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Survey on human-designated antiretroviral (ARV) drug residues in broiler chicken, domestic pigs, and animal feeds in, Tanzania

Zuhura I. Kimera^{1*}, Peter Shimo², Emmanuel C. Balandya³, Mecky I. N. Matee⁴ and Lisa V. Adams⁵

Abstract

Background Recent reports have indicated the use of antiretroviral (ARV) drugs in animal production in neighboring Uganda, with further reports of use in several African countries. This cross-sectional survey was conducted in nine districts in Tanzania and involved screening for the presence of three first-line ARVs (lamivudine, nevirapine, and efavirenz) residues in the muscle and blood of domestic pigs and broiler chickens and in sampled animal feed and water. Residues were determined using liquid chromatography and mass spectrometry (LC–MS/MS). The method involved calibration of the lower limit of quantitation (LLOQ) and limit of detection (LOD). ARVs were detected and quantified using the multiple reaction monitoring (MRM) system.

Results 131 (66.8%) of the 196 samples of muscle, blood, and animal feed were found to contain lamivudine residues, with the highest concentration detected in domestic pig blood and muscle (7.58 mg/kg) and the lowest concentration (0.01 mg/kg) in broiler chicken feed. There was a significant relationship between the presence of lamivudine by sample type and sample origin ($p=0.000$). Nevirapine and efavirenz drugs were not detected in any of the collected samples. No ARV residues were detected in water samples ($n=37$).

Conclusions This survey confirms the use of ARVs in animal production in Tanzania as evidenced by the presence of residues in animal feeds. We found lamivudine residues in domestic pigs and broiler chickens at concentrations higher than those recently reported in other East African studies. Farmers living with HIV may be using ARVs from their prescribed medication, which may lead to poor adherence and the emergence of drug resistance. Besides direct human and animal health issues, these residues in animal feeds and animal excreta can lead to environmental contamination leading to several negative impacts. We recommend a total ban on human-designated ARVs in animal production and advocate for comprehensive studies and monitoring systems across African countries to reveal potential societal and other reasons for their use and provide comprehensive solutions using One Health approaches.

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Background

Human immunodeficiency virus (HIV) infection is one of the global health problems, particularly in sub-Saharan African (SSA) countries (WHO 2023). In 2022, approximately 39 million people were living with HIV globally of whom 25.6 million, over two-thirds of all HIV infections, were living in SSA (UNAIDS 2023). According to UNAIDS (2024), statistics Tanzania has a total of 1,700,000 adults and children living with human immunodeficiency virus (HIV), of whom 1,400,000 are on antiretroviral (ARV) drugs (UNAIDS 2024). The coverage of pregnant women who receive ARV for prevention of mother-to-child transmission (PMTCT) of HIV infection is 98%, averting 18,000 new HIV infections (UNAIDS 2024). The main ways that HIV is transmitted in Tanzania are through heterosexual sexual contact (contributing up to 80%), injecting drug use (16–51%), men who have sex with men (MSM) (22–42%), and sex workers (14–35%) (URT 2018).

According to the national guidelines for the management of HIV and AIDS (URT 2019), which are in line with WHO consolidated recommendations (WHO 2021), the first ARV regimen for treating and preventing HIV infection recommended for adults and adolescents consists of tenofovir disoproxil fumarate (TDF) + lamivudine (3TC) (or emtricitabine, FTC) + efavirenz (EFV). For the past 20 years, Tanzania has received significant support for purchasing antiretroviral drugs (ARV) from international organizations and initiatives, witnessing a remarkable increase in the number of HIV-infected individuals on ARV from 22% in 2009 to over 98% in 2023 (Tarimo 2023). ARVs are widely and freely available at all levels of service delivery from dispensaries to health centers and public and private hospitals (Mziray et al. 2021).

The free and widespread availability of ARVs, along with lax enforcement of laws, has resulted in their unchecked use beyond their intended purpose.

In Uganda, ARVs have been used to treat viral diseases in animals, such as African swine fever and alcohol fermentation, and to promote the growth of pigs and poultry. (Nakato et al. 2020; Ndoboli et al. 2021; Obonyo 2013; Odongo 2016; Opoka 2018; Valentine 2013). There are also reports of misuse of ARVs in neighboring Kenya (Valentine et al. 2013) and several other communities in East Africa (Hatari 2013; Oketch 2016; URN 2017). According to a recent Tanzanian study, farmers who raise domestic pigs and broiler chickens use ARVs together with other human and indigenous medications to promote growth and treat illnesses, including African swine fever (ASF), a prevalent viral disease that affects domestic pigs (Kimera et al. 2024). The ARVs that are provided to animals originate from a variety of sources including HIV-infected patients who share their medications

with their animals, medical institutions, pharmacies, and other farmers who bought expired ARVs for \$0.20 to \$2.00 per tablet (Ndoboli et al. 2021). There are also reports of unfaithful health workers selling ARVs to people who are not on therapy for various purposes, including animal farming (Kimera et al. 2024), and black-market sales for profit by unscrupulous traders (Kasang et al. 2011). Not surprisingly, studies from Uganda have detected a considerable amount of ARV residues in food animals citing the source of the drugs to be HIV-infected patients who self-treat their animals (Nakato et al. 2020; Ndoboli et al. 2021).

Although ARV drugs are readily available and widely used in Tanzania, as well as accusations of abuse in animal husbandry, there is no information on whether active pharmaceutical ingredients are present in animal products, animal feed, or water sources. This study aims to determine the presence of lamivudine (3TC), efavirenz (EFV), and nevirapine (NVP) residues in broiler poultry and domestic pigs, animal feeds, and water sources. These panels of ARVs were selected because they are the first-line drugs for the management of HIV and AIDS in Tanzania (URT 2019). We hypothesize that the use of ARVs in animal feeds for growth promotion will lead to their deposition in animal tissues, and when excreted through urine or feces will contaminate the surrounding environment and potentially remain bioactive, leading to wide-ranging chemical and biological effects with potential impact on public health and the environment.

Methods

Study area

This cross-section survey was conducted in 9 districts in Dar es Salaam, Mbeya, and Iringa regions as shown in the map (Fig. 1). The Dar es Salaam region is the largest city in Tanzania and biggest consumer of chickens and domestic pigs originating from all parts of the country (Mubito et al. 2014). Mbeya, Iringa, Morogoro, Rukwa, and Ruvuma regions from the Southern Highlands are the leading domestic pig producers contributing to 54% of the domestic pigs in Tanzania (Kimbi et al. 2015).

Sampling strategy

The survey involved 9 districts; Temeke, Ilala, and Kinondoni in the Dar es Salaam region, Mbeya Town Council, Mbeya District Council and Mbalizi in the Mbeya region, and Iringa Municipal Council, Kilolo and Mafinga in Iringa region. In each of the selected districts, the abattoir/slaughter slabs were identified for sampling because they receive animals from different localities. Broiler chicken samples were collected from the Dar es Salaam region only because the city is a major producer and market for broiler poultry. Information on the origin of the

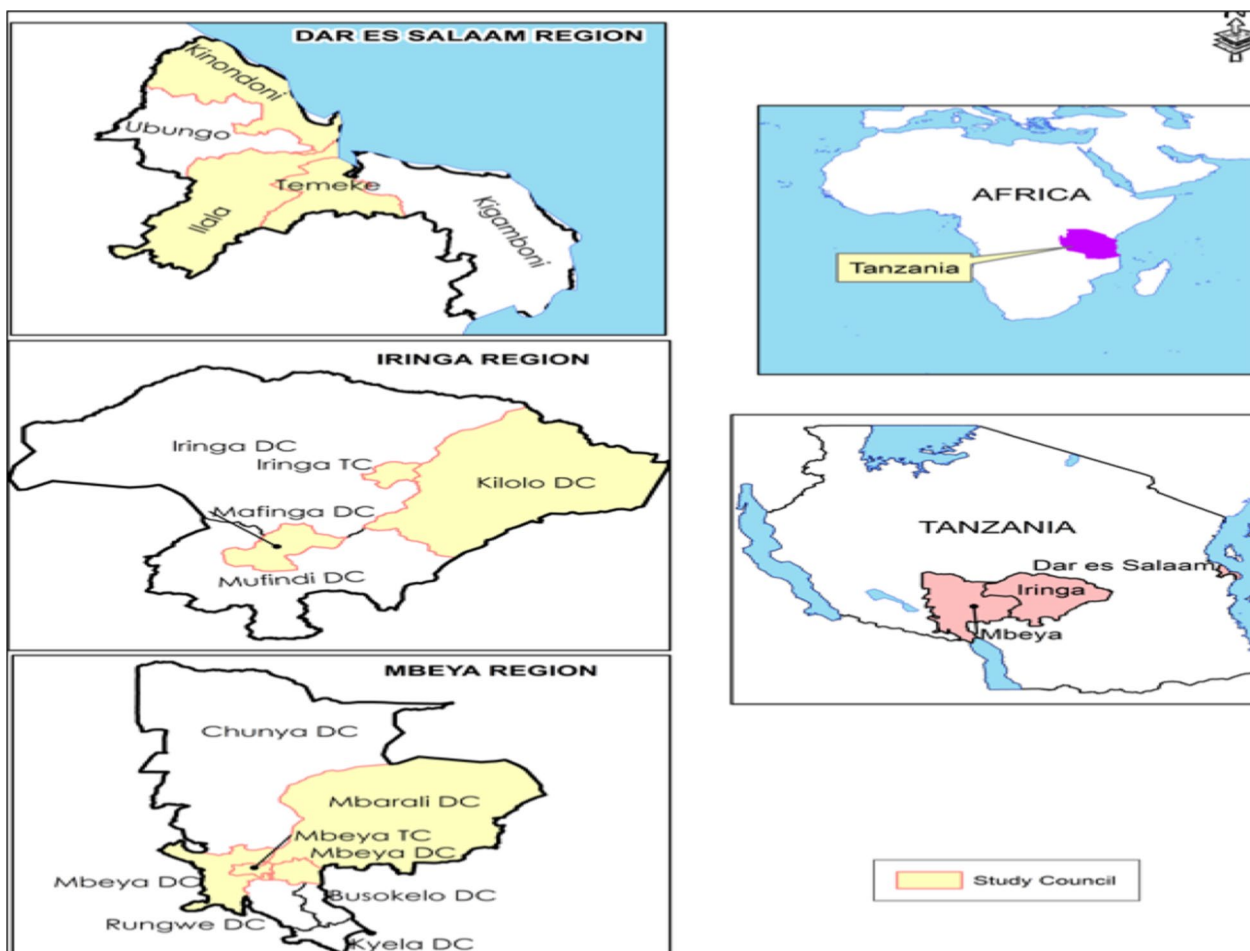


Fig. 1 Map showing the Dar es Salaam, Mbeya, and Iringa regions with the nine districts involved in this survey

animal was collected before taking blood and tissue to avoid having samples originating from a single source.

Sample collection

About 10 mL of blood was collected using BD Vacutainer EDTA tubes, and 25 g of muscle tissue was collected from the freshly slaughtered animals. The water sample was collected in 50-mL bottles that had been rinsed with a mixture of hexane and methanol. River water was collected using a rope tied to the bottle. Samples from dams/wells were collected by grab sampling from approximately 30 cm below the water surface and in shallow areas, water was collected into the bottle using by gloved hand. Samples from the tap water were collected after allowing the water to flow for about 30 s from the tap. With animal feed, about 50 g was collected and placed in sterile polythene bags. The samples were labeled and immediately transported in an icebox at 4 °C to the Department of Microbiology and Immunology at the Muhimbili University of Health and

Allied Sciences for storage at – 20 °C pending analysis. The sample size was determined from the following formula $n = z^2 p (1 - p) / e^2$ whereby z is the 95% confidence interval (which is 1.96), p is the estimated proportion of an attribute, and e is the standard error of the proportion (which is 0.05). The proportion of 14.8% reported by Kasang et al. (2011) was used to make a sample size of 196 samples.

Laboratory procedures

Determination of ARVs in the collected samples was conducted at the Government Chemistry Laboratory Authority (GCLA) using liquid chromatography with tandem mass spectrometry (LC–MS/MS). The LC–MS/MS is a powerful analytical technique that combines the separating power of liquid chromatography with the highly sensitive and selective mass analysis capability of triple quadrupole mass spectrometry.

Chemicals

Reagents included the internal standards (IS) of efavirenz, nevirapine, and lamivudine purchased from Millipore Sigma Aldrich (USA). These ARVs are available in mono-component type and fixed-dose combination (FDC). Acetonitrile, methanol, formic acid, water, and all LC-MS hyper-grade for the mobile phase were purchased from Biosolve (Dieuze, France). The HPLC-grade acetonitrile and methanol that were used for protein precipitation, and hydrochloric acid used as analytical reagent were purchased from Merck Research laboratory (Whitehouse Station, NJ, USA).

Conditions of chromatographic and mass-spectrophotometric assessments

The chromatographic and mass-spectrometric conditions were set as described by (Djerada et al. 2013) with some modifications. Briefly, a standard liquid chromatographic (LC-MS) system (Q-Exacte Orbitrap Ms, UK), equipped with a cooled auto-sampler, column oven, and Xevo TQ mass spectrometer (Waters Corp., Milford, MA, USA) was used. The mobile phase (A) consisted of water + formic acid 0.1% (V/V) and the mobile phase (B) had acetonitrile + formic acid 0.1% (V/V). The mobile phase gradient was set at 0.6 mL/min flow rate; 0.0 min at 95% of mobile phase A, followed by an increase and decrease of mobile phase B of 90% from 0.0 to 5.0 min, to 5% from 5.0 to 5.1 min, respectively. At mobile phase A, the flow rate was maintained at 95% of mobile phase A from 5.1 to 5.5 min. The electrospray probe was kept free from non-retained components using a 0.1 min solvent/diverts delay to waste. At the end of the spectrometric acquisition, the column eluent was again diverted to waste.

Preparation of stock solutions, calibration standards, and quality control samples

Stock solutions of internal standard nevirapine, efavirenz, and lamivudine were prepared in HPLC-grade methanol, containing 0.005N HCl, to obtain a final concentration of 1 mg/mL. Working solutions were diluted with a suitable volume of methanol and finally in the blank sample (<1/9 V/V) to prepare calibration standards (STD). Quality control (QC) samples were prepared with stock solutions different from those used to prepare the calibration standards and were prepared in blank samples then kept at -20 °C for subsequent use for a period not exceeding one month.

Sample preparation

Antiretroviral (ARV) drug residues in the collected samples were extracted as described by Djerada et al. (2013). The amount of 2 g or 2 mL of the sample was

weighed and was followed by the addition of 2 mL of 8:2 methanol:water and vortexed for 1 min. Thereafter, 4 mL of acetonitrile was added and the mixture was centrifuged at 5,000 rpm for 10 min, and then 1 mL of the supernatant was filtered and placed in a glass vial for chromatographic separation. ARV residues in broiler chickens and pig meat and blood, animal feeds, and wastewater were qualitatively quantified by LC-MS/MS. The ARVs residues were separated on a VF-5 ms (Ultra inert) 100 mm × 2.1 mm × 2.2 μM column and detected by Q-TOF triple quadrupole mass spectrometry (MS/MS) operating with electron energy at 35 eV. The injection volume was 5 μL. All ARV residues were detected and quantified in the multiple reaction monitoring (MRM).

Method validation

Method validation included calibration of the lower limit of quantitation (LLOQ) and limit of detection (LOD). The limit of quantification (LOQ) was considered the lowest calibration standard detected, and the LOD was the estimated concentration that gives chromatographic peaks with a ratio of five (5) as described by Djerada et al. (2013). The lower limit of quantitation (LOQ) was estimated by decreasing the amounts of analytes in samples and was calculated as the concentration estimated from 10 to 0.01 ppm. Calibration standards ($n=6$) were prepared and analyzed with a minimum of six (6) independent runs for each compound at a concentration of 0.5–10 ppm. Thereafter, a six (6)-point calibration curve was constructed using least squares linear or nonlinear regression quadratic regression equation, with r^2 between 0.995 and 0.996. The recovery tests were performed by spiking three (3) levels 0.5, 2.5, and 5.0 ppm with recovery ranging from 76.60 to 91.78 for lamivudine, 71.68–116 for nevirapine, and 86.88–105.72 for efavirenz. The detailed information on validated data is shown in Table 1.

Matrix effect

The matrix effect was assessed as recommended (European Medicines Agency 2012). Absolute matrix effect was assessed for all analytes by comparing the chromatographic peak areas of spiked blank sample extracts (i.e., after protein precipitation with methanol and acetonitrile) from 6 different sources to peak areas obtained from the same concentration of analytes in the same composition of the extract (100 μL of methanol + 200 μL of acetonitrile + 450 μL of water containing 0.1% formic acid) without sample. Additionally, matrix effects of the entire chromatographic run were evaluated using a post-column infusion of the analytes to ensure that no interfering peaks of the blank sample ($n=7$) extract were

Table 1 ARV reference standards used for data validation

Matrix	ARV reference standards	Retention time (min.)	Recovery (%)	LOD	LOQ
Samples of animal origins	Lamivudine (mg/kg)	0.90	120.37	0.001	0.01
	Nevirapine (mg/kg)	7.90	106.26	0.005	0.05
	Efavirez (mg/kg)	8.40	105.72	0.005	0.05
Water	Lamivudine (mg/kg)	0.90	91.79	0.001	0.01
	Nevirapine (mg/kg)	7.90	71.68	0.005	0.05
	Efavirez (mg/kg)	8.40	100.86	0.005	0.05
Animal feeds	Lamivudine (mg/kg)	0.90	91.79	0.001	0.01
	Nevirapine (mg/kg)	7.90	112.22	0.005	0.05
	Efavirez (mg/kg)	8.40	100.86	0.005	0.005

found at the retention time corresponding to each analyte. The blank sample was extracted and injected into the LC–MS/MS system with concurrent post-column infusion of analytes.

Recovery

Recovery was determined by comparing the peak area obtained from spiked samples with the peak area from a standard solution of all analytes in a solution of (100 µL of methanol+200 µL of acetonitrile+450 µL of water containing 0.1% formic acid at the same concentrations.

Results

A total of 196 samples were collected from nine (9) districts within three regions. The number of samples per region was Dar es Salaam (124), Mbeya (32), and Iringa (40). Out of 196 samples, 66.8% (n=131) were found to have lamivudine residues while no nevirapine and efavirenz residues detected. No ARV residues were detected from all of the water samples (n=37). By district, Temeke had the highest number of positive samples (90%, n=18) followed by Kinondoni (83%, n=58), compared to other districts across the three regions (Table 3). Both Temeke and Kinondoni districts are in the Dar es Salaam region. The occurrence of ARV lamivudine per region and district is presented in Table 2.

Distribution of occurrence of lamivudine residues based on type of sample

As shown in Table 3, all samples of broiler chicken meat (100%, n=30) had lamivudine residues. The same table shows that more than half of the samples collected from broiler chicken blood, domestic pig meat, and blood and animal feeds were found to have different concentrations of lamivudine residues.

Table 2 The distribution of lamivudine residues by region and districts (n = 196)

	Samples collected (No of positive)	% of positive (95% CI)
<i>Distribution of lamivudine residues per Region</i>		
Dar es Salaam	124 (91)	73.4 (61.53 to 86.85)
Mbeya	32 (15)	47 (33.52 to 64.14)
Iringa	40 (25)	62.5 (50.32 to 77.82)
<i>Distribution of lamivudine per District</i>		
Kinondoni	70 (58)	83 (72.19 to 95.62)
Ilala	34 (15)	44 (30.17 to 61.35)
Temeke	20 (18)	90 (80.44 to 102.44)
Mbeya CC	15 (9)	60 (48.81 to 76.81)
Mbeya DC	11 (2)	18 (2.54 to 38.9)
Mbalizi	6 (4)	66.7 (58.79 to 85.45)
Iringa MC	28 (16)	57 (44.67 to 73.24)
Mafinga	7 (6)	85.7 (77.77 to 100.62)
Kilolo	5 (3)	60 (52.8 to 80.8)

Table 3 Distribution of occurrence of lamivudine residues per sample type (n = 196)

Sample type	Sample collected (No of positive)	% of positive (95% CI)
Broiler chicken meat	30 (30)	100
Broiler chicken blood	20 (10)	50 (37.4 to 87.4)
Domestic pig meat	39 (36)	92.3 (82.41 to 103.94)
Domestic pig blood	49 (49)	77.6 (66.67 to 91.16)
Broiler chicken feed	17 (15)	88.2 (78.73 to 101.08)
Domestic pig feed	4 (3)	75 (69.19 to 99.19)

The concentration of lamivudine residues detected among the collected samples

As shown in Table 4, higher levels of lamivudine (7.58 mg/kg) were detected in both pig meat and

Table 4 Concentration of ARV Lamivudine (mg/kg) based on sample types

Sample type	Lowest conc. (mg/kg)	Highest conc. (mg/kg)	Mean (95% CI)
Broiler chicken meat	0.22	1.69	0.97 (0.81 to 1.12)
Broiler chicken blood	0.09	0.92	0.16 (0.05 to 0.27)
Domestic pig meat	0.07	7.58	2.92 (2.12 to 3.71)
Domestic pig blood	0.06	7.58	1.93 (1.26 to 2.60)
Broiler chicken feed	0.01	0.43	0.21 (0.14 to 0.28)
Domestic pig feed	0.14	0.22	0.09 (−0.08 to 0.26)

blood, while the lowest concentration (0.12 mg/kg) was detected in domestic pigs.

Association between ARV lamivudine residues against sample type and sample origin

The level of lamivudine residues detected was significantly related to regions ($p=0.014$), district of sample collection ($p=0.000$) and sample type ($p=0.000$) associated with origin ($p=0.009$), regions ($p=0.133$), or district of sample origin ($p=0.583$).

Discussion

This study is the first to document the existence of ARVs in domestic animals and commercial animal feed in Tanzania. Only two similar studies exist in sub-Saharan Africa (SSA), and both are from Uganda (Nakato et al. 2020; Ndoboli et al. 2021). The use of antibiotics and other drugs in animals has been the subject of most SSA investigations (Founou et al. 2016; Kimera et al. 2020; Mshana et al. 2013). A recent study from Tanzania reported on the use of ARVs in food animals for growth promotion in broiler chickens and domestic pigs and for disease treatment of ASF in domestic pigs (Kimera et al. 2024). However, the investigators did not screen for ARV residues a gap that needed to be filled.

Screening for first-line ARVs used in Tanzania, this study found two-thirds (66.6%, $n=131$) of the 196 samples of muscle, blood, and animal feed to contain lamivudine residues, with the highest concentration detected in domestic pig blood and muscle (7.58 mg/kg) and the lowest concentration (0.01 mg/kg) in broiler chicken feed. There was a significant relationship between the presence of lamivudine by sample type and sample origin ($p=0.000$). Temeke and Kinondoni districts in Dar es Salaam had the highest prevalence of residues at 90% and 83%, respectively. We did not detect nevirapine or efavirenz in any of the tested samples.

The proportion of samples with lamivudine residues detected in this study is significantly higher than that

reported in Uganda where efavirenz and nevirapine residues were detected in 13.6% and 13.9% of sampled pork meat (Nakato et al. 2020). Another study conducted in Uganda detected 5.5% of saquinavir residues and 2.5% of lopinavir residues in pork and chicken samples, respectively (Ndoboli et al. 2021).

There are notable differences between our study and those conducted in Uganda. The study conducted in Uganda by Nakato et al. (2020) found efavirenz in one-quarter of the samples, while we did not find any. The likely reason we did not detect efavirenz (EFV) or nevirapine (NVP) is that our samples were collected after these drugs were excluded by the WHO from the recommended first-line regimen which now consists of tenofovir, lamivudine, and dolutegravir (DTG) (WHO 2018, 2019). The change was made after several studies found the new combination to induce a more rapid viral suppression, higher barrier to drug resistance, and lower potential for drug-drug interactions (Paul et al. 2020; Kandel and Walmsley 2015; Osterholzer and Goldman 2014) and better patient experience (Twimukye et al. 2021).

The higher proportion of pork samples with ARV residues seen in the Dar es Salaam region, the commercial hub and largest city in Tanzania, is rather concerning given that the region receives supplies from all over the country and might indicate widespread use of ARVs in animal farming. The finding of ARV residues in animal food products and feeds lends support to a recently published work conducted in three regions where ARVs and other veterinary and human drugs have been reported to be used in animal farming as growth promoters (Kimera et al. 2024). In this study, farmers were quoted saying that the ARVs bring quick results as growth promoters, especially in domestic pigs. Conversely, the lack of ARV residues in water testing indicates that the drugs are not administered in drinking water. Contrary to our study, pharmaceutical products including ARVs in drinking water have been reported in several African countries signifying differences in animal farming practices (Swanepoel et al. 2015; Adeola and Forbes 2022; Ngumba et al. 2020).

Our findings have several implications. Given the level of residues seen in the samples, it is given that consumers are slowly exposed to sub-therapeutic levels of ARVs which might contribute to health issues including toxicity, allergic reactions, and carcinogenicity as previously reported by Odey et al. (2023). Secondly, since the HIV-infected farmers share their medication with their animals, an issue of medication adherence can be a challenge, leading to and contributing to the rise of HIV drug resistance. Thirdly, the negative effects on animal health and contamination of the environment cannot

be underestimated and should be carefully investigated. Fourthly, it is unclear from a pharmacological standpoint whether the concentration of ARV residues in animal food products can be destroyed by heat treatment during cooking and what kind of metabolites are formed as a result. This depends on several factors such as individual meat preparation techniques, dose of the ARV administered to the animal, time of administration prior to slaughter as well as state of the consumer such as age and physical well-being as reported by Ndoboli et al. (2021). This uncertainty necessitates further investigations on a broader scale using a one health approach that involves humans, animals, and the environment.

Notably, Tanzania has several legislations that are intended to safeguard animal farming activities to ensure the welfare of animals and address public safety issues. These include the Veterinary Act No.16 2003, the Animal Welfare Act 2008, and the Meat Industry Act 2006, operating in conjunction with the National Public Health Act 2009 (URT 2003, 2006, 2008, 2009). However, none of these acts focuses on ARV residues in animal products, as the results of this study are highly indicting. We recommend the following measures to safeguard animal and human health (1) raise public awareness of the negative effects of using ARVs in animal farming; (2) establish well-coordinated surveillance and monitoring systems for the residues using relatively cheaper technologies; (3) revise legislation and acts governing animal farming and products; (4) the veterinary council of Tanzania and other regulatory agencies should oversee veterinary professional ethics and coordinate the formulation of appropriate guidelines and standards; (5) educational advancement of veterinary professionals, paraprofessionals, and paraprofessional assistants; and (6) deploy relatively cheap technologies that can be used at the community level to detect low concentrations of analytes of the more broadened spectrum, include second-line ARV regimens.

In summary, the results of this study shed light on the use of ARVs and the presence of ARV residues in animal farming in Tanzania highlighting the public health threats and the need for immediate action. The strength of our study is that samples were analyzed through LC–MS/MS, a method capable of detecting even trace amounts of drug residues that might be present in analyzed samples.

However, we acknowledge some limitations of our study including (1) we only screened for a handful of ARVs leaving aside second-line ARV regimes; (2) we could not relate the occurrence of ARV residues with farming practices since the samples were collected at the abattoir/slaughter slabs; and (3) we did not analyze samples from the environment associated with animal

farming to track the spillover of ARV to the environment through animal manure.

Conclusions

Our study has confirmed the use of ARVs in domestic pigs and broiler chickens in Tanzania, with potential exposure of residues to humans and the threat of environmental contamination, with potential severe consequences. There is a need for well-coordinated cost-effective measures to monitor ARV residues in animal products. Larger surveys are encouraged to determine the magnitude of the problem and reasons for this practice to guide the development and institution of proper One Health interventions. Such surveys should include qualitative methods to determine why ARVs are used in animal production, the sources of the ARVs, and knowledge, attitudes, and practices of farmers regarding ARVs in farming. Revision of the training curriculum and educational advancement of veterinary professionals, paraprofessionals, and paraprofessional assistants will be essential to change the current practices. Finally, the regulations guiding animal production activities should be revised.

Abbreviations

AIDS	Acquired immunodeficiency syndrome
ARV	Antiretroviral
EFV	Efavirenz
FTC	Emitricitabine
HIV	Human immunodeficiency virus
LC–MS/MS	Liquid chromatography with tandem mass spectrometry
LLQD	Lower limit of quantification
LOQ	Limit of quantification
LOD	Limit of detection
MRM	Multiple reaction monitoring
PMTCT	Prevention of mother-to-child transmission
QC	Quality control
SSA	Sub-saharan Africa
TDF	Tenofovir disoproxil fumarate
UNAIDS	United Nations Programme on HIV/AIDS
URT	United Republic of Tanzania
WHO	World Health Organization

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Author contributions

ZIK did the study design and sample collection and wrote the article. PS participated and supervised data analysis. ECB and LVA supervised the overall conduction of the study. MINM, reviewed the manuscript, supervised the writing of the manuscript, and edited the manuscript. The final document was reviewed and approved by all authors.

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Availability of data and materials

All data generated or analyzed during this study are included in this article.

Declarations

Ethics approval and consent to participate

The Medical Research Coordinating Committee of the National Institute for Medical Research of Tanzania approved this study (Reference No. NIMR/HQ/R.8a/Vol.IX/4500) and Muhimbili University of Health and Allied Sciences (Permit No. DA.282/298/01.C/1446). Additionally, permission was granted from the Regional Administrative offices of Dar es Salaam (EA.260/307/02B/102), Mbeya (DC.109/251/01) and Iringa (Fa.255/265/01/282) regions.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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References

- Adeola AO, Forbes PBC (2022) Antiretroviral drugs in African surface waters: prevalence, analysis, and potential remediation. *Environ Toxicol Chem* 41(2):247–262. <https://doi.org/10.1002/etc.5127>
- Djerada Z, Feliu C, Tournois C, Vautier D, Binet L, Robinet A, Marty H, Gozalo C, Lamiabie D, Millart H (2013) Validation of a fast method for quantitative analysis of elvitegravir, raltegravir, maraviroc, etravirine, tenofovir, boceprevir and 10 other antiretroviral agents in human plasma samples with a new UPLC-MS/MS technology. *J Pharm Biomed Anal* 86:100–111. <https://doi.org/10.1016/j.jpba.2013.08.002>
- European Medicines Agency (2012) Guideline on bioanalytical method validation. In: EMA guidance document, pp 1–23. https://www.ema.europa.eu/en/documents/scientific-guideline/guideline-bioanalytical-method-validation_en.pdf
- Founou LL, Founou RC, Essack SY (2016) Antibiotic resistance in the food chain: a developing country-perspective. *Front Microbiol* 7:1–19. <https://doi.org/10.3389/fmicb.2016.01881>
- Hatari! (2013) Wafugaji Kutumia ARV (Dawa ya Ukimwi) Kunenepesha Kuku, Phars Blogspot. Available from: <https://www.phars.blogspot.com/2013/11/hatari-wafugaji-kutumia-arv-dawa-ya-9230.html>. Retrieved on 18–09–2019
- Kandel CE, Walmsley S (2015) Dolutegravir—a review of the pharmacology, efficacy, and safety in the treatment of HIV. *Durg Design Dev Ther* 9:3547
- Kasang C, Kalluvya S, Majinge C, Stich A, Bodem J, Kongola G, Jacobs GB, Mlewa M, Mildner M, Hensel I, Horn A, Preiser W, van Zyl G, Klinker H, Koutsilieris E, Rethwilm A, Scheller C, Weissbrich B (2011) HIV drug resistance (HIVDR) in antiretroviral therapy-naïve patients in Tanzania not eligible for WHO threshold HIVDR survey is dramatically high. *PLoS ONE* 6(8):2–12. <https://doi.org/10.1371/journal.pone.0023091>
- Kimbi E, Lekule F, Mlangwa J, Mejer H, Thamsborg S (2015) Smallholder pigs production systems in Tanzania. *J Agric Sci Technol* 5(1):47–60. <https://doi.org/10.17265/2161-6256/2015.01A.007>
- Kimera ZI, Mshana SE, Rweyemamu MM, Mboera LEG, Matee MIN (2020) Antimicrobial use and resistance in food-producing animals and the environment: an African perspective. *Antimicrob Resist Infect Control*. <https://doi.org/10.1186/s13756-020-0697-x>
- Kimera ZI, Balandya EC, Matee MI, Adams LV (2024) The use of human antiretroviral drugs (ARVs) in broiler chicken and domestic pig farming in Tanzania. *Bull Natl Res Centre* 48(1):133. <https://doi.org/10.1186/s42269-024-01296-x>
- Mshana SE, Matee M, Rweyemamu M (2013) Antimicrobial resistance in human and animal pathogens in Zambia, Democratic Republic of Congo, Mozambique and Tanzania: an urgent need of a sustainable surveillance system. *Ann Clin Microbiol Antimicrob* 12(1):1. <https://doi.org/10.1186/1476-0711-12-28>
- Mubito EP, Shahada F, Kimanya ME, Buza JJ (2014) Antimicrobial use in the poultry industry in Dar-es-Salaam, Tanzania and public health implications. *Am J Res Commun* 2(4):51–63
- Mziray S, Maganda BA, Mwamwitwa K, Fimbo AM, Kisenge S, Sambu G, Mwalwisi YH, Bitegeko A, Alphonse E, Khea A, Shewiyo DH (2021) Quality of selected anti-retroviral medicines: Tanzania Mainland market as a case study. *BMC Pharmacol Toxicol* 22(1):46
- Nakato R, Tumwine JK, Nanzigu S, Naluyima S, Buzibye A, Alinayitwe L, Makoha C, Mukonzo JK (2020) Antiretroviral drugs found in pork on Ugandan market: Implications for HIV/AIDS treatment. *One Heal* 9:100125. <https://doi.org/10.1016/j.onehlt.2020.100125>
- Ndoboli D, Nganga F, Lukuyu B, Wieland B, Grace D, von Braun A, Roesel K (2021) The misuse of antiretrovirals to boost pig and poultry productivity in Uganda and potential implications for public health. *Int J One Heal* 7(1):88–95. <https://doi.org/10.14202/IJOH.2021.88-95>
- Ngumba E, Gachanja A, Nyirenda J, Maldonado J, Tuhkanen T (2020) Occurrence of antibiotics and antiretroviral drugs in source-separated urine, groundwater, surface water and wastewater in the peri-urban area of Chunga in Lusaka, Zambia. *Water SA* 46(2):278–284. <https://doi.org/10.17159/wsa/2020.v46.i2.8243>
- Obonyo O (2013) Shock of farmers using anti-retroviral (ARV) drugs, to “fatten” chicken. <https://www.standardmedia.co.ke/arti-cle/2000096749/shock-of-farmers-using-arvs-to-fatten-chicken>. Accessed 27 July 2023
- Odey TOJ, Tamimowo WO, Afolabi KO, Jahid IK, Reuben RC (2023) Antimicrobial use and resistance in food animal production: food safety and associated concerns in Sub-Saharan Africa. *Int Microbiol* 27(1):1–23. <https://doi.org/10.1007/s10123-023-00462-x>
- Odongo R (2016) Lira farmers probed for feeding pigs on ARV drugs. <https://ugandaradionet.com/story/lira-district-probing-use-of-arv-drugs-to-feed-pigs-by-farmers>. Accessed 27 July 2023
- Oketch B (2013) Residents use ARVs to fatten pigs, daily monitor newspaper. Available from: <https://www.monitor.co.ug/uganda/news/national/kitgum-locals-usearvs-to-brew-alcohol-fatten-pigs-1794894>. Retrieved on 08–03–2021
- Oketch B. (2016) Lira farmers share ARVs with their pigs, daily monitor newspaper. Available from: <https://www.monitor.co.ug/specialreports/lira-farmers-share-arvspigs/688342-3172864-u57a0pz/index.html>. Retrieved on 18–09–2019
- Opoka D (2018) Uganda: kitgum locals use arvs to brew alcohol, “fatten” pigs. Daily monitor newspaper, August 2014. <https://www.monitor.co.ug/News/National/Kitgum-locals-use-ARVs-to-brew-alcohol-fatten-pigs-/-/688334-4889624-nht7m6/index.html>
- Osterholzer DA, Goldman M (2014) Dolutegravir: a next-generation integrase inhibitor for the treatment of HIV infection. *Clin Infect Dis* 59(2):265–271. <https://doi.org/10.1093/cid/ciu221>
- Paul NI, Ugwu RO (2020) Dolutegravir (DTG) based fixed dose combination (FDC) of Tenofovir/Lamivudine/Dolutegravir (TLD) and viral load suppression in children in Port Harcourt, Nigeria. *J Sci Res Rep*. <https://doi.org/10.9734/jsrr/2020/v26i230224>
- Swanepoel C, Bouwman H, Pieters R, Bezuidenhout C (2015) Presence, concentrations and potential implications of HIV-ARVs in selected water sources in South Africa. *Water Res Commun* 2144:1–49. <https://doi.org/10.13140/RG.2.2.20637.51688>
- Tarimo A (2023) With PEPFAR's support, pact and partners transform Tanzania's battle against HIV. <https://www.pactworld.org/features/pepfars-support-pact-and-partners-transform-tanzanias-battle-against-hiv>
- Twimukye A, Laker M, Odongpiny EAL, Ajok F, Onen H, Kalule I, Kajubi P, Seden K, Owarwo O, Kiragga A, Armstrong-Hough M, Katahoie A, Mujugira A, Lamorde M, Castelnovo B (2021) Patient experiences of switching from Efavirenz- to Dolutegravir-based antiretroviral therapy: a qualitative study in Uganda. *BMC Infect Dis* 21:1154. <https://doi.org/10.1186/s12879-021-06851-9>
- UNAIDS (2023) The path that ends AIDS: UNAIDS global AIDS update 2023. <https://www.unaids.org/en/regionscountries/countries/unitedrepublicoftanzania>
- UNAIDS (2024) United Republic of Tanzania: HIV and AIDS estimates <https://www.unaids.org/en/regionscountries/countries/unitedrepublicoftanzania>
- URN (2017) Farmers feed pigs on ARVs, The observer. Available from: <https://www.observer.ug/news/headlines/53961-farmers-feed-pigs-on-arvs>. Retrieved 18–09–2019.
- URT (2003) United Republic of Tanzania: The Veterinary Act No. 16. <https://www.mifugouvuvu.go.tz/publications/45>. Accessed 1 Apr 2020

- URT (2006) United Republic of Tanzania: The Meat Industry Act No.10. <https://www.mifugouvuvu.go.tz/publications/45>. Accessed 18 Dec 2019
- URT (2008) United Republic of Tanzania: The Animal Welfare Act No.19. <https://www.mifugouvuvu.go.tz/publications/45>. Accessed 1 Apr 2020
- URT (2009) United Republic of Tanzania: The Public Health Act No.1. https://doi.org/10.5005/jp/books/11420_56. Accessed 16 Aug 2024
- URT (2018) United Republic of Tanzania: Tanzania HIV impact survey 2016–2017. https://phia.icap.columbia.edu/wp-content/uploads/2019/06/FINAL_THIS-2016-2017_Final-Report__06.21.19_for-web_TS.pdf. Accessed 03 Jan 2025
- URT (2019) United Republic of Tanzania: national guidelines for the management of HIV and AIDS. In: Ministry of Health, Community Development, Gender, Eldery, and Children. https://differentiatedservicedelivery.org/wp-content/uploads/national_guidelines_for_the_management_of_hiv_and_aids_2019.pdf. Accessed 11 May 2023
- Valentine K (2013) How Kenyans are misusing antiretroviral drugs (ARVs). <https://www.kenyaplex.com/resources/10130-how-kenyans-are-misusing-antiretroviral-drugs-arvs.aspx>. [cited 23/May/2019]
- WHO (2018) Dolutegravir (DTG) and the fixed-dose combination (FDC) of tenofovir/lamivudine/dolutegravir (TLD). World Health Organisation: Geneva, Switzerland
- WHO (2019) Update of recommendations on first-and second-line antiretroviral regimens. World Health Organisation: Geneva, Switzerland
- WHO (2021) Consolidated guidelines on HIV prevention, testing, treatment, service delivery and monitoring: recommendations for a public health approach. Geneva. In World Health Organization. license: CC BY-NC-SA 3.0 IGO
- WHO (2023) HIV and AIDS: key facts. <https://www.who.int/news-room/fact-sheets/detail/hiv-aids>. Accessed 22 July 2024

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