

Impact of groundwater samples and leachates from Gbagede dumpsite, Amoyo, Kwara State, Nigeria, on testes and prostate of male Wistar rats: A biochemical and histological study

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Abstract

This study evaluated the impact of groundwater samples and leachate from Gbagede dumpsite in Amoyo, Kwara State, on the testicular and prostatic function indices of male rats. The groundwater sample 1 (GW1), groundwater sample 2 (GW2), 2.5%, 5.0%, 7.5% and 10.0% leachate progressively reduced ($p < .05$) feed intake, groundwater and leachate intake, body weight, weights of testes and prostate, and testes-body weight ratio. The groundwater and leachates significantly ($p < .05$) reduced the sperm count, motility, normal morphology and testicular volume; activities of semen acid phosphatase (ACP) and α -glucosidase, testicular alkaline phosphatase, ACP, γ -GT, lactate dehydrogenase, glutathione reductase, catalase and superoxide dismutase; testicular total protein, glycogen, total cholesterol, sialic acid, testosterone, reduced glutathione, total antioxidant capacity, zinc, iron and copper; serum LH and FSH; prostatic calcium and phosphate. Treatments increased testicular malondialdehyde, prostate-specific antigen and ACP whilst prostatic pH remained significantly unaltered. Only the leachates reduced prostate-body weight ratio. The treatments induced distortions of seminiferous tubules, destroyed spermatogenic cells and degenerated prostatic acinus. The study concluded that metals in the groundwater and leachate samples have adversely impacted on the testes and prostates of the male rats via endocrine disruption and oxidative stress, with attendant implications on reproductive capacity.

KEYWORDS

Gbagede dumpsite, groundwater, leachate, prostatic function, testicular function

1 | INTRODUCTION

The testes are the major reproductive organs of male rats. The rat testes are giant, pillow-like shaped organ whose sizes and weights vary with the age of the animals. The testes which are located in the scrotum perform both exocrine and endocrine functions. The exocrine aspect of testicular function is related to production of spermatozoa via spermatogenesis whilst the endocrine aspect involves the secretion of steroidal hormones such as testosterone, oestrone

and progesterone. The five accessory sex glands of the reproductive system of male rats are the vesicular glands, coagulating glands, Cowper's glands, preputial glands and prostate glands. The male rat prostate gland is a dense gland that is positioned at the back and a little under the urinary bladder, is also partly enclosed within the vicinity of the penis (Suckow, Weisbroth, & Franklin, 2005). The prostate gland produces virtually all the fluids in the semen in varying quantity and thus contributes to male fertility (Flint, McAlister, Agarwal, & Plessis, 2015).

However, the entire reproductive system of male rats, including the testes and the prostate at both the functional and structural levels are susceptible to hazardous effects of municipal landfill leachates (generated when municipal solid waste encounters water that penetrate through the landfill sites) and groundwater (from leakage of leachate) resulting in myriads of deleterious effects that include mutations, chromosomal changes, sperm abnormalities, decreased maternal body weights, early or late foetal loss, still births, reduced birth weights, altered sex ratio, birth defects and childhood malignancies (Tiware & Bhargava, 2013). Although most of these hazardous effects have been well documented for municipal landfill leachates in Olushosun (Ojota, Lagos, Nigeria), Akure (Nigeria), Igando area (Lagos, Nigeria), Rowfabad (Chittagong, Bangladesh) and Erbil city (Iraq) (Adedara et al., 2014; Akinbile & Yusoff, 2011; Hossain, Das, & Hossain, 2014; Salami & Susu, 2019; Shekha, Al-Attar, Saleem, Toma, & Abdulla, 2017), information is scarce on that of the groundwater and leachates from Gbagede dumpsite of Amoyo, Nigeria.

Gbagede dumpsite, (Figure 1), is a major dumping ground of waste, located in Amoyo, Kwara State, Nigeria. Most of the disposed wastes are mainly domestic and household in nature. Leachate from this dumpsite may enter the soil and ground water and bio-accumulate in food webs. The leachates may consequently get into humans through drinking water or by ingestion and affect myriads of organs in the animals, disrupting several biological processes. Yakubu and Omar (2019) reported that 5% and 53% of the physicochemical parameters of the groundwater samples and leachates respectively from the Gbagede dumpsite exceeded both the World Health Organization (WHO, 2001) Standard and Nigeria Standard Drink and Quality Water (NSDWQ, 2007) reference limit. In the study under review, the clear groundwater sample 1 (GW1, collected from a well that was located at 15 m away from the dumpsite) with a pH of 7.34 contained 0.018 mg/L, 0.008 mg/L, 0.009 mg/L, 0.03 mg/L, 0.09 mg/L and 0.025 mg/L of copper, lead, nickel, cadmium, aluminium and zinc respectively whilst the particulate groundwater sample 2 (GW2, collected from a well that was located at 150 m away from the dumpsite) with a pH of 8.56 contained 0.015 mg/L, 0.007 mg/L, 0.048 mg/L, 0.002 mg/L, 0.005 mg/L and 0.019 mg/L of copper, lead, nickel, cadmium, aluminium and zinc respectively. In addition, the greenish-brown coloured leachate with a pH of 9.83 contained 0.031 mg/L of lead, 0.007 mg/L of cadmium, 0.010 mg/L of zinc, 0.028 mg/L of copper, 0.024 mg/L

of aluminium and 0.011 mg/L of nickel. The chloride ion contents of GW1, GW2 and the leachate were found to be 110.4 mg/L, 56.7 mg/L and 112.48 mg/L respectively whilst the phosphate ions in GW1, GW2 and the leachates were quantified as 4.2 mg/L, 1.7 mg/L and 5.8 mg/L respectively. The GW1, GW2 and the leachate contained 2.3 mg/L, 0.1 mg/L and 43.0 mg/L of nitrate and 0.017 mg/L, 0.005 mg/L and 0.024 mg/L of nitrite respectively. However, since the report on the physicochemical properties of groundwater and leachate by Yakubu and Omar in 2019, there has not been any other study, to the knowledge of the authors, on the groundwater samples and the leachates of Gbagede dumpsite in Amoyo, Kwara State, Nigeria.

Herein, this study gives an account of the impact of the groundwater samples and leachates collected from the Gbagede dumpsite on the testes and prostate of Wistar rats using biochemical and histological approaches.

2 | MATERIALS AND METHODS

2.1 | Sampling location

The area under study (Figure 2) was Amoyo (along Ilorin-Ajase Road, Ilorin, Kwara State, Nigeria), located within the basement complex of South West Nigeria. It lies between longitudes 4° 38' 45.82" E and 4° 40' 13.46" E and latitudes 8° 26' 52.94" N and 8° 24' 13.53" N. Amoyo is relatively situated on a crest of depression with a well-dissected landscape covered by laterite. The landfill is surrounded by some residential houses and farmlands. The dumpsite is mainly used by Kwara State Waste Management Board and other private waste management companies in the State. To a very large extent, wastes that are dumped in the site are mainly of domestic and household origin that includes food leftovers and residues, hair, dungs, faeces, damaged appliances and used clothes.

2.2 | Chemicals and assay kits

The assay kits for acid phosphatase (ACP), glutathione peroxidase (GPx), calcium, phosphate, total cholesterol, lactate dehydrogenase (LDH), Gamma glutamyl transferase (γ -GT), alkaline phosphatase (ALP), α -glucosidase and superoxide dismutase (SOD) were products of Randox Laboratories Ltd. Co-Atrim, UK. Total prostate-specific antigen (PSA), testosterone, follicle-stimulating hormone (FSH), luteinising hormone (LH), zinc, iron and copper assay kits were factory made by Fortress Diagnostics Limited, Antrim, UK. All other reagents used were of analytical grade obtained from Merck Pharmaceutical Company, Darmstadt, Germany.

2.3 | Experimental animals

Thirty-five, male Wistar rats (134.04 ± 0.66 g), procured from the Animal Facility in the Department of Biochemistry, University of



FIGURE 1 Gbagede dumpsite in Amoyo, Kwara State, Nigeria

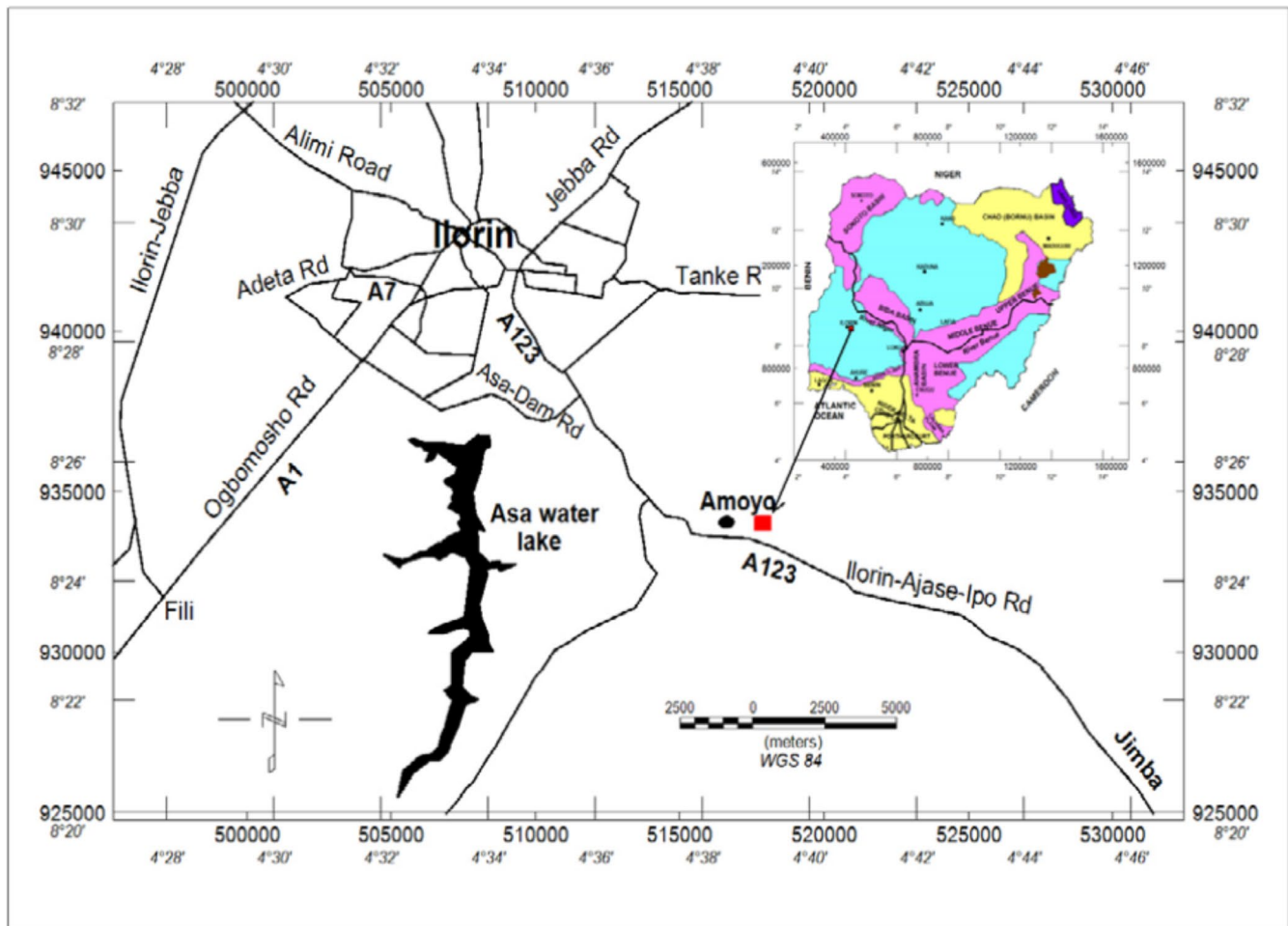


FIGURE 2 Map of part of Ilorin showing the studied area, Amoyo

Ilorin, Ilorin, Nigeria, were housed in plastic cages, placed in well-ventilated room (temperature: $22 \pm 3^\circ\text{C}$; relative humidity: 40%–45%; 12-hr light and 12-hr dark cycle) and allowed free access to rat pellets (Vital Feed, Grand Cereals, Vom, Jos, Nigeria) and contaminant free tap water. Acclimatisation was done for 2 weeks before the commencement of exposure of the male rats to the samples (groundwater and leachates) and distilled water.

2.4 | Collection of groundwater and leachate samples

The polyethylene bottles were treated before being used to collect the groundwater and the leachates from the dumpsite. Briefly, the bottles were left for 24 hr in 15% (v/v) nitric acid and thereafter washed with deionised water and allowed to dry at 28°C . These polyethylene bottles were then flushed with the water source a couple of times before collecting the groundwater and leachate samples. Water samples collected from a well that was located at a distance of 15 m from the dumpsite was termed Groundwater sample 1 (GW1) whilst the water samples from a well that was at a distance of 150 m from the dumpsite was referred to as

Groundwater sample 2 (GW2). Also, raw leachates aseptically collected from the three sampling spots of the landfill, A, B and C (the distance between spot A and those of spots B and C was 20 m whilst between B and C was 2 m) were thoroughly mixed to provide a homogenous sample. These samples were filtered with glass wool and Whatmann® No. 42 filter paper to remove suspended particles, centrifuged at $894 \times g$ for 10 min and stored at 4°C throughout the experimental period. The resulting GW1 and GW2 were administered to the animals whereas the stock leachates were reconstituted into four different levels of 2.5%, 5.0%, 7.5% and 10.0% (v/v) before being administered to the animals (Yakubu & Omar, 2019).

2.5 | Animal grouping and treatment of animals

Thirty-five male rats were assigned into seven groups (A–G) and exposed to distilled water, groundwater samples and leachates as follows:

Group A (Control) rats were maintained on distilled water

Group B rats were maintained on groundwater sample 1 (GW1)

Group	Day 1 (ml)	Day 14 (ml)	Day 28 (ml)	Day 56 (ml)
Control	64.80 ± 1.75	71.78 ± 1.29	72.92 ± 0.64	74.10 ± 1.38
Groundwater 1	54.64 ± 3.58 ^a	59.64 ± 0.81 ^a	58.14 ± 1.13 ^a	57.60 ± 0.50 ^a
Groundwater 2	60.44 ± 2.92 ^b	60.60 ± 0.42 ^a	62.42 ± 2.23 ^b	62.60 ± 2.04 ^b
2.5% leachate	60.24 ± 2.52 ^b	62.18 ± 2.03 ^b	63.48 ± 0.84 ^b	65.10 ± 0.44 ^c
5.0% leachate	60.68 ± 2.46 ^b	62.84 ± 2.11 ^b	65.48 ± 3.30 ^c	69.80 ± 0.53 ^d
7.5% leachate	60.34 ± 1.54 ^b	63.30 ± 0.67 ^b	63.80 ± 0.16 ^b	63.30 ± 0.77 ^b
10.0% leachate	52.92 ± 1.75 ^a	63.00 ± 2.02 ^b	60.70 ± 0.18 ^a	60.30 ± 3.71 ^b

Note: Data were expressed as mean ± SEM; n = 5.

^ap < .05, versus control;

^bp < .05, versus Groundwater 1;

^cp < .05, versus Groundwater 2;

^dp < .05, versus 2.5% Leachate

Group C rats received groundwater sample 2 (GW 2)

Group D rats were maintained on 2.5% inclusion level of leachates

Group E rats were exposed to 5.0% inclusion level of leachates

Group F rats were maintained on 7.5% inclusion level of leachates

Group G rats were exposed to 10.0% inclusion level of leachates.

The animals were exposed to the distilled water, groundwater samples (GW1 and GW2) and leachates (2.5%, 5.0%, 7.5% and 10.0%) *ad libitum* for 60 days. The 60-day experimental period adopted in this study was informed by the 53 days of the spermatogenic process (1 complete cycle of spermatogenesis) and maximum of 7 days of final transit through the epididymis (Simões et al., 2016). The intake of GW1, GW2 and the leachates and the amount of feed consumed by the male rats were monitored on days 1, 14, 28 and 56 as described by Adams and Yakubu (2020). All the animals were handled strictly in accordance with the National Research Council Guidelines on the Care and Use of Laboratory Animals (NRC, 2011).

2.6 | Preparation of serum and tissue supernatants

The male rats, after weighing, were euthanised by placing the animals in a glass tank containing cotton wool soaked in diethyl ether. When the animal became unconscious, their jugular veins were cut after which the collected blood sample (5 ml) were allowed to clot for 10 min and centrifuged (Uniscope Laboratory Centrifuge, model SM800B, Surgifriend Medicals, England) at 894 x g for another 10 min. The serum which was collected with the aid of Pasteur pipette was used within 12 hr of preparation.

The rats were thereafter quickly dissected and the epididymis, testes and prostate were removed. A known weight each of the prostate and testes was separately homogenised in ice-cold 0.25M sucrose solution (1.5 w/v) using a laboratory homogeniser (C-Gen Biotech, Hambala, Aryana, India). The homogenates were then centrifuged at 1,398 x g for 15 min after which the resulting supernatants were used within 24 hr of preparation for the analyses of the biochemical parameters.

Group	Amount of feed consumed (g)/rat			
	Day 1	Day 14	Day 28	Day 56
Control	15.20 ± 1.75	20.22 ± 0.29 ^a	28.11 ± 1.11 ^b	28.46 ± 0.82 ^b
Groundwater 1	15.22 ± 1.66	15.24 ± 0.65 ^c	17.24 ± 1.13 ^d	18.11 ± 1.02 ^d
Groundwater 2	15.34 ± 1.56	15.20 ± 1.42 ^c	18.02 ± 0.93 ^d	18.15 ± 0.74 ^d
2.5% leachate	14.59 ± 2.09	17.11 ± 0.49 ^d	20.02 ± 0.04 ^e	20.10 ± 0.16 ^e
5.0% leachate	15.41 ± 1.20	17.14 ± 0.31 ^d	19.93 ± 1.02 ^e	20.07 ± 0.22 ^d
7.5% leachate	14.50 ± 2.44	15.56 ± 1.67 ^c	17.01 ± 0.13 ^d	17.08 ± 0.09 ^d
10.0% leachate	14.61 ± 2.88	15.00 ± 0.20 ^c	12.00 ± 0.05 ^f	10.10 ± 2.31 ^f

Note: Data were expressed as mean ± SEM; n = 5.

^ap < .05, versus control;

^bp < .05, versus Groundwater 1;

^cp < .05, versus Groundwater 2;

^dp < .05, versus 2.5% Leachate;

^ep < .05, versus 5.0% Leachate;

^fp < .05, versus Other Treatments.

TABLE 1 Consumption of the groundwater and leachate from Gbagede Dumpsite in Amoyo, Nigeria, by male Wistar rats

TABLE 2 Feed intake by male Wistar rats after exposure to groundwater and leachate from Gbagede Dumpsite in Amoyo, Nigeria

TABLE 3 Body weight of male rats exposed to groundwater and leachates from Gbagede dumpsite in Amoyo, Nigeria

Groups	Body weight (g) before exposure	Body weight (g) after exposure	Change in body weight (%)
Control	135.24 ± 3.09	182.4 ± 17.41 ^a	34.87
Groundwater 1	134.21 ± 9.30	137.00 ± 14.09 ^a	2.24
Groundwater 2	133.62 ± 9.05	137.60 ± 9.53 ^a	2.98
2.5% leachate	133.20 ± 6.19	141.81 ± 2.35 ^a	6.46
5.0% leachate	133.61 ± 5.87	140.92 ± 4.63 ^a	5.47
7.5% leachate	134.20 ± 7.00	137.25 ± 13.99 ^a	2.27
10% leachate	134.20 ± 6.85	130.63 ± 11.03 ^a	-2.66

Note: Data were expressed as mean ± SEM; *n* = 5.

^a*p* < .05, versus control

2.7 | Collection and analyses of semen

Semen was collected from the male rats using the procedure described by Dorostghoal, Seyyednejad, Khajehpour, and Jabari (2013). Briefly, the caudal epididymis was lacerated with scissors after being carefully separated from the testis. The semen was then standardised to minimise and/or avoid variation in secretion by aspirating 10 µl from the caudal epididymis of each rat using a polyester capillary tube and releasing into Petri dishes containing 1.0 ml of 0.1 M phosphate buffer (pH 7.4). The dishes were gently swirled for homogeneity and left for 10 min at 37°C for the sperm cells to disperse into the solution. The following semen parameters were determined as described for sperm count using Neubauer Improved Haemocytometer (Marienfeld Laboratory Glasswares, Laudakönigshofen, Germany) and motility (Dias et al., 2014), normal morphology (Lopes, Simoes, Ferreira, Martins-Bessa, & Rocha, 2009), semen ACP (Wright, Leathwood, & Plummer, 1972a) and semen α-glucosidase activity (Kim, Jeong, Wang, Lee, & Rhee, 2005).

2.8 | Determination of testicular function indices and serum gonadotropins

The procedures outlined by Spiegel, Symington, Hordynsky, and Babson (1972), Wright et al. (1972a), Gjerde and Morland (1985) and Wright, Leathwood, and Plummer (1972b) were used to determine LDH, ACP, γ-GT and ALP activities in the rat testes. Other testicular parameters evaluated included sialic acid (Sydow, 1985), total cholesterol (Lakshmy, Reddy, & Jalkhani, 2001), total protein (Hartree, 1972) and glycogen (Murat & Serfaty, 1974). The volume of the testes was computed using the expression of Sakamoto et al. (2007). The testicular testosterone was quantified by the procedure of Rato et al. (2013) whilst that of Ambali, Dada, Adeleye, and Jide (2007) was adopted for the determination of serum LH and FSH. The testicular zinc, iron and copper were determined as highlighted by Awofolu (2005).

2.9 | Determination of prostatic function parameters

Prostate indices evaluated in this study were as described for calcium (Parentoni, Pozeti, Figueiredo, & de Faria, 2001), phosphate (Parsons, Dawson, Callahan, & Potts, 1970), PSA (Arneth, 2009) and ACP (Wright et al., 1972a). The pH of the prostatic fluid was determined by dipping the pH cooperative paper strip (British Drug House Chemical Limited, Poole, England; pH 1.0 to 14.0) into the prostate fluid and matching the colour that developed against that of known standards.

2.10 | Determination of testicular antioxidant parameters

Testicular SOD, GPx and catalase (CAT) activities were determined as described by Misra (1989), Mohandas, Marshall, Duggin, Horvath, and Tiller (1984) and Clairborne (1995) respectively whilst the procedures highlighted by Rubio, Hernandez-Ruiz, Martinez-Subiela, Tvarijonaviute, and Ceron (2016), Varshney and Kale (1990) and Zheng, Duan, Shen, and Duan (2015) were adopted for the determination of the levels of total antioxidant capacity (TAC), malondialdehyde (MDA) and reduced glutathione (GSH) respectively.

2.11 | Histological examination

The histological examination of the testes and prostate of the male rats was done as described by Wei et al. (2011). The photomicrographs of the testes and prostate of the male rats that were maintained on GW1, GW2 and the different inclusion levels of leachates were examined at x400 and compared with those maintained on distilled water for any histological changes.

TABLE 4 Semen characteristics of male Wistar rats after exposure to groundwater and leachate from Gbagede Dumpsite, Amoyo Nigeria

Parameters/ Groups	Sperm count ($\times 10^6$ sperm/ml)	Sperm motility (%)	Sperm morphology (%)	Semen acid phosphatase ($\text{nM}^{-1} \text{min}^{-1} \text{mg protein}$)	Semen α -glucosidase ($\text{U mg}^{-1} \text{protein}$)
Control	54.00 ± 1.64	89.02 ± 2.11	94.54 ± 3.21	711.36 ± 13.97	0.62 ± 0.03
Groundwater 1	35.88 ± 4.31^a	59.94 ± 0.85^a	66.72 ± 6.23^a	590.07 ± 16.77^a	0.24 ± 0.05^a
Groundwater 2	37.68 ± 5.81^a	72.02 ± 3.65^b	71.41 ± 2.11^b	605.69 ± 18.81^b	0.41 ± 0.03^b
2.5% leachate	41.26 ± 3.24^b	68.76 ± 3.70^c	66.75 ± 5.43^a	615.87 ± 15.99^b	0.40 ± 0.02^b
5.0% leachate	45.56 ± 2.80^b	72.90 ± 1.11^b	66.71 ± 7.21^a	588.48 ± 15.53^a	0.45 ± 0.03^b
7.5% leachate	45.00 ± 3.32^b	72.46 ± 1.22^b	52.45 ± 3.42^c	528.73 ± 12.55^c	0.25 ± 0.05^a
10.0% leachate	43.20 ± 3.15^b	64.96 ± 4.12^c	39.18 ± 2.34^d	536.61 ± 14.52^c	0.20 ± 0.03^a

Note: Data were expressed as mean $\pm$ SEM; $n = 5$.

^a $p < .05$, versus control;

^b $p < .05$, versus Groundwater 1;

^c $p < .05$, versus Groundwater 2;

^d $p < .05$, versus 2.5% Leachate.

2.11.1 | Data analysis

Data were presented as the mean $\pm$ Standard Error of Mean (SEM) of five experiments ($n = 5$). To compare results of the variables among the different groups, one-way analysis of variance was employed whilst the level of significant differences (*Post hoc* comparisons) among the different treatments was done with Duncan's multiple range test at $p < .05$ using computer software SPSS 20.0 version (SPSS, Chicago, IL).

2.12 | Results

Salivation, lachrymation, cleaning of face, squinted eyes, exophthalmia, writhing, impairment of spontaneous movement, convulsion, tremors, ataxia, biting, scratching, licking of paw, penis and tail, diarrhoea, yellowing, loss and excretion of fur and mortality were not noticed in the animals at any time throughout the exposure period.

The intake of GW1, GW2 and the leachates (2.5%, 5.0%, 7.5% and 10.0%) and the amount of feed consumed by the male rats were progressively and significantly ($p < .05$) reduced on each day of intervention (Days 1, 14, 28 and 56) as against those of the control male rats that were maintained on distilled water (Tables 1 & 2).

Unlike the control animals that produced 34.87% gain in body weight, those of male rats that were maintained on GW1, GW2 and the leachates were marginally very low (2.24%–6.46%) (Table 3). On the other hand, the 10% leachate reduced the body weight of the animals by –2.66% (Table 3).

The sperm count, sperm motility, normal sperm morphology, semen ACP and α -glucosidase activity of the animals after exposure to GW1, GW2 and the leachates at 2.5, 5.0, 7.5 and 10.0% inclusion levels reduced significantly ($p < .05$) when compared with the control (Table 4).

The absolute weight of the testes and the testes–body weight ratio of all the animals maintained on GW1, GW2 and the leachates decreased significantly ($p < .05$) when compared with the distilled

water exposed control animals (Table 5). The most profound drop in the absolute weight of the testes and testes–body weight ratio occurred in the male rats that were maintained on 10.0% leachate (Table 5). The testicular volume, concentrations of total protein, testosterone, total cholesterol, glycogen and sialic acid, in addition to γ -GT, ALP, ACP and LDH were significantly ($p < .05$) reduced in the testes of the male rats that were maintained on GW1, GW2 and leachates with the 10.0% leachate producing the most pronounced reduction in all of the testicular parameters investigated (Table 5). Furthermore, the exposure of the rats to GW1, GW2 and leachates significantly ($p < .05$) dropped the levels of testicular zinc, iron and copper when compared with the distilled water exposed control male rats (Table 5).

The levels of serum FSH and LH of the animals also dropped significantly ($p < .05$) after exposure to GW1, GW2, 2.5%, 5.0%, 7.5% and 10% leachates, with the 10% leachates producing the most striking drop in the contents of the gonadotropins (Table 6).

The absolute weight of the prostate of all the male rats maintained on GW1, GW2 and leachates decreased significantly ($p < .05$) when compared with the distilled water exposed control male rats (Table 7). The prostate–body weight ratio decreased significantly at all the concentrations (2.5%, 5.0%, 7.5% and 10.0%) of leachates whereas the GW1 and GW2 did not significantly ($p > .05$) alter the prostate–body weight ratio when compared with that of the control male rats (Table 7). The prostatic pH of the animals that were maintained on the GW1 and GW2 and the 2.5, 5.0, 7.5 and 10.0% leachate were not significantly ($p > .05$) different from the control value (Table 7). Conversely, the levels of prostatic calcium and phosphate ions in animals that were maintained on GW1, GW2 and 2.5%, 5.0%, 7.5% and 10% leachate were significantly reduced ($p < .05$). Furthermore, the level of PSA and ACP activity of the male rats increased significantly ($p < .05$) after exposure to GW1, GW2 and the leachates (Table 7). In addition, the 10.0% leachate produced the most profound drop in the phosphate content and most striking elevations in PSA and ACP activity of the male rats (Table 7).

TABLE 5 Testicular function indices of male Wistar rats after exposure to groundwater and leachate from Gbagede Dumpsite, Amoyo, Nigeria

Groups/ Parameters	Control	Groundwater 1	Groundwater 2	2.5% leachate	5.0% leachate	7.5% leachate	10% leachate
Absolute weight of testes (g)	1.35 ± 0.07	1.13 ± 0.04 ^a	1.14 ± 0.01 ^a	1.19 ± 0.01 ^b	0.98 ± 0.03 ^c	0.96 ± 0.07 ^c	0.74 ± 0.01 ^d
Testes-body weight ratio (%)	7.40 ± 0.40	0.82 ± 0.02 ^a	0.83 ± 0.01 ^a	0.84 ± 0.04 ^a	0.70 ± 0.03 ^b	0.70 ± 0.01 ^b	0.57 ± 0.01 ^b
Glycogen (mg/100mg)	10.96 ± 0.19	6.79 ± 0.06 ^a	7.81 ± 0.02 ^b	7.72 ± 0.15 ^b	7.59 ± 0.13 ^b	4.93 ± 0.16 ^c	4.73 ± 0.04 ^c
Total cholesterol (mmol/L)	950.50 ± 15.21	459.00 ± 12.73 ^a	678.30 ± 8.02 ^b	532.85 ± 9.79 ^c	497.25 ± 12.37 ^d	438.90 ± 13.67 ^a	404.60 ± 4.42 ^e
Total protein (mg/ml)	2.56 ± 0.04	1.47 ± 0.04 ^a	1.64 ± 0.02 ^b	1.33 ± 0.03 ^c	1.07 ± 0.09 ^d	1.48 ± 0.04 ^a	0.92 ± 0.07 ^d
Sialic acid (mg/g)	4.70 ± 0.05	2.15 ± 0.13 ^a	1.36 ± 0.04 ^b	1.27 ± 0.13 ^b	1.07 ± 0.06 ^c	1.64 ± 0.04 ^d	1.21 ± 0.07 ^b
Acid phosphatase (nM ⁻¹ min ⁻¹ mg protein)	176.05 ± 10.01	121.09 ± 10.24 ^a	122.30 ± 9.03 ^a	125.06 ± 7.44 ^a	123.44 ± 10.21 ^a	86.21 ± 7.79 ^b	82.67 ± 6.83 ^b
Alkaline phosphatase (nM ⁻¹ min ⁻¹ mg protein)	41.74 ± 2.96	28.34 ± 2.61 ^a	25.09 ± 2.49 ^a	24.75 ± 2.98 ^b	18.08 ± 2.16 ^c	11.79 ± 1.56 ^d	11.01 ± 0.90 ^d
Gamma glutamyl transferase (nM ⁻¹ min ⁻¹ mg protein)	37.45 ± 2.78	18.32 ± 4.56 ^a	20.64 ± 7.29 ^a	19.62 ± 3.92 ^a	13.64 ± 2.90 ^b	12.07 ± 2.49 ^b	6.03 ± 0.06 ^c
Lactate dehydrogenase (nM ⁻¹ min ⁻¹ mg protein)	77.14 ± 6.30	56.10 ± 3.32 ^a	44.72 ± 3.62 ^b	20.68 ± 5.82 ^c	28.02 ± 3.08 ^d	24.22 ± 2.13 ^c	23.32 ± 2.76 ^c
Testicular volume (ml)	2.11 ± 0.04	1.60 ± 0.02 ^a	1.59 ± 0.002 ^a	1.33 ± 0.01 ^b	1.30 ± 0.04 ^b	1.02 ± 0.07 ^c	0.72 ± 0.05 ^d
Testicular testosterone (ng/mL)	102.30 ± 0.91	55.11 ± 0.61 ^a	34.01 ± 0.13 ^b	24.60 ± 0.59 ^c	4.50 ± 0.91 ^d	4.50 ± 0.29 ^d	4.20 ± 0.34 ^d
Zinc (ppm)	2.44 ± 0.10	1.04 ± 0.08 ^a	1.05 ± 0.05 ^a	0.96 ± 0.03 ^a	0.96 ± 0.05 ^a	0.69 ± 0.04 ^b	0.34 ± 0.01 ^c
Copper (ppm)	1.95 ± 0.01	1.15 ± 0.02 ^a	1.13 ± 0.04 ^a	0.85 ± 0.03 ^b	0.83 ± 0.02 ^b	0.52 ± 0.01 ^c	0.12 ± 0.01 ^d
Iron (ppm)	1.07 ± 0.01	0.82 ± 0.02 ^a	0.61 ± 0.03 ^b	0.41 ± 0.01 ^c	0.25 ± 0.01 ^d	0.20 ± 0.03 ^d	0.10 ± 0.01 ^e

Note: Data were expressed as mean ± SEM; n = 5.

^ap < .05, versus control;^bp < .05, versus Groundwater 1;^cp < .05, versus Groundwater 2;^dp < .05, versus 2.5% Leachate;^ep < .05, versus Other Treatments.

The activities of testicular SOD, CAT and GPx as well as the levels of TAC and GSH of the male rats that were exposed to GW1, GW2, 2.5%, 5.0%, 7.5% and 10.0% leachates reduced significantly ($p < .05$) (Table 8). On the other hand, the GW1, GW2 and the leachates increased ($p < .05$) the serum MDA content of the male rats. In all, the 10.0% leachate produced the most noticeable drop in the activities of SOD, CAT, GPx and the levels of both the TAC and GSH. The highest level of MDA was also obtained in the male rats that were exposed to the 10.0% leachate (Table 8).

The testicular histology revealed that all the treatments caused distortion of the seminiferous tubules and cellular degeneration whereas the same treatments produced cellular degeneration in the prostate of the animals. Specifically, when compared with the well-preserved lumen, well-layered seminiferous tubules with complete normal cells of the spermatogenic lineage at different stages of development in the testes of control male rats (Plate 1), there were severe distortions of the seminiferous tubules, obliterated boundaries, in addition to destroyed spermatogenic cells that were devoid of embryonic cells in the male rats that received GW1, GW2, 2.5% and 5.0% leachates (Plates 2–5). In addition to all of these, the 7.5% and 10.0% leachates caused loss of germ cell attachment from the epithelium of the seminiferous tubule with no distinct lumen (Plates 6 and 7). Furthermore, when compared with the well-preserved acinus and acinar cells in the prostate of the control male rats (Plate 8), all of the treatments induced degeneration in the acinus and acinar cells (Plates 9–14).

3 | DISCUSSION

In vivo investigation of the impact of groundwater and leachates obtained from landfills on the biochemical function indices of reproductive organs and their accessory sex glands can reveal information on reproductive toxicity in experimental animals. Studies have correlated the presence of metals like chromium, lead, copper, cadmium, manganese, zinc, aluminium, iron and nickel with disruption of spermatogenesis (Pizent, Tariba, & Zivkovic, 2012), reduction in sperm count and motility (Meeker et al., 2009), enlargement of intracellular spaces and substantial loss of sperm cells (Marouani et al., 2012) and prostate cancer (Soisungwan, Scott, Mary, & Donald, 2010). Also, these metals may act individually, synergistically, antagonistically, competitively and collectively with biochemical processes and biomolecules in the testes to form strong and stable chemical bonds and in the process, mutate their structures, hamper their functions, suppress steroidogenesis, interact with nuclear proteins and deoxyribonucleic acid (DNA) and alter the pro-oxidant/antioxidant balance leading to excessive generation of free radicals. All of these result in testicular dysfunction, oxidative stress on germ cells, sperm toxicity, reproductive toxicity and male infertility (James, Lisa, & Barbara, 2010). Furthermore, Miao et al. (2013) also opined that low doses of cobalt, zinc and copper act as reproductive toxicity risk factors via depleting testicular antioxidants including glutathione and sex hormones.

According to Yakubu, Oyagoke, Quadri, Agboola, and Oloyede (2019), salivation, lachrymation, ptosis, squinted eyes, writhing, tremors, convulsion, loss of hair and yellowing of fur are valuable indicators of toxicity, whilst exophthalmia and erection of fur are physical indicators of stress. Also, behavioural abnormalities are indicated by imbalance in spontaneous movement, climbing, ataxia, other postural changes and face cleaning whilst aggressive behaviour is represented by scratching and biting behaviours and licking of paw, penis and tail. The absence of all of these aforementioned signs implied that there were no treatment-related visible signs of toxicity, stress, behavioural abnormality and aggressive behaviour.

The GW1, GW2 and the leachates adversely affected the general status of the rats by suppressing their appetite as evidenced by the progressive drop in the intake of the feed, and this might account for the drop in body weight of the male rats. Appetite regulates the desire of the body of the animals for food and plays vital role in weight regulation (Ugwah-Oguejiofor et al., 2019). Such weight loss might be a risk factor of male infertility (Dan Guo et al., 2019). Also, the drop in absolute weight of the testes and prostate, testes- and prostate-body weight ratios and the reduction in testicular volume which might be the consequence of atrophic changes validate testicular and prostatic toxicities. The reduction in both the absolute weight of the testes and testicular volume may be due to direct impairment of the testicular-pituitary-hypothalamic axis by the Pb, Cd and Al in GW1, GW2 and leachates leading to reduced tubule size (revealed by the histological study), spermatogenic arrest and inhibition of steroid biosynthesis in the Leydig cells of the testes. It may also be traced to depleted number of germ cells, inhibition of enzyme activities of both spermatogenesis and steroidogenesis, drastic reduction in sex/serum hormones. Hence, the significant loss of absolute weight of the testes, testes-body weight ratio and testicular volume after treatment with the GW1, GW2 and the leachates speculate its reproductive toxicity.

TABLE 6 Effects of groundwater and leachates from Gbagede dumpsite in Amoyo, Nigeria on the levels of serum gonadotropins of male Wistar rats

Groups/Hormones	Luteinising hormone (mIU/ml)	Follicle-stimulating hormone (mIU/mL)
Control	3.44 ± 0.08	6.22 ± 0.07
Groundwater 1	1.90 ± 0.07 ^a	3.74 ± 0.04 ^a
Groundwater 2	1.62 ± 0.05 ^b	4.68 ± 0.06 ^b
2.5% Leachate	2.22 ± 0.08 ^c	3.52 ± 0.08 ^a
5.0% Leachate	1.80 ± 0.15 ^a	3.23 ± 0.03 ^a
7.5% Leachate	1.52 ± 0.32 ^d	3.19 ± 0.07 ^a
10.0% Leachate	1.16 ± 0.06 ^e	2.92 ± 0.05 ^a

Note: Data were expressed as mean ± SEM; $n = 5$.

^a $p < .05$, versus control;

^b $p < .05$, versus Groundwater 1;

^c $p < .05$, versus Groundwater 2;

^d $p < .05$, versus 2.5% Leachate;

^e $p < .05$, versus Other Treatments.

TABLE 7 Prostatic function parameters of male Wistar rats after exposure to groundwater and leachates from Gbagede dumpsite, Amoyo, Nigeria

Groups	Control	Ground water 1	Ground water 2	2.5% leachate	5.0% leachate	7.5% leachate	10.0% leachate
Absolute weight of prostate (g)	0.24 ± 0.04	0.15 ± 0.02 ^a	0.15 ± 0.01 ^a	0.11 ± 0.01 ^a	0.10 ± 0.01 ^a	0.10 ± 0.01 ^a	0.10 ± 0.02 ^a
Prostate-body weight ratio (%)	0.13 ± 0.03	0.11 ± 0.01	0.11 ± 0.01	0.08 ± 0.01 ^a	0.07 ± 0.01 ^a	0.07 ± 0.01 ^a	0.08 ± 0.01 ^a
Prostatic pH	9.82 ± 0.91	9.80 ± 0.31	9.58 ± 0.08	9.50 ± 0.03	9.68 ± 0.20	9.64 ± 0.05	9.52 ± 0.04
Calcium (mg/dL)	7.47 ± 1.13	5.19 ± 0.23 ^a	2.78 ± 0.07 ^b	3.69 ± 0.09 ^c	2.07 ± 0.12 ^d	2.09 ± 0.04 ^d	2.10 ± 0.12 ^d
Phosphate (mmol/L)	21.40 ± 1.14	13.40 ± 0.55 ^a	17.50 ± 0.87 ^b	13.70 ± 0.45 ^a	13.00 ± 0.71 ^a	12.40 ± 0.55 ^a	11.60 ± 0.89 ^a
Total Prostate-specific Antigen (mg/ml)	1.68 ± 0.33	2.68 ± 0.19 ^a	3.04 ± 0.23 ^b	2.20 ± 0.26 ^c	2.92 ± 0.22 ^a	3.00 ± 1.21 ^b	3.96 ± 0.92 ^d
Acid Phosphatase (nM ⁻¹ min ⁻¹ mg protein)	140.55 ± 14.58	213.30 ± 21.68 ^a	262.95 ± 63.20 ^b	194.19 ± 29.50 ^a	215.65 ± 23.91 ^a	243.30 ± 14.37 ^b	292.09 ± 9.33 ^c

Note: Data were expressed as mean ± SEM; n = 5.

^ap < .05, versus control;

^bp < .05, versus Groundwater 1;

^cp < .05, versus Groundwater 2;

^dp < .05, versus Other treatments.

TABLE 8 Testicular antioxidant parameters of male Wistar rat after exposure to groundwater samples and leachates from Gbagede, Amoyo Dumpsite

Parameters/Groups	Control	Ground water 1	Ground water 2	2.5% leachate	5.0% leachate	7.5% leachate	10.0% leachate
Superoxide dismutase activity (U/mg protein)	17.04 ± 0.05	13.14 ± 0.05 ^a	13.18 ± 0.08 ^a	8.21 ± 0.06 ^b	7.05 ± 0.04 ^c	3.86 ± 0.15 ^c	1.08 ± 0.02 ^d
Catalase activity (μmoles ⁻¹ H ₂ O ₂ consumed ⁻¹ min ⁻¹ mgprotein)	22.28 ± 1.49	16.21 ± 1.14 ^a	13.51 ± 0.78 ^b	12.96 ± 1.88 ^b	9.21 ± 0.72 ^c	5.58 ± 0.10 ^d	2.66 ± 0.04 ^e
Glutathione Peroxidase (nM NADPH oxidised ⁻¹ min ⁻¹ mg protein)	121.28 ± 7.22	109.11 ± 1.44 ^a	83.82 ± 2.00 ^b	67.07 ± 1.05 ^c	62.97 ± 5.22 ^c	40.12 ± 2.31 ^d	18.64 ± 1.38 ^e
Reduced Glutathione (μg ⁻¹ mg protein)	37.62 ± 5.19	28.14 ± 2.90 ^a	25.02 ± 6.39 ^a	27.39 ± 3.19 ^a	17.80 ± 2.74 ^b	11.36 ± 0.59 ^c	5.21 ± 0.05 ^d
Total antioxidant capacity (μmol ⁻¹ ml)	4.53 ± 0.10	2.37 ± 0.07 ^a	2.40 ± 0.07 ^a	2.33 ± 0.06 ^a	2.41 ± 0.03 ^a	1.17 ± 0.02 ^b	0.22 ± 0.02 ^c
MDA (nmol ⁻¹ g)	27.28 ± 4.16	39.11 ± 1.80 ^a	45.08 ± 3.28 ^b	54.44 ± 4.22 ^c	55.08 ± 3.63 ^c	66.06 ± 2.05 ^d	82.07 ± 3.88 ^e

Note: Data were expressed as mean ± SEM; n = 5; MDA, Malondialdehyde.

^ap < .05, versus control;

^bp < .05, versus Groundwater 1;

^cp < .05, versus Groundwater 2;

^dp < .05, versus 2.5% Leachate;

^ep < .05, versus 5.0% Leachate.

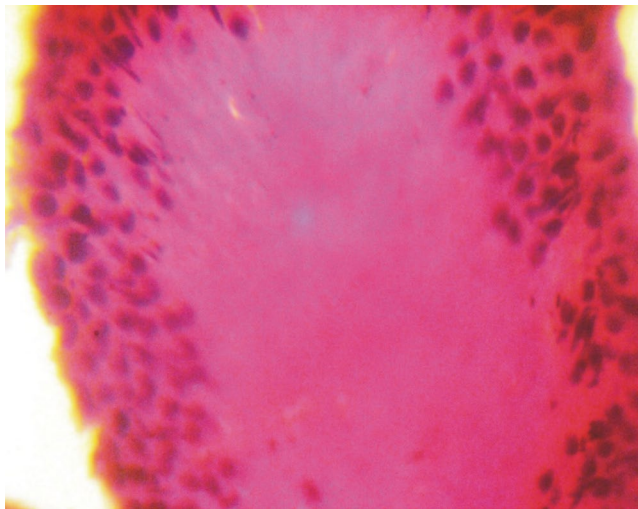


PLATE 1 Cross section of testis of male rats exposed to distilled water (x400; H&E). There was well-preserved lumen and well-layered seminiferous tubules with complete normal cells of the spermatogenic lineage at different stages of development

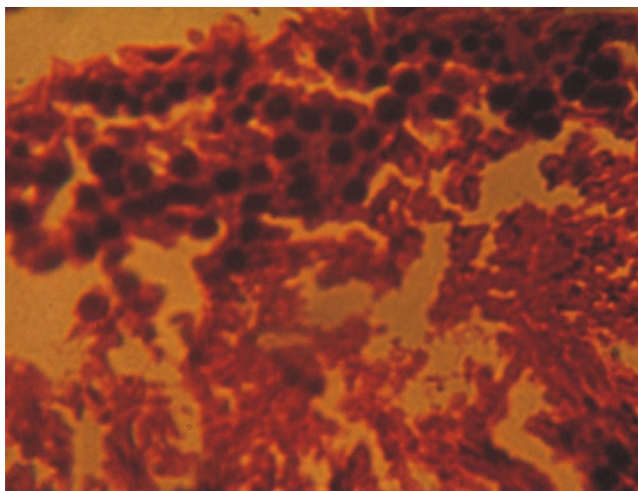


PLATE 2 Cross section of testis of male rats exposed to groundwater 1 (x400; H&E). The photomicrograph shows severe distortion of the seminiferous tubules, obliterated boundaries as well as evidence of destruction of spermatogenic cells with no embryonic cells

Sperm count, motility (progressive motile) and morphology (% normal) are the prime markers of testicular spermatogenesis and epididymal maturation (Rato et al., 2012). Therefore, the drop in sperm count in the present study may not be unconnected with Sertoli cells that have been harmfully distorted whilst similar drop in sperm motility may be the consequence of decreased semen ACP since a reduction in the activity of the enzyme will drastically drop the quality of semen produced. Therefore, interactions of metals like Cd, Al and Pb in GW1, GW2 and leachates may account for not only the low quality of the sperm cell and depleted activities of γ -GT, an indicator of Sertoli cell dysfunction, but also the drop in sialic acid, LDH and glycogen in the testes, since they are responsible for the maturation of germinal epithelial layer of seminiferous tubules and post-meiotic

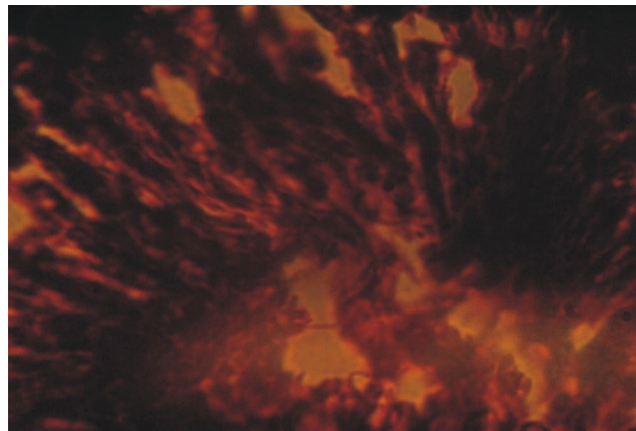


PLATE 3 Cross section of testis of male rats exposed to groundwater 2 (x400; H&E). There was severe distortion of the seminiferous tubules and evidence of destruction of spermatogenic cells with no embryonic cells

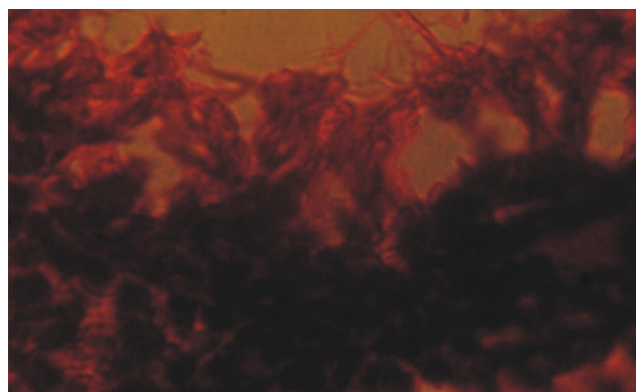


PLATE 4 Cross section of testis of male rats exposed to 2.5% leachate (x400; H&E). The photomicrograph shows severe distortion of the seminiferous tubules, obliterated boundaries as well as evidence of destruction of spermatogenic cells with no embryonic cells

spermatogenic cells, providing the reserve of carbohydrate for the seminiferous tubular cells and spermatogonia in the various phases of spermatogenesis (Rato et al., 2012), and providing adequate substrate for the cellular metabolism in the Sertoli cell as well as promoting frictional force or hindering lubrication between the sperm cells respectively. The drop in normal sperm morphology in this investigation might be associated with the damage exerted on differentiated spermatogonia, or at the point at which the spermatogonia is differentiating to form spermatocytes. The impairment in both sperm maturation and spermatogenesis is also buttressed by the depletion in the testicular total protein content in this study. The bioaccumulation and interactions between Pb, Cd, Zn, Cu, Al and Ni in GW1, GW2 and the leachates and the testes might as well account for the drop in sperm count, reduction in sperm motility and normal morphology of the sperm cells (Meeker et al., 2009). Consequentially, all of these validate reproductive toxicity of the GW1, GW2 and the leachate leading to diminished fertilising capacity of the spermatozoa. The

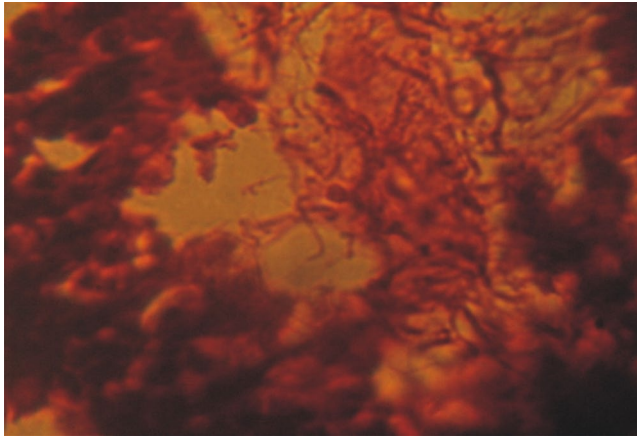


PLATE 5 Cross section of testis of male rats exposed to 5.0% leachate (x400; H&E). The photomicrograph shows severe distortion of the seminiferous tubules, obliterated boundaries as well as evidence of destruction of spermatogenic cells with no embryonic cells

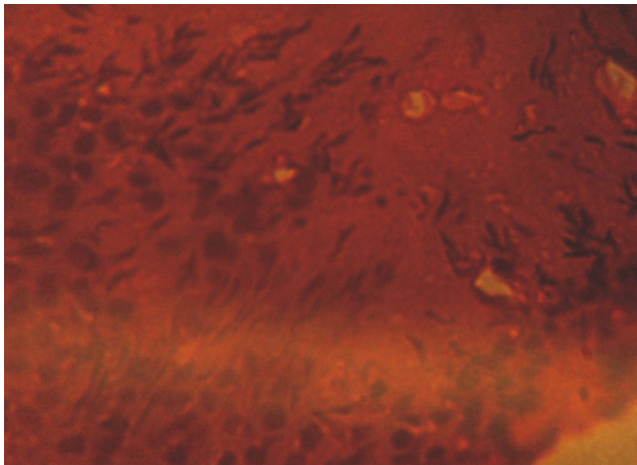


PLATE 6 Cross section of testis of male rats exposed to 7.5% leachate (x400; H&E). The photomicrograph shows severe distortion of the seminiferous tubules and loss of germ cell attachment from the seminiferous epithelium with no distinct lumen

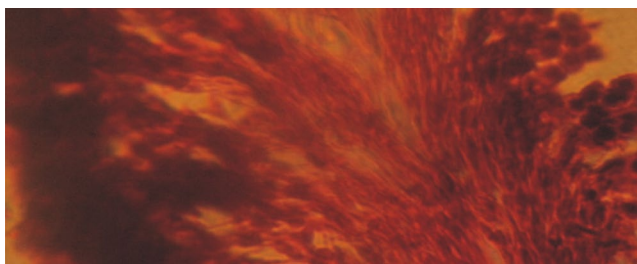


PLATE 7 Cross section of testis of male rats exposed to 10.0% leachate (x400; H&E). The photomicrograph shows severe distortion of the seminiferous tubules and severe loss of germ cell attachment from the seminiferous epithelium with no distinct lumen

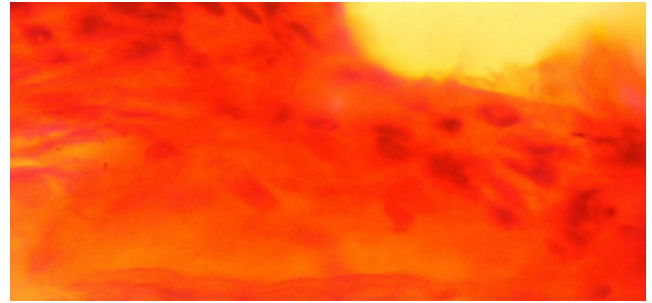


PLATE 8 Cross section of prostate of male rats exposed to distilled water (x400; H&E). The photomicrograph indicates well-preserved acinus and acinar cells.

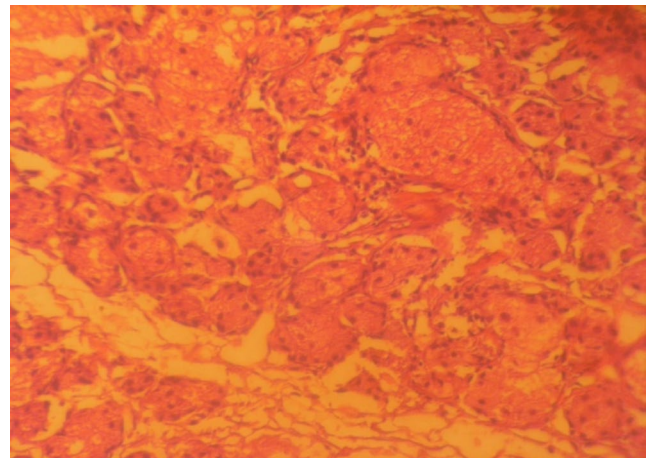


PLATE 9 Cross section of prostate of male rats exposed to groundwater 1 (x400; H&E). The photomicrograph indicates degenerated acinus with scanty acinar cells

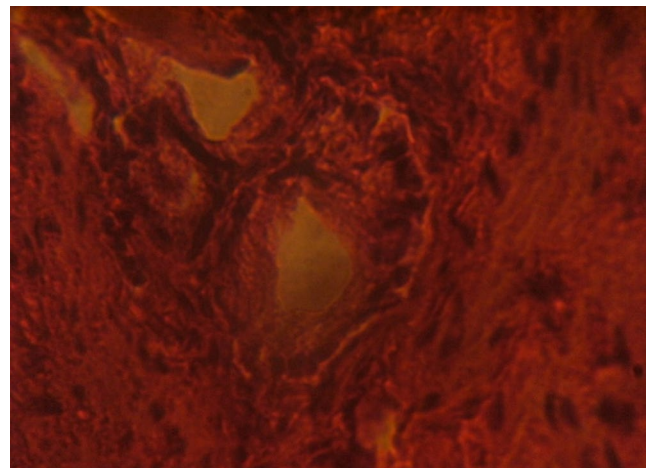


PLATE 10 Cross section of prostate of male rats exposed to groundwater 2 (x400; H&E). The photomicrograph indicates degenerated acinus with well dispersed acinar cells

observation herein is in line with that of Akintunde, Oboh, and Akindahunsi (2015) after sub-chronic exposure of rats to Elewi Odo Municipal Battery Recycling Site leachates in Ibadan, Nigeria. Also,

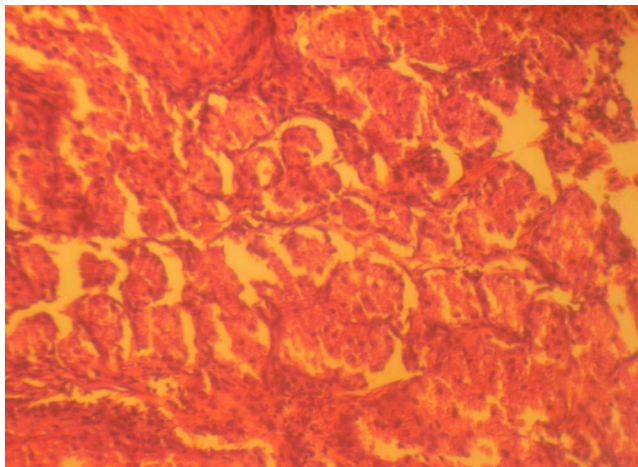


PLATE 11 Cross section of prostate of male rats exposed to 2.5% leachate (x400; H&E). The photomicrograph indicates degenerated acinus with scanty acinar cells

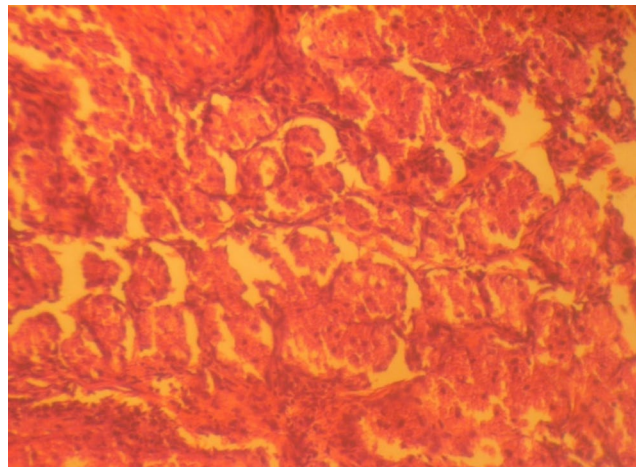


PLATE 14 Cross section of prostate of male rats exposed to 10.0% leachate (x400; H&E). The photomicrograph indicates degenerated acinus with well dispersed acinar cells

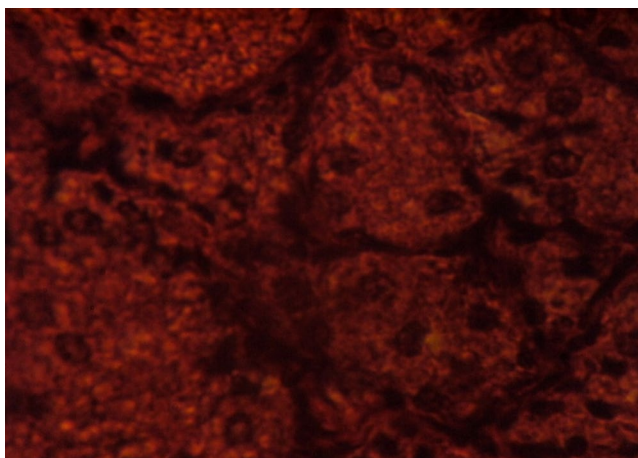


PLATE 12 Cross section of prostate of male rats exposed to 5.0% leachate (x400; H&E). The photomicrograph indicates degenerated acinus with well dispersed acinar cells

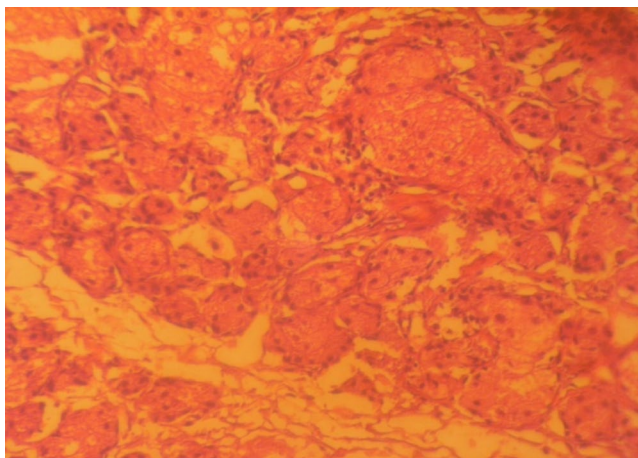


PLATE 13 Cross section of prostate of male rats exposed to 7.5% leachate (x400; H&E). The photomicrograph indicates degenerated acinus with scanty acinar cells

the drop in semen α -glucosidase activity which correlated with the decrease in sperm count can be attributed to epididymal obstruction leading to functional changes at both the physiological or anatomical levels (Krause & Bohring, 2002).

The requirement for constant supply of cholesterol by mammalian cells and its role as precursor molecule in the synthesis of most steroid hormones has been widely accepted. The reduction in the concentration of testicular cholesterol of male rats after exposure to GW1, GW2 and the leachates most especially at 10% inclusion level might have adversely affected steroidogenesis, as corroborated by the drop in the activities of the phosphatases (ALP and ACP) that are essential for the normal intra- and inter-cellular transport of metabolites needed for steroidogenesis and the testicular mobilisation of carbohydrates and lipids for the accessory sex cells or by spermatozoa in the seminal fluid. Such reduction in the testicular testosterone by Pd and Cd contents of GW1, GW2 and leachates might have impacted negatively on the number and function of somatic and germinal cells.

Homma-Takeda, Nishimura, Watanabe, and Yukawa (2007) have stated that trace elements like copper, zinc and iron plays pivotal role in spermatogenesis. A marked increase in zinc normally correlate with elevation in the activities of ALP and zinc phosphatase, occurring concomitantly with the appearance of spermatids and mature sperm cells (Guha & Vanha-Perttula, 1983). The depletion in testicular zinc content may therefore explain the reduction in the activities of the phosphatases and the impaired spermatogenesis. Similarly, the depletion in testicular zinc content will adversely affect testosterone metabolism by hindering the conversion of androstenedione to testosterone in the periphery and, consequently, the action of other androgens, since the DNA-binding domain of the androgen receptors is a cysteine-rich zinc-finger protein (Grumbach & Conte, 1992). In addition, the reduction in testicular copper contents in the present study will promote oxidative process (Leonhard-Marek, 2001) by overcoming the spin restriction of oxygen and donating a single electron, giving rise to free radical species and chain reactions.

However, this school of thought is supported by the elevated MDA levels. Furthermore, the reduction in testicular iron concentration may in part be linked with Sertoli cell dysfunction earlier advanced in this study (Leonhard-Marek, 2001).

Testosterone, FSH and LH are primarily involved in the performance of the male reproductive system. The toxic effects of GW1, GW2 and leachates on these primary hormones of reproduction manifested as endocrine disruptor, diminishing the levels of serum FSH and LH. Therefore, the reduction in both the LH and FSH most especially by the 10% leachate may be associated with the presence of Pb and Cd in GW1, GW2 and leachates that have accumulated to toxic levels in the male rats and this may adversely affect the stimulatory effect of the hormones on the testes that are essential for normal reproduction. Toxic metals such as Pb and Cd have been implicated to affect hormones responsible for sperm production (Benoff, Jacob, & Hurley, 2000).

Prostate secretes a myriad of complex fluids that assist in the transportation and sustenance of spermatozoa in both the male and the female genital tracts. The reduction in the levels of calcium and phosphate ions in the present study might not be unconnected with the drop in testosterone level, since the secretory activity of the prostate gland and the degenerative changes in the epithelial lining of the prostate in this study are extremely sensitive to androgen levels. Also, the elevated levels of PSA and the activity of ACP are indications that the GW1, GW2 and the leachates can pre-dispose the animals to prostate cancer, since high levels of PSA and ACP activity are found in metastasized prostate cancer (Haroun et al., 2011). The absence of an effect on the prostatic pH suggests that the GW1, GW2 and the leachates did not interfere with the buffering capacity of the organ or there was the absence of an increase in the relative concentration of alkaline seminal vesicular components. The reports by Goyer, Liu, and Waalkes (2004) and Telisman, Colak, Pizent, Jurasovic, and Cvitovic (2007) implicating Cd and Pb in prostate cancer development suggests that these metals in the groundwater samples and leachates in the present study may have a role to play in pre-disposing and development of prostate cancer in the male rats.

Superoxide dismutase rapidly converts superoxide anion to a less dangerous hydrogen peroxide which when acted upon by GPx and CAT will produce water. Generally, it seems that the testicular antioxidant system of the male rats was overwhelmed in the present investigation by the Pb, Ni, Cd, Fe and Cu constituents of GW1, GW2 and the leachate sample, as evidenced from the depleted antioxidant molecules (SOD, GPx, CAT and GSH) and the TAC. This might have led to the production of free radicals that aggravated lipid peroxidation and oxidative stress (Aitken & Drevet, 2020) as buttressed by the elevation in the levels of MDA with the 10% leachate demonstrating the most pronounced effect. Uncontrolled production of these free radicals can oxidise the polyunsaturated fatty acid constituents of the sperm cells, testes and prostate leading to the observed biochemical (reduced secretory activity) and histoarchitectural (degenerative) changes. All these will promote the risk of infertility, miscarriage and serious disease in the offspring (Aitken & Drevet, 2020).

The proposed mechanism of toxicity of GW1, GW2 and leachate samples is not unconnected with the individual, synergistic, antagonistic, competitive or collective interactions of Pb, Cd, Zn, Cu, Al and Ni with the normal testicular and prostatic biochemical processes and/or biochemical constituents of the organs via disruption of the hypothalamic-pituitary-gonadal axis, neuroendocrine system, Sertoli cells and Leydig cells as well as impairment of DNA integrity with increased oxidative stress.

Overall, the study concluded that the interaction and bioaccumulation of Pb, Cd, Zn, Cu, Al and Ni present in the Gbagede dumpsite groundwater samples and leachates have directly impacted on the testes and prostate and indirectly on the neuroendocrine system culminating in spermatotoxicity, testicular and prostate toxicities via endocrine disruption and oxidative stress mechanisms. This will have attendant implications on the reproductive capacity and fertility of the male rats.

CONFLICT OF INTEREST

The authors declare no competing financial interest. The authors alone are responsible for the content of the paper.

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