 (1.96)	1 (1.34)	4 (2.13)	****
Oedema of the eyelids	2 (1.63)	2 (1.75)	2 (1.67)	2 (1.85)	NS
Kids survival	3 (1.94)	1 (1.23)	3 (1.94)	1 (1.19)	****
Excessive salivation	4 (2.15)	4 (2.01)	4 (2.17)	3 (1.96)	NS

Values in parentheses indicate means for ranks. The lower the rank (mean rank score), the higher the health indicator is occurring.

NS not significant ($P \geq 0.05$)

*P≤ 0.01, **P ≤ 0.001; ***P ≤ 0.0001, ****P ≤ 0.0001

Table 3.8: Ranks for health status indicators of water intoxication in goats.

Variables	Contaminated	Non-contaminated	Significance
Health indicator			
Urine colour	1 (1.28)	4 (2.00)	****
Oedema of the eyelids	2 (1.33)	2 (1.42)	NS
Kids mortality	3 (1.94)	1 (1.23)	****
Excessive salivation	4 (2.07)	3 (1.96)	NS
Loss of condition	5 (4.96)	5 (5.66)	****

The lower the rank (mean rank score), the higher the health indicator is occurring.

Values in parenthesis indicates means for ranks *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$; ****$p \leq 0.0001$; NS: Not significant ($p \geq 0.05$)

Table 3.9: Odds ratio estimates, lower (LCI) and Upper (UCI) confidence interval of households located in tailings contaminated and non-contaminated water source.

Predictors	Odds ratio	LCI	UCI	Significance
Age (youth vs older)	2.958	1.074	8.146	*
Education (Informal vs formal)	37.319	4.597	8.927	*
Kid mortality (High vs Low)	0.020	0.003	0.119	*
Water source (River vs rainwater)	18.999	0.843	1.973	NS
Loss of coordination (Dull vs normal)	5.482	0.723	41.543	NS

N.B: Higher odds ratio estimates indicate greater differences in occurrence between levels of predictors. If the upper confidence interval >1- * significantly difference; If the upper confidence interval <1- not significantly (NS) different

Findings that suggest water quality is the primary constraint in regions close to mines could be explained by tailings polluting the soil, groundwater, and surface water bodies that goats use for drinking. These results complement earlier studies from Serbia and Romania (Tech, 2013; Isvoran *et al*., 2021), which showed that mining operations may contaminate surface water bodies that animals utilize for drinking through tailing dust dispersed through air into river systems. This can be explained by the fact that the cool-dry and hot-dry seasons are favourable periods for the production and dispersion of tailing dust because there is lower mineral precipitation and higher evapotranspiration. During the cool-dry and hot-dry seasons, there is less rainfall, less mineral precipitation, increased evapotranspiration, and higher saline levels in the surface drinking water that goats utilize to drink. Goat productivity is negatively impacted during this time, especially those owned by farmers with limited resources, which causes economic loss. In the current study, water quality is lower in the cool-dry and hot-dry seasons in regions close to the mine tailing dam. These findings are comparable with the findings of Cleaver *et al*. (2021b) who reported variation in water pH and contamination levels based on seasonality and location.

Findings that water quality is a major concern in hot-dry seasons coincide with Potgieter *et al*. (2006) who indicated that lack of rainfall in hot-dry seasons results in a high concentration of tailings in water sources which forces communal farmers to supplement with either freshwater or greywater. The findings that goats farmers located close to the mine supplemented with freshwater throughout the year coincide with an earlier study in Tanzania by Mgode *et al*. (2021), who indicated that resource-limited farmers share the freshwater that they use for human purposes with their livestock. This could best be explained by no seasonal change in the contamination levels during the rainy and post-rainy seasons (Cleaver *et al*., 2021c). The findings of this study showed that physical location affected the supplementation of drinking water for goats. This could be further explained by the movement of water-soluble dust particles from tailings that contain high concentrations of heavy metals during the freeze-thaw and sublimation processes that occur in cold, windy conditions (Zwissler, 2016).

Findings that urine colour and high kid mortality were health indicators of water intoxication in regions close to the mine are best explained by high Cu, Cr, and Pb levels above the recommended standards in drinking water (Table 3.1). The findings that the colour of urine is a health indicator for water toxicity in goats in areas near mining sites agree with an earlier report from Cushny. (2002) who reported high levels of Pb in drinking water for livestock to cause kidney damage resulting in highly concentrated or bloody urine. The findings that tailing contamination in drinking water causes kids mortality are consistent with earlier findings from Oyeyemi and Akusu. (2005) who observed high Pb levels in drinking water to cause gastrointestinal infections, diarrhoea, hence, kids mortality. The findings that tailings contamination in drinking water for goats results in a loss of condition are in agreement with Mdletshe. (2017c), who observed decreased feed intake for goats drinking saline water with sodium chloride that is higher than the acceptable level and results in a loss of condition due to low nutrient intake. Therefore, more information concerning the effect of tailings contamination in river systems on the growth performance and health status of goats needs to be provided for effective management and control of tailings dust.

3.5. Conclusion

Farmers perceived the distance from the mining area to affect how tailing dusts, and contamination of surface drinking water sources influences goats' physiological, health, and nutritional health status. Although farmers perceived freshwater supplementation as a measure to reduce water intoxication from tailing dust, those who were located close to mining areas experienced higher contamination levels and health problems for goats. Areas located close to the mines should be the target of water contamination mitigation strategies from tailings dust. Further research should focus on the behavioural, physiological, and blood haematology responses of goats living near mining areas.

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Chapter 4: Differences in the physiological responses of does drinking water contaminated by tailing dust in subtropical regions

Abstract

Tailing dust in surface water bodies, which goats use as drinking sources, remains a challenge for their health in subtropical regions. A cross-sectional study was conducted to assess the effect of tailing dust contamination on water used by goats for drinking on the health status of dry non-lactating does. Body condition score (BCS), body weight (BWT), FAMACHA score, and corneal opacity (ES) were determined for non-descript dry non-lactating does (n=100). The area of the cornea that was extremely opaque was assessed to determine the degree of corneal opacity. Contaminated areas were correlated ($P \leq 0.05$) with BCS, BWT, and ES in goats. Goats reared in contaminated areas had lower BCS and BWT ($P \leq 0.001$) than goats reared in uncontaminated areas. Goats in contaminated areas had higher ES and FAMACHA scores ($P \leq 0.001$) than those in uncontaminated areas. Body condition score (BCS) had a positive ($P \leq 0.001$) correlated relationship with ES. Responses of does drinking water contaminated by tailing dusts include lower BCS and BWT, in addition to higher ES and FAMACHA scores. Therefore, the integration of BCS and ES is required for assessing the health status of does that consume water that has been contaminated by tailing dust. The integration of BCS and ES should be taken into consideration in goat programme strategies for assessing the health status of goats consuming water contaminated by tailing dust.

Keywords: corneal opacity; tailing dust; subtropical regions

4.1 Introduction

Goats play an integral role in the livelihood of resource-limited farmers (Rotberg, 2013). They provide meat, milk, fibre, and manure. Since they require less land, feed, and veterinary care due to their ability to forage and survive in marginal regions, goats additionally assist resource-limited households with the generation of additional income through the sale of live animals (McGregor, 2004; Rumosa Gwaze *et al*., 2009). Goats are adapted to Ecozones with low rainfall and sand-based soils, and they can tolerate low water quality because they have an effective renal system that reduces water loss. Goat productivity is generally low in resource-limited households of developing countries (Qokweni *et al*., 2020). Although goats are relatively profitable compared to other livestock species reared under communal production systems, the main challenges that limit optimal productivity are high disease prevalence, gastrointestinal parasites, poor management, quantity and quality of nutritional supplements, and water quality.

Poor water quality continues to be a constraining factor in goat production and productivity (Mdletshe *et al*., 2018; Ndlela *et al*., 2022). The ecological management of tailing dusts varies with climatic conditions, and distance from the neighbouring settlements or communities (see Chapter 3). In subtropical regions, contamination of surface water bodies used by goats for drinking with tailing dusts is one of the limiting factors to goat productivity. Drinking surface water bodies that have been contaminated by heavy metals from tailing dust has been associated with impaired reproductive performance and health problems such as depressed feed intake, weight and condition loss, anaemia, and blindness (Pandey and Madhuri, 2014; Mseleku *et al*., 2020; see chapter 3).

Waste from tailing dams, that dries up and is dispersed by the wind as dust, remains the main cause of contamination for surface water bodies in subtropical regions. Various types of tailings are generated depending on the mineral being mined. In sulfide-containing tailings, waste produced is high in heavy metals such as lead (Pb), copper (Cu), chromium (Cr), and magnesium (Mg) (Lu and Wang, 2012). Surface water bodies with heavy metal pollution from tailing dust levels differ based on distance from the tailings, with contamination levels near the tailings being high and contamination levels far from the tailings generally lower (Mihaljevič *et al*., 2019). Goats that drink surface water in areas near tailings are more likely to experience health problems caused by contamination with heavy metals. According to Pandey and Madhuri. (2014), reduced appetite in wild animals drinking lead (Pb)-contaminated water can lead to decreased feed and water intake, which could lead to live body weight loss and body condition score. Furthermore, fish that drink water contaminated with chromium (Cr) lose blood. The accumulation of heavy metals in the corneal tissue has been associated with a worsening of cloudiness in human eyes by obscuring the iris details (Rektor *et al*., 2020).

Impaired vision due to corneal opacity, body weight and condition loss, and anaemia are all related to exposure to high levels of heavy metals in drinking water (Govind *et al*., 2014). Corneal opacity grading is a clinical assessment of the surface of the eye through cloudy patches in the small transparent disc inside the eye (Rektor *et al*., 2020). Anaemia in goats is evaluated using the Faffa Malan Chart (FAMACHA) scoring system, which assesses the severity of anaemia by observing the colour of the conjunctival mucous membrane (Van Wyk and Bath, 2002). However, there is limited information available on the impact of heavy metal pollution in drinking water from tailing dust on the occurrence of corneal opacity, anaemia, weight loss, and body condition in goats raised in areas where surface water bodies used by goats for drinking are contaminated by tailing dust. Understanding how heavy metal pollution from tailing dust influences corneal opacity, anaemia, live weight, and body condition score loss could assist goat producers in designing effective strategies to reduce heavy metal intoxication that is area-specific. The objective of the study was to assess the effect of tailing dust contamination on water used by goats for drinking on the health status of dry non-lactating does. It was hypothesized that the goat's health would not be affected by drinking water contaminated by tailing dust.

4.2 Materials and Methods

4.2.1 Description of the study site

The study was conducted in two communities: Ga-Makhushane (exposed to tailings) and Ga-Mashishimane (not exposed to tailings) villages of Ba-Phalaborwa (23° 55′ 0″ S, 30° 50′ 0″ E) local municipalities, Limpopo province, South Africa. Details of the site are described in Chapter 3 (section 3.2.1). The research was approved by the University of Limpopo Animal Research Ethics Committee (Registration no. AREC-290914-017) (Appendix 3).

4.2.2 Water and Treatments

Six water samples were collected using single-use, narrow-mouth polyethylene bottles with screw caps from the villages of Ga-Makhushane and Ga-Mashishimale, for a total of twelve samples. The water samples were kept in a cooler box with ice at a temperature less than 2℃ and transported for testing of heavy metals at the University of Limpopo. The concentrations of chromium (Cr), copper (Cu), magnesium (Mg), and lead (Pb) were determined using inductively coupled plasma atomic emission spectrometry (ICPE-900) (ICP-MS, IRIS Advantages, USA). Based on the physical and chemical characteristics of the drinking water used by goats from different water sources at the study site (see Table 3.1), goats were assigned to treatments of either contaminated or uncontaminated areas.

4.2.3 Goats and experimental design

One hundred non-lactating (about 24-27 months of age) dry does ranging from 20 to 28 kg (average) were used and were assessed twice during the cool-dry season (May-July). Age was identified before data collection, and 24-27 months age to be available and consistent across both areas. Goats underwent a full general eye health examination (conjunctivitis, ocular discharge, blepharospasm, and lacrimation) to exclude those with infectious ophthalmia, Moraxella, Chlamydia, and Mycoplasma. The selection of goats was based on historical records of tick vaccinations and seasonal deworming against gastrointestinal parasites. Selected goats were stratified based on body weight and villages (access to contaminated and uncontaminated water sources), thus ensuring that body weights were similar among the two treatment groups. To improve the data accuracy, farmers having a flock of 20 or more goats were given preference.

4.3 Measurements

4.3.1 Body condition scoring (BCS)

The goat's nutritional status was assessed using body condition scores (BCS). It was determined by the amount of fat covering, over and around the lumbar vertebrae, rib cage and sternum area of each lamb. Furthermore, hands were used to carefully feel the spinous process along each goat's back, which is located behind the final rib and in front of the hip bone. Body condition scores (BCS) were assessed using a scale of

1 (emaciated), 2 (thin), 3 (average condition), 4 (fat) and 5 (obese), as described in Table 4.1 (Suiter, 1994; Mahieu *et al*., 2007).

4.3.2 Body weight (BW)

Body weight (BW) was measured in the morning between 0600 and 0900h. The body weights were estimated using a goat weight band as described by (Asefa *et al*., 2017). Live body weight was measured three times, with the average result used as the final reading.

4.3.3 Corneal opacity assessment (ES)

The corneal opacity was assessed and graded considering the general eye care parameters such as cornea, iris, and conjunctivitis following the method described in Table 4.2.

4.3.4 FAMACHA Score

The FAMACHA technique was used as a proxy indicator of the level of anaemia in goats. The method was implemented as per the protocol detailed by Kaplan et al. (2004). Each goat was manually restrained, with the upper thumb of the right hand placed gently on the right eye, while the left thumb was used to lower the eyelid. The colour of the mucous membrane of the lower eyelid was evaluated and scored according to the FAMACHA score in Table 4.3. The examination of goats took place between 0930h and 1000h.

4.3.5 Statistical analysis

The Statistical Analysis Software (SAS, 2023) was used to analyze all the data. To determine the impact of tailings contamination on the water, the body condition score (BCS), body weight (BW), corneal opacity (ES) and FAMACHA score were evaluated using PROC GLM of SAS (2023). Model used:

$$Y_{ij} = \mu + T_i + \boldsymbol{\varepsilon_{ij}}$$

Where:

Table 4.1: Body condition scoring scale used in the study.

Condition scale	Body condition score (BCS)
1	Emaciated: Abnormally thin (Visible rib cage)
2	Thin: Even fat cover (slightly visible rib cage)
3	Good condition: Smooth even fat (invisible ribs, but can be felt)
4	Fat: Thick fat (invisible ribs, only indents can be felt between ribs)
5	Obese: No individual vertebrae (invisible ribs and no indents between ribs)

Sources: Suiter. (1994) and Mahieu *et al*. (2007).

Table 4.2:Corneal opacity scores.

Numerical grading	Reaction
4	Opaque, swelling with lids about half-closed to completely closed.
3	No details of the iris is visible or size of the pupil barely discernible with greater than three-quarters of the area of the cornea involved, diffused beefy red with swelling with lids about half-closed, and discharge with moistening of lids and hairs, and considerable area around the eye.
2	Easily discernible translucent areas with greater than one-half of the cornea area involved, no reaction to light with gross destruction of the iris, individual vessels not easily discernible with obvious swelling with partial eversion of lids, and discharge with moistening of the lids and hairs just adjacent to lids.
1	Scattered or diffused areas of the cornea with greater than one-quarter of the iris involved but less than half, folds of the iris above normal with vessels definitely injected above normal with swelling above normal, and any amount of discharge above the normal.
0	No opacity, one-quarter or less area of cornea involved, normal iris with no swelling and discharge.

Source: Baran and Gad (2014).

Table 4.3: FAMACHA scoring table used in the study.

Rating	Classification (Colour)	Hematocrit (% red blood cells)
1	Red	28
2	Red/Pink	22-27
3	Pink	18-22
4	Pink/White	13-17
5	White	≤ 12

Kaplan *et al*. (2004).

Y_{ij} = Response variables (body condition score, body weight, corneal opacity and FAMACHA score).

μ = Overall mean response

T_i = the i^{th} effect of tailings contamination in water

ε_{ij} = Residual error term

The PROC CORR procedure was used to determine the Pearson correlation coefficients between body condition score, body weight, corneal opacity scores, and FAMACHA score.

4.4 Results

4.4.1 Body condition score, body weight, corneal opacity assessment and FAMACHA score.

As shown in Table 4.4, goats reared in uncontaminated areas had higher body condition scores ($P \leq 0.001$) than goats in contaminated areas. Goats reared in contaminated areas had higher BWT than goats in uncontaminated areas ($P \leq 0.001$). Goats in contaminated areas had higher ($P \leq 0.001$) corneal opacity assessment scores than goats in uncontaminated areas. Body condition score had a positive correlation with ES ($r = 0.37^{***}$; $p \leq 0.001$) (Table 4.5).

4.5 Discussion

The objective of this study was to assess the effect of tailing dust contamination in surface water bodies used by goats for drinking on the general health status of dry non-lactating does. The findings that BWT and BCS were lower for goats in contaminated areas are consistent with findings from Pandey and Madhuri (2014) and Bersényi (2003). The observations could be explained by high-level exposure of Cr, Cu and Pb to be associated with depressed water and feed intake resulting in a decrease in live BWT and BCS of goats. Chromium, Cu, and Pb bio-accumulate in the bloodstream and inhibits the activity of cellulose and xylanase, which are essential fibrolytic enzymes required to digest fibre in the rumen (Sardar *et al*., 2013). The inability of the fibrolytic enzymes to digest fibre leads to excessive accumulation of undigested feeds in the rumen, and this may likely have depressed feed, and water intake (Iyengar and Nair, 2000) affecting BWT and BCS of goats in the current study. An increase in the concentration of lead (Pb) in the body results in a depletion of vital elements causing slow growth and problems associated with BWT loss and BCS

Table 4.4: Mean herd/flock sizes (± SE) of goats located close and far from tailings according to their BCS, BWT, ES, and FAMACHA score of goats.

Variables	Contaminated	Non-contaminated	Significance
Body condition score	2.58 ± 1.33	3.33 ± 1.33	***
Body weight	20.44 ± 1.20	27.87 ± 1.20	***
Corneal opacity assessment	2.80 ± 0.17	1.35 ± 0.17	***
FAMACHA score	3.00 ± 0.04	2.90 ± 0.05	NS

SE: Standard error; NS: Not significant (P ≥ 0.05); *P ≤ 0.05; **P ≤ 0.001; ***P ≤ 0.0001).

Table 4.5: Correlations between Body Condition score (BCS), Corneal opacity (ES), Body Weight (BW), and FAMACHA score.

Variables	BCS	ES	BW	FAMACHA
BCS		0.37***	0.14	0.04
ES			0.01	0.07
BW				-0.04
FAMACHA				

Correlated at *$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$.

(Türkdoğan *et al*., 2003; Arora *et al*., 2008). These findings support the results of Begovic et al. (2008) who found that elevated levels of copper (Cu) and lead (Pb) in the blood can lead to delayed gastric emptying (gastric stasis) and gastric tonus (gastric ptosis). Both Cu and Pb cause a decrease in the haeme body pool, resulting in impaired cyto-dynamics that negatively affect nerve conduction and lead to stomach paralysis. Stomach paralysis can delay digestion, leading to a decrease in feed intake and nutrient absorption. Body weight and condition loss decline due to reduced nutrient intake.

Findings that body condition score (BCS) was positively correlated to corneal opacity agree with Marg (2011). Overall, the low BCS value between contaminated and uncontaminated areas is characterised by depressed water and feed intake, reducing the nutritional status of goats (Mdletshe *et al*., 2017). This implies that reduced nutritional status affected the mucosal integrity. Further studies to determine the effect of nutritional status on goat mucosal integrity should be done in assessing glucose, cholesterol, total protein, albumin, urea, and creatinine blood metabolites (Rumosa Gwaze *et al*., 2010).

The observation that goats reared in contaminated areas had higher corneal opacity scores is consistent with earlier studies by Dereure. (2001) and McLain. (2007). High toxicity of Cu causes inflammation of the peripheral corneal epithelial "stem cells" that maintain a normal clear corneal epithelium, thus, affecting the eyesight in goats (Gan and Thorne, 2012). Therefore, a decrease in condition from Cu toxicity, causes a decrease in corneal opacity in goats.

The findings which contradicted a previous study by Ma *et al*. (2020) and Alvarez (2020), showing heavy metal pollution levels in drinking water did not affect FAMACHA scores, were unexpected. The presence of Cr, Cu, and Pb over the normal permitted range (1, 0.5 and 0.01 mg/L respectively) in goat drinking water provides the best explanation for these findings. Such caused goats in both contaminated and non-contaminated locations to generate lower haemoglobin, generate fewer red blood cells, and have impaired iron metabolism. Since FAMACHA is for the assessment of gastrointestinal load in goats, anaemia through the assessment of haematological indices including the erythrocyte count, packed cell volume (PCV), and total blood protein merits further investigation to achieve accurate conclusions.

4.6 Conclusion

Differences in the physiological response of nondescript goats drinking water contaminated with tailing dust are associated with proximity to the tailing dam. Higher body weight and condition scores were observed in areas far from tailings with less cloudiness of the corneal. To minimize the negative effects of tailing dust on goat productivity, one should integrate BWT, BCS, and ES based on distance from tailings. Further research should be done to measure packed cell volume, liver, and renal enzymes in goats consuming surface water bodies in contaminated areas with tailing dusts.

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Chapter 5: General discussion, conclusions and recommendations

5.1 General discussion

The study's broad objective was to assess the health status of goats reared in subtropical regions in both tailing dust-contaminated and uncontaminated areas. The main hypothesis tested was that tailing dust in contaminated and uncontaminated areas wouldn't influence dry, non-lactating does' health status. However, it is important to understand the effects of tailing dust pollution in drinking water on goat productivity before knowing the health status of goats reared in subtropical regions in both contaminated and uncontaminated areas.

The hypothesis tested in Chapter 3 was that there would be a similar perception about the health status of goats for households with access to polluted and non-polluted drinking water contaminated by tailing dust in contaminated and uncontaminated areas. Although the perception of goat productivity varied with area and seasonality, smallholder farmers ranked water contamination as the major constraint in areas contaminated with tailing dust. Smallholder farmers also ranked urine colour, kid survival, and body condition loss as health indicators for goats drinking water contaminated with tailing dust, considering their understanding that constraints varied with area and seasonality. Therefore, the hypothesis that there are similar household perceptions about the influence of tailing dust contamination on goat health was rejected. It is important to assess the factors that influence goat productivity and their health indicators in tailing dust-contaminated areas.

A monitoring study (Chapter 4) was conducted to test the hypothesis that tailing dust contamination in drinking water will not influence the physiological response of dry non-lactating does. Goats reared in contaminated areas showed lower BCS, BWT, and ES scores in addition to higher FAMACHA scores. These findings might imply that goats drinking contaminated water sources had lower BCS and higher ES, which are physiological responses.

5.2 Conclusions

Tailing dust contamination is more likely to occur in areas close to tailings. Farmers perceived contaminated areas by tailing dust on drinking water to influence goats' physiological, health, and nutritional health status. Higher body weight and condition scores were observed in uncontaminated areas with less cloudiness in the corneal. Tailings dust contamination in drinking water did not affect the FAMACHA score of goats. It can be concluded that tailing dust contamination in drinking water depresses the body condition, body weight and corneal opacity of goats. These findings also indicate that health parameters such as body weight, body condition, and corneal opacity can be used to assess the health status of goats drinking water contaminated by tailing dust in subtropical regions.

5.3 Recommendations

It can be advised that resource-limited farmers be educated on the impact of tailings on their goats' health in addition to kid's mortality. Alternatively, they can use BCS, BWT, FAMACHA and ES scores as indicators of goats drinking water contaminated with tailing dust since the methods are sustainable and readily available. To reduce the negative effect of tailings dust in drinking water on the health of goats, effective integrated tailing management strategies are recommended.

Aspects that require further research include the following:

1. Determination of behavioural and physiological responses of goats reared in contaminated areas.
2. To assess the packed cell volume, liver, and renal enzymes of goats reared in contaminated areas. Since tailing dust contamination varies with season, the effect of tailing dust contamination on the health of goats can be evaluated based on seasonality, sex, and class.

6. Appendices

Appendix 1: Structured questionnaire

FACULTY OF SCIENCE AND AGRICULTURE

SCHOOL OF AGRICULTURAL AND ENVIRONMENTAL SCIENCES

DEPARTMENT OF AGRICULTURAL ECONOMICS AND ANIMAL PRODUCTION

Cell No: 063 321 4893

Email: 201736602@keyaka.ul.ac.za

Web: www.ul.ac.za

COPPER SULFATE IN DRINKING WATER ON THE BLOOD HAEMATOLOGY AND BIOCHEMICAL RESPONSES OF NON-DESCRIPT GOATS

Objective:

To assess farmer's attitudes and beliefs on the influence of copper sulfate on the health status of goats.

Questionnaire number………………… Village name………………………………

Enumerator name…………………. Traditional council……………………………...

Date…………………………………………………..

SECTION A: Household demographics

1. Head of the household

a) Sex: M □ F □

b) Age: <18 □ 18-30 □ 31-50 □ > 50 □

c) Highest education level: No formal education □ Grade 1-7 □ Grade8-12 □ Tertiary □

d) Have you ever received any training on goat production? Yes □ No □

2. Types of livestock species kept? (Please tick the first column as appropriate. The second column is for the number of that appropriate livestock species. The last column is for rank levels of the other types of livestock species kept – 1 is for the highest priority)

Livestock species	Tick (appropriate)	Rank
Cattle		
Goats		
Sheep		
Chickens		
Pigs		
Other (Specify)		

SECTION B: Goat production

1. What are the constraints to goat production?

Variables	Rank
Water shortage	
Water quality	
Diseases	
Parasites	
Theft	

Predation	

SECTION C: Water accessibility and quality

1. What is the most common water source for goats?

Variables	Rank
Dam/ponds	
River	
Rainwater	

2. Is poor water quality a major challenge for goats in your area? 1. Yes □ 2. No □
3. When is poor water quality a major challenge for goats?

Season	Rank
Rainy	
Post-rainy	
Cool-dry	
Hot-dry	

4. What is the cause of poor water quality for goats?

Variables	Rank
Heavy metal	
Blue-green algae	
Organic materials	
Chemicals (e.g: fertilizers; pesticides etc)	

5. Do you supplement goats with drinking water? 1. Yes □ 2. No □

6. How do you supplement drinking water for goats?

Water Source	Rank
Freshwater	
Greywater	
Borehole	

7. Season where supplementation is mostly required?

Water Source	Seasons	
	Rainy	Hot-dry
Freshwater		
Greywater		
Borehole		

SECTION D: Goat health

1. How do you assess the health in your goats? 1. Loss of condition □ 2. Kid's mortality □ 3. Oedema of the eyelids □ 4. Excessive salivation □ 5. Loss of condition □
2. Do you experience mortality in your goats? 1. Yes □ 2. No □
3. What causes mortality in your goats?
   1. Water scarcity □ 2. Water quality □ 3. Feed shortage □ 4. Predators (Jackals) □ 5. Diseases □
4. Season where urine colour change is often experienced in goats? 1. Rainy □ 2. Hot-dry □
5. Season were Oedema of the eyelids is often encountered in goats? 1. Rainy □ 2. Hot-dry □
6. Which season is excessive salivation mostly experienced? 1. Rainy □ 2. Hot-dry □
7. How many kids have died in the past 12 months? 1. 1-3 □ 2. 4-7 □ 3. 8-10 □ 4. >10 □
8. Which season is high kid mortality experienced? 1. Rainy □ 2. Hot-dry □

Appendix 2:TREC clearance certificate for questionnaire

University of Limpopo
Department of Research Administration and Development
Private Bag X1106, Sovenga, 0727, South Africa
Tel: (015) 268 4713, Fax: (015) 268 2306, Email: moore.hutamo@ul.ac.za

TURFLOOP RESEARCH ETHICS COMMITTEE

ETHICS CLEARANCE CERTIFICATE

MEETING: **22 MARCH 2023**

PROJECT NUMBER: **TREC/79/2023: PG**

PROJECT:

Title:	Copper metal salts in drinking water on the blood haematology and biochemical responses of non-descript goats.
Researcher:	NW Serakalala
Supervisor:	Dr ZM Mdletshe
Co-Supervisor/s:	N/A
School:	Agricultural and Environmental Sciences
Degree:	Master of Science in Agriculture (Animal Production)

PROF D MAPOSA
CHAIRPERSON: TURFLOOP RESEARCH ETHICS COMMITTEE

The Turfloop Research Ethics Committee (TREC) is registered with the National Health Research Ethics Council, Registration Number: **REC-0310111-031**

Note:

i) **This Ethics Clearance Certificate will be valid for one (1) year, as from the abovementioned date. Application for annual renewal (or annual review) need to be received by TREC one month before lapse of this period.**

ii) **Should any departure be contemplated from the research procedure as approved, the researcher(s) must re-submit the protocol to the committee, together with the Application for Amendment form.**

iii) **PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES.**

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Appendix 3: Ethical approval for the goat trial

UNIVERSITY OF LIMPOPO

University of Limpopo
Department of Research Administration and Development
Private Bag X1106, Sovenga, 0727, South Africa
Tel: (015) 268 4713/3766, Fax: (015) 268 2306, Email: moore.hutamo@ul.ac.za

ANIMAL RESEARCH ETHICS COMMITTEE CLEARANCE CERTIFICATE

MEETING:	**26 JUNE 2023**
PROJECT NUMBER:	**AREC/30/2023: PG**
PROJECT:	
Title:	Copper sulfate in drinking water on the blood haematology and biochemical responses of non-descript goats.
Researcher:	NW Serakalala
Supervisor:	Dr ZM Mdletshe
Co-Supervisor:	N/A
School:	Agricultural and Environmental Sciences
Degree:	Master of Science in Agriculture (Animal Production)

PROF JW NGAMBI
CHAIRPERSON: ANIMAL RESEARCH ETHICS COMMITTEE

The Animal Research Ethics Committee (AREC) is registered with the National Health Research Ethics Council, Registration Number: **AREC-290914-017**

Note:

i) **Should any departure be contemplated from the research procedure as approved, the researcher(s) must re-submit the protocol to the committee.**
ii) **The budget for the research will be considered separately from the protocol.**
iii) **PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES.**

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