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*Full Length Research Paper*

# **Pit latrine faecal sludge solid waste quantification and characterization to inform the design of treatment facilities in peri-urban areas: A case study of Kanyama**

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The purpose of the study was to quantify waste content in faecal sludge using an appropriate method and characterise the solid wastes inherent with the faecal sludge into categories. A total of eight (8) domestic pit-latrines were analysed in the peri-urban area of Kanyama settlement in Lusaka from July to October, 2018. From each latrine, three (3) samples were obtained for analysis of solid waste and sand/grit quantities. The quantified solid waste was further characterised to generate its composition. The method of estimation involved separation of the excreta from the solid waste and grit/sand of the faecal sludge by means of washing and drying of the contents. The results indicated high content of total waste, taken as the summation of all the solid waste including grit/sand which averaged  $34.2 \pm 10.3\%$  (n=24) per wet mass of faecal sludge and  $68.9 \pm 8.0\%$  (n=24) per dry mass of faecal sludge. Characterisation of the solid waste in the faecal sludge (n=24) showed a composition of  $54.4 \pm 13.3\%$  textiles,  $16.7 \pm 6.4\%$  plastics,  $8.6 \pm 9.3\%$  others,  $8.6 \pm 5.8\%$  organic waste,  $7.6 \pm 4.8\%$  paper,  $3.1 \pm 3.6\%$  metal and  $1.0 \pm 1.2\%$  glass. The high content of waste has an implication on the handling of faecal sludge especially at the stages of desludging, treatment and disposal/re-use. The study proposed and recommended implementation of user education, improving solid waste management systems in peri-urban areas and studying the feasibility of placing some facilities like biogas digesters above ground to facilitate removal of grit, which is usually problematic with underground facilities. The study also proposed and recommended strengthening the regulation on the construction and operations of latrines, which should be supported by enacting a responsive regulatory framework to ensure all measures, are effectively implemented.

**Key words:** Faecal sludge, peri-urban area, pit latrine, solid waste management.

## **INTRODUCTION**

Strande et al. (2014) reports that between 65 and 100% of the urban population in most Sub-Saharan African countries access sanitation exclusively through onsite systems. Of the onsite facilities used, pit latrines are the

most prevalent especially in low cost areas of large cities (Jenkins et al., 2015; Templeton et al., 2015; WHO/UNICEF, 2014; Thye et al., 2011). This is because pit latrines are the cheapest means of excreta disposal



and provide the most inexpensive means of improving sanitation coverage especially in developing countries (Graham and Polizzotto, 2013). Worldwide, it has been acknowledged that one of the biggest shortcomings of pit-latrines is their finite capacity which leads them to fill up within a few months or years of usage (Murungi and van Dijk, 2014; Still and O'Riordan, 2012; Still et al., 2005). Management of the full latrine is through either burying or replacement with a new one or if it is desired to continue using the same latrine, it can then be emptied and put back into service (Jenkins et al., 2015; Still and O'Riordan, 2012; Pickford and Shaw, 1997). The option of burying works well in areas where there is sufficient space that allows for digging of new replacement latrines when the old ones fill up. For Peri-Urban Areas (PUAs) in large cities, pit emptying is a more practical option since most of these areas are normally faced with lack of space (Akumuntu et al., 2017). In addition to space constraints, high costs associated with the construction of a decent new latrine superstructure make emptying a more attractive option (O'Riordan, 2009; Muller and Rijnsburger, 1994).

Emptying a single pit latrine can cause a serious health hazard if not properly handled Mwale, 2013, as the freshly deposited sludge at the top of the latrine contain pathogenic microorganisms, hence the need for Faecal Sludge Management (FSM) systems. FSM is the process of managing faecal sludge from onsite sanitation facilities like pit latrines and septic tanks at all stages of the sanitation service chain which includes storage, desludging, transportation, treatment, disposal and/or re-use (Strande et al., 2014). This means, appropriate means of faecal sludge containment, desludging, treatment and disposal or re-use need to be sought. In addition, there is need for an enabling environment especially as it relates to faecal sludge and solid waste management regulation.

Torondel (2010) defines faecal sludge as a mixture of human excreta, water and solid wastes that are disposed of in the pits, tanks or vaults of onsite sanitation systems such as anal cleansing materials, menstrual hygiene materials, diapers, plastics, paper. Some of these materials like plastics are non-biodegradable. Other non-biodegradable materials are deliberately disposed of in pit latrines. For PUAs in Lusaka, which are defined as "Areas within the jurisdiction of the local authority, having high population density and low cost housing units

lacking basic services such as water supply, roads and sewerage (MLGH, 2014; NWASCO/ DTF, 2005), Tembo et al., (2016), contend that one of the reasons for the disposal of solid waste in pit latrines is the absence of functional solid waste management systems in these areas which leaves residents with no other option of solid waste disposal. Regardless of the source, solid waste usually poses a challenge in processing of faecal sludge. The diversity of this material influences the decomposition process that occurs in the pit latrines. The accumulation of these solid wastes can be significant, causing problems with desludging and resulting in clogged pipes and pumps within the treatment facilities. The solid waste also takes up space in reactors effectively reducing reactor retention times and consequently affecting the quality of the treatment products (Strande et al., 2014). Strande et al. (2014) further submit that grit/sand concentrations are also important to consider in the treatment of faecal sludge as their presence influence the required size of treatment facilities. This is because grit affects the filling rates of treatment facilities and can increase the frequency of clogging in pipes and pumps.

Lusaka, the capital city of Zambia has about 70% of its population residing in PUAs (MLGH, 2014). According to SMEC (2016), about 90% of people residing in PUAs use unimproved pit latrines. This is indicative of the need for an effective FSM system in the city. In recent years, Zambia's FSM, landscape, has been improving fast with the advent of the Lusaka Sanitation Programme (LSP), which is a five year initiative by the Lusaka Water and Sewerage Company (LWSC). This initiative partly seeks to improve onsite sanitation and FSM in Lusaka City. This has led to development of strategies for enhanced provision of onsite sanitation and FSM services. For instance, in 2018, the framework for provision of urban onsite sanitation and FSM was launched to assist with the creation of a regulatory framework for onsite sanitation and FSM that supports the proper functioning of an integrated management system covering the whole sanitation chain (NWASCO, 2018). However, solid waste management has not received the same attention and has therefore continued to lag behind. In his study, Sibanda (2010) indicated that the existing regulatory framework for solid waste management in Zambia was comprehensive but enforcement was weak. He also submitted that most people in Zambia are not

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**ABBREVIATIONS:** **CBD:** Central business district; **FSM:** Faecal sludge management; **LWSC:** Lusaka water and sewerage company limited; **PUAs:** Peri-urban areas.

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environmentally conscious, which promotes indiscriminate waste disposal.

Generally, implementation of an effective FSM system requires availability of quality and quantity data on the faecal sludge to be managed to aid in the design of facilities (Strande et al., 2014; Bassan et al., 2013). Data on quantities of solid waste is also cardinal in the design of FSM facilities. Worldwide, it has been acknowledged that solid waste content in the faecal sludge heavily impacts on the performance of the FSM especially at desludging, treatment and disposal/re-use stages. In the FSM being piloted in Lusaka under LWSC in Zambia, mechanical desludging of faecal sludge is impossible due to high content of solid waste. This has resulted in the use of modified garden tools as a means of desludging (Mikhael and Drabble, 2014).

Strande et al. (2018) submit that governments and other stakeholders have started to acknowledge the importance of FSM. However, they observe that efforts to enhance FSM predominantly focus on FSM infrastructure development. The required studies on quantities and qualities of faecal sludge are usually rare despite the fact that this is critical requirement in the design of adequate faecal sludge treatment facilities (Fanyin-Martin et al., 2017). With this status on the availability of the general faecal sludge quantity and quality, specific data on the relative quantities and characteristics of the solid waste contained in pit latrine faecal sludge are even more obscure. This means that the design of appropriate faecal sludge treatment facilities becomes a challenge because of lack of exact data of physiognomies and quantities of the solid waste present in the pit latrines (Mwale, 2013). Secondly, accepted methodologies for representative characterisation and quantification of the solid waste in pit latrine faecal sludge do not exist. In line with aforementioned, the purpose of this study was therefore to come up with a suitable method to employ in the generation of the quantities and characteristics of solid waste found in domestic pit latrines in PUAs of Lusaka using Kanyama as a study area. The study ultimately designed a suitable method and quantified and characterized the solid waste inherent with pit latrine faecal sludge. The generated data will inform the appropriate designs of FSM facilities to adequately address challenges associated with the presence of solid waste and grit in faecal sludge.

## METHODOLOGY

### Overview

The study sought to design a method for and quantifying solid waste and grit in pit latrine faecal sludge. A quantitative

methodology utilizing experimental methods was therefore employed. The main steps taken in ensuring successful execution of the study included, selecting the study area, designing a sampling frame, selecting pit latrines to be sampled, sample collection, determination of the content of various constituents of waste in the sludge and data analysis as detailed in the ensuing sections.

In this study, solid waste in the faecal sludge was put in two categories; as either grit/sand; and other forms of solid waste including plastics, glass, textiles (sacks, rugs, sanitary pads and diapers), paper, metals, organic waste (including vegetation matter like grass and logs) and others. Therefore, in the rest of the paper, solid waste will refer to the inorganic constituents found in pit latrines excluding grit/sand, which is also considered separately.

### Study area

The study area, Kanyama settlement, is an improvement area, which was legalized in 1999 by the Ministry of Local Government under the statutory and improvement areas act of 1999. The settlement is located 7 km west of the Central Business District (CBD). It is bordered by Los Angeles and Mumbwa roads on the western and eastern sides respectively (Figure 1). The settlement covers an estimated area of 14.25 km<sup>2</sup>. According to the Central Statistics Office (CSO), the 2010 population density of Kanyama was approximately 5,636 people/ km<sup>2</sup> (Brinkhoff, 2018). The population is estimated at 366,170 (CSO, 2010) with 78, 995 informal housing units that rely on onsite sanitation facilities for excreta disposal (Nyambe, et al., 2014). Most of the residents live in rented multi-roomed dwellings that accommodate more than one family. Its proximity to the city's CBD is responsible for its big size and high population density as most of its residents are primarily migrants from the rural areas coming to seek employment opportunities in the city especially the CBD. Access to adequate sanitation and the existence of service like solid waste collection is very poor in the settlement. The low access to sanitation facilities, unavailability of an effective FSM system, a porous geology as the area is sited on dolomite and a high water table perpetuates outbreaks of water borne diseases such as cholera and typhoid. During the 2017/2018 cholera outbreak in the city of Lusaka, Kanyama PUA alone accounted for over 1,000 cholera cases (WHO/MoH, 2018), making it one of the worst affected areas in the country.

Selection of Kanyama settlement as a study area was dictated by availability of an FSM enterprise in the area. In the study area, Kanyama Water Trust offers faecal sludge desludging services. Since samples were collected as the pit latrines were being desludged (as detailed under sample collection), it was imperative that the study area be an area where formal pit latrine desludging services were available hence the selection of Kanyama Settlement.

### Sampling frame and selection of pit latrines to be sampled

The sampling frame for this study included all households within the study area utilising pit latrines for disposal of excreta. Selection of pits to be sampled was random. As it was only possible to collect samples as the pit latrines were being desludged, the pits sampled were not pre-selected. Rather, they were selected by virtue of them having been earmarked for desludging by the desludging enterprise. A total of eight (08) pits were sampled for this purpose.

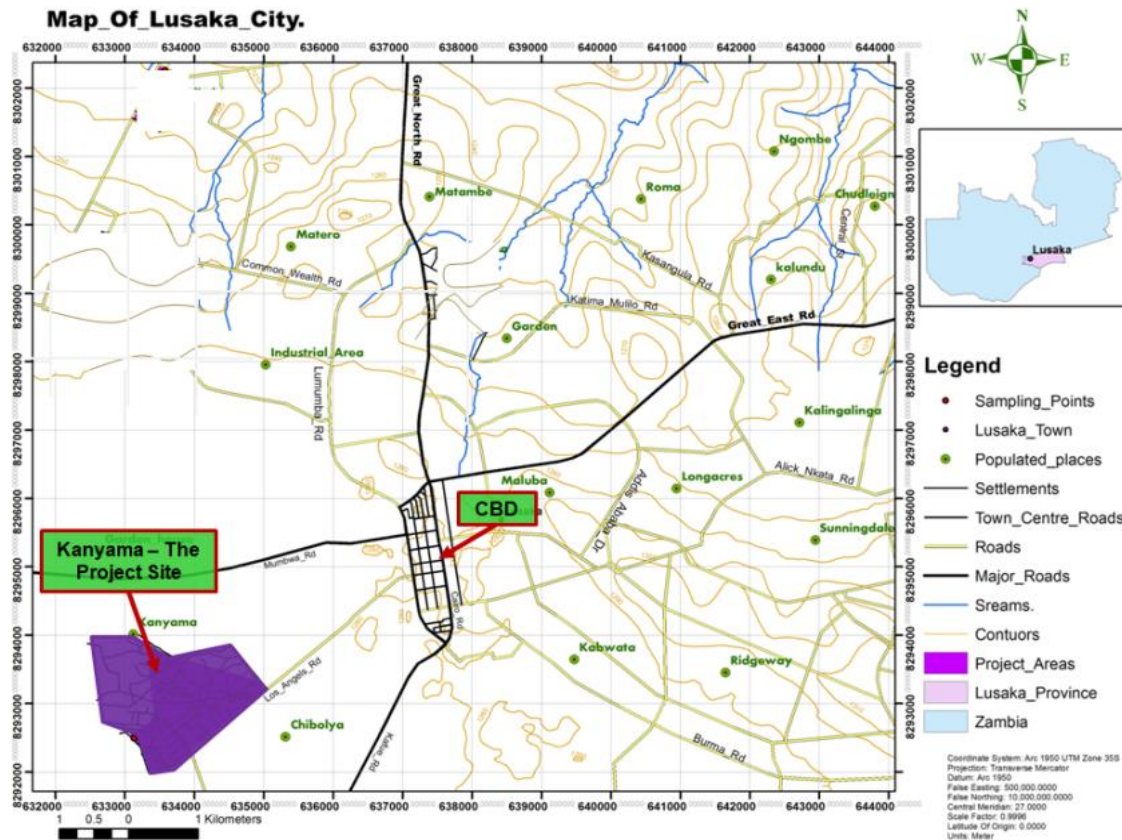


Figure 1. Location Map of the Kanyama study area in Lusaka, capital city of Zambia.

**Equipment and materials**

The study required the collection of samples from pit latrines which were consequently to be separated through washing into the various constituents which were then dried and weighed to determine the composition of the various components as required. Equipment and materials employed in the study are presented subsequently.

**At desludging stage**

Desludging tools included shovels, picks and modified tools for scooping of sludge, disinfectants for cleaning the desludging tools and sanitising the area after desludging 60 L barrels for collection of samples and 250 mL plastic containers for collection of samples for laboratory determination of moisture content.

**At the separation stage**

Scales for weighing of sludge and the respective constituents; a hosepipe to aid with the washing of the sludge in the separation process, a source of water and a polythene sheet for storage of separated waste components.

**At the stage of laboratory moisture content determination**

Crucibles; a laboratory scales for weighing samples for moisture content determination; an oven with a provision for temperature setting at 103°C to 105°C; and a desiccator.

**Sample collection**

All samples were collected from pit latrines that were being desludged by the Water trust. Sampling was conducted from July to October, 2018 which was during the dry season. Prior to the desludging process, an assessment on the structural integrity of the structure was first carried out by the Kanyama water trust personnel. After certification that the structure was sound enough, a hole measuring approximately 30 to 50 cm was made on the side to provide access to the pit latrine contents. This process involved removal of a few blocks from the side of the latrine’s vault to create access. The faecal sludge was then scooped out using modified garden tools and a ‘Kanjote’, which is a tin attached to a long metallic handle (Figure 2).

The sampling was designed based on the number of barrels that were to be desludged. The desludging team offered three options for desludging as follows (Holm et al., 2015): 12 barrels of 60 L capacity; 24 barrels of 60 L capacity; and 32 barrels of 60 L





**Figure 2.** Sample collection: Left: A hole made on the side of the latrines; Middle: Some of the desludging tools including a modified garden rake and a 'Kanjote'; Right: Filling the barrel in the Kanyama study area.

**Table 1.** Barrels to be collected for waste content analysis depending on the number of barrels being desludged.

Number of barrels to be desludged	Number of barrels collected per pit	Sequencing of barrels collected for analysis
12	3	4 <sup>th</sup> , 8 <sup>th</sup> and 12 <sup>th</sup>
24	3	4 <sup>th</sup> , 14 <sup>th</sup> and 24 <sup>th</sup>
32	3	4 <sup>th</sup> , 18 <sup>th</sup> and 32 <sup>nd</sup>

Source: Designed by author.



**Figure 3.** Faecal sludge sampling for analysis (Left: Collection of three 60 liter barrels per Pit latrine; Right: Three samples collected from each barrel for Moisture Content analysis).

capacity. Depending on the number of barrels being desludged, a sampling criterion was devised for the selection of barrels to be collected for analysis as presented in Table 1. The rationale for this criterion was in order to have representative samples covering the full depth profile of the pits.

Therefore, from each pit that was being emptied, three 60 L barrels were collected. The selected barrels were properly labelled and were later transported to the Kanyama faecal sludge treatment plant where separation of the grit, solid waste and excreta components of the faecal sludge was done. From each of the three barrels earmarked for quantification and characterization, three

smaller samples were collected for analysis of moisture content (Figure 3). This moisture content was intended to help in the approximation of the dry excreta component of the faecal sludge. The collection of these samples was therefore done in a way that avoided collection of solid waste and grit as far as it was possible.

**Procedure for laboratory moisture content analysis**

The laboratory analysis of moisture content for all the collected samples was carried out at University of Zambia Environmental



**Figure 4.** Weighing of the barrel together with the faecal sludge before separation, Kanyama study area.



**Figure 5.** Washing of faecal sludge to separate the sludge from grit and solid waste, Kanyama study area.

Engineering Laboratory. The analysis was done in accordance with the standard protocols specified in the Standard Methods for the Examination of Water and Wastewater (APHA, 1998).

#### **Procedure for quantification of the solid waste and grit**

The quantification started with the weighing of the faecal sludge contained in the barrels (Figure 4). This was done by weighing the total mass of barrel filled with sludge, which was recorded as mass (A). The mass of the dry barrel was also recorded after all the contents had been removed, which was recorded as (B).

#### **Separation of the excreta component of the faecal sludge from the grit and solid waste**

Separation of the excreta component of the faecal sludge from the rest of the contents (that is, grit and solid waste) was done using water. In order to reduce on chances of washing out the solid waste and grit due to agitations as the water was flowing out, the contents of the barrel were first divided into two portions to create enough

room for expansion of the FS bed during washing. Each portion was then washed separately and gently using a hosepipe in each respective barrel. The washing continued until all the excreta component was washed off from the sand/grit and the solid waste. This separation was facilitated by the differences in densities, the agitation and continued injection of water into the barrels. The overflowing water, which carried with it the excreta component of the faecal sludge was channelled into the anaerobic digester (Figure 5).

#### **Quantification of the solid waste and grit**

During the washing of the faecal sludge, the solid waste was manually separated from the contents. After all the excreta had been washed off, the remaining solid waste that could not be separated during washing was manually sorted out from the grit. The solid waste was then thoroughly air dried for two days. The dried waste was then weighed and the mass was recorded (Mass C).

Total Mass of Sludge = A – B

Total Mass of Dry Solid Waste = C

$$\text{Solid Waste Content (D as \% of wet sludge)} = (C/(A-B)) \times 100 \quad (1)$$

After the thorough washing and removal of all the solid waste, the grit that remained was also air dried for two days as was the case for the solid waste. The air dried grit was then weighed in the field and the mass was recorded (Mass E). As the drying of grit was not thorough, samples were then collected from the air dried grit for moisture content analysis in the laboratory. The mass of the dried grit was then computed as in the Equation 2.

Mass of air dried grit = E  
Moisture content of air dried grit = X%

$$\text{Mass of dried grit (F)} = (E \times (1-X/100)) \quad (2)$$

The grit content in the wet sludge expressed as a percent was then computed using Equation 3.

$$\text{Grit content (G as \% of wet sludge)} = (F/(A-B)) \times 100 \quad (3)$$

Both solid waste and grit content in the dry faecal sludge was computed by expressing the masses of the computed dry solid waste and grit as a percentage of the total mass of dry faecal sludge. The total dry mass was computed by summing up the masses of the dried solid waste, the dried grit and the dry mass of excreta, which was approximated by multiplying the mass of the excreta component of the faecal sludge by the solids content percentage. Thus, the excreta component of the dry faecal sludge was computed as per Equation 4.

$$\text{Mass of dry excreta component of FS} = ((A-B)-(C+F)) \times (1-MC/100) \quad (4)$$

where, MC is the moisture content of the faecal sludge.

#### **Characterisation of the solid waste**

After the solid waste was quantified as explained previously, it was sorted into the following categories: plastics, glass, textiles, paper, metals, organic waste and others (Figure 6). The sorting was done manually. The separated fractions were then weighed and their masses were computed as percentages of the total dry mass of the solid waste.

#### **Data analysis**

For each pit latrines, mean results were computed from the three sets of results that were obtained for the three samples collected from each latrine. Sample standard deviation was computed to measure the degree of spread of the data. The overall mean for both solid waste and grit was computed by summing up all the individual results. Solid waste characterisation results were manipulated using excel software to generate graphs.

#### **Limitations**

The major limitation of the study was on the inflexibility of sampling. It was not possible to pre-select the latrines to be sampled as the

study team had to follow the program for desludging as designed by the water trust. Secondly, it would have been ideal to have samples collected over the whole pit latrine depth profile. However, this was not possible as all latrines that were sampled were only partially desludged. The study was also limited to the dry season (July to October) implying that impacts of seasonal variations on the results could not be assessed.

## **RESULTS**

The results are herein presented.

### **Moisture content**

As presented in the methodology section, moisture content in this study was analysed to aid the conversion of the excreta and grit components to their respective dry masses. The mean moisture content in the faecal sludge and the air dried grit from respective pit latrines is presented in Table 2.

The results of the mean moisture content of the faecal sludge and the air dried grit (n=24) were found to be 81.1±6.4% and 26.0±5.8%, respectively.

### **Solid waste content**

The solid waste content ranged between 3.4±2.3% and 34.6±8.5% (n=3) in wet sludge and was between 12.0±7.8% and 54.5±2.9% (n=3) in dry sludge. The means were 17.6±10.4% and 31.1±13.5% in wet and dry sludge, respectively (Table 3).

### **Grit content**

Grit content ranged between 12.6±3.2% and 22.6±4.8% (n=3) in wet sludge and 23.3±5.2% and 58.0±2.7% (n=3) in dry sludge. The averages were 17.3±6.7 and 33.9±13.3% (n=24) in the wet and dry sludge, respectively (Table 4).

### **Total waste content in faecal sludge**

The total waste content in the sludge, which was a summation of the solid waste and grit/sand content in each of the respective sampled latrines presented ranges of 20.9% to 54.2% and 58.5% to 84.6% (n=3) in wet and dry faecal sludge respectively. The computed averages were 34.2±10.3% in wet sludge and 68.9±8.0% (n=24) in dry sludge (Table 5).





**Figure 6.** Examples of some constituents from the fractionated solid waste (Left: Plastics; Middle: organic waste; Right: Textiles (note the high content of diapers within the textile component), Kanyama study area.

**Table 2.** Mean moisture content results in the FS and the air dried grit from respective pit latrines, Kanyama study area.

Pit ID	Moisture Content in the FS (%)	Moisture Content in the Air Dried Sand (%)	Number of Samples (n)
PIT 01	74.5±4.2	24.9±3.8	3
PIT 02	84.9±5.5	25.3±6.7	3
PIT 03	84.5±2.0	25.9±3.3	3
PIT 04	88.2±2.8	24.9±1.8	3
PIT 05	80.4±2.4	23.7±2.2	3
PIT 06	72.9±1.1	33.5±1.4	3
PIT 07	81.8±3.6	25.8±7.6	3
PIT 08	81.0±3.1	23.4±4.8	3
Mean (%)	81.1±6.4	26.0±5.8	24

Source: Compiled by author.

**Table 3.** Solid waste composition content in faecal sludge from Kanyama Study area.

Pit ID	Composition of solid waste in FS (As % of wet mass)	Composition of solid waste in FS (As % of dry mass)	Number of Samples (n)
PIT 01	14.4±1.6	27.6±1.3	3
PIT 02	18.9±6.3	39.8±3.1	3
PIT 03	15±4.6	36.6±3.45	3
PIT 04	3.41±2.3	12.0±7.8	3
PIT 05	34.6±8.5	54.5±2.9	3
PIT 06	25.1±11.0	44.6±14.0	3
PIT 07	10.4±9.4	25.0±16.8	3
PIT 08	13.3±6.3	29.9±13.9	3
Mean (%)	17.6±10.4	31.1±13.5	24

Source: Compiled by author.

### Solid waste characterization

Solid waste characterisation showed a general trend across all the surveyed pits with textiles registering the

highest values and glass and metals registering the least (Table 6).

On average textiles registered the highest composition at 54.4±13.3% (n = 24) with glass registering the least at

**Table 4.** Sand content in faecal sludge from Kanyama study area.

Pit ID	Composition of grit in FS (As % of wet mass)	Composition of grit in FS (As % of dry mass)	Number of Samples (n)
PIT 01	22.6±4.84	30.9±2.9	3
PIT 02	18.7±6.7	28.2±4.5	3
PIT 03	16.3± 13.8	34.8±16.0	3
PIT 04	17.5±2.9	58.0±2.7	3
PIT 05	19.6±6.4	30.1±4.8	3
PIT 06	12.6±3.2	23.3±5.8	3
PIT 07	12.7±2.9	35.2±5.4	3
PIT 08	18.7±7.3	40.9±11.6	3
Mean (%)	17.3±6.7	33.9±13.3	24

Source: Compiled by author.

**Table 5.** Total waste content (grit plus solid waste) in the faecal sludge from Kanyama study area.

Pit ID	Content of total waste (% in wet sludge)	Content of total waste (% in dry sludge)	Number of Samples (n)
PIT 01	37	58.5	3
PIT 02	37.6	68.0	3
PIT 03	31.3	71.4	3
PIT 04	20.9	70	3
PIT 05	54.2	84.6	3
PIT 06	37.7	67.9	3
PIT 07	23.1	60.2	3
PIT 08	32	70.8	3
Mean (%)	34.2±10.3	68.9±8.0	24

Source: Compiled by author.

**Table 6.** Characterised solid wastes across pit latrines from Kanyama study area.

Category	Pit Identification							
	PIT 01	PIT 02	PIT 03	PIT 04	PIT 05	PIT 06	PIT 07	PIT 08
Plastics	8.9±1.1	7.1±4.5	12.5±4.1	21.7±22.2	18.1±5.8	23.5±9.9	22.1±7.8	20.0±5.9
Glass	0.7±1.2	3.0±3.1	0.8±1.5	0.0±0.00	2.7±4.7	0.0±0.0	0.0±0.0	0.5±0.9
Textiles	28.7±10.7	50.4±7.2	55.9±9.4	68.4±11.5	71.8±9.7	60.1±22.2	49.9±16.1	50.3±9.1
Paper	6.9±4.3	5.5±2.9	8.9±3.3	5.4±5.6	1.5±0.6	4.2±1.2	11.4±8.5	16.9±6.1
Metals	6.8±6.2	7.3±12.7	7.4±8.3	0.0±0.0	0.0±0.0	0.0±0.0	3.4±5.7	0.0±0.0
Organic waste	20.6±12.9	10.4±11.0	4.9±2.6	4.6±5.8	2.7±1.4	5.6±7.6	8.1±10.5	12.0±10.9
Others	27.4±6.5	16.4±11.1	9.7±5.0	0±0.0	3.2±1.4	6.6±6.6	5.1±8.8	0.2±0.4
No. of Samples (n)	3	3	3	3	3	3	3	3

Source: Compiled by author

1.0±1.2% (n=24). The contents varied significantly across pit latrines as evident from the huge standard deviation



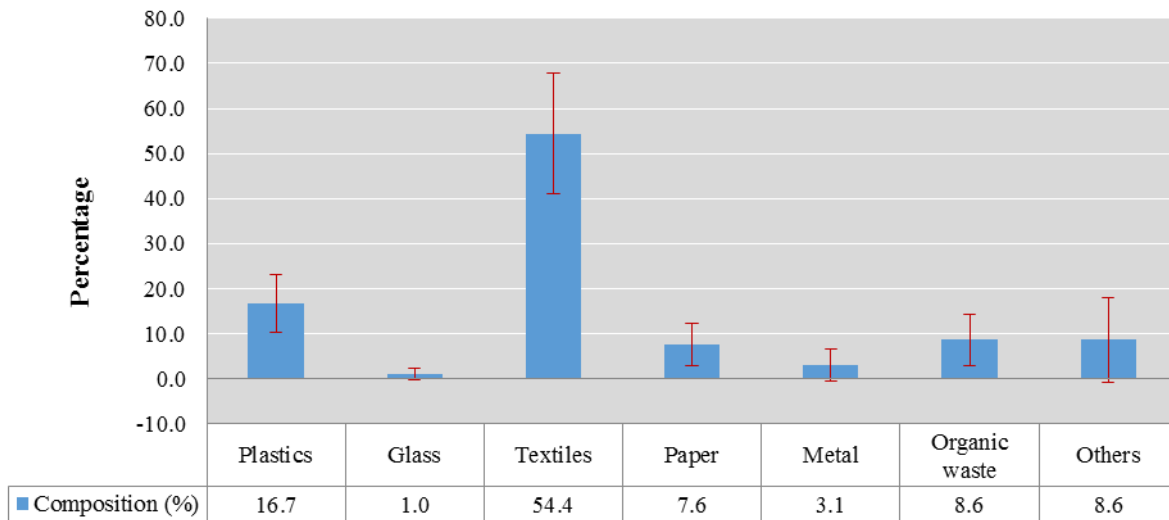


Figure 7. Solid waste characterization results with standard deviations for each category from Kanyama study area.

values especially for glass and metals (Figure 7).

**DISCUSSION**

The study set out to formulate a method to generate reliable data on quantities of waste in faecal sludge from pit latrines in PUAs using Kanyama settlement as a case study area. Generally, results showed higher contents of both solid waste and grit. Solid waste averaged 17.6±10.4% (n=24) in wet sludge. This result closely agrees with the findings by Parker et al. (2015) of 12% using a similar method as the one used in this study. The mean content in dry mass of the faecal sludge was almost at 34 percent (n=24). The observed high content of waste can be attributed to the socio-cultural perceptions and the socioeconomic setup of PUAs. Culturally, there is stigma attached to menstruation in most of the Zambian cultures where pads and materials used during menstruation have to be disposed of in a manner that ensures maximum secrecy. Secondly, the introduction of diapers to replace napkins has also exacerbated the situation. Although diapers can be disposed of together with the other forms of solid waste, in PUAs, they also end up in pit latrines and is one of the biggest contributor to textile component as is evident in Figure 6 above. Solid waste disposal in pit latrines is also a result of unavailability of functional solid waste management systems in these areas (Tembo et. al., 2016).

The observed high content of grit results from a number of sanitation practices, which include construction and

usage of pit latrines. Some latrines in the study area are constructed with large squatting holes beyond the 25 cm recommended by WHO (1996) making them dangerous for young children. Others are just not accessible to children due to the way they are constructed (Figure 8).

Following from these inadequacies in construction, children are allowed to defecate on the ground within the household premises after which the excreta is picked and deposited into the latrine. A shovel or hoe is usually used to pick the excreta. When the excreta is picked, an appreciable amount of soil is also collected and this ends up in the latrine. Grit also comes from the unlined portions of the latrines (Tembo et al., 2016). However, the majority of the grit ending up in the emptied sludge was observed to have been from the desludging method used. Desludging was observed to be a “two-stage” scooping system. The sludge was first scooped from the pit using modified garden tools into a temporary pit that was dug to receive the sludge from the pit. The sludge was then scooped from the temporary pit into the barrels (Figure 2). As the temporarily pit was unlined with a lot of loose sand, it was a source of most of the grit.

High contents of both solid waste and grit content complicates treatment processes especially if adequate units are not put in place to address the challenges inherent with the waste. High content of solid waste leads to system blockages, which result in high frequency of reactor maintenance. This requires putting the reactor out of service for some time hence disrupting the treatment process. This was observed for the two pilot plants managed for LWSC by the water trusts in Kanyama and Chazanga. At re-use stage, high solid waste content also



**Figure 8.** Example of latrine construction and interfaces that discourage direct latrine usage by young children from Kanyama study area.

poses challenges. For example, in the valorisation of faecal sludge to generate power, demineralised water and ash using an Omni processor, grit seriously hampers the processes. For sludge with grit content in excess of 5 percent of the dry mass, the Omni processor's operations are impaired (Malo, 2017, Dakar, Senegal, personal communication). This implies that with the current grit content in desludged sludge, the Omni processor technology is not an option for the pit latrine faecal sludge from PUAs. Non-biodegradable waste like rags and plastics, which were found to be present in large quantities in this study is an aspect that compromises the ultimate re-use of the sludge in agricultural activities. When present in form of sharp objects, solid waste may also pose health and safety risks especially to workers handling the sludge (IWMI, 2003).

From the foregoing, it is evident that the high content of waste in pit latrine faecal sludge is an aspect that culminates from number of aspects including social-cultural, lack of understanding on the part of residents, absence of adequate solid waste management systems and the construction and operation aspects of the latrines, which result in introduction of waste. For grit, the adopted means of desludging, which is due to the unregulated construction exaggerates the amounts. The latrines are constructed without any provision for desludging. Non availability of standards for construction of pit latrines results in construction of facilities that are not user friendly especially to children resulting in practices that introduce grit into the pit contents. Grit content is exacerbated by the adopted method of desludging, which is due to inappropriate construction of latrines. High solid waste content in the sludge due to indiscriminate disposal of waste into the latrines was another problem that was observed. All these challenges point to the need for regulation of latrine construction, awareness creation and usage to enhance the desludging and treatment of the sludge. It is imperative at design stage to adequately take cognisance of the high content of solid waste in pit latrine faecal sludge to have units that are adequately designed to address the

challenges inherent with the observed quality of the pit latrines faecal sludge as well as to create awareness among the users of the facilities.

## CONCLUSION AND RECOMMENDATIONS

The study aimed at coming up with a method for the estimation and characterisation of solid waste and grit in pit latrine faecal sludge. This was achieved. The developed method was gravimetric making its application universal. The obtained results indicated high content of both solid waste and grit with textiles contributing the highest percentage for the solid waste content. From these results, it is evident that these high values of waste have implications on the method of desludging employed as well as on the treatment efficiencies and effectiveness of plants and the ultimate disposal/re-use of the faecal sludge. The limitations imposed on the study arising from the inflexibility of sampling and the inability to sample the full depth profile of the pit latrines as highlighted in the limitations section do not result in significant impacts on the results as these are not variables that have a bearing on the content of solid waste. However, quantities of both grit and solid waste may vary with seasons as in partially lined pit latrines, moisture content is likely to increase in the rainy season thereby reducing the solids content of the excreta component.

Based on the findings, it was clear that the latrines in PUAs do not only serve as excreta disposal facilities, but also as receptors of solid waste. If the management of the faecal sludge from these facilities is to be improved measures for reducing high waste in faecal sludge need to be implemented. These include: implementation of user education in PUAs as a way of averting challenges inherent with solid waste disposal; operationalizing alternative solid waste management systems in PUAs so that the collection and disposal of the waste in these areas is improved; and to regulate the construction of latrines so that all facilities are constructed with easy means of desludging to avoid desludging methods that

increase sand/grit content in the sludge that ends up at the treatment plant. It would also be important to investigate the feasibility of building some of the critical facilities in the treatment of faecal sludge, like biogas digesters, above ground for easy removal of accumulated grit and solid waste, which is usually a challenge when the unit is underground as is usually the case with biogas digesters. Ultimately, there is need for a responsive regulatory framework to ensure that all measures are effectively implemented.

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## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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*Full Length Research Paper*

# **Reported driving factors of land-use/cover changes and its mounting consequences in Ethiopia: A Review**

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Obviously, there is land-use/cover change with multifaceted driving factors and associated adverse impacts out there in different parts of Ethiopia. Evidence from published journals justifies this fact but not yet compiled in a manner to convey information on the trend of change and its criticality with the aim to handle the problems. Thus, filing up all the driving factors and its adverse out come from different corners of Ethiopia together under one reviewed journal would help for policy measures and management aspects. In view of this, critical driving factors of land-use/cover change and all its possible consequences bridged together by reviewing highly relevant published journals. Deforestation, high human and livestock population, investment (coffee, tea plantations), agricultural activities ranging from small-scale subsistence agriculture to large-scale commercial agricultural schemes, urban sprawling, charcoal production, woodland collection, poor law enforcement, land rotation searching for better grazing land, resettlement (spontaneous and planned), prevalence of drought, were the leading drivers of land-use/cover change in Ethiopia. In response to these driving factors, the following are major identified adverse effects such as loss of biodiversity and ecosystem service degradation, deterioration of wetlands, creation of new landscape, rainfall variability, reduction in stream flow, increase frequent extreme in weather, conflicts of interest due to resource scrambling, soil and land degradation, prevalence of drought, increase in runoff and sedimentations, increased risk of desertification and woody land cover reduction. In general, these systematic reviews hopefully uncover all the existing scenarios and give mental picture of wide range driving factors of land-use/cover change and associated problems for stakeholders across the country as they might develop ways to end/reduce further vulnerabilities.

**Key words:** Land-use/cover change, driving factors, adverse impacts, Ethiopia.

## **INTRODUCTION**

Obviously, there is land-use/cover change with multifaceted driving factors and associated adverse impacts out there in different parts of Ethiopia. Evidence

from published journals justifies this fact but not yet compiled in a manner to convey information on the trend of change and its criticality with the aim to handle

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the problems. Hence, understanding factors that drives land-use/cover change and its impacts in general is important for modeling, predicting environmental change and help respond to the change in most positive way to benefit the people (Tilahun and Teferi, 2015; Rawat and Kumar, 2015). Different places have different pushing factors and its consequences too. Causes for land-use/cover change are broadly grouped in to two namely; Natural and human with diverse driving forces. However, we sense natural effects like climate effect in the long run but impacts due to human intervention is most of immediate when compared with natural effects (Woldeamlak, 2002). Filing up all the driving factors and its out come from different corners of Ethiopia together under one reviewed journal would help for policy measures and management aspects. Hence, these systematic reviews could identify its wide range discrepancy, level of criticality and give mental picture particularly for experts dedicated in conservation role.

Change in land-use/cover in some localities might bring some benefits but less weighted when compared with consequences in the long run particularly in rural areas. The adverse impact of land-use/cover change also varies from place to place as the fashion of the people in approaching and causing land-use/cover change varies.

To better understand the driving factors of land-use/cover change and its wide range adverse impacts, these study systematically reviewed recently published journals related with these issues. In the courses of review, different places of the country were characterized depending on the existing situations: from identification of driving factors to consequences of its change. This study therefore bridges drivers of land-use/cover change to intermingled adverse impacts of its change in Ethiopia. It was also aimed to bring together the potential consequences of various places under one theme so as to make easy understanding of management strategies and assist policy makers for better interventions. To this end, driving factors and its consequences each treated/reviewed section by section and pinpointed under one file in way to support better management strategies.

### Data sources and methods

Driving factors and adverse impacts of land-use/cover change were logically assessed and each multifaceted driving factors and adverse impacts were pinpointed by reviewing reliable literatures touching different parts of the country. Information used to reinforce the evidence with the logical reasoning were collected from different ranges of journals dealt with land-use/cover change using geospatial data backed by GIS and Remote Sensing technology and other methods to minimize uncertainties in the study. Two themes/components separately assessed and some overlapping of publication citations could be appeared repeatedly mainly to support the discussion more lively.

### Limitations

One cannot find a published scientific research in every corners of the country in all aspects. This area is not yet fully researched and scientific research findings on these issues are at the infant stage in most cases. Hence, for areas where there is lack of published research findings, other variables like agro-climatic conditions, livelihood styles , population settlements and land-use/cover - patterns were considered in order to inference and minimize bias against established knowledge. The study also assumes the present scenarios as valid for the future and doesn't consider shift in technology that best welcomes the adverse changes and converts it to other fortune. This is because of the fear that the future is uncertain and mostly in state of changing (Verburg et al., 2010) that might bring fallacies against the established knowledge. Hence, the assessments and implications of different review are based on the existing status-quo keeping other possible opportunities and change kept constant.

### Driving factors of land-use/cover change in Ethiopia

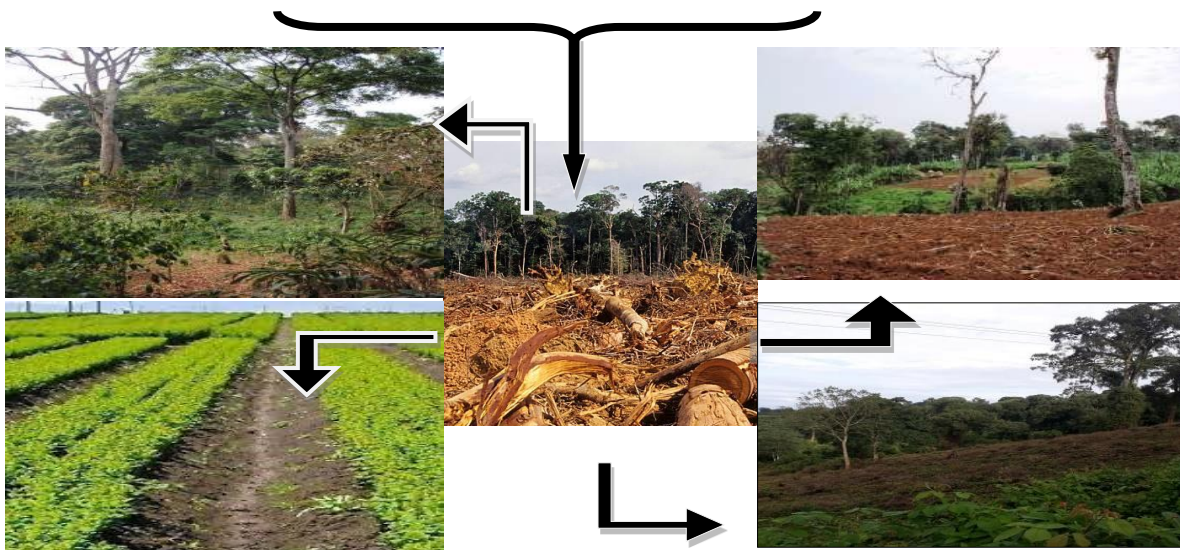
There are many studies pin-pointing the driving factors of land-use/cover changes identified via different scientific approaches. The driving factors were multifaceted by their nature due to different governing reasons and vary largely from place to palace.

Causes for land-use/cover change attributed to resource scrambling and forest land grabbing often misquoted as bare land or lacks signs of agriculture for investment like coffee, tea plantations and agricultural activities (small-scale subsistence agriculture to large-scale commercial agricultural schemes), poor law enforcement, resettlement (spontaneous and planned), land tenure policy, shifting cultivation have been significant drivers identified in SW Ethiopia and to some extent in Gambella and Benishangul regions (Brhane and Zemenu, 2018; Obang et al., 2017; Alemayehu, 2015; Azeb et al., 2018; Azeb, 2018; Henok et al., 2016; Kefelegn et al., 2017; Teshome et al., 2019; Semeneh et al., 2016; Yenenesh et al., 2018; Kero et al., 2018). Figure 1

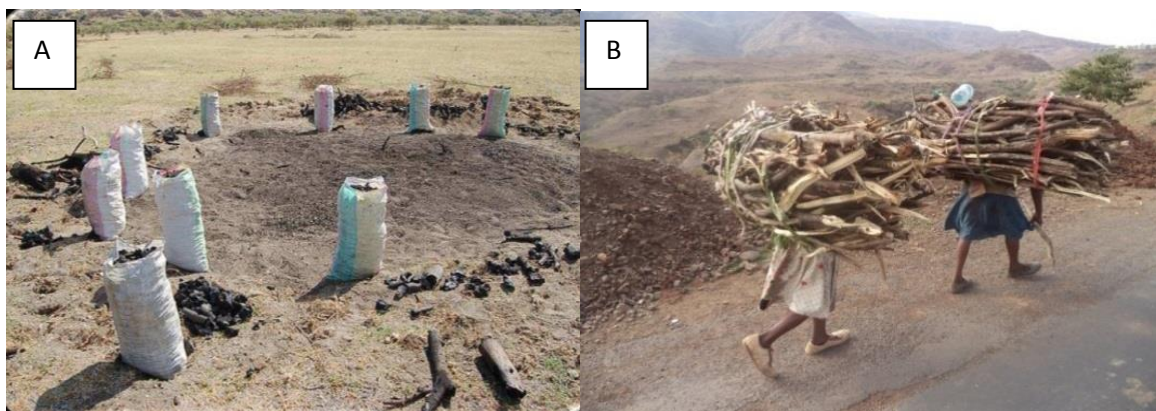
While over grazing and charcoal production as means of livelihood income are dominantly seen drivers in Afar and Somali regions. These regions almost share common agro-climate, livelihood and living style fashion (Anteneh et al., 2018). The recent studies made by Wakshum et al. (2018), identified *Prosopis juliflora* invasions effects as one of the unique driving factors of land-use/cover change in South Afar, Northeast Ethiopia.

Common causes in eastern parts of Ethiopia particularly in Diredawa administration and Harari regional state were collection of woods for fuel consumption, population growth, agricultural expansion, charcoal production,





**Figure 1.** Sheka forest and cover change indicating how dense forest cover converted to other land-use/cover type (Atlas of maps land cover change 1973 to 2013).



**Figure 2.** (a) Illegal charcoal production in Arsi Negele district. Source: Mikias (2014); (b) Deforestation in activities in Kanchama, Arbaminch zone. Source: Habtamu et al. (2017).

livestock ranching and settlement expansion (Amisalu and Toru, 2018). Factors like farmland expansion, population pressure, deforestation and collection of woods for construction and charcoal production for fuel consumption, poor land tenure policy and land fragmentations have been significant driving factors in Southern Nations, Nationalities and Peoples Regional (SNNPR) state, central and southern Oromiya regional states (Berhan and Woldeamlak, 2014; Habtamu et al., 2018; Habtamu et al., 2017; Mikias, 2014; Gebrekidan et al., 2014; Hagos, 2014) Figure 2a and b.

Driving factors prevailed in Tigray and Amhara regional states were associated with deforestations, high human and livestock population, charcoal production, agricultural expansion, prevalence of drought, resettlement (Samuale

et al., 2014; Kebrom and Hedlund, 2000; Binyam et al., 2015; Miheretu and Yimer, 2017; Negasi et al., 2018; Mesfin et al., 2016; Worku and Csaplovics, 2015).

Expansion in urbanization and urban sprawling by itself is cause and effects of land-use/cover change in most of parts of the developed and developing countries (Hassan et al., 2016; Mohan et al., 2011; Duguma, 2017). Currently urban expansion mostly unplanned advancement is the highest among zonal, regional and capital city of the country often resulted in converting rural landscape to urban landscape. This urban sprawling considered usually as sign of economic influence despite the expansion is at the expense of encroaching potential rural areas (Afera et al., 2018; Sisay et al., 2016).

Unlike to other places, land-use/cover change in pastoral areas were largely imposed by large number of livestock population leading to overgrazing, recurrent drought due to rain fall variability, poor policy, land rotation for searching better grazing land (Teka et al., 2018).

### Adverse impacts of land-use/cover change in Ethiopia

Causes for land-use/cover change dynamics were diverse as extensively reviewed above and likewise, its adverse impacts are also diverse and differ largely from place to place. A review from different journals evidenced that there are a wide range of adverse impacts so far identified due to land-use/cover changes. The adverse impacts ever identified/reviewed hereunder were attributed to environmental qualities while some others are associated to socio- economic impacts.

Major underlying consequences due to land-use/cover change in Gambella, Benishangul and most parts of Southwestern Ethiopia were loss of biodiversity and ecosystem service degradation (Figure 1), deterioration of wetlands, creation of new landscape, rainfall variability, reduction in stream flow, increase frequent extreme in weather, conflicts of interest, soil lose and decline in soil fertility (Henok et al., 2016; Mathewos and Bewuketu, 2018; Getachew et al., 2014)

Amahara, North eastern parts of Benishangul, and South western parts of Tigray having similar agro-climate, landscape and livelihood of the communities experienced common problems. Hence, according to the evidence from different journal, the impacts dominantly seen were soil and land degradations, prevalence of drought, rainfall variability, decrease in wetland, increase in runoff resulting in soil and land degradation and sedimentations (Woldeamlak, 2002; Eleni et al., 2013; Woldeamlak and Solomon, 2013; Miheretu and Yimer, 2017; Negasi et al., 2018; Tesfa et al., 2018; Jacob et al. 2015; Mesfin et al., 2016; Menberu, 2014, Kassahun and Yitbarek, 2018). Figure 4

Southern Nations, Nationalities and Peoples Regional (SNNPR) state and around central and southern parts of Oromia regional state, major identified effects of land-use/cover were loss of biodiversity, soil fertility decrease, land fragmentations, forest resource deteriorations (Mikias, 2015; Mohammed et al., 2017; Shegena et al., 2016; Desalegn et al., 2014; Terefe et al., 2017; Adane and Mezgebu, 2017)

The problems dominantly reviewed in Tigray, Afar and Somali regional states were land fragmentations, fluctuations in rainfall patterns and extremisms, incidence of extremisms in weather conditions leading to drought, soil and land degradations, decrease in stream flow, wetland deterioration, increased risk of desertification (Samuale et al., 2014; Diress et al., 2010). Rugged topography with inappropriate agricultural practice is also the reasons behind land degradation particularly in

Amhara and Tigray regions. Whereas high livestock population pressure fueled with overgrazing in Afar, Harari and Somali regions facilitated the loss of soil due to erosion, decline in soil fertility and land degradation Figure 3.

There is significant woody land cover reduction in pastoral areas due to large livestock population. In areas where there is overgrazing, the density of wood land cover largely decreased and often resulted in shifting to other places (Teka et al., 2018). On the other hand, the invasion of woody plants referred to as *Prosopis juliflora* to rangelands becomes a potential threat to pastoral production in South Afar, Northeast Ethiopia (Wakshum et al., 2018). Currently, *Prosopis juliflora* is advancing in alarming rate to eastern parts of Ethiopia including Somalia, Afar, Harari regions and around Diredawa.

Study made by Yohannes et al. (2017), identified ecosystem deterioration due to land-use/cover change leading to disturbance of an aquatic animals and species around central rift valley lakes regions, Ethiopia. Despite all these effects, the degree of criticality however varies from place to place and ranges from localized to global level impacts. The important note here we should underline is that one impact by itself can be cause and effects for others if left for long period of time without any management schemes in placed. For example, poverty by itself is cause and effects of climate change (prolonged decrease in stream flow, rainfall variability) and this if left unmanaged lead to other adverse crises and effects like deterioration of environmental quality as a whole.

## RESULTS AND DISCUSSION

This study is evidence based identifications of driving factors of land-use/cover change and its level of impacts on the environment and socioeconomic activities. We should not always attribute/give negative connotations to land-use/cover change for the fact it has also positive impacts. However, land-use/cover change induced by human for human need satisfaction often competed with yielding adverse impacts on human and the environment. Because of these, causes and effects are often complex to fully understand due to multi pushing factors such as natural and human induced factors and varies among localities, regions and largely at country level. Diversity in land-use/cover change caused by numerous factors and its adverse effects becoming a big challenge to make a distinction and the undergoing process is intermingled (Thi-Thanh-Hien et al., 2015). For instance, there are many direct and indirect impacts associated with forest deforestations. But if you ones sense the presence of deforestations, you can expect diverse associated consequences (Solomon, 2016).

In general, demographic, socioeconomic, and cultural changes were the leading drivers in most parts of





**Figure 3.** Overgrazing and its effects on wetlands (From Lecture Slides-Integrated River Basin Management MSc courses).



**Figure 4.** Soil and land degradation in North western parts of Ethiopia, Koga catchment. Source: Eleni et al. (2013).

Ethiopia resulting change in cover and land use pattern. In response to these driving factors of land-use/cover change, the adverse impacts ever identified and reviewed were attributed to environmental qualities while some others are associated to socio- economic, cultural and political impacts.

Resource scrambling and forest land grabbing for investment, agricultural activities (small-scale subsistence agriculture to large-scale commercial agricultural schemes), poor law enforcement, resettlement (spontaneous and planned), land lease policy, shifting cultivation have been significant drivers identified in south western parts of Ethiopia in general. Associated with these driving factors, loss of biodiversity and ecosystem service degradation, deterioration of wetlands, creation of new landscape, rainfall variability, reduction in stream flow, increase frequent extreme in weather, conflicts of interest, soil lose and decline in soil fertility were underlying causes ever reported in south western parts of Ethiopia.

Some driving factors like charcoal production and livestock production are common but it is one of the key livelihood incomes for Somali, Afar and Harari regions resulting in woody land cover reduction. Despite other places, these regions also uniquely threaten by the invasion of Woody plants referred to as *Prosopis juliflora* to rangelands as a potential threat to pastoral production. Unlike to other places, study made by Yohannes et al. (2017) identified ecosystem deterioration due to land-use/cover change leading to disturbance of an aquatic animals and species around central rift valley lakes regions.

Common driving factors so far identified in most parts of Oromia, Amahra and Southern and central parts of Ethiopia were agricultural expansion, population pressure and deforestation often resulted in land fragmentation, soil and land degradation, forest and woodland cover reduction. The ups and down curvature of the surface nature in Amahara and Tigray regions resulted in soil and land degradation often fueled by inappropriate agricultural

expansion, population pressure and overgrazing. As a result, increase in runoff, soil fertility loss and stream flow reduction is the case in most cases.

Unplanned urban expansion in the form of lease policy in every parts of the country is another big causes and effects of land-use/cover change. Due to urban sprawling, rural lands are now becoming parts of residential areas resulting in significant changes in land use patterns. In areas where there is shortage of rainfall particularly in pastoral areas, land-use/cover change were largely determined by large number of livestock population leading to overgrazing, recurrent drought due to rain fall variability, poor governing policy, land rotation for searching better grazing land (Teka et al., 2018).

The worst case scenario is that some changes in land-use/cover were irreversible or take long period of time to restore back (Afera et al., 2018; Thompson, 2017). For instance, loss of biodiversity and soil and land degradation may take several decades to restore back. This early warning might help to save UNESCO registered biosphere reserves in the unique landscape of Sheka and Majang zone, south western parts of Ethiopia. This place among other is a biodiversity-rich ecosystem area but threaten recently by investment (tea and coffee plantation), poor and narrowly conceived policy regarding land awarding to investors and tenure, settlement (mostly spontaneous) and cereal crop based agricultural expansions. Many research findings ensured all these identified common driving factors behind land-use/cover change and easy to think of mounting impacts on ecosystem services in general Figure 1.

Some effects of land-use/cover change are only confined to particular places but effect on the environment is common to all places despite the criticality varies (Hu and Nacun, 2018; Verburget al., 2010). Moreover, agricultural expansion is also common to all parts of the country as one of the major causal factors for land-use/cover changes. But one should not be misquoted in valuing only its positive aspects because the expansion is to compensate the soil infertility. Journals reviewed so far pointed out that one of the land-use cover change effect is loss of soil fertility due to erosion and this imposed farmers to practice extensive than intensive farming in most of the highland places. Hence, despite the expansion in agricultural practice; there is very limited yield to support the growing population demand.

Thus, this study was built from systematic meta-analysis based on wide range of reviewed studies including different perspectives, approaches and provides a common national framework for taking corrective measures with the aim to end the management challenges. Valid and timely information on land-use/cover change and its associated driving factors is indispensable strategies for national or regional based conservation strategies (Mathewos and Bewuketu, 2018; Teshome, et al., 2019; Temesgen et al., 2017). It is therefore important to bridge established knowledge with

designed policy for better environmental management.

## CONCLUSIONS

The dynamics of land-use/cover change is complex due to its multivariate nature made up of intermingled proximate and underlying factors. This complexity is fueled by scattered findings across the country and challenged in drafting common and widely accepted frame work or applicable policy to manage the causes. For common understanding, all the causes and effects of each part of the country was reviewed. Generally, demographic, socioeconomic, and cultural changes were the leading drivers in most parts of Ethiopia resulting change in cover and land use pattern. In response to driving factors of land-use/cover change, the adverse impacts ever identified and reviewed were attributed to environmental qualities while some others are associated to socio- economic, cultural and political impacts. Thus, this review brought all the reported geospatial evidence based drivers, of land-use/cover change and its associated impacts, under one theme for better understanding and management of the problems in place. But, it should be noted here, that, these adverse effects in the future will be handed and cannot be threats due to technological advancement and thus might create fallacies against established knowledge. Moreover, these studies also don't considered future uncertainties as we are living in dynamic and steadily changing world.

## CONFLICT OF INTERESTS

The author has not declared any conflict of interest.

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*Full Length Research Paper*

# **Balancing land management under livestock keeping regimes: A case study of Ruvu and Zigi catchments in Tanzania**

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Land degradation has become a global concern that requires countries to take prompt actions. The objective of the study was to assess land management in respect to activities of livestock keeping in the Ruvu and Zigi river basins in Eastern Tanzania. The two basins attract a huge number of livestock from nearby and relatively distant areas in pursuit of pasture and water resources. The results indicated that modes of livestock keeping differs with more free grazing in the lowland and zero grazing in the mountainous areas. Overall, the free grazing in the lowland is dominated by seasonal movement of livestock in and out of the basins in various times of the year. Of the two basins, Ruvu is highly affected by haphazard livestock keeping compared to Zigi. Challenges associated with excessive number of livestock include forest degradation, increased incidences of wildfire, soil degradation, poor maintenance of water resources and ensued conflicts with crop farmers. The number of livestock involved in both basins is under reported due to the non-cooperation received from the pastoralists during livestock census. Pastoralists in the two basins often times defies the government decrees prohibiting movement of livestock from district to another. Limited conflicts have been reported among pastoralists from different tribes while the situation is critical with crop farmers. This study observed that monitoring of livestock movement in the two basins is crucial. The study recommends assessment of the carrying capacities of the basins and subsequent development of the basin-wide rangeland management plans.

**Key words:** Rangeland management, livestock management, land degradation, water catchment.

## **INTRODUCTION**

Land degradation (LD) has become a global concern that requires countries to undertake immediate measures to mitigate the situation. Depletion of the natural resource base triggered by human-induced disturbances and some

natural processes contribute to LD. The LD remain the important discussion point as it entails not only loss of productivity but accelerate biodiversity loss and directly linked to climate change. Water catchments and wetland

areas are among areas that have been affected by LD, leading to water scarcity. It is estimated that by 2025, about 1.8 billion people will be expected to live in countries or regions with absolute water scarcity, and two-thirds of the world population could be under water stress conditions (WWAP, 2006). In Tanzania, freshwater is abundantly distributed in form of surface water which account for about 615,000 km<sup>3</sup> (URT,<sup>1</sup> 2010). Water bodies traverses through various land uses including reserved lands, village lands and general lands, which attracts various access and user rights. Freshwater for productive use remain plenty in the country but face challenges due to unequal distribution and access by various stakeholders, hence creating frequent conflicts among users.

Climatic factors as influenced by precipitation, temperature and wind cause people to feel comfortable or not comfortable in the area because the planning and management aspects. Some of studies show that there is the range of bioclimatic comfort zone which people feel comfortable. Drought evaluation is very important as well as climatic ranges. Drought assessments give people an active scenario in the landscape to protect the damaging socioeconomic and politic problems (Yigit et al., 2016b; Cetin and Sevik, 2016a, b; Cetin, 2015a; Cetin et al., 2018a, b; Yucedag et al., 2018; Kaya et a;., 2018).

Land use change is due to human activities and natural factors. Land cover is one of the most important data used to demonstrate the effects of land use changes, especially human activities. Production of land use maps can be done by using different methods on satellite images. By using land cover maps, the changes in urban development and green areas over time have been evaluated. At the same time, the relationship between changes in the land cover over time and changes in the urban population has been examined (Cetin, 2015a, b, c, d; Cetin and Sevik, 2016a, b; Cetin, 2016a, b; Cetin et al., 2018a, b; Yucedag et al., 2018; Kaya et al., 2018).

In Tanzania areas with large number of livestock are vulnerable to LD. Tanzania ranks third in Africa in terms of number of livestock. The country has 25 million cattle, 16.7 million goats, 8 million sheep, 2.4 million pigs, and 36 million chickens. Traditional breeds and processes dominate the Tanzania livestock sector. Distribution of the livestock is dominated by the agro-pastoralists (80%), pastoral communities (14%) and the remaining commercial ranches and dairy sector (6%) (URT, 2010).

The country has extensive rangelands and diverse natural vegetation that support livestock development. About 60 million (ha) of land are suitable for grazing countrywide (URT, 2007). However, distribution of the livestock may not necessarily reflect the distribution of the grazing land but rather skewed and concentrated in some few areas. The rangelands in the country faces dual pressure of over-exploitation and land conversion.

Rangelands are increasingly converted to other land uses by farming or other development.

Livestock activities contribute 7.4% to the country's GDP. The annualized growth rate of the sector is low at 2.2%, characterized by increase in livestock numbers rather than productivity gains. Domestic livestock populations have been increasing by 5% per annum over the past 15 years. The livestock sector is severely constrained by low livestock reproductive rates, high mortality and high disease prevalence (URT, 2010).

Despite the fact that the LD and livestock might not be a cause-effect relationship, but this represent widespread perception. Areas such as Shinyanga in central Tanzania are known to be highly affected by overgrazing to the extent of triggering national emergency plan for restoration. In mid 1980s the government and development partners launched a program for land restoration popularly known as *Hifadhi Ardhi Shinyanga* (HASHI) literally soil conservation in Shinyanga, which was meant to address issue of land degradation specifically soil erosion and vegetation depletion through use of traditional rangeland management system called *Ngitili*<sup>2</sup> (Duguma et al., 2013).

Policy and legal instrument to support livestock management are very weak, as they are overridden by other land management legal instruments. This has led the livestock management to remain under restrictive measures including prohibition of free livestock movement from one place to another. There is no harmonization of the bylaws by adjacent district authorities hence subjecting livestock keepers to multiple and varied bylaws. The objectives of the current study were to i) assess the livestock management regimes in the Ruvu and Zigi river basins, and ii) assess vulnerability livestock management system in the two basins and can be used to develop in-depth studies and interventions to address land degradation that may be caused by pastoralism.

## METHODOLOGY

### Study sites

The study sites include the Zigi River Basin in the East Usambara Mountains and the Ruvu River Basin in the Uluguru Mountains (Figure 1). The two basins are important landscapes with mosaics of multiple land uses, and they form part of the larger Eastern Afromontane biodiversity hotspot of Tanzania. Zigi River Basin is composed of three main sub-catchments, which are (i) Zigi, (ii) Kihuhwi and (iii) Muzi; while Ruvu River Basin is composed of five main sub-catchments, (i) Mgeta, including Msoro, (ii) Ngerengere, (iii) Upper Ruvu, (iv) Middle Ruvu, and (v) Lower Ruvu.

<sup>1</sup> URT = United Republic of Tanzania

<sup>2</sup>Ngitili is an Agrosilvopasture technique common among the Sukuma tribe of North Western Tanzania "*ngitili*" (i.e. dry-season fodder reserves) is kind of fodder bank among the Sukuma agropastoralists of Shinyanga which is a key practice in range management and forest restoration.



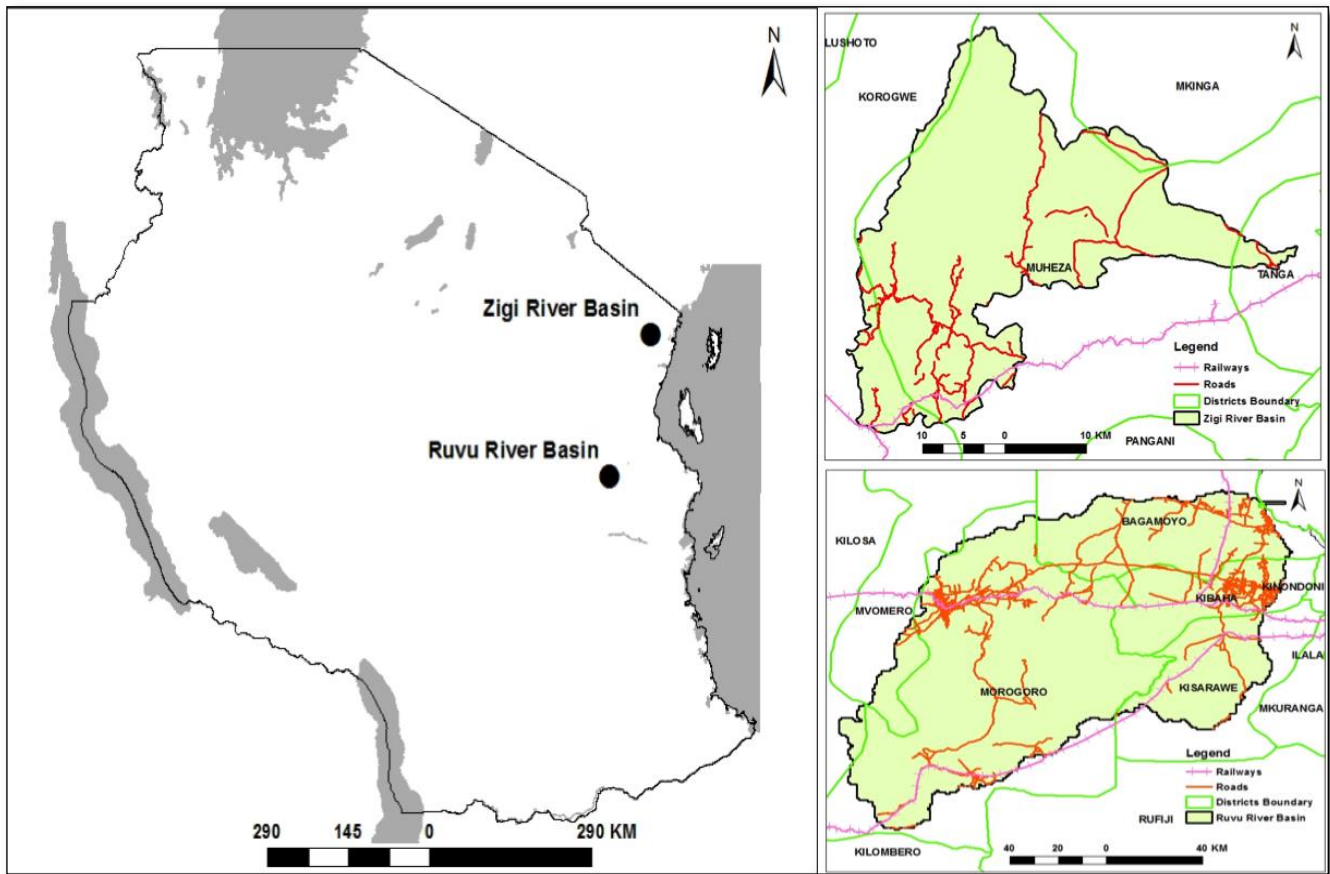


Figure 1. Composite map showing location of Zigi and Ruvu basins in Tanzania.

### Description of Zigi and Ruvu River Basins

General characteristics of the study sites (Table 1) include mountainous zone and lowland flat area and the flood plains.

### Data collection

Socio-economic data related to livestock management were collected through Key Informant Interview (25 individuals were interviewed), Focused Groups Discussion (246 individual participated) and Individual Questionnaire Survey (128 individuals were interviewed). Key informants interviewed included people with broad knowledge in the local settings related to the livestock management including leaders in the villages, wards and experts from District Authorities. Feed Assessment Tool (FEAST) developed by ILRI (<https://www.ilri.org/feast>)<sup>3</sup> was used in conducting Focus Group Discussions (FGD), involving about 12 to 16 people selected objectively from different categories of livestock

<sup>3</sup>The Feed Assessment Tool (FEAST) is a systematic method to assess local feed resource availability and use. It helps in the design of intervention strategies aiming to optimize feed utilization and animal production. The tool comprises two main elements: (a) a focused PRA exercise which provides an overview of the farming system with particular emphasis on livestock feed aspects, and (b) a simple and brief quantitative questionnaire, designed to be completed by experts under the guidance of the Feast facilitator.

keepers. As per FEAST protocol, the Individual Questionnaire Survey was administered among participants of the FGD to gather further insights about livestock management at household level as recommended by Mangesho et al. (2013).

Participatory field observations were done in selected areas villages (Table 2) through Transect Walk method, 5 and 3 transect walks were done at Ruvu and Zigi Basin respectively. Establishment of the transects were done in collaboration with local leaders taking into account areas designated for livestock grazing as per existing village land use plans. In absence of land use plans, areas designated and used for grazing were also identified, visited and assessed and recorded. Participatory GIS was used to allow local people familiar with long term historical narrative of the area to record spatial details of existing land cover and land use (URT, 2015). It was also used to pinpoint areas affected by degradation, the extent of land that is currently under settlement and later correlate this with population sizes and densities; and the extent of land in each basin used for grazing migration routes. It was further used in mapping seasonal movements of livestock and identify (by type, location and scale), a suite of prospective sustainable livestock management technologies.

### Data analysis

Standard methods for data analyses were applied for both socio-economic and biophysical information. Description statistics were computed for mean, standard deviation, standard error, maximum

**Table 1.** Description of the study sites in Ruvu and Zigi River basins.

Description	Ruvu River Basin	Zigi River Basin
Location	60°05' and 70°45' S and 37°15' and 39°00' E	4°48' and 5°14' S and 38°32' and 38°48' E
Altitudinal range	150 m and 2,638 m.	300 and 1174 m
Size	17,700 km <sup>2</sup>	1,082 km <sup>2</sup>
Rainfall distribution	Rainfall varies in different places ranging from 900 mm per annum on the north-western slopes to 1200- 3100 mm on the drier western slopes to 2500-4000 mm on the wetter eastern slopes.	1918 mm with up to 2262 mm near Kwamkoro on the Amani plateau.
Rain season	Rainfall on the eastern side is continuous throughout the year with no distinct dry season, while in the western part there are two rains seasons distinguished as long rains from February to June, and short rains in October to January; with dry season extending between July to October.	Rainfall distribution is bi-modal peaking between March and May and between September and December. The dry seasons are from June to August and January to March
Temperature	Average monthly minimum and maximum temperatures are almost the same throughout the basin; the coldest month is August (about 18°C) and the hottest month is February (about 32°C). The annual average temperature is about 26°C.	The mean annual temperature at about 900 m altitude is 20.6°C with a mean daily maximum temperature of 24.9°C and a mean daily minimum temperature of 16.3°C
Soil condition	Soils are acidic Lithosols and Ferralitic red, yellow and brown latosols, which have developed from Precambrian granulite, Gneiss and Migmatite rocks. The soils in the sub-basin range from sandy clay with excessive drainage to sandy loam with excessive drainage in the highlands of the Uluguru. In the middle of the sub-basin the soils range from sandy loam to sandy clay loam, both with imperfect drainage. As the sub-basin drains towards the coastal area, soils range from loamy sand with good drainage to sandy with moderate drainage.	The soils of the East Usambara Mountains are largely clay and clay-loams usually between 1-5 m in depth. Soils at lower altitudes have more or less the same visual appearance as at the higher altitude, but are less leached and much less acidic. Soil pH falls off from about pH 7 at 300 m to about pH 6.5 at 850 m and then diminishes rapidly below pH 5 at 900 m and to about pH 4 at 1050 m
Human population	High populated areas include those close to urban areas especially around Morogoro municipal and Bagamoyo town. It is also similar to peri-urban areas such as Kiroka, Mlali, Vigwaza and Kiwangwa which are very popular for agricultural production and livestock management. They also attract off-farm businesses due to their accessibility and links to the major markets.	Population density in the basin is relatively higher in the highlands compared to the lowland, with highest one reported in Amani plateau standing at 140 people/km <sup>2</sup> , with some villages estimated at 300 people/km <sup>2</sup> .
Crop farming	Multi-strata agroforestry system is dominant in the mountainous areas comprised of trees-crops-livestock. In the lowland, dominant crop includes maize, cassava and paddy rice.	Agroforestry is the main farming practice in the highland with dominated by spices such as cardamom, cloves, cinnamon and black pepper. The main food crops cultivated are maize, cassava, bananas and beans. Other crops which are popular include sugarcane and production of fruits such as mango and oranges

Source: IUCN (2010a).

and minimum. Combination of multiple tools/software was used including SPSS and excel spreadsheet for socio-economic and simple arithmetic data, while FEAST tool version 2.2 and R-software (<https://www.r-project.org/>)<sup>4</sup> were used. Remote sensed data were analyzed using IMPACT software developed by the EU Joint Research Centre. Narratives from local people were useful in

providing understanding of the socio-economic forces behind land use and land cover modifications. The land degradation map was generated by using weighted overlay tool in ArcGIS. The tool combines the following four steps:

- (i) Identification of the input rasters. The major factors which were used for the weighted multi-criteria evaluation includes; distance from rivers, distance from roads, distance from cultivated lands.
- (ii) Reclassification of values in the input raster into a common evaluation scale of risk. All the raster were reclassified into a common risk scale of 1 to 3, with 3 being the most vulnerable and 1

<sup>4</sup>R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. (URL <http://www.R-project.org/>.) Accessed 24th April 2018.



**Table 2.** Sampled villages in the study sites.

Basin	Villages/streets/township
Zigi River Basin	Sakale, Mlesa, Amani (Shebomeza), Kwemwewe, Kihara site, Ubiri, Longuza
Ruvu River Basin	Mkonowa Mara, Mvuha, Kongwa, Bonye, Kibangile, Mbwade, Tandai, Kalundwa, Amini, Bagilo, Tegetero, Mifulu and Hewe, Nyandira, Mgeta Kibaoni, Bunduki, Mlali, Kinyenze, Tangeni, Mzumbe

being the lowest vulnerable to land degradation.

(iii) Assigning of weights to factors. Weights were assigned to each factor in order of its importance (distance from river = 0.4, distance from major road = 0.3, distance from cultivated lands = 0.3) and a total score was obtained for each alternative by multiplying the importance weight assigned to each attribute by the scaled value.

(v) Overlay analysis. Add the resulting cell values together to produce the output raster indicating high, medium and low vulnerable areas to land degradation.

The landscape degradation was limited to distance from rivers, from roads and cultivated lands only because of the study objective was to undertake a comprehensive biophysical resources assessment of the Ruvu and Zigi catchments for development of decision support tools to enable effective management, with emphasis on:

- (i) Updating land-cover data for Ruvu and Zigi catchments
- (ii) Identifying and map badly degraded areas both within and outside of protected areas, especially those that might require specific rehabilitation measures
- (iii) Assessing the extent of land that is currently under settlement and correlate this with population sizes and densities

Under such circumstance it was important to focus on a key predictors that enabled to isolate key drivers of land degradation.

## RESULTS

### Livestock concentration in Ruvu and Zigi catchments

Livestock is unevenly distributed in the two catchments (Table 3) with higher number in the Ruvu compared to Zigi. The number of cows and goats in Ruvu is almost double that of Zigi catchment. The livestock density in Ruvu catchment has been indicated to be around 2.25 to 8 ha per livestock unit (LU) per year (Millao, pers. comm. 2018). The overall current carrying capacity ranges from 2 to 8 LU per ha per year. This state of affair has rendered the catchment into large livestock population.

The management strategies of livestock in the catchment is diverse because of the aggregate nature of the study area and the livestock keeping practices (Table 4). There are basically two predominant practices which are nomadic and zero grazing. The management strategies employed are either stand alone or a combination of more than one strategy. Results

from stakeholders' consultations indicated that livestock migration in Ruvu and Zigi River basins occurs in three patterns; i) inward flow, ii) outward flow and iii) internal movements within the basins (Figure 2). The migration occurs mainly from the onset of dry season, and the distance ranges from few to tens of kilometres while time ranges from weeks to months.

### Land degradation in the Ruvu and Zigi Basins

Results from combination of tools including participatory mapping, remote sensing and geographic information system (GIS), and stakeholders' consultations have indicated that some areas in the Ruvu and Zigi basins have been degraded and remain vulnerable to further degradation (Figures 3 and 4) due to rapid population growth, natural resources exploitation and abject poverty (USAID, 2008). It should be noted that the extend of land degraded in specific wards of the study areas were classified using the rank to indicate from less degraded to more degraded in hectare as was observed during baseline survey of the Sustainable Land Management (SLM) project, it does not rank degradation as severe or less severe. The area range is just indicative of the extent for ease aggregation of the extent.

## DISCUSSION

### Number of livestock vs. carrying capacity

Livestock keeping in Tanzania is dominated by agro-pastoral communities that engage in both crop farming and animal husbandry (URT, 2015). Due to this dual livelihood practices, most of the communities are attracted to areas that are fertile to enable crop farming but also access to grazing land (Engida et al., 2015).

The Ruvu and Zigi basins provide best landscapes to the realization of these agro-pastoral communities IUCN, 2010a). In terms of livestock, the two basins harbour a considerable number of livestock (Table 4).

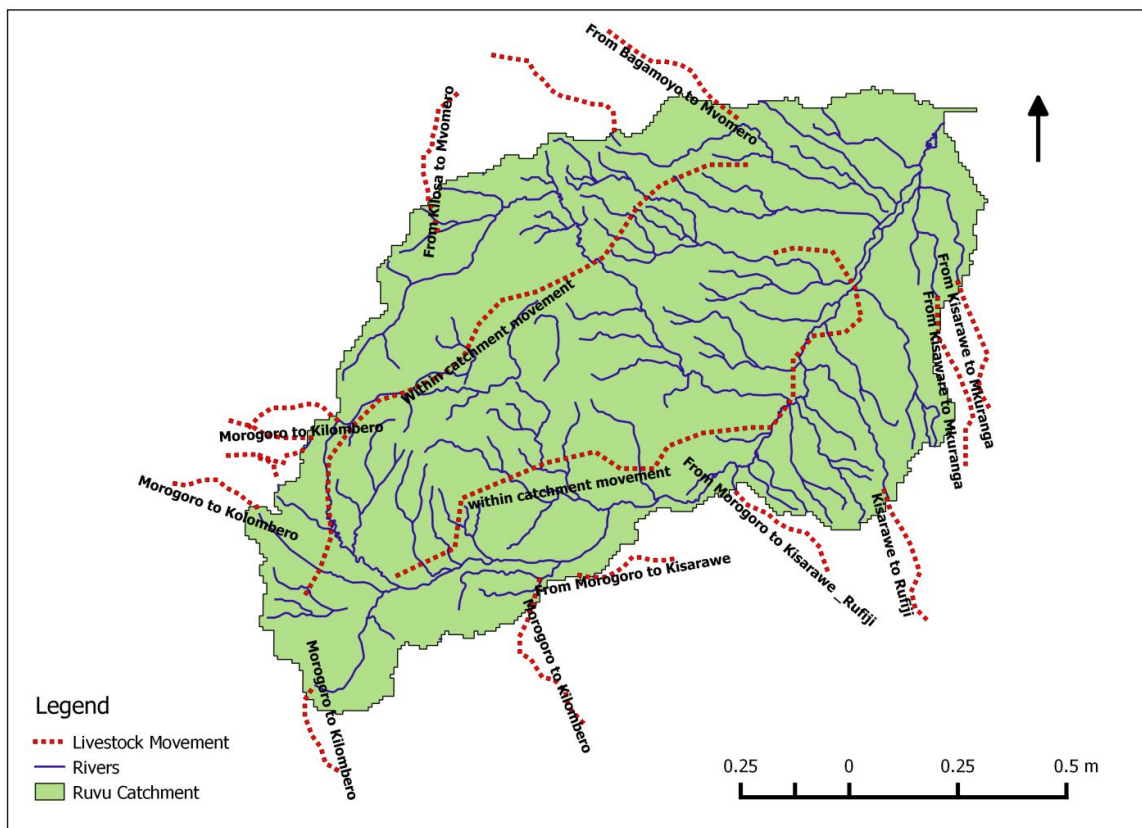
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**Table 3.** Livestock population in the catchments.

S/N	Catchment	Cows	Goats	Sheep
1	Ruvu	363,519	75,624	33,428
2	Zigi	151,414	37,409	4,106
	<b>Total</b>	<b>514,933</b>	<b>113,033</b>	<b>37,534</b>

**Table 4.** Management strategies applied for livestock.

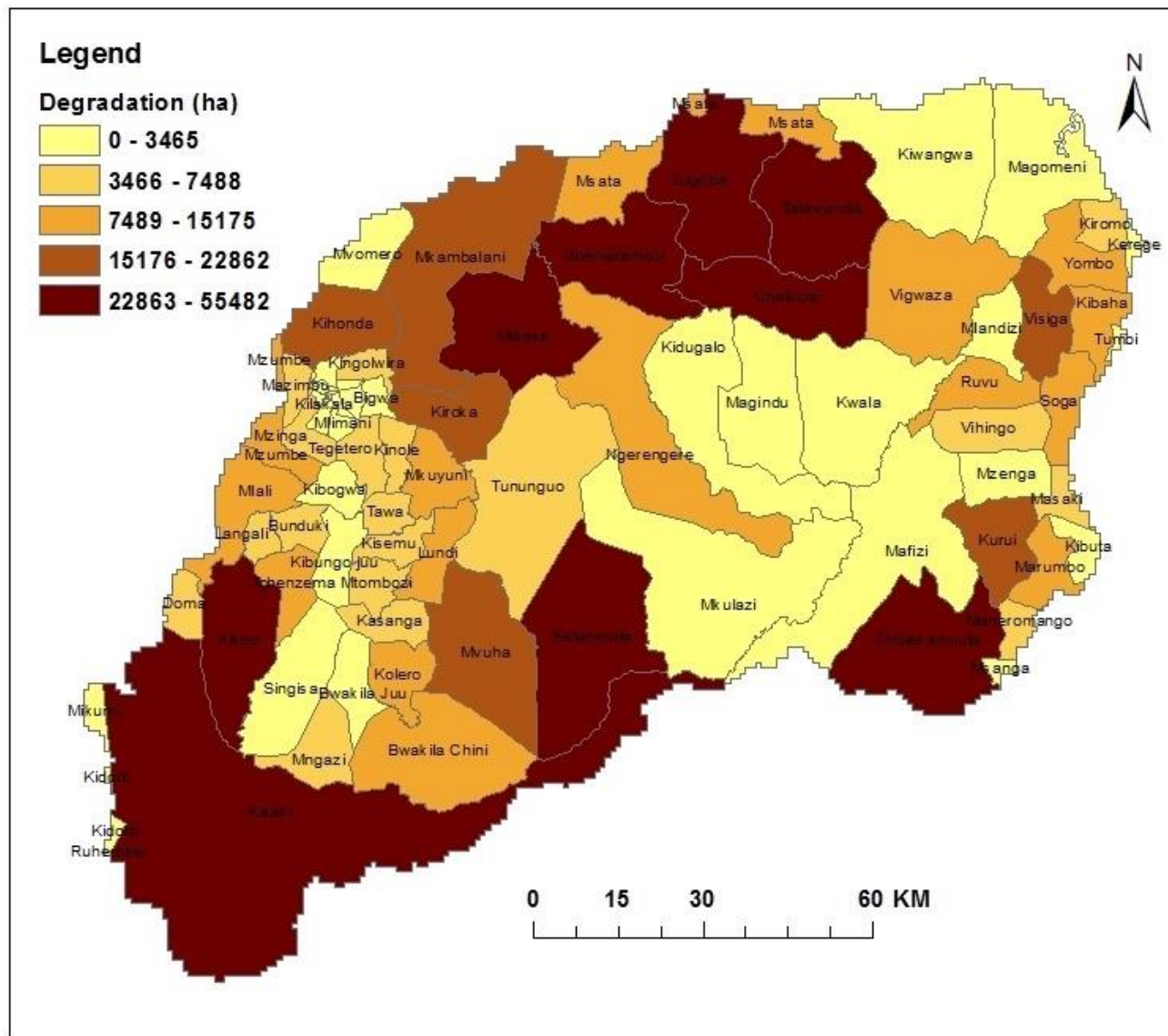
S/N	Management Strategy	Extent	Practice
1	Free range grazing	Common and wide spread	Nomadic pastoralists
2	Fodder bank	Very limited	Nomadic pastoralists notable
3	Fodder fetching	Common and wide spread	Zero grazing
4	Tethering	Common and wide spread	Zero grazing
5	Planting fodder	Common and wider spread	Zero grazing
6	Manageable livestock	Minimal	Nomadic and zero grazing
7	Seasonal Migration	Common during drought period	Nomadic pastoralists



**Figure 2.** Sketch map showing livestock migration routes during dry season.

(However, Ruvu basin accommodate more livestock compared to Zigi basin due to its large size and

connectivity to other livestock rich areas (IUCN, 2010a). At current levels, the number of livestock in Ruvu basin



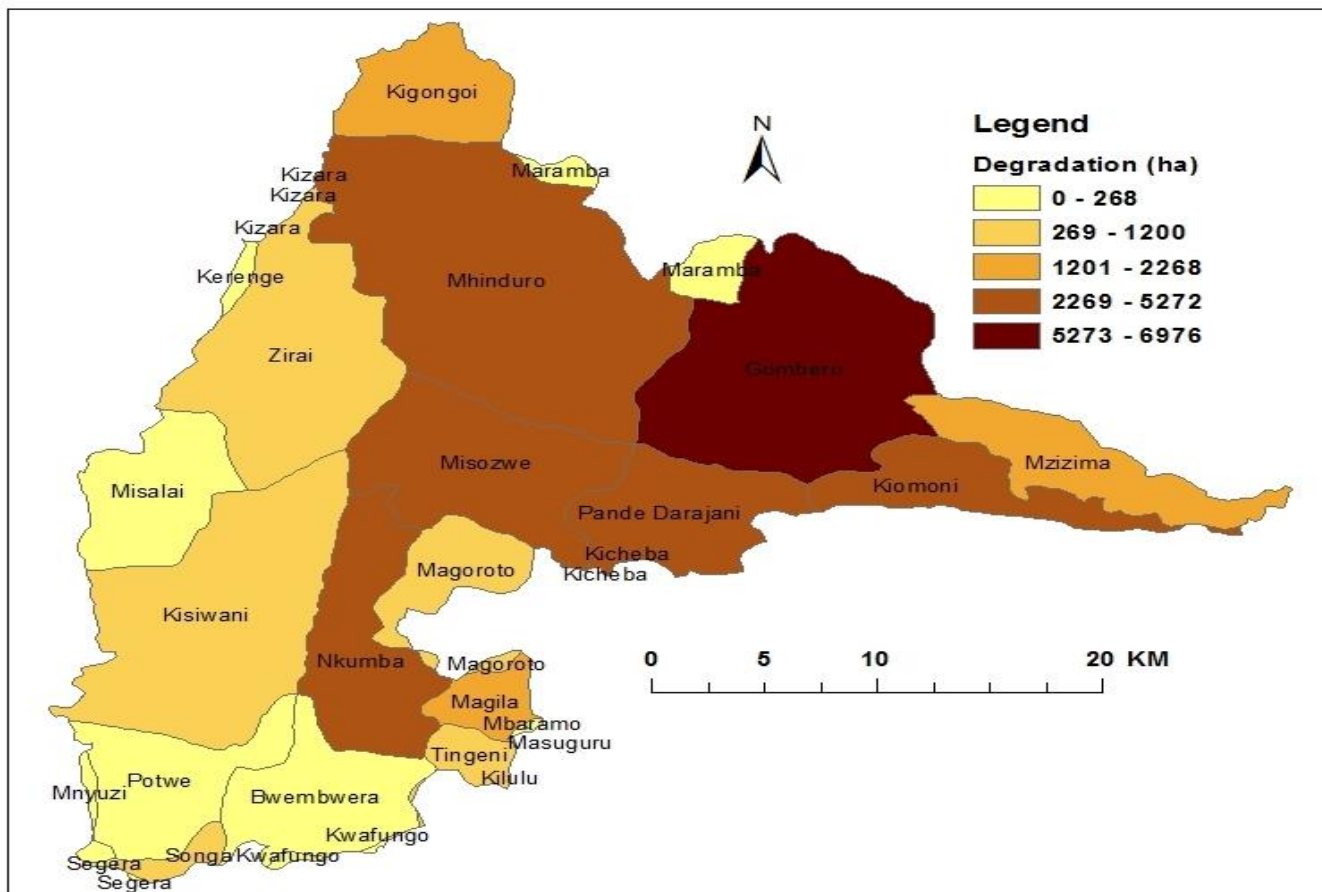
**Figure 3.** The extent of degraded land in specific wards in Ruvu Catchment.

exceeds its carrying capacity (it should be noted that the average carrying capacity for both catchments ranges from 2 - 8 LU per ha per year), mainly with large amount of livestock located in the lowland areas. In contrast, the livestock keeping in Zigi basin is much more lucrative compared to the Ruvu basin, partly contributed by use of improved breeds and presence of formalized milk trade (AECF, 2011).

The terrain of these two basins influence the management practices of livestock keeping, whereby in the mountainous areas it is mostly zero grazing while in the lowland is mostly free grazing (Mangesho et al., 2013, Covarrubias et al., 2012). Sharp contrast exists in Ruvu and Zigi basins in terms of livestock keeping as different management strategies are employed. While

Ruvu is dominated by free range, extensive and seasonal migration model, the situation is different in Zigi basin which exhibits zero grazing and limited stock size. In the Ruvu basin, large rangeland plains are found throughout the southern part of the basin, extending in Ngerengere plains, around Wami-Mbiki Wildlife Management Area and Chalinze woodland area (IUCN, 2010b). This vast area contains forests and woodlands that are less inhabited by humans hence provide extensive ground for livestock grazing.

Livestock grazing under free range in Ruvu basin have contributed to the accelerating reduction of the tree cover of the basin through tree cuts in favour of grasses (IUCN, 2010a). The strategy of undertaking tree cuts to allow creation of open spaces for grasses to flourish have been



**Figure 4.** The extent of degraded land in specific ward in Zigi Catchment.

responsible for land degradation in other parts of Tanzania including Shinyanga (Duguma et al., 2013). The southern part of the Ruvu basin has also served as a source of charcoal to Morogoro, Pwani and Dar es Salaam regions (Malimbwi and Zahabu, 2007). The parallel objectives of charcoal extraction as a means to open areas for grazing have not been systematic but rather undertaken by two different groups with its own goals. While the charcoal extraction individuals do it as a means of livelihood during dry season, the latter keeps the livestock in the areas to suppress regenerations and coppicing of the trees and shrubs to make it permanently grassland. Lessons from sustainable charcoal production in Kilosa district have shown that in areas where charcoal has been extracted, prevention of livestock from grazing in that area has led to about 88% regeneration of the tree and shrubs vegetation (Sangeda and Maleko, 2018). Therefore, with unchecked charcoal extraction in the Ruvu basin the risks of land degradation stand very high. Along the Morogoro-Dar es Salaam highway, one could see a sharp difference of the vegetation cover on opposite sites near Kitulangalo and Ubena-Zomozi, between protected and unprotected areas that just in previous 30 year's time used to be similar.

### Seasonal migration of livestock in the basins

Movement of livestock to and from the two catchment is very prominent in pursuit of seasonal grazing lands and in search for water resources (IUCN, 2010b). The influx of livestock in Ruvu catchment is mainly from neighbouring districts, while for Zigi catchment, the influx is mainly from very distant districts. The Ruvu basin is in close proximity to areas with large stocks of livestock including Kilosa, Mvomero, Kilombero, Rufiji and Mkuranga districts, which are renown for higher concentrations of livestock. Regular conflicts have been reported between pastoralists and crop farmers in the neighbouring districts of Kilosa and Mvomero due to overpopulation of the livestock and dwindling grazing areas (IUCN, 2010a; URT, 2015). Therefore, Ruvu basin is oftentimes used as a buffering area to accommodate additional livestock from other areas during dry season. However, the movement of livestock is not regulated, causing overcrowding in the Ruvu basin, and hence contribute to land degradation.

Similarly, Ruvu basin forms the traditional end of the long migration route of livestock which seasonally traverse from Kiteto to Bagamoyo districts (URT, 2015).



Currently, the National Land Use Planning Commission (NLUPC) of Tanzania is developing a pilot scheme to allow gazettement of livestock migration route in the eastern zone traversing the eastern part of the Ruvu basin. The effort will address land use conflicts due to improper tenure regime between pastoralists and agriculture. The government of Tanzania has also launched a countrywide program to label and mark livestock per each district to restrict unwarranted movements.

### Livestock vs. land degradation

Landscape degradation in the two basins is eminent mainly due to excessive human induced disturbances (USAID, 2014, Yanda and Munishi, 2007). Scale of degradation differs among various categories of land uses in the landscape, for instance, the highlands vs. lowland, protected vs. unprotected areas, farming practices and charcoal extraction. Within the protected areas, degradation is mostly due to encroachment of human activities which are considered to be illegal and should be contained by effective law enforcement. Incidences of livestock grazing within protected areas such as forest reserves and Wami-Mbiki WMA have been very common in the Ruvu basin. Detrimental effect of grazing in the forest reserves has been related to trampling of the seed banks and regenerants hence compromising natural recruitment of the trees and shrubs similar to the observation by Armour et al. (1994) in Western Riparian Ecosystem. However, the degradation within protected areas is relatively small in terms of magnitude but significant. Despite that some of the degradation are not easily recorded or conceptualized in terms of vegetation cover, but they interfere with the functioning of the ecosystems. It has also been noted that high risks for land degradation face areas that are closer to the main access roads, close proximity to rivers and where there is intensive cereal crops cultivation, this observation matches with what was observed by Yanda and Munishi (2007).

In the zone outside protected areas, management of land uses falls under the jurisdiction of village government, town and district councils, municipals and/or city's authorities. The challenge of land degradation outside protected areas is a result of improper planning of the land uses and its enforcement (URT, 2009). Key drivers include; Overgrazing: Livestock keeping in the lowland areas of the two river catchments are exercised by free range. However, there signs of overgrazing due to excessive opening up of areas that are neither cultivation land nor used in other economic activities (URT, 2009). This trend further exacerbates land degradation due to soil compaction and erosion, damage to water sources and impairs biodiversity. Two types of grazing are experienced in the basins; one is the permanent inhabitation of the livestock with amounts to hundreds of

thousands, and secondly is the seasonal influx of livestock looking for pasture and water from other distance areas. It is recognized that during certain seasons, livestock from outside the basin as far as Simanjiro and Kiteto cross all the way to part of Tanga and then to the Coast regions, ending up spreading to the lower parts of the two catchments (Msuya, 2009). The seasonal influx of livestock is very detrimental as the numbers are very large herds of cattle, beyond the carrying capacity of the land.

### Conclusion

The Ruvu and Zigi basins are important in hydrological and biodiversity perspective in supporting human livelihood. The two basins are renowned for their state of ecosystem services, regarded as part of the water towers in the eastern bloc of the country. In pursuit for pasture and water, concentration of livestock in the basins has exceeded the carrying capacity, and thus threatening their ecosystem integrity. Uncontrolled influx of livestock from nearby and distant areas, has contributed to the deterioration of the state of ecosystem services. Range lands are not delineated, grazing is done all over the catchments, these situations have been causing frictions in the community between farmers and pastoralists. The outcome of the uncontrolled livestock management is increasing degradation of the land resources in various areas within the two basins. The study recommends agroforestry practices in the mountainous areas, and development and enforcement of land use plans in the lowland areas. Range land for grazing should be delineated, with subsequence installation of necessary infrastructures and markets for livestock products. The rangeland carrying capacity should be maintained to avoid excessive number of livestock. Use of both modern and indigenous knowledge on maintenance of pasture area should be stressed.

### CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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*Full Length Research Paper*

# **Residues of the transformation of halieutics products: An alternative substrate for energy valorization of wastes by methanisation for a local sustainable development (preliminary results)**

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The purpose of this study is to evaluate the biogas productivity potential of residues of the transformation of halieutics products. Experiments were conducted in two digesters of PUXIN model of 20 m<sup>3</sup>, where the temperature is 35°C. Multirae analyser was used to know the composition of biogas produced. A gas counter was also used for counting the amount of biogas produced during the experiment. There was also a balloon of storage of 10 m<sup>3</sup> downstream from the digester, for storing the biogas produced. The total volume with 2970 kg of substrate was 9.67 m<sup>3</sup>. The maximum daily volume of produced biogas was 1.561 m<sup>3</sup> at the 5th day after the installation of the gas counter. The potential biogas is then, 3.25 m<sup>3</sup>/T of wastes. While the potential biogas found in earlier study is 53 m<sup>3</sup>/T of wastes. For analyses of produced biogas, maximum percentages of methane, oxygen, carbon monoxide and hydrogen sulfide are, respectively 91%, 20.9%, 196 ppm and 44.7 ppm. Method of cooking halieutics products with biogas takes much time than that using wood of heating.

**Key words:** Substrate, biogas, potential biogas, digester.

## **INTRODUCTION**

Since the crisis of agriculture caused by years of drought, fishing season occupies an important place in the economy of Senegal, in terms of export earnings. Thus, it strongly contributes to the reduction of the

unemployment rate and the need for the animal protein populations. Conscious of this fact, the state of Senegal with the assistance of its partners sets up transformation units of halieutics products, in all regions where the

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**Abbreviations:** %, Percentage; °C, degree Celsius; kg, kilogramme; m<sup>3</sup>, cube meter; m<sup>3</sup>/T, cube meter per ton; ppm, parts per million.

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fishing season is practiced. These units currently employ many women, and make it possible to these last to take part in the development of our country.

In the region of St-Louis, 700 women work at the site of the transformation of halieutics products. They transform every day (that is to say 10 months out of 12) 6000 tons of fish per year, for obtaining different products like dried fermented products, dried salted fishes, dried braised fishes, and dried smoked fishes (Le Partenariat, 2015). This last, which is transformed the most, requires much energy at the time of the stage of cooking of fish. Generally, women use wood of heating and even, as of time, plastics. What created pollution of the atmosphere and in particular health problems for these women. Also, wastes coming from the transformation are not used, and then are most often dumped in the river or the sea, or exposed to free air. However, these wastes can be used as substrate for a biogas unit for example.

To meet the energy needs of the grouping, but also the need for cleansing for the site, "The Partnership", technical partner of National Program of Domesticated Biogas of Senegal, accounts to help the transformer women to develop waste halieutics present in the site by the installation of a collective unit of methanisation. This project lies within the scope of the biogas project of St-Louis.

Biogas comes from anaerobic digestion of organic wastes from animal or vegetable origin. It is composed of methane  $\text{CH}_4$  (50 to 75%), carbon dioxide  $\text{CO}_2$  (25 to 40%), water  $\text{H}_2\text{O}$ , oxygen  $\text{O}_2$ , hydrogen sulfide  $\text{H}_2\text{S}$  (Abdoulaye Fall, 2013). This fermentation is done in the absence of air in a fermenter called digester. The digestate which is also a byproduct of digestion can be used as fertilizer for crops. Among the waste that can be methanized, we can cite cow dung, livestock effluents, sludge, cultures, etc (Chen and Neibling 2014). Cow dung is the most used substrate by National Program of domesticated biogas of Senegal, due to its availability across the country (Abdou Ndour 2014). The choice of the substrate used during anaerobic digestion is important. To maximize methane production, it is better to use products rich in lipids, carbohydrate and proteins. This is why we're interested in residues of the transformation of fish products for biogas production; because they are substrates rich in lipids and proteins (Kaffe and Kim, 2012), which can speed up the process of forming methane during anaerobic digestion.

This work was done within the framework of technical, social and organizational feasibility of project of installation of digesters at the site of transformation of halieutics products

## MATERIALS AND METHODS

### Substrate

Residues of the transformation of halieutics products are the

substrate used for anaerobic digestion in this experimentation. They were collected at the site of transformation of halieutics products of Hydrobase at St-Louis. The components of fish wastes are nonfresh fish, head, internal organs, and guts. They decompose themselves rapidly due to their high composition of lipids and proteins. These wastes come from the transformation of fishes by women who constitute themselves in small enterprises. Women who work in the site, can transform around 20 cases per day according to the woman, that is, 1000 kg of fishes per woman and per day, and this generates 500 kg of wastes per day in period of strong season (Le Partenariat, 2015). All this to say that the amount of fish wastes generated in the site is very important and would allow to develop biomethanisation using fish wastes.

### Experimental setup

For having biogas using residues of transformation of halieutics products, the experimentation took place on two digesters of PUXIN model, which has been developed by a Chinese society named PUXIN (Figure 1).

The volume of each digester is  $10 \text{ m}^3$ . In each digester, we have a mixture of residues of halieutics products with water in the same proportion. And when the gas is produced, it leaves the digester, passes by the gas pipes and arrives at the balloon of storage, which has a volume of  $10 \text{ m}^3$ . If the amount of biogas in the balloon is sufficient, to be used for the transformation of halieutics products, furnaces will be connected to the balloon. And the biogas from residues of halieutics products will be tested by women who work in the site, to compare it with their old cooking method.

For a first filling of the digesters, on 18th May 2017, each of them were placed in 1000 kg of residues of halieutics products, mixed with the same amount of water. Which represents on the whole, 2000 kg of residues of halieutics products in the two digesters. Nineteen days after the first filling, it was noticed that there was no gas in the balloon. This is due to the fact that with Puxin model, water must be above the gasometer to avoid gas leakage. It was then necessary to increase the amount of water, to have a change of state of the balloon.

## RESULTS AND DISCUSSION

### Volume of biogas produced and its composition

After the first filling of the two digesters with 2000 kg of substrate, the gas generation has not started at once. It was then necessary, at the 19th day after the first filling, to increase the amount of water until it reaches the bell. And the gas starts to pass in the balloon of storage at the 19th day and gas generation continues then 63 days later.

According to the work of Salam et al. (2009), the gas generation started on the 7th day with anaerobic digestion of fish waste, and fish waste in co digestion with cow dung. Which means that much gas was lost during the time of first filling and on the 19th day.

At the 28th day, the gas counter was installed. Figure 2 shows the volume of produced gas for residues of transformation of halieutics products during the 63 days. The total volume of produced gas is  $9.67 \text{ m}^3$ .

The filling has been repeated during the experience on different dates. Table 1 shows some information





Figure 1. 2 Digesters of PUXIN model.

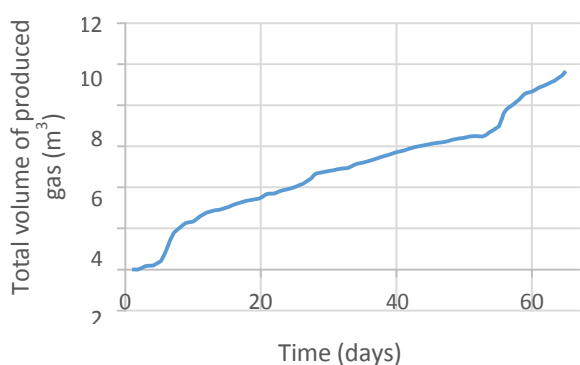


Figure 2. Total volume of produced gas.

Table 1. Quantity of substrate put into the digester.

Date	Amount of substrate (kg)
18th May 2017	2000
13th June 2017	600
02nd July 2017	40
10th July 2017	20
02nd August 2017	200
10th August 2017	35
16th August 2017	75
Total	2970

about the quantity of substrates put in the digesters during the experiment.

To have the amount of gas produced during the experience, upstream of the balloon of storage, has been installed a gas counter. That allows us to know with precision, the amount of gas that have passed through the balloon of storage.

The produced gas needs to be analyzed to know its composition in different gas. This is why a MULTI RAE ANALYSER, which gave the rate of four gases found in

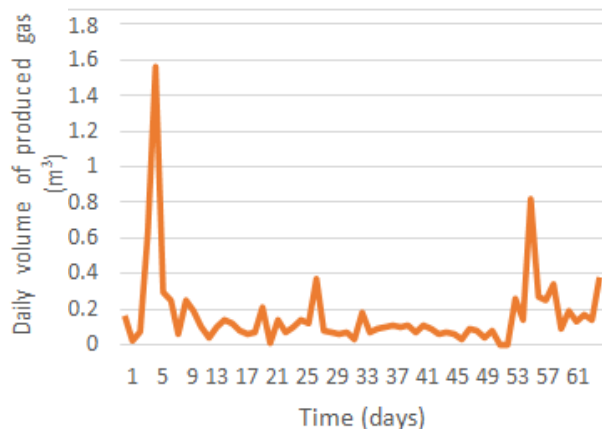


Figure 3. Daily volume of produced gas.

the biogas, was used. These gases are carbon monoxide (CO), methane (CH<sub>4</sub>), dioxygen (O<sub>2</sub>) and hydrogen sulfide (H<sub>2</sub>S) with different proportion in the biogas.

After the gas has been produced, tests of cooking have been done by two women to compare two manners of cooking: one using biogas and the other using wood of heating. It is clear that cooking with biogas respect more the environmental procedures and is more ecological than using the wood of heating. But we have searched for the manner of cooking that takes less time between biogas and wood of heating.

Figure 3 shows the daily volume of produced gas with residues of transformation of halieutics products. Figure 3 shows greater production at the 5th day with 1.561 m<sup>3</sup> and at the 54th day with 0.82 m<sup>3</sup>.

For Figures 2 and 3, time is counted starting from the assembly of gas meter. These information could not be obtained only after the installation of gas meter. The greater gas production was obtained at:

- (1) 5, 6, 7 and 9th day: at the beginning of the experiment, the balloon of storage was not installed. The biogas which was in the gasometer have passed thus in the balloon of storage.
- (2) 19 and 26th day: there was a filling of the digesters with the residues of the transformation of halieutics products.
- (3) 52, 54, 55, 56 and 57th day: there was also a filling of the digesters with more than 200 kg of residues of the transformation of halieutics products.

During the experiment, without counting the gas lost, the amount of gas produced is about 9.67 m<sup>3</sup>. The potential biogas is then, 3.25 m<sup>3</sup>/T of wastes. However, the potential biogas found in the work of Tomczak-Wandzel et al. (2013), is 53 m<sup>3</sup>/T of wastes. There is a great difference between these two results; this could be due to the fact that much gas was lost during the

**Table 2.** Comparison of two methods of cooking, with biogas and wood heating.

Method of cooking	Biogas	Wood heating
Water to be heated (L)	15	15
Quantity of fish (kg)	25	25
Time of heating of water (min)	37	30
Time of cooking of fish (min)	164	41
Quantity of biogas for all the transformation (m <sup>3</sup> )	2.491	-
Quantity of wood heating for all the transformation (kg)	-	4

experiment.

The biogas obtained after fermentation of residues of transformation of halieutics products was analyzed in order to know its composition in different gas such as methane (CH<sub>4</sub>), carbon monoxide (CO), oxygen (O) and hydrogen sulfide (H<sub>2</sub>S).

For many analyses that were done, different rate of gas was found composing of biogas. For each gas, different values were found varying:

- (1) Methane: 80 to 91%
- (2) Carbon monoxide: 22 to 196 ppm
- (3) Oxygen: 10 to 20.9%
- (4) Hydrogen sulfide: 0 to 44.7 ppm.

These values proved that the biogas produced with residues of transformation of halieutics products is rich in methane. And the other gas like hydrogen sulfide is not an important component due to their low rate.

All this to say that anaerobic digestion using fish waste as a substrate is quite possible, but the volume of gas produced is not sufficient compared to the experiments made previously with fish wastes or co-digestion of fish wastes with other substrates.

### Test of cooking

Biogas produced by fermentation of residues of transformation of halieutics products was tested by two transformers women. The purpose of these tests was to evaluate the cooking time and the volume of gas used and to compare the method of cooking of halieutics products with biogas and using wood of heating.

Table 2 gives information about the two methods of cooking of halieutics products. A difference was observed between the two methods of cooking; transformation with biogas being too slow. This would not be due to a low pressure of biogas, because during the transformation, a pump was used for recording the pressure of gas. This slowness would then be due to the stove used for the transformation of fish with biogas. The design of the stoves should then be remade to improve the output of the transformation with biogas.

### Conclusion

The production of biogas with residues of the transformation of halieutics products is possible. With this substrate, the amount of gas for cooking test was 9.63 m<sup>3</sup> during the experiment.

These tests were done at the site of transformation of halieutics products to test the capability of the residues of transformation of halieutics products to produce biogas. During this test, some information were collected, such as the amount of total biogas produced and the daily biogas produced, and the composition of the biogas produced. Tests of cooking were also done to know if it is possible to use this gas for cooking halieutics products. The total retention time in this study is about 65 days.

But these information are not sufficient scientifically. Different parameters like the temperature of the digesters, the composition of the substrate, the pH, the pressure of gas, and the composition of the digestate were not determined.

This is the reason why subsequent studies will be carried out for more information on this. And these parameters are essential for increasing the anaerobic efficiency of residues of the transformation of halieutics products. Co-digestion of residues of halieutics products with other substrate will also be done soon to enhance the anaerobic efficiency of this substrate (Kassuwi et al., 2012; Serrano et al., 2013).

### CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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