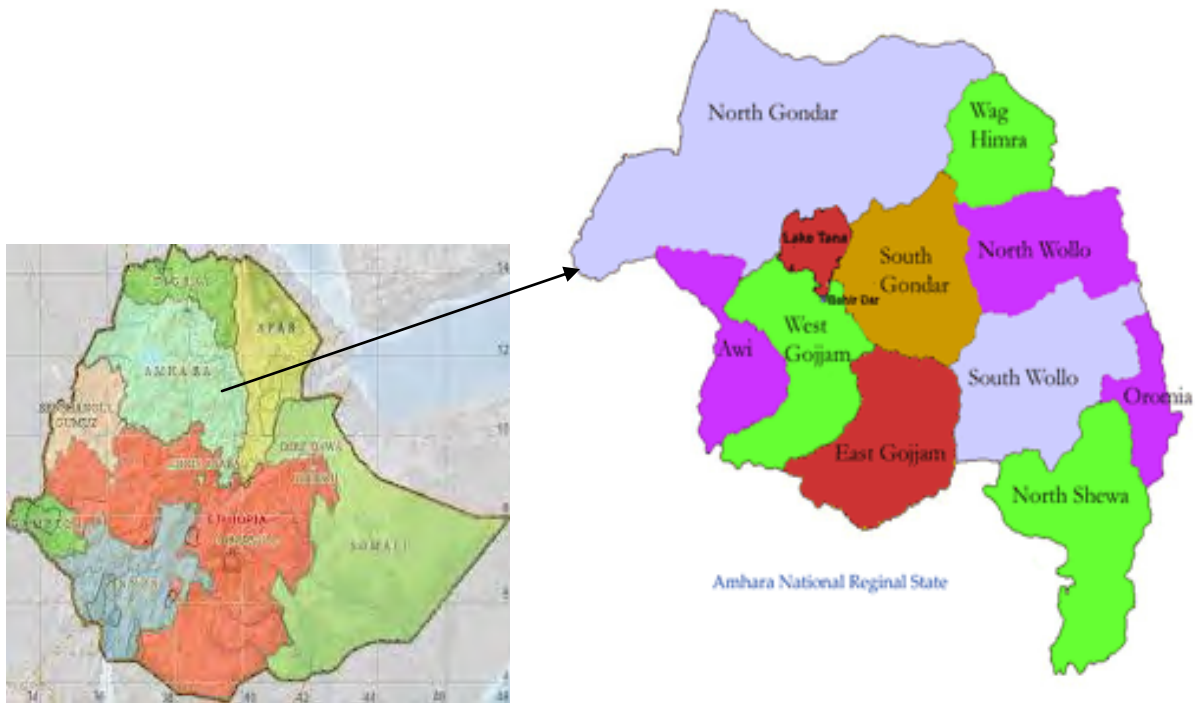




**HEALTHCARE WASTE IN ETHIOPIA**  
**A STUDY OF WASTE GENERATION, COMPOSITION AND**  
**MANAGEMENT IN THE AMHARA NATIONAL REGIONAL**  
**STATE, ETHIOPIA**  
**ESUBALEW TESFAHUN**



**Dissertation for the Degree of Doctor of Philosophy (PhD)**  
**Addis Ababa University, Ethiopia**  
**July, 2015**



**ADDIS ABABA UNIVERSITY**  
**SCHOOL OF GRADUATE STUDIES**  
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**A Dissertation submitted to the School of Graduate Studies of Addis  
Ababa University in partial fulfilment of the requirements for the  
Degree of Doctor of Philosophy (PhD) in Public Health**

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**July, 2015**

**DISSERTATION APPROVAL  
ADDIS ABABA UNIVERSITY  
SCHOOL OF GRADUATE STUDIES**

**Dissertation title: Healthcare Waste in Ethiopia  
A study of Waste Generation, Composition and Management  
in the Amhara National Regional State, Ethiopia**

**By: Esubalew Tesfahun**

**SCHOOL OF PUBLIC HEALTH, ADDIS ABABA UNIVERSITY  
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<b>Internal Examiner</b>	<b>Date</b>

## ORIGINAL PAPERS

This dissertation is based on the following four papers, which will be referred to in the text by their Roman numerals.

- I. Esubalew Tesfahun, Abera Kumie & Abebe Beyene. **Critical assessment of healthcare waste management practice in Ethiopia.** (Under review- International Journal of Occupational & Environmental Health).
- II. Esubalew Tesfahun, Abera Kumie, Worku Legesse, Helmut Kloos and Abebe Beyene. **Assessment of composition and generation rate of healthcare wastes in selected public and private hospitals of Ethiopia.** Waste Management & Research 2014, Vol. 32 (3) 215–220.
- III. Esubalew Tesfahun, Abera Kumie, and Abebe Beyene. **Selection of best fit models for the prediction of hospital healthcare waste generation rate.** (Under review-Waste Management & Research)
- IV. Esubalew Tesfahun, Abera Kumie and Abebe Beyene. **Healthcare waste management practices: systematic review.** (Under review- International Journal of Environment and waste management)

## ACRONYMS

ANRSHB	Amhara National Regional State Health Bureau
BMW	Biomedical Waste
BOO	Built, Owen, and Operate
BOT	Built, Operate, and Transfer.
EG	Emission Guideline
EPA	Environmental Protection Agency
EST	Environmentally Sound Technology
GEF	Global Environmental Facility
HBV	Hepatitis B Virus
HCC	Health Care Centres
HCFs	Health Care Facilities
HCV	Hepatitis C Virus
HCRW	Health Care Risk Waste
HCW	Health Care Waste
HCWH	Health Care Without Harm
HCWM	Health Care Waste Management
HWM	Hospital Waste Management
MoE	Ministry of Environment
MoH	Ministry of Health
MSW	Municipal Solid Waste
MW	Medical Waste
NGO	Non-Governmental Organization
NSPS	New Source Performance Standard
PAHs	Polyhalogenated Aromatic Hydrocarbons
PCB	Poly Chlorinated Biphenyls
PCDD	Poly Chlorinated Dibenzo-p-Dioxins
PCDF	Poly Chlorinated Dibenzo Furans
PI	Principal Investigator
POP	Persistent Organic Pollutant
PVC	Poly Vinyl Chloride
RCN	Royal College of Nursing
RSA	Republic of South Africa
SARS	Severe Acute Respiratory Syndrome
SNNPR	Southern Nations Nationalities and Peoples Region
SPSS	Statistical Package for Social Science
UNICEF	United Nations Children's Emergency Fund
US-EPA	United State Environmental Protection Agency.
WHO	World Health Organization
WIS	Waste Information System

## GLOSSARY OF DEFINITIONS AND CONCEPTS

(Based on World Health Organization definitions)

**Chemical waste:** Consists of discarded solid, liquid, and gaseous chemicals, for example from diagnostic and experimental work and from cleaning, housekeeping, and disinfecting procedures. Chemical waste from healthcare may be hazardous or nonhazardous; in the context of protecting health.

**General waste:** Is all solid waste not including infectious, chemical, or radioactive waste. This waste stream can include items such as packaging materials and office supplies. Generally, this stream can be disposed of in a communal landfill or other such arrangement. Segregation of materials which are able to be reused or recycled will greatly reduce the impact burden of this waste stream.

**Genotoxic waste:** Is consisting of, or containing substances with genotoxic properties, including cytotoxic and antineoplastic drugs; genotoxic chemicals. It can be found in vomit, urine, or faeces from patients treated with cytostatic drugs, chemicals, and radioactive material.

**Hazardous waste** (another subset of healthcare waste): This has multiple sources in a Facility and includes both chemically hazardous materials, infectious and radioactive materials.

**Healthcare waste:** Is defined as the total waste stream from a healthcare establishment, research facilities, laboratories, and emergency relief donations. Healthcare waste includes several different waste streams, some of which require more stringent care and disposal.

**Heavy metals:** Consisting of both materials and equipment with heavy metals and derivatives, including: batteries, thermometers, manometers.

**Infectious waste:** Discarded materials from healthcare activities on humans or animals which have the potential of transmitting infectious agents to humans. These include discarded materials or equipment from the diagnosis, treatment and prevention of disease, assessment of health status or identification purposes, that have been in contact with

blood and its derivatives, tissues, tissue fluids or excreta, or wastes from infection isolation wards.

**Pathological waste:** Consists of tissues, organs, body parts, human fetuses and animal carcasses, blood, and body fluids. Within this category, recognizable human or animal body parts are also called **anatomical waste**. This category should be considered as a subcategory of infectious waste, even though it may also include healthy body parts.

**Pharmaceutical waste:** Consisting of/or containing pharmaceuticals, including: expired, no longer needed; containers and/or packaging, items contaminated by or containing pharmaceuticals (bottles, boxes).

**Radioactive materials:** Includes: unused liquids from radiotherapy or laboratory research; contaminated glassware, packages or absorbent paper; urine and excreta from patients treated or tested with unsealed radio nuclides; sealed sources.

**Sharps:** These are items that could cause cuts or puncture wounds, including needles, hypodermic needles, scalpel and other blades, knives, infusion sets, saws, broken glass, and nails. Whether or not they are infected, such items are usually considered as highly hazardous healthcare waste.

Source: Pruss et al. 2013

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## ABSTRACT

**Background:** Hospitals are among the complex institutions which generate a broad range of hazardous waste materials in the course of healthcare activities. The hazardous and toxic parts of wastes from healthcare establishments consists of infectious, bio-medical, chemical, sharps and radioactive material pose serious environmental and public health risks, if they are not properly treated and disposed. Despite the great potential for environmental hazards and public health risks of healthcare waste, its proper handling and management is substantially undermined in many developing countries. The hazardous waste has a small portion of healthcare waste, but the absence of appropriate waste segregation practices leads mixing hazardous waste with general (non-hazardous) waste results the entire bulk of waste becoming potentially hazardous.

In Ethiopia, there is a continued growth in the number of hospitals and other health facilities to meet the healthcare demand of the alarming population growth. Increasing the number of health institution and development of technology combined with an increase in the use of disposable medical products has contributed to the large amount and diversity in composition of healthcare waste being generated. The high generation rate compounded by poor handling and disposal practices has been increasing the risk of environmental contamination and disease transmission. To establish proper healthcare waste management system, it is crucial to know the current practice, healthcare waste composition and predicting the generation rate. The actual amount of healthcare waste generated and its composition in Ethiopia is not well defined; consequently, estimating different figures in healthcare waste management is becoming very problematic. Therefore, a comprehensive research is required for the development of effective healthcare waste management system that can minimize the health and environmental risks.

**Objectives:** This study aimed to determine the composition and generation rate of healthcare wastes with a predictive model and assess the current practices of healthcare waste management system.

**Methods:** The study was conducted using random selection method. Accordingly, the hospitals were selected using lottery method from private and government hospitals that are found in Amhara National Regional State, Ethiopia. Nine hospitals were selected for the study. A longitudinal study design was conducted to investigate the healthcare waste composition, and generation rate. Based on the seasonal variability data, generation rate predictive models were selected. A cross-sectional study design was used to assess the current practice of healthcare waste management system using interviews and observation. Comparative cross-sectional study

design was used to evaluate the effect of segregation practice on hazardous healthcare waste generation rate before and after intervention.

The quantity of waste generated was estimated by collecting and weighting healthcare waste from all departments of the sampled hospitals using a calibrated sensitive weight scale every day at 6:00 PM for seven consecutive days (Monday to Sunday) for two seasons.

The data were entered, compiled and analysed using EPI info version 7 and Statistical Package for Social Science (SPSS) version 16 statistical software packages. The important variables that affect the quantity of waste generated from the hospitals were identified using regression analysis. Simple and multiple linear regression models were applied to estimate or predict the hospitals healthcare waste generation rate. The analysis were done first separately for each of the 9 hospitals and then grouped by ownership and level of hospitals as well as by the categories of healthcare waste. Data description was made using mean, Standard Deviation (SD), frequency, and percentage. Data from key informant interviews and observation were analysed by theme.

**Results:** The mean healthcare waste generation rate of hospitals was for inpatients 1.5 kg/bed/day and outpatients 2.5 kg/outpatient/day. The average generation rate estimated in kg/bed/day and kg/outpatient/day has a statistical significance difference ( $P < 0.03$ ). The generation rate of general healthcare waste in private hospitals was 1.85kg/bed/day and a public hospital was 0.78 kg/bed/day. The generation rate kg/bed/day in private and public hospitals also has a statistical significance difference ( $P < 0.02$ ).

The compositions of healthcare waste in public hospitals were 46.4%, 34.3%, 3.8%, 9.1%, 6.2% and 0.2% for general, infectious, sharps, pharmaceutical, pathological and radioactive wastes respectively. The compositions of healthcare waste in private hospitals were 45.3%, 29.7%, 6.7%, 17.3%, 0.5% and 0.5% for general, infectious, sharps, pharmaceutical, pathological and radioactive wastes respectively. The compositions of healthcare waste in public and private hospitals were almost similar except for pathological and pharmaceutical wastes.

There were no clear local guidelines to facilitate segregation of healthcare waste in both public and private hospitals; segregation was not practiced in all hospitals. The common waste treatment method used by hospitals was incineration; all the incinerators were found to be inefficient because of faulty design, construction and operation. All public hospitals had open pits in their backyards that were used for the final disposal as burial or open incineration, while private hospitals were mixing their healthcare waste with the municipal solid waste.

The healthcare waste generation rate has a strong positively correlation with the number of inpatients  $R^2= 0.935, 0.908$  and  $0.936$  for public referral, public district and private general hospitals respectively. Similarly, the waste generation rate has positively correlated with the number of outpatients  $R^2= 0.57, 0.868$  and  $0.456$  for public referral, public district and private general hospitals respectively.

The implementation of segregation practice was able to reduce the generation rate from 61.04 % to 42.2 % of hazardous healthcare waste. Nevertheless, with this reduction rate, the total percentage of hazardous waste (44%) was higher than that of the range (10-25%) reported by World Health Organization (WHO).

**Conclusions:** The effect of number of inpatients and outpatients treated in the hospitals on healthcare waste generation rate varied from hospital to hospital (private general, public district and public referral hospitals). The rate also varied by ownership where private hospitals were produced significantly higher (kg/bed/day) total and hazardous waste than government-run hospitals. It was observed that as the number of inpatients and outpatients increase, the healthcare waste generation rate will also increase. The results indicated that both measurement units (kg/bed/day and kg/outpatient/day) should be used in order to precisely quantify the waste generation rates for different types of wastes at each hospital. With the current malpractices of healthcare waste management the percentage of hazardous waste was estimated to be very high (61.04%) and considering the segregation practice alone can reduce the percentage of hazardous waste by 17%. Overall, proper waste management system was almost not yet instituted in all sampled hospitals.

**Recommendations:** A number of gaps exist regarding proper hospital healthcare waste management in the Region. Therefore, there is an urgent need for raising awareness among healthcare workers and supporting staff on healthcare waste management issues (segregation, storage, collection, transport, treatment and disposal) and their relevance in addressing public health and environmental risks.

### **Keywords**

Hazardous, hospital, healthcare waste, generation rate, waste composition, waste management, private, public, Ethiopia

# 1. INTRODUCTION

## 1.1. Statement of the problem

Countries all over the world are continually looking solution and alternative to improve their health standards. A way to improve the standards can be achieved by establishing various public or private healthcare institutions. However, different healthcare activities in these health institutions lead to the generation of tremendous amount healthcare waste (1). Hospitals are health facilities that provide preventive, curative, and rehabilitative services to patients (2). The hospital waste management is one of the major environmental concerns, which may significantly increase exposure to infectious pollutants (3). Hospital waste in particular has increased largely because of rapid advances of medical activities and hospitals use relatively more disposable items (4).

Waste produced in the course of healthcare activities entails a higher risk of infection and injuries than municipal waste. Hence, the management of healthcare wastes requires special attention and needs to be assigned high priority (5). Researches indicated that in the past, healthcare waste has done much damage to the environment and to public health. One estimate shows that some 5.2 million people (including 4 million children) die each year from waste-related diseases (6). Healthcare waste contains a large proportion of polyvinyl chloride (PVC) plastics. When PVC plastics are incinerated, they emit dioxin into the atmosphere. Dioxin is a lipophilic and bio-accumulative toxin, which moves up the food chain easily from plants to animals, then to human beings. Dioxin is a known human carcinogen, and also related to other endocrine and immune disorders. It is transported by water and air (7).

Evidence concerning health problems related to poor healthcare waste management indicate that, in 2003 the occurrence of a severe outbreak of acute respiratory syndrome in Taiwan enforced the authorities to take more serious steps in managing healthcare waste (8). Study indicates a clear association between exposure to incinerator emissions and increased adverse health impacts. Studies conducted in Japan, Spain, and Germany show that incinerator workers or children and other residents living near incinerators have significantly higher blood or urine levels of dioxins, furans, and hydrocarbons compared

to control groups or to national averages (9). Similar studies in Finland, Germany and the United States showed higher prevalence of urinary mutagen and promutagen levels in incinerators workers and higher levels of mercury in the hair, cadmium and lead in the blood, arsenic in urine among incinerator workers or residents living closer to incinerators (10).

A study conducted in France, Japan, Italy, United Kingdom, and Sweden found a cluster of soft tissue sarcoma and non-Hodgkin's lymphoma, a twofold cancer risk, increases in laryngeal cancer, increases in lung cancer or lung cancer mortality and generally higher risks of all cancers but specifically of stomach, colorectal, liver, and lung cancer among populations living near incinerators. Incinerator workers in Italy, U.S., and Sweden had significantly higher gastric cancer mortality; a high prevalence of hypertension and related proteinuria; and excessive deaths from lung cancer and ischemic heart disease (11). Another study in the United Kingdom also confirmed the associations have been found between incineration and increased risk of lethal congenital anomalies, in particular, spinal bifida and heart defects, with mothers living close to incinerators; and an increased risk of stillbirths and anacephalus among mothers living around the incineration site (12). Study in Belgium found incidences of congenital malformation and a statistically significant increase in multiple pregnancies among residents born in a neighbourhood between two incinerators. Another study in the U.K. found an increased frequency of twinning among residents in areas at most risk from incinerator emissions. Children near an incinerator in Germany showed hormonal effects as determined by blood thyroid hormone levels (11, 12). A study done in Botswana school children living near a wire-reclamation incinerator showed that the higher air pollution levels in the area near the incinerator were associated with a detrimental effect on lung function in the children and also the purchase of respiratory medication decreased as the distance of residences from incinerators increased (13). Therefore, healthcare waste management becomes a current issue in many developing countries (14).

In developing countries, the quantity of healthcare waste has sharply risen in recent years as a result of rapid population growth and thus increasing demand for health services (15). In spite of the large investment in expanding public and private healthcare facilities in most developing nations (16), healthcare wastes are usually rampantly

disposed in the environment without any treatment (17, 18). Under this situation, healthcare waste management is the most neglected activity of most health service providers, which results a significant exposure to occupational risks among healthcare workers (19), high incidence and prevalence of noso-comial and environmental contamination (20, 21). WHO estimate that injections with contaminated syringes caused 21 million hepatitis B virus (HBV) infections (32% of all new infections), 2 million hepatitis C virus (HCV) infections (40% of all new infections) and 260 000 HIV infections (5% of all new infections) (22).

In many developing countries, the unavailability and inadequacy of data about the quantity and composition of healthcare waste is one of the major reasons for inadequate and improper healthcare waste management (23).

Uncontrolled combustion of medical waste accounted for 26% of the annual total dioxins/ furans release in 2003 in Ethiopia (24). Recently, considerable gap exists with regard to the assessment of healthcare waste management practices in Ethiopia. The nature and quantity of healthcare waste generated as well as institutional practices with regards to sustainable methods of healthcare waste management, including waste segregation and waste recycling are often poorly examined and documented in Ethiopia (25). In developing countries like Ethiopia, where many health concerns are competing for limited resources, it is not surprising that the management of healthcare wastes has received less attention and the priority it deserves. Unfortunately, relevant information on this important aspect of healthcare management is inadequate and research on the public health implications of inadequate management of healthcare wastes are few in number and limited in scope (26).

Ethiopia is signatory to the Stockholm Convention on Persistent Organic Pollutants (POPs), a global convention with the aim of eliminating some of the most long-lived anthropogenic pollutants (27). WHO Policy Paper on safe healthcare waste management supports the Stockholm and Basel Conventions. It directs countries to develop and implement plans, policies, legislation and manual on safe healthcare waste management; allocate human and financial resources for safe healthcare waste management and scale up the promotion of non incineration treatment alternatives (23). The aim of healthcare

waste management is to clean up the surrounding environment and realize that the waste does not have a detrimental effect on our health. Nowadays, waste management has gone a step further and not only plans for proper disposal, but also attempts to see whether we can reuse and recycle certain materials from waste matter (28).

Predicting the amount of healthcare waste in Ethiopia is very difficult due to lack of comprehensive research that shows the type of waste generated from healthcare activities in the country is not yet known. Only very little researches have been done in the area, making it difficult for decision makers and experts bring the issue into the priority agenda so as to develop a management plan and policy. Therefore, this study was conducted with the intension of assessing healthcare waste generation rate, physical composition and producing predictive models in Amhara National, Regional State hospitals to recommending appropriate healthcare waste management options.

## **1.2. Rationale of the study**

Only a few case studies have been conducted on the generation rate and composition of healthcare waste in Africa. In those case studies, a wide range of variation of generation rate and percent composition were reported. For instance, healthcare waste generation rates were 0.01-3.98 kg/bed/day in Nigeria (18), 7.0-8.0 in Tanzania (29) and 0.95-8.2 in Ethiopia (30, 31). The percent composition of hazardous waste reported was 28% in Libya (32), 39.3% in South Africa (33), 20 to 63% in Ethiopia (30, 31, 34). Those variations were associated with healthcare facilities (HCFs) with different levels of specialization, the proportion of patients treated daily, ownership and waste management approaches (16). Therefore, the generation rate and composition should be estimated separately considering all those different factors.

The studies conducted in Ethiopia so far about hospital healthcare waste did not consider different levels of hospitals (teaching, referral, district), and ownership (private and government). All of them are also case studies focusing on limited number of hospitals of similar type within the same city. In other words, the studies lacked representative samples. This study attempts to investigate healthcare waste generation rate and assess its management practices at different level and ownership of hospitals by considering the representative samples.

For proper handling of waste generated, it is equally important to predict the amount of waste generation beforehand (35). Before selection of the best fit models a detailed survey should be conducted on existing norms and trends. This necessitates the need for predicting waste generation rates that can improve the waste management system by reducing environmental burden, processing costs, and improving social acceptability. In addition, the model would enable waste managers to make long term strategies by adopting several waste management options and waste treatment technologies throughout the year for a given bed occupancy (36).

The prediction model can be used either at a regional or national level for the purpose of setting guidelines for healthcare waste management. In addition, it can be used at local level with the purpose of choosing a more environmentally beneficial strategy. Identifying and improving one or more of the processes that make potential impacts can optimize the prevailing strategy (37). Unfortunately, there is virtually no study conducted so far in Ethiopia that can predict waste generation rate throughout the year. This study investigated the main influence of the operating parameters of the overall factors that affect the healthcare waste generation rate and develop prediction model to estimate healthcare waste generation rate beforehand.

Based on key findings, this research is expected to have the following significant contributions:

- Determine and predict healthcare wastes generation rate in different hospitals.
- Verify hospital healthcare waste compositions.
- Identify the gaps from the current practices of healthcare waste management practices and then forward appropriate intervention.
- Select pilot intervention on the main components of healthcare waste management systems and demonstrate some new concepts introduced in the study to improve the existing healthcare waste management systems and to inform the development of the tender documents.

### **1.3.Literature review**

To assess the different experiences on healthcare waste generation rates and practices applied to the management, a literature search was conducted based on agreed research questions. Relevant papers were found through computerized literature search engines of scholarly articles. They included MEDLINE, EMBASE, Science Direct and Google Scholar. Furthermore, hand search were done.

#### **1.3.1. Background information**

All healthcare facilities generate Health Care Risk Waste (HCRW) that pose risk to human health as a result of its content of infectious materials, sharps, hazardous chemicals and / or radioactivity (38). Hospitals are among the complex institutions which generate a broad range of hazardous waste materials in the course of healthcare activities (39). Healthcare waste contains a large component (75-90%) of non-risk or “general” healthcare waste, comparable to Municipal Solid Waste (MSW) and a smaller component (10-25%) of hazardous waste may pose a variety of health risks (2). Improper waste management in which the infectious waste is mixed with the general waste can lead to the entire bulk of the wastes becoming potentially infectious (40).

Hospitals produce a tremendous amount of medical waste that is defined as any solid waste which is generated as a result of patient diagnosis, treatment, or immunization of humans or animals (2). According to WHO, the waste produced by hospitals carries a higher potential for infection and injury than any other kind of waste (22). Healthcare waste is a major problem in most developing countries of the world due to its growing and endless generation coupled with poor management (41).

The process of storing, collecting, transporting, treating and disposing waste material is known as waste management (42). The aim is to clean up the surrounding environment and realise that the waste does not have a detrimental effect on our health. Nowadays, waste management has gone a step further not only planning proper disposal but also attempting to see whether can reuse and recycle certain materials from waste matter (28). The safe and effective disposal of healthcare waste starts with a healthcare practitioner. There is a real need to reduce both the cost and environmental impact arising from the generation and disposal of waste in healthcare settings (43).

### **1.3.2. Hospital waste generation rate**

Healthcare activities lead to the production of waste. The generation rate varies across the different types of hospitals. There exists different generation rate does not only vary from country to country, but also within a country (44). Based on WHO (2013) report; factors affecting healthcare waste generation are: established waste management methods, type of healthcare establishment, hospital specializations, proportion of reusable items employed in healthcare, and proportion of patients treated on a day-care basis (2). In addition, the research confirmed that healthcare waste generation rate depends on the level of economic development of a country, reimbursement payment by National health insurance, location of healthcare establishment, proportion of disposable substance used in healthcare activities and season of the year; This seasonal variation may be due to the fact that with change in season the nature of illness of patients being admitted to hospitals also changes (36).

The generation rate of middle-income countries compared to low-income countries indicates that lower in low-income countries. However, the range of values for countries of similar income level is probably as wide in high income countries as in less wealthy countries (22).

The WHO assessment of healthcare waste generation rate indicated that 80% general healthcare waste, 15% pathological and infectious waste, 1% sharps waste, 3% chemical or pharmaceutical waste, and less than 1% special waste, such as radioactive or cytostatic waste, pressurized containers or broken thermometers and used batteries (2).

**Table 1:** Hospital waste generation rate in different Regions of the world, 1999.

<b>Region</b>	<b>Kg/bed/day</b>	<b>Proportion of hazardous waste (%)</b>
North America	7-10	5-20
Latin America	3	5-20
Western Europe	3-6	No data
Eastern Europe	1.4-2	No data
Middle East	1.3-3	No data
East Asia High income	2.4-4	5-10
East Asia Middle Income	1.8-2.2	No data
Africa	No data	No data
Rural Sub Saharan Africa	0.3-1.5	2-10
Low Income Countries	0.3-3	No data

Source: Pruss A. et al. (1999)

A study conducted in Sylhet city, Bangladesh (2006) observed that the average waste generation rate for hospitals was 0.934 kg/bed/day; the percentage of non-hazardous waste produced in the Hospitals was 77.08% and hazardous waste 22.92% (45). A survey done in Irbid, Jordan, showed the generation rates of healthcare waste in three hospitals 6.904 kg/pat/day (4.315 kg/bed/day) at the Princess Basma Hospital, 5.718 kg/pat/day (3.212 kg/bed/day) at Princess Bade'ah Hospital, and 4.532 kg/pat/day (2.556 kg/bed/day) at Ibn Al-Nafis Hospital (37).

Determination of healthcare waste generation rate study done in Istanbul, Turkey by Eker & Bilgili (2011) revealed that the generation rate based on bed capacities was determined as 2.11 to 3.83 kg/ bed/day and this rate was 1.45 to 9.84 kg/outpatient/day for the evaluation of outpatient numbers. The observed significant P values ( $P>0.05$ ) indicate that the evaluation of the waste streams in healthcare services based upon outpatient numbers did not show any reasonable change according to service category (46).

A study conducted in Greece (2012) indicated that there is a large variation in the healthcare waste generation rate, even among hospitals of the same category. Average total healthcare waste generated varied from 0.012 kg/ bed/day for the public psychiatric hospitals to up to 0.72 kg/bed/day for the public university hospitals. Within the private hospitals, average healthcare waste generated ranged from 0.0012 kg/bed/day for the psychiatric clinics to up to 0.49 kg/bed/day for the delivery clinics. Based on non-parametric statistics, healthcare waste was statistically similar to the birth and general hospitals in both the public and private sector. The private birth and general hospitals generated statistically more wastes compared to the corresponding public hospitals. The infectious/toxic and toxic medical wastes appeared 10 % in the Public cancer hospital and 50% in the University Hospital of the total hazardous medical wastes generated (47).

A study conducted on healthcare waste generation rate in Chittagong Medical College Hospital, Bangladesh (2008) showed the generation rate was 1.28 kg/ bed/ day and the rate was 0.57 kg /outpatient/day for the evaluation of outpatient numbers. The observed significant P values ( $P > 0.05$ ) indicates that the evaluation of the waste streams in healthcare services based upon outpatient numbers did not show any reasonable change according to service category. From the total healthcare waste 37% was infectious. The amount of healthcare waste was positively correlated with the number of inpatient treated in the hospital (48). Another study done in Dhaka, Bangladesh (2009) showed that the proportion of hazardous waste was found to be approximately 21%. The amount of waste, and the proportion of hazardous waste, was found to vary significantly with the size and type of a healthcare establishment (49).

A study conducted in Abbottabad, Pakistan (2003) revealed that the total healthcare waste generation rate was 464 kg/day, out of this 37.4 kg/day (8%) was infectious and 427.3 kg/day (92 %) was non-infectious healthcare waste (50). A study done on healthcare waste generation rate in Taiwan (2008) indicated that the average waste generation rates ranged from 2.41 to 3.26 kg/bed/day was general and 0.19–0.88 kg/bed/day was infectious wastes. The total average quantity of infectious wastes generated was the highest from medical canters, or 3.8 times higher than that from regional hospitals (267.8 Tons/year versus 70.3 Tons/ year). The multivariate regression analysis was able to explain 92% of infectious wastes and 64% of general medical

wastes, with the amount of insurance reimbursement and number of beds as significant predictive factors (51).

The healthcare waste generation rate in Nigeria (2011) in eight hospitals found in Ibadan Metropolis revealed that the public hospitals generated waste was between 0.37 to 1.25 kg/patient/day, while private hospitals generated between 0.12 to 0.28 kg/patient/day. Regarding the composition of healthcare waste, infectious waste represented 26 to 37% (52). In Kenya, the amount of infectious waste was higher than the general waste which indicates lack of proper segregation of waste (16). A study done in Amana District Hospital, Tanzania showed that the average medical waste generation rate was 1.8kg/patient/day (29).

Locally, a study conducted in Hawassa City, Southern Nations, Nationalities and Peoples Region (SNNPR) Ethiopia (2011) showed that 48.73% (range: 41.0\_67.7%) was infectious and 6.16% sharps (range: 2.12\_9.98%) (31). A study done in Gondar University Teaching Hospital (2007) indicated that the average generation rate of solid healthcare waste estimated based on the number of inpatient was 0.95 kg/bed /day and 0.142 kg/outpatient/day. There were statistically significant correlation between patient flow and the generation rate of solid healthcare waste with P-value less than 0.002 (30). A study conducted in Addis Ababa, Ethiopia (2011) revealed that non-hazardous healthcare waste (median: 58.69%, range: 46.89–70.49%) and hazardous healthcare waste (median: 41.31%, range: 29.5 –53.12%), the majority of which was infectious (median:13.29%, range: 6.12-20.48%) and pathological waste (median:10.99%, range: 4.73-17.25%) and the rest sharps and pharmaceutical were (median: 8.74%, range:6.41-11.07%) and (median: 6.14%, range:3.54-8.73%) respectively. The total quantity of healthcare waste generated from public hospitals was significantly more ( $p < 0.05$ ). But, there was no a statistical significant difference between the amount of healthcare waste generated from public versus private hospitals (34).

The literature review confirmed that hospitals' healthcare waste generation rate varies from hospital to hospital, even in same country. Therefore, in order to determine healthcare waste generation rate of hospitals, it is required to deal with the nature and

purpose of hospitals; that is, private, public, district, zonal, referral or teaching hospitals in the Ethiopia context.

### **1.3.3. Predictive models of hospital healthcare waste generation rate**

Healthcare waste generation rate varies from hospitals to hospitals and at different times (53). Hospitals require trend of healthcare waste generation rate for the development of a realistic solution for hospital waste management (29). The quantities of different kinds of healthcare waste generation rate of hospitals can be determined by identifying the relationship between the weight of the healthcare waste generated and factors that affect healthcare waste generation rate such as, type of healthcare establishment, hospital specialization, established waste management methods, proportion of reusable items employed in healthcare, hospital size, the segregation practice and proportion of patients treated on a daily basis (4, 54-57). Statistical analysis should be performed to evaluate the relationship between these important factors and the amount of healthcare waste generated (58).

A study conducted in Jordan (2007) confirmed that there was high statistically significant (linear) correlation between the number of patients and the amount of daily healthcare waste generated and lower statistically significant correlation between the number of beds and the daily healthcare waste generated (37). A study done in Taiwan (2008) indicated that the quantity of healthcare waste generated correlated to the number of hospital beds at ( $p < 0.05$ ). A study conducted in Irbid, Jordan (2004) indicated that the quantity of healthcare waste has a strong correlation with the number of patients ( $R=0.973$ ), number of beds ( $R= 0.956$ ), and type of hospital ( $R=0.368$ ) (35, 51). In addition, the study conducted by Komilis and Kasafaros (2011) indicated that a linear statistical significant at ( $p < 0.05$ ) with  $R^2$  coefficient equal to 0.43 trend was observed between daily healthcare waste generation rate and the number of beds occupied (47). But Katoch and Kumar (2007) confirmed that the seasonal variation in the biomedical waste production rate remained nearly the same (36).

The hospital waste generation prediction models can help to optimize healthcare waste management systems, set guidelines and evaluate the prevailing strategies for healthcare waste handling as well as disposal (36). From the review of available literatures, we

confirm that only few predictive models are available. The available models are presented in equations 1 up to 5.

$$\text{Generation rate in kg/day} = -17.77 + 1.049(\text{PAT}) + 0.818(\text{BED}) + 12.22(\text{Type}) \dots \text{Eq.1}$$

Where, PAT= the number of patients, BED= the number of beds and TYPE= the type of hospital (35).

**Monthly average biomedical waste generation rate (Wo) of hospitals** in kg/day in terms of average bed occupancy rate, B (beds/day) equals:

$$W_o = K_1 + K_2 \cdot B + K_3 \cdot B^2 \dots \text{Eq. 2}$$

Where, coefficients  $K_1$ ,  $K_2$  and  $K_3$  are constants for a particular type of hospital (36).

$$\text{Generation rate in kg/day} = -21.7 + 0.06(\text{PAT}) + 0.372(\text{CAP}) \dots \text{Eq.3}$$

Where, PAT is the number of inpatients and CAP is the number of beds (18).

$$Y = (T_{hb} \cdot W_{hb}) + (T_{cb} \cdot W_{cb}) + (T_{dt} \cdot W_{dt}) \dots \text{Eq.4}$$

Where, Y=total healthcare waste generated per day in kg/day,  $T_{hb}$  = total number of hospital beds in sampled facilities,  $W_{hb}$ = average waste per hospital bed per day in sampled hospitals;  $T_{cb}$  = total number of clinic beds in sampled facilities,  $W_{cb}$  = average waste per clinic bed per day in sampled clinics;  $T_{dt}$  = total number of diagnostic centres tests per day in sampled facilities and  $W_{dt}$  = average waste per diagnostic test in sampled diagnostic centres (3).

$$GW = -15.76 + 1.21(\text{PAT}) + 0.714(\text{BED}) + 10.74(\text{TYPE}) \dots \text{Eq.5}$$

Where, GW is generated waste quantity, PAT the number of patients, BED number of beds and TYPE = dummy variable (0 for private and 1 for public and teaching hospitals) (37).

All the equations (Eq.1 to 4) shows that the healthcare waste generation rate predictive models varied based on the difference of the study area. This indicates, estimating the generation rate of healthcare wastes in developing countries should consider the local determinant factors. Nevertheless, there is no any predictive model available in Ethiopia that can be used for predicting healthcare waste generation rate. Therefore, this research has a paramount importance for improving healthcare waste management system at local and national level.

#### **1.3.4. Hospital healthcare waste management**

Based on the World Health Organization, the standard practice in each component of healthcare waste management are: Healthcare waste should be segregated based on their potential hazard characteristics, treatment requirement, and disposal route, by the person who produces each waste item (23). Separate labelled colour code containers (infectious waste yellow, chemical and pharmaceutical waste brown, general waste black) should be available for each medical area for each category of healthcare waste. Closed colour-coded labelled containers are kept away from patient indoors for interim or short-term storage (depending upon the type of waste not more than 12 hours) of healthcare waste in each medical room. Waste bags and sharp containers should be filled with not more than three quarters full (22). The Collection should be fixed and appropriate to the quantity of waste, but not more than a day. The collection of healthcare waste must follow specific routes through the hospitals in order to reduce the passage of loaded carts through wards and other clean area. The unusable waste materials should preferably be treated to reduce their potential health or environmental hazard and volume, with remaining residues sent for land disposal to a suitably constructed site. In all healthcare waste systems, the removal of the remaining healthcare waste materials after minimization or treatment will require access to land for final disposal. Desirable features of a landfill are restricted access to prevent scavenging, daily soil cover to prevent odours and regular compaction and isolation of waste to prevent contamination of groundwater and surrounding areas (2).

It is to be noted that no single technology is ideal for all kinds of healthcare waste and for all scales of operation. Commonly used technologies are incineration, land filling, burning, autoclaving and chemical treatment. Moreover, microwave disinfections, plasma touch technique, detoxification, and advanced wet oxidation are some emerging technologies. In addition, a new solar treatment technology was developed in India (59).

In healthcare wastes there are batteries, which come in all sizes and shapes, these substances contain toxic chemicals that should never be incinerated (60). Batteries depending up on types may contain mercury, lead, cadmium, and/or lithium. Some of the solutions related to the problems of battery waste are whenever possible, rechargeable batteries should be employed. When this is not possible, a careful battery rounds up

should be implemented to capture and recycle or appropriately dispose of the batteries (61).

In many hospitals mercury from damaged thermometers and blood pressure apparatus disposed without proper precaution could contaminate the environment(62). If a country decided to use incineration as a healthcare waste treatment options it should be the national governments might utilize emission limits and other requirements to ensure effective waste treatment, minimize emissions, and decrease exposure and risks to workers and the community (45).

The spread of blood borne pathogens in healthcare waste motivated the world health organization to issue a policy in 2004 calling for the development of national policies, guidance, and plans for healthcare waste management. The policy paper, however, also recognizes the risks associated with incineration, which in developing countries can be problematic due to the lack of capacity for emission testing or regulatory enforcement (16). A significant amount of Polyhalogenated Aromatic Hydrocarbons (PAHs) are found in healthcare waste and those substances have been of concern over several decades because of their increasing occurrence and persistence in the environment and their biochemical and toxic effects (63).

In India there have been improvements in the management of healthcare waste in the last decade and developing countries have been drawn lessons from India's experience. Since 1995, India has made great progress in managing healthcare waste, notwithstanding delays caused by weaknesses in the country's legal and institutional framework for healthcare waste management (36). The National Government has formulated healthcare waste Rules, prepared national guidelines, and implemented a national training program. Countries have devised their own healthcare waste management strategies and guidelines and provided assistance to government hospitals to implement healthcare waste management initiatives. Non-Governmental Organizations (NGOs) have played a major role in bringing the HCW management agenda to the attention of government officials, creating public awareness of HCW issues and training healthcare facility personnel (64).

WHO in 2004 prepared a policy paper calling on developing countries and countries in transition to develop national policies, guidance manuals, and implementation plans for

sound management of healthcare waste(22). The management of healthcare waste in many developing countries has been often poor and it raises concerns about inappropriate HCW management methods employed in such states. Inappropriate treatment and final disposal of HCW, leads to an adverse impact on public health, occupational health and safety, and the environment (65).

A study done in South Africa showed that incineration was a dominant option for treatment technology of healthcare waste with most of the incinerators situated on the healthcare facility sites. Similar to many first world countries, however, non-incineration technologies are rapidly becoming the dominant treatment technologies, primarily due to increased costs associated with raised air emission control standards required for incineration facilities (66).

In Ethiopia, there is no specific healthcare waste management legislation. However, there are policies and legislations with provisions that may offer a legal frame for the management of healthcare waste (67). The Ethiopia Environmental Pollution Control Proclamation, No 300 of 2002, after defining hazardous waste as “an unwanted material that is believed to be deleterious to human safety or health or the environment” pronounces the following prohibitions and restrictions in its management. “No person shall pollute or cause any other person to pollute the environment by violating the relevant environmental standards (Article 3-sub article 1). Concerning the management of hazardous waste, it states that the generation, keeping, storage, transportation, treatment or disposal of any hazardous waste without a permit from the Environmental Protection Authority or the respective Regional Environmental Agency is prohibited (68).

The Ethiopia 2000 Public Health Proclamation No.200 pronounces the following prohibitions and restrictions about hospital waste “Any solid, liquid and other wastes generated from hospitals should be handled with special care and their disposal procedures should meet the standards set by the public health authorities”. The proclamation neither provided a clear definition of the various categories of HCW nor did it indicate the legal obligations that HCW producers have with regard to segregation, safe handling, treatment and disposal. In addition, it did not indicate specifications for record keeping and reporting, and inspection systems for enforcement of the law (69). The

Environmental Impact Assessment Proclamation no. 299/2002 requires proponents to undertake Environmental Impact Assessment (EIA) for those projects considered to have significant environmental impacts and listed as such in directives issued pursuant to this proclamation. According to the EIA guideline issued by the Federal Environmental Protection Authority (FEPA), large hospitals waste incineration facilities, chemical treatment facilities and landfills for toxic, hazardous and dangerous wastes are among the list of projects considered to have adverse and significant environmental impacts and hence require full environmental impact assessment (70).

A study conducted in Hawassa City showed that most (67%) of the HealthCare Facilities (HCFs) had no segregation of waste at their facility. In two (22%) of the HCFs, the waste was segregated into sharps and other waste. Only one (11%) HCF reported using a complete colour coding system (yellow puncture-proof plastic container for infectious waste, black for general waste and puncture-proof safety box for sharps waste). However, even at this facility it was observed that general waste was often mixed with infectious waste. Six (67%) of the HCFs did not use safety boxes for sharps, of which two mix sharps with other waste in simple waste bins. The absence of waste segregation at most of those HCFs and the improper segregation in other facilities indicate a low level of awareness of the importance of waste segregation by those who manage the waste at those HCFs. For instance, the study results showed that in most of these HCFs, waste management issues were under the responsibilities of administrators, without health backgrounds, who probably have little knowledge about healthcare waste management (31). Another study conducted in 2009 on the Evaluation of Injection Safety and Healthcare waste management in Ethiopia showed absence of segregation practices in 75% of the HCFs and mixing of hazardous HCW with other wastes in healthcare facilities in addition observed burning of HCW in open holes, enclosures and open areas in 65% of the healthcare facilities (26).

A study done by Crown (2007) in preliminary health centre assessment findings from three Regions of Ethiopia in 2007 indicated that in some instances, improper use of incinerators were observed (71). A study conducted in Addis Ababa (2011) revealed that almost in all of the hospitals there was no segregation of waste into infectious, pathological and pharmaceutical, and had no separate bins for the collection of infectious

waste. Non-Hazardous healthcare waste was often mixed with infectious waste. Four of the surveyed hospitals disposed of their waste on-site in their own incinerators and one hospital disposed of at both off-site (non-pathological waste) and on-site (pathological waste), while the remaining one hospital disposed of the waste at off-site (because the incinerator was not working at the time of data collection). Pre-treatment of highly infectious lab waste was not done in any of the hospitals (34).

It is clear that there is much more to be achieved in healthcare waste management, but in a developing country like Ethiopia the management of wastes produced in healthcare facilities continues to pose considerable problems for human health and the environment. Therefore, in developing countries still need a great effort to reduce public health and environmental impact related to poor healthcare waste management system.

A health policy of Ethiopia emphasizes on the development of environmental health, the promotion of occupational health and safety, and on the prevention of environmental pollution with hazardous chemical waste as part of promote and preventive activities. In Ethiopia, there is no specific healthcare waste Management Legislation for the management of healthcare waste (72).

In Ethiopia currently there are two national guidelines and one voluntary code of practice formulated independently by the Federal Ministry of Health, Federal Environmental Protection Authority and Quality Standard Authority of Ethiopia that exclusively deal with healthcare waste management (73, 74). Because of inadequate research data on the existing situation of healthcare waste management in the country, the national guidelines have been developed by considering the general situation in developing countries and based on the biomedical and healthcare waste guideline prepared by the United Nations Environment Program (74).

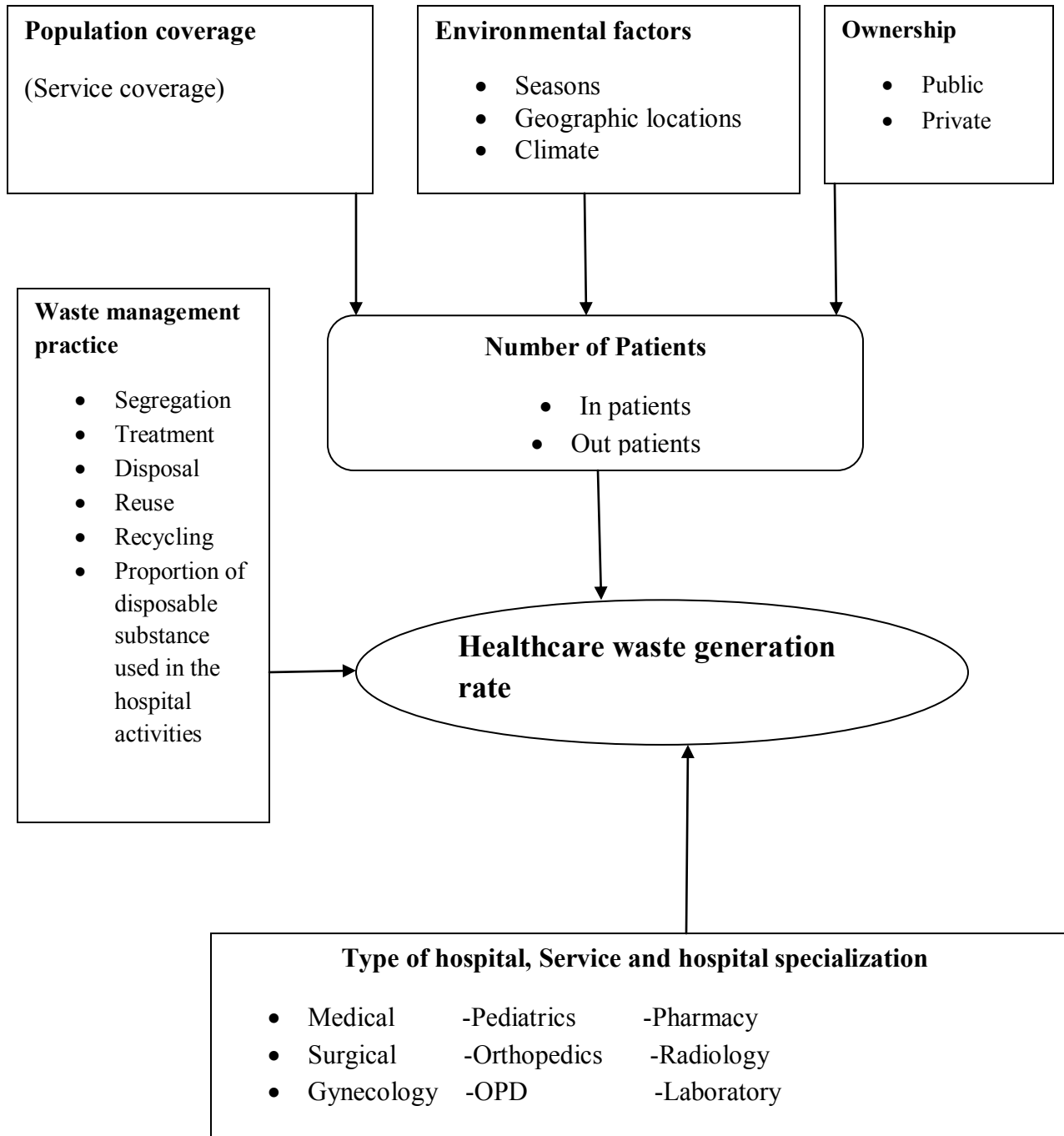
From the research conducted so far in different areas and time, we realize that appropriate healthcare waste management can be achieved by: the presence of the responsible waste management team, preparing compressive plan, the waste handlers equipped with the latest information, skill and practices, allocation of adequate financing, the estimation of the quantities and type of healthcare waste, use of enforced codes of practice and guidelines, provision of regular training for staffs, and full participation of all staffs.

From the literature review, it has been stressed that information regarding healthcare waste has paramount importance in developing a healthcare waste management intervention strategy. It is against this background that this investigation (auditing healthcare waste in the public and private hospitals in the Region) was planned. The research findings in Africa indicate that the current situation of healthcare waste management cannot guarantee safety to healthcare establishment's staff, patients and general population. Instead, current mismanagement constitutes a threat to public health and also to the environment. In Ethiopia, like other Africa Countries often, the level of safety in healthcare waste handling and management is very low. The management of healthcare waste is of great concern. The assumptions are generally there is a lack of proper healthcare waste management practices at healthcare facilities. Thus, there is an urgent need for the development of a healthcare waste management intervention strategy that should be implemented consistently and universally in the Amhara Region. Healthcare waste generation rate and composition are not known, which makes it difficult to plan and develop an appropriate intervention strategy in order to provide better healthcare waste management. Therefore, there was a need to do an investigation of healthcare waste management practices, determining generation rate and select predictive models for public and private hospitals found in the Region.

#### **1.4. Conceptual framework**

Based on the reviewed so far, hospital healthcare waste generation rates can be affected directly by the number of patients (the numbers of patients determine by the type of service, geographic location and the seasons of the year). In addition, healthcare waste generation rate can be affected by the waste management practices of the hospitals for example the presence of waste recycles practices and the proportion of disposable substance used in the hospital activities directly affect the amount of waste generated. These are briefly expressed in the following conceptual framework.

## Conceptual framework of factors determining hospital waste generation rate



**Figure 1:** Conceptual framework showing the relation between factors affecting healthcare waste generation rate, 2014.

## **2. RESEARCH QUESTIONS AND OBJECTIVES**

### **2.1. Research questions**

#### **2.1.1. Major research question**

Does healthcare waste management system of hospitals in Ethiopia pose risk to human health and pollute the environment?

#### **2.1.2. Specific research questions**

1. Does storage, segregation, collection, transportation, treatment and disposal of healthcare waste in Amhara Region pose risk to human health and pollute the environment?
2. What is healthcare waste generation rate in public and private hospitals?
3. Is it possible to select the best fit predictive model to estimate hospital waste generation rate?
4. Is implementing segregation practice according to the categories reducing hospital hazardous waste generation rate?

### **2.2. Objectives**

#### **2.2.1. General objective**

The general objective of this study was to determine the solid healthcare waste generation rate and evaluate the Management System in the Amhara National Regional State of Ethiopia.

#### **2.2.2. Specific objectives**

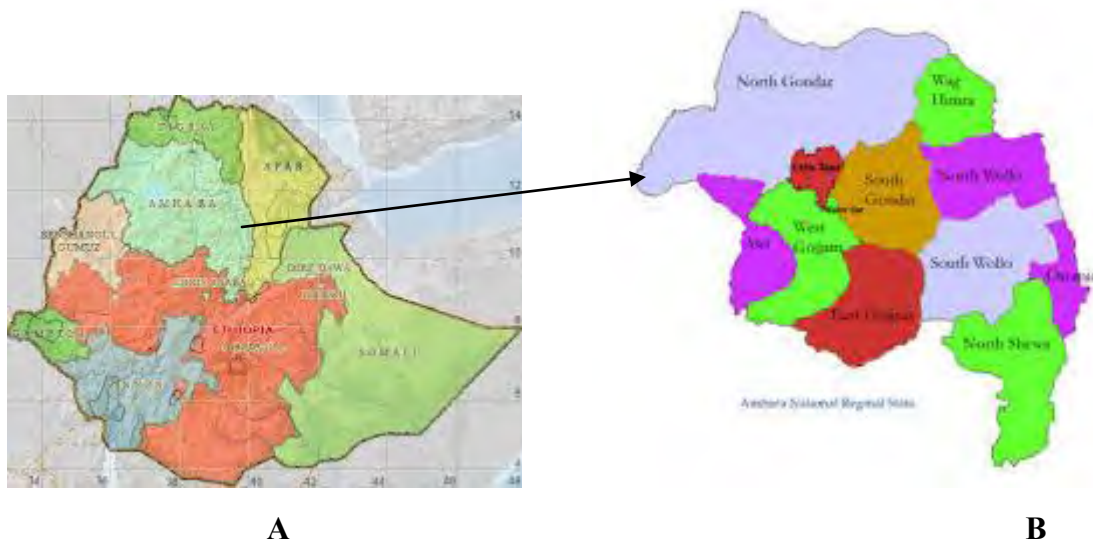
1. To assess the current practices of hospitals on solid waste management
2. To determine solid hospital waste generation rate and composition based on seasonal variability data.
3. To select the best fit predictive models that can be used as a tool to precisely estimate hospitals solid waste generation rate using the seasonal variability data
4. To evaluate the effect of segregation practice on hazardous hospital waste generation rate.

### 3. METHODS AND MATERIALS

#### 3.1. Study area and setting

The Amhara National, Regional State is located in the northwest part of Ethiopia between 9°20' and 14°20' North latitude and 36° 20' and 40° 20' East longitude. Its land area is estimated at about 170000 square kilometres. The Amhara Regional State is bordered by Tigray Region in the North, Afar in the East, Oromiya in the South, Benishangul-Gumiz in the Southwest and Sudan in the west. The Amhara Regional State is divided into 11 zones, and 140 Weredas. The Region has 3429 kebeles. Based on the 2007 Census, the total population of the Region in mid-2008 is 20,136,000 with similar male to female ratio. Of those, 2,408,000 (only 12%) are urban residents. The percentage of the urban population is below the national average (75).

In the Region, there are two teaching, three referrals, two zonal, ten district, six general private hospitals and seven hospitals are under construction providing services for more than 20 million people. The USAID estimated a population growth rate of 3% per year and a doubling time of 25 years (76).



Source: mereja.com, [www.maplandia.com/ethiopia/amhara](http://www.maplandia.com/ethiopia/amhara)

**Figure 2:** (A) Map of Ethiopia shows all Regional States, (B) Map of Amhara National, Regional State shows administrative Zones, 2014.

### **3.2. Study design**

The study applied institution based quantitative studies with descriptive and analytic components to address its specific objectives. To assess the current practices of solid healthcare waste management systems, cross-sectional study design was used using interview and observation. In order to evaluate the effect of segregation practices on the hazardous healthcare waste generation rate, comparative cross-sectional study design was used. Longitudinal study design was used to determine healthcare waste composition, generation rate and selection of best fit predictive models for estimation of healthcare waste generation rate by considering the seasonal variability, this seasonal variation might affect the nature of the illnesses of patients treated and admitted to hospitals.

#### **Time frame of the study**

The dry season data were collected from November to December, 2013 and the rain season were collected from July to August, 2014. The reason for these data collection time is to represent the dry and wet seasons of the study Regional State.

### **3.3. Source and study population**

This research aimed to represent the entire Amhara Regional State hospitals waste generation rate and management practice, hence, the source population included all teaching, referral, zonal, district and private hospitals in the Region. The study units are nine hospitals from different types namely teaching, referral, zonal, district and private general hospitals of both government and private owner. Healthcare system organization in Ethiopia, classify the hospitals by the number of people served, this are 250, 000, 1 million, 1.5 million and 3.5 to 5 million people designed to serve in District, Zonal, Referral and Tertiary (Teaching ) hospitals respectively (67).

### **3.4. Sample size and sampling techniques**

#### **Sample size**

Based on the previous study, the mean generation rate of hospital healthcare waste: 41.358kg/day, SD 5.02 kg/day (77).

$$n = (Z_{\alpha/2})^2 \times \delta^2 / d^2 \quad (78)$$

Standard normal variance of approximately 95% confidence ( $Z_{\alpha/2}$ )=1.96

$\delta$ =population standard deviation (SD), estimated by sample Standard Error (SE)

$$d=(Z_{\alpha/2}) \times SE$$

$$SE (\delta)=SD/\sqrt{n}=1.05$$

$d$ =margin of error corresponding 95% of certainty;  $1.96 \times 1.05=2.058$

2.058 of 41.358=10% (i.e. within 10% from 41.359)

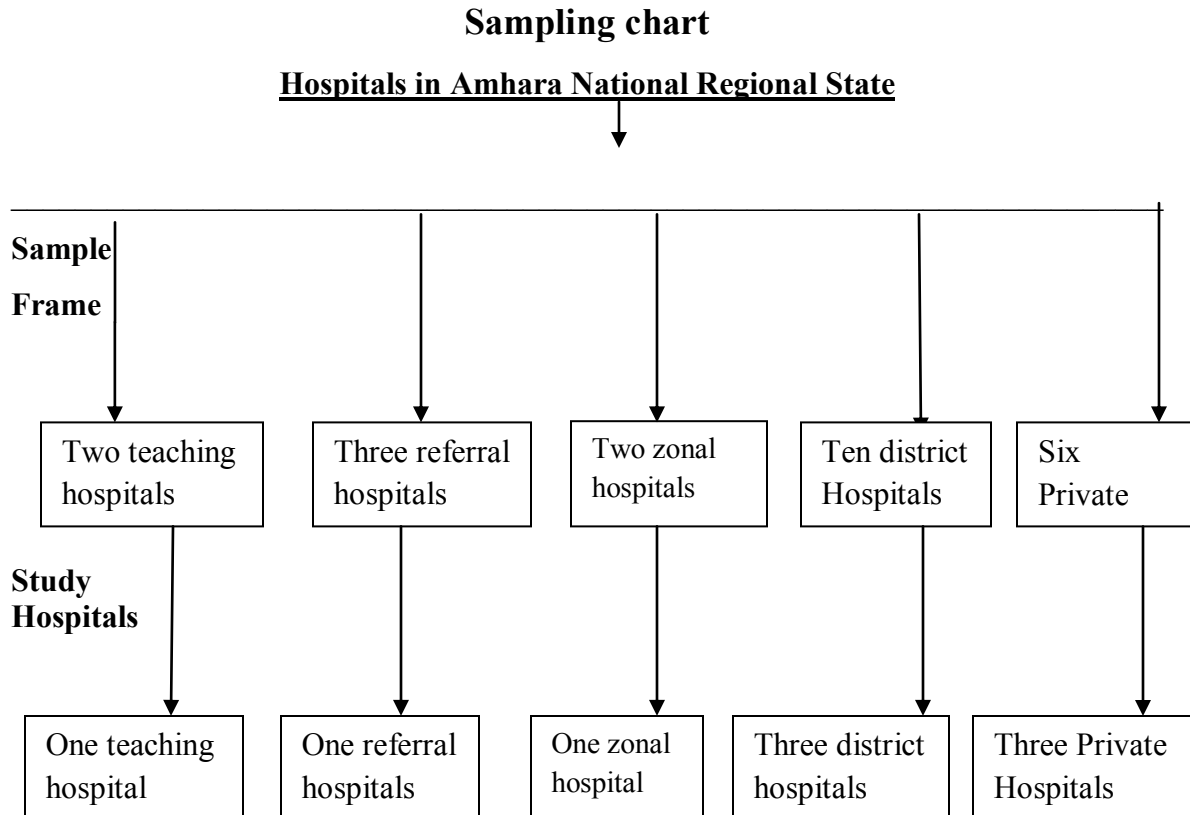
**Table 2:** Assumptions and given used for sample size calculation, 2014.

<b>% of mean</b>	<b>d</b>	<b>(Z<sub>α/2</sub>)</b>	<b>(Z<sub>α/2</sub>)<sup>2</sup></b>	<b>SD</b>	<b>SD<sup>2</sup></b>	<b>d<sup>2</sup></b>	<b>n</b>
2.5%	5.27	1.96	3.8416	5.02	25.2004	27.7	3.5
5%	4.03	1.96	3.8416	5.02	25.2004	16.2	6.0
7%	3.43	1.96	3.8416	5.02	25.2004	11.76	8.23
10%	2.82	1.96	3.8416	5.02	25.2004	7.95	12.17

Based on the above calculation 7% precision of mean, 9 hospitals were selected for this study. These nine hospitals are sufficient to address all specific objectives.

### **Sampling techniques**

In order to ensure representativeness of samples, various types of hospitals were considered from the region. The sampling frame was prepared based on stratification of teaching, referral, district/primary and private hospitals and then random sampling methods were employed to select from each stratum based on the proportion of hospitals (figure 3). From these hospitals the weight of all the solid wastes generated in two rounds (first and second round of data collection) were measured for two different seasons. In each season seven consecutive days of collection and measuring waste were made. The seasonal variability of healthcare waste generation rates for each hospital was determined.



**Figure 3:** Sampling chart shows the steps to select the study hospitals, Amhara National Regional State, Ethiopia, 2014.

### 3.5. Data collection tools and procedures

#### **Assessment of healthcare waste management practice (paper I)**

To investigate the overall practice of healthcare waste management we used both semi-structured questionnaire and observational checklist adapted from World Health Organization healthcare waste management rapid assessment tools (79). Both interviews and observations were conducted by principal investigators from November to December 2013. The interview was administered involving 90 hospital staff (administrators, medical directors, and heads of all departments; for example, Pharmacy, laboratory, pathology, surgery, environmental health and workers directly involved in waste handling). The main questions were regarding segregation, collection, transportation, storage, treatment, disposal, waste re-cycling and re-use, occupational health and safety, internal policies and administration, training, and budget for healthcare waste management. In addition, observation was conducted to see the waste management

performance of the hospitals; consisting of the six characteristics of waste management descriptors and indicators of healthcare waste management, namely: general management strategy, collection, segregation, recycling, storage and disposal of waste using an observational checklist.

**Determining hospital solid healthcare waste generation rate, composition, and to select the best fit predictive models (paper II and III)**

Data collection to determine solid hospital waste composition, generation rate and select fit predictive models, the data collection was conducted in two rounds; the first round from November to December 2013 and the second round was from July to August 2014. The data collection period was depending on the variation of seasons. Fifteen data collectors had secondary school certificates, and three supervisors, had BSc degree in Environmental Health. In both rounds of data collection, one day training was given about data collection and data collection tools and protocols were demonstrated for data collectors and supervisors.

All waste collection buckets, safety boxes and plastic bags obtained for the study were labelled to indicate the different categories of healthcare waste, date of collection and sample number. The quantity of waste generated was estimated by collecting and weighting healthcare waste from all departments of the study hospitals using a calibrated sensitive weight scale nürulä Export model made in India every day at 6:00 PM for seven consecutive days (Monday–Sunday). The waste characterization was done in accordance with World Health Organization (WHO) guidelines (2). The daily generation of waste together with the number of beds occupied and patients treated in outpatient departments were recorded daily. The healthcare waste generation rates were estimated on the basis of kg/bed/day, kg/patient/day and kg/outpatient/day, as described by world health organization pruss et al. (2013), Awad et al. (2004) and Engdaw et al. 2007 (2, 30, 35).

To evaluate the effect of segregation practise on hazardous healthcare waste generation rate, data were collected from Debre Birhan referral hospital in two rounds for seven consecutive days in each round.

### **3.6. Data management and statistical analysis**

To address the current practices of solid hospital waste management, Data from interviews and observation were analysed by theme. We conducted a thematic analysis of the data manually, by sorting and organizing information according to thematic similarities and differences. Then, we categorized and studied the information to understand relationships in the overall context of the research.

To determine solid hospital waste generation rate and composition and to select the best fit predictive models that can be used as a tool to precisely estimate hospitals solid waste generation rate, used EPI- INFO <sup>TM</sup> 7 for data entry. After the screening and correction of the data entry errors, the data were exported to SPSS version 16 statistical software for analysis. The analysis was performed separately for each of the 9 hospitals, which were grouped by category of ownership; i.e., government and private hospitals and by category of healthcare waste. First, we explored the distribution of the data, including normality using a normality test, which showed that the data were normally distributed after combining the data of two rounds. Therefore, we used Pearson correlation test for the bivariate associations. Data description was made using mean, Standard Deviation (SD), frequency, percentage and graph.

The important variables that affect the quantity of wastes generated from the hospitals were identified and then multiple linear regression analysis was done in order to select the best fit predictable models that can be used in estimating or predicting the waste generation rate of hospitals. Establishing the simple correlation matrices between different variables were the first step in the model selection. This step was helpful to investigate the strength and the form of the relationship between the variables included in the analysis.

In order to see the effect of the parameters and their confidence levels on the waste generation rate in healthcare services, analysis of variance (ANOVA) was performed to compare the rate by the type of hospitals. The F-test was a tool to see which parameters had a significant effect on the removal efficiency. The data quality was maintained by calibrating the instruments used for measurement, recruitment professional for

supervisors and daily on-site supervision was made by the investigator during the actual measurements.

In the intervention study the data were compared with measurement before the implementation of intervention (segregation based on the categories of healthcare waste) and after the implementation of segregation using descriptive statistics and comparison of two proportions for testing the presence of statistical significant differences before and after intervention measurements.

### **3.7. Data quality assurance mechanisms**

#### **At data collection tools design stage**

In order to improve **validity** all questions and checklist were logically related to the variables measured, and to the overall study aims. In addition, the instrument was designed to measure all components of the variables and also use an existing instrument that was already tested in other studies and calibration/standardization of the measuring instrument were helped to improve the validity of the study. A peer review of the questionnaire is the initial stage of testing the validity and reliability of the measuring instrument.

To ensure **reliability during data collection**, different strategies were employed. First, the measuring instruments were calibrated. Second, professionals were recruited for supervisors. In addition, two follow up sessions were conducted. There was also daily on-site supervision by the investigator during the actual measurements.

**During data analysis**, EPI info statistical software was used for data entry and cleaning. In addition, selected appropriate statistics also helped for the **validity** and **reliability** of the study.

#### **Reducing bias**

Interviewer bias was reduced by using a standardized and validated measuring instrument. The researcher used an existing instrument that had already been tested in other studies. To avoid information response bias, the researcher was also informed about the purpose of the research. Selection bias was avoided by including both the public and private hospitals.

### **3.8. Ethical issues**

Ethical approval and clearance were obtained from the Institutional Review Board of the College of Health Sciences, Addis Ababa University. Written permission was obtained from Amhara National, Regional State Health Bureau (ANRSHB) and hospital administration of the study units. All respondents were informed about the study procedures and the interview was conducted after obtaining their written informed consent. The participants were assured of the confidentiality as they participate in the investigation. Furthermore, participants were assured that no disciplinary action would be instituted against them based on the findings of this research.

The research does not have a short term financial, healthcare and capacity building benefit to the research participant as an individual or as a group, but in the long run it will help the concerned organization and policy makers to have a policy consideration and direction and formulation of strategy and design of sound hospital healthcare waste management system based on the findings and recommendations. This research did not have any inhumane treatment of research participants and any physical harm, social discrimination, psychological trauma and economic loss.

### 3.9. A tabular summary of the methods applied in the dissertation, 2014.

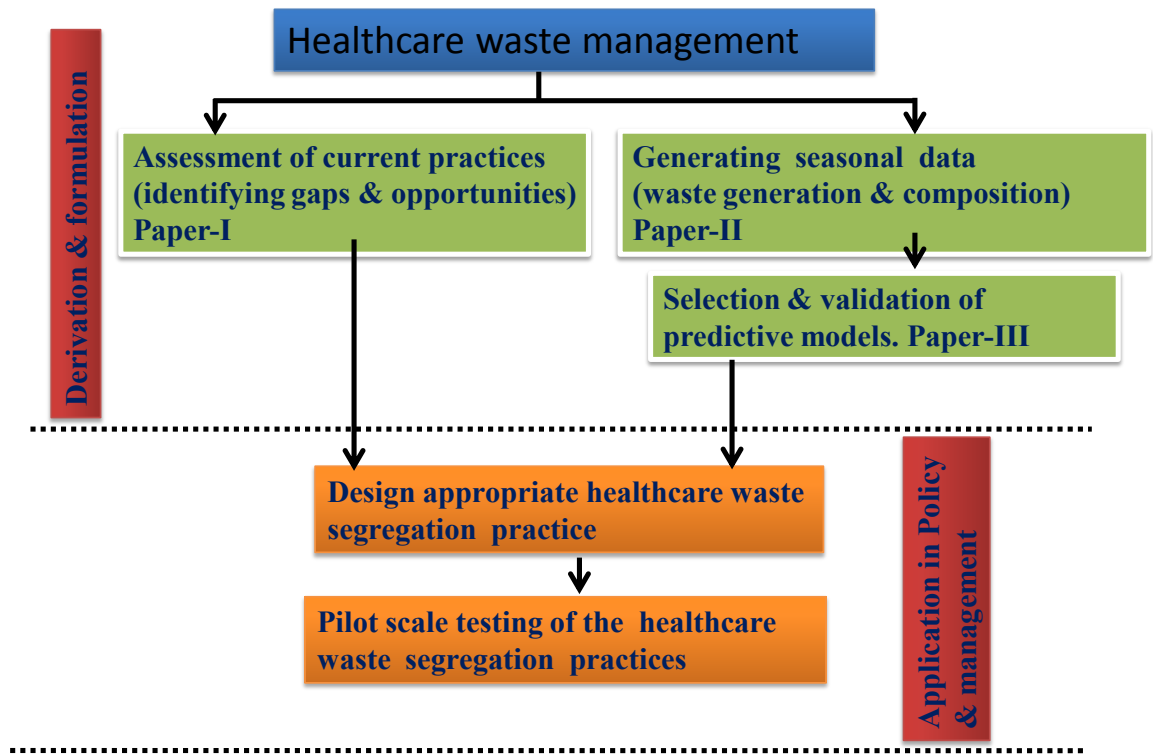
**Table 3:** Summary of methods based on the objectives of the study

No	Objectives	Study design	Method of analysis
1	To assess the current practices of solid hospital waste management systems	Cross-sectional	Descriptive analysis of the data by theme. Information organized according to thematic similarities and differences.
2	To determine solid hospital waste generation rate and composition based on seasonal variability data.	Longitudinal	Descriptive statistics and Pearson correlation test for the bivariate associations. Analysis of variance (ANOVA) was performed to compare the rate by the type of hospitals.
3	To select fit predictive models that can be used as a tool precisely estimate solid hospital healthcare waste generation rate.	Longitudinal	Multiple linear regression analysis, establish the simple correlation matrices between different variables for investigating the strength and form of the relationship between the variables included in the analysis.
4	To evaluate the effect of segregation practices on hazardous healthcare generation rate	Comparative cross-sectional	Descriptive statistics such as mean and SD and comparison of two proportions.

#### Summary of the Brief Outlines of the Dissertation Work

The overall framework of the PhD thesis is presented in the figure 4 below. The first step was the derivation and formulation stage consisting of assessment of current practices, generation of seasonal variability data on generation and composition of healthcare waste and selection of the best fit predictive models. Assessment of current practices helped in identifying major needs or problems that were a target of intervention in this study and major opportunities or current practices that needs to be strengthened. To select and validate predictive models so as to precisely estimate the healthcare waste generation rate. The second step was applied in policy and management. This step includes design

and evaluates the healthcare waste segregation practice. Using the healthcare waste segregation practice tools that areas developed in the first step, design and evaluate the impact of healthcare waste segregation practice in the reduction of hazardous waste generation rate.



**Figure 4: Analytical framework of the PhD Dissertation, 2014.**

## 4. RESULTS

### 4.1. The practice of hospital healthcare waste management (paper I)

#### Hospital healthcare waste segregation practice

In all public hospitals, only segregation of sharp waste using the safety box was practiced. However, sharp waste segregation was missing in all of the private hospitals. Placentas and blood stained cotton pads were kept in separate containers in all public and private hospitals. The use of waste containers with a colour code and labelling at the point of generation was not implemented in all hospitals. Overall, the practice of healthcare waste segregation was found to be very limited.

#### Temporary storage of hospital healthcare waste practice on point of source

All public and private hospitals temporarily stored all waste in open and substandard dustbins for about 12 hours (figure 5). Pathological and sharp wastes were stored in closed plastic containers and collected in less than an hour. Public hospitals use standard safety boxes to store sharp wastes (figure 5), while private hospitals use non-standard storages, such as carton boxes that can be easily damaged or torn out. In all hospitals, lack of proper and purpose-built waste storage areas was apparent.



**Figure 5:** Photo shows, hospital healthcare waste temporal storage at the point of sources in Gondar teaching hospital (Photo: Esubalew Tesfahun, July 17, 2014).

## Collection and transportation of hospital healthcare waste

There was no structured collection and transportation system for general and hazardous waste in both private and public hospitals. In four out of six public hospitals (67%), open plastic bins (capacity of 25 liters) were used to collect and transport mixed wastes, while one public hospitals (11.11%) used closed plastic container (capacity of 50 liters) and one public hospitals (11.11%) used both open container and carton box. Only sharps and pathological wastes were collected and transported separately. Mixed waste was collected and transported in carton or open plastic bins in private hospitals. Almost in all private and public hospitals, healthcare waste was collected and transported to incineration facilities without using wheeled trolleys (leak-proof made with stainless steel) twice a day in the morning before 8:00 am and in the evening after 6:00 pm by cleaning personnel (Figure 6). The waste from delivery, operation and intensive care units was collected in less than 2 hours.



**A**

**B**

**C**

**Figure 6:** Photo shows, hospital healthcare waste collection and transportation in Gondar teaching (figure A), Debre Tabor zonal (figure B), and Boru district Hospital (figure C) (Photo: Esubalew Tesfahun, August 23, 2014).

## Hospital healthcare waste treatment and disposal practice

Except in one public hospital (Enat District Hospital), the practice of pre-treatment of highly infectious waste was not practiced. The Laboratory Department in Enat District Hospital treated infectious waste by autoclave machine. A local brick made incinerator was used to burn sharps waste in all hospitals. Nevertheless, the incinerators used for the treatment of healthcare wastes were not proper in design and construction. None of them

are able to burn waste completely; consequently they were not reducing waste volume significantly and produced high smoke emission. The partial burned healthcare waste was disposed in an open pit. In addition to incinerators, all public hospitals had an open hand dug pit in their backyard that was used for the direct dumping and open burning of healthcare wastes. All public and one private (Selam) hospital had a placenta pit for disposal of pathological waste generated from the delivery and operating rooms (figure 7). Two private (Ayu and IBEX) hospitals (67%) had no placenta pit and those hospitals disposed pathological waste by burial within the compound.



**Figure 7:** Photo showing incinerator, open pit, open burner container and placenta pit for Debre Birhan, Mehal Meda, Gondar, Debre Tabor, Debre Birhan and Enat Hospital respectively used for waste disposal of all types of hospital solid healthcare waste (photo: Esubalew Tesfahun, July, 2014).

### **Hospital healthcare waste reuse and recycling practice**

Healthcare waste reuse and recycling practice were almost absent in all public and private hospitals, except reusing drug containers (example: cans, plastic and bottles) in all hospitals without any precautions and recycling of silver from a radiology waste in one of the public hospital (Gondar Teaching Hospital).

### **Supervision and budget for healthcare waste management**

The Ethiopian Federal Ministry of Health (Ethiopian-FMOH) developed a checklist for supervisors of healthcare waste management. However, it was observed that regular supervision was not practiced in both public and private hospitals. Neither the hospital administrators nor health professionals were informed about the presence of the Ethiopian-MOH (Ministry of Health) supervision guideline. There was one focal person responsible for healthcare waste management in all surveyed hospitals.

There was no separate budget allocated for healthcare waste management in both public and private hospitals. Two public hospitals (Debre Tabor and Debre Birhan) confirmed that there was budget allocated for healthcare waste management. However, these two hospitals could not able to provide proof during data collection. Consequently, shortage of waste handling materials that could be used for healthcare waste management was observed in all public and private hospitals.

### **Hospital healthcare waste management guideline and instructions**

Ethiopian-MOH prepared the National Healthcare Waste Management Guideline in 2008. But none of the hospitals used this guideline. Only one public hospital (Debre Tabor hospital) had its own directives and written instructions to implement waste segregation. Standard operational manuals on healthcare waste management were absent in almost all hospitals. This study had also confirmed that none of the hospitals had well defined institutionalized healthcare waste management strategic plans and guidelines.

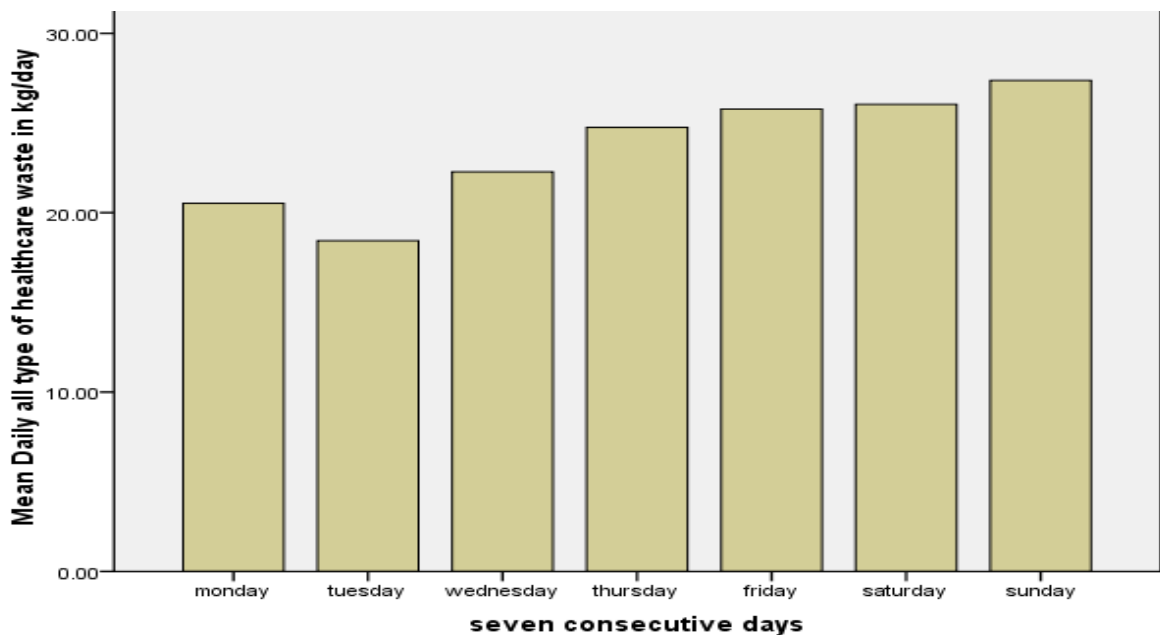
### **Training and safety device**

Public hospitals had organized training related to infection prevention and healthcare waste management to waste handlers, environmental health professionals and heads of departments. However, there was no regular training or on the job orientation for all healthcare workers. All private hospitals had not provided any training related to healthcare waste management and infection prevention to health providers. Waste handlers had heavy duty gloves, boots, and clothes in all public hospitals, but in private hospitals they had only heavy duty gloves, and clothes. Only two public hospitals (Debre Tabor and Debre Birhan) had a system of treatment support and reporting during injuries

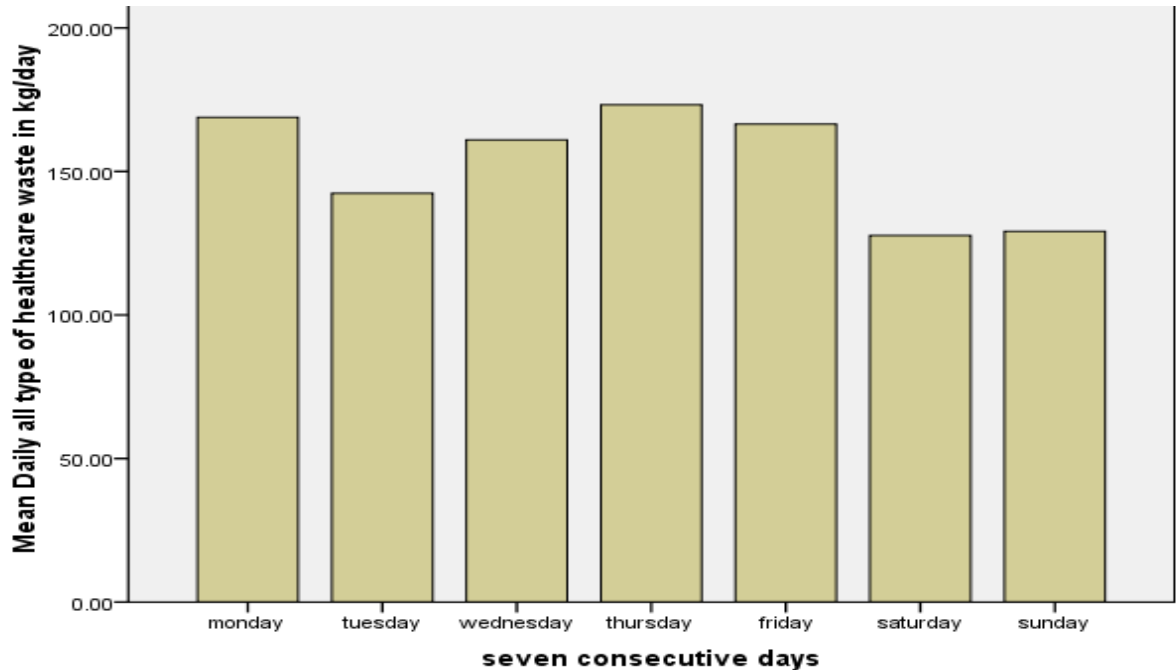
in the process of waste handling practices. Confirmed from the record of those hospitals, there were five needle stick injuries within ten months. None of the hospitals had formal guidelines and procedures for prevention of occupational injuries.

#### **4.2. Assessment of composition and generation rate of hospital healthcare wastes in selected public and private hospitals (paper II)**

The average total healthcare waste generation rate estimated in kg/patient/day (sum of inpatient and outpatient) was  $0.49 \pm 0.2$  (Table 4). The average generation rate estimated in kg/bed/day and kg/outpatient/day has a statistical significance difference ( $P < 0.03$ ). Based on the estimation of the number of inpatients, the average generation rate of hospital healthcare waste was  $1.5 \pm 0.6$  kg/ bed/day (Table 5) and outpatients was  $2.5 \pm 12$  kg/outpatient/day.



**Figure 8:** The average daily distribution of all types of healthcare waste generation rate in private hospitals (kg/day), Amhara National Regional State, Ethiopia, 2014.



**Figure 9:** The average daily distribution of all types of healthcare waste generation rate in public hospitals (kg/day), Amhara National Regional State, Ethiopia, 2014.

The daily distribution of healthcare waste generation rate for seven consecutive days in private hospitals was higher in the weekend and less in public hospitals (figure 8 &9). These were directly related to the variation of the number of patient treated in the hospitals on a daily bases.

The composition of healthcare waste in Public hospitals 46.40 %, 34.28%, 3.83%, 9.07%, 6.19% and 0.23% were general, infectious, sharps, Pharmaceutical, pathological and radioactive waste respectively. In private hospitals 45.29%, 29.71%, 6.72%, 17.27%, 0.47% and 0.54% were general, infectious, sharps, Pharmaceutical, pathological and radioactive waste respectively. The composition for all sampled hospitals 46.32%, 33.95%, 4.04%, 9.66%, 5.78% and 0.25% were general, infectious, sharps, Pharmaceutical, pathological and radioactive waste respectively.

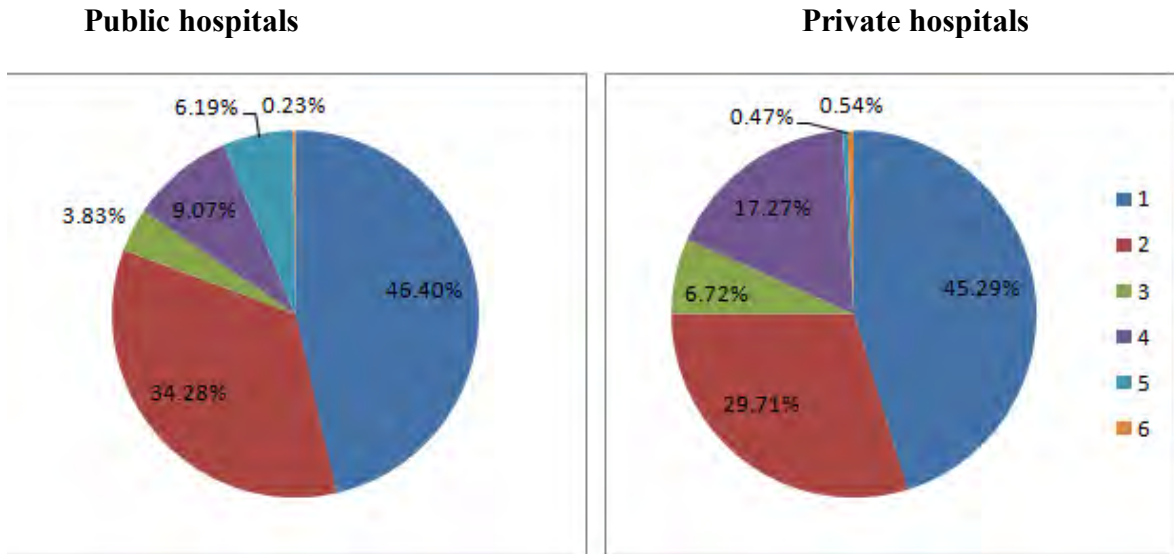
**Table 4:** Composition and generation rate of healthcare wastes based on the number of total patients (kg/patient/day) in the nine study hospitals, Average with standard deviation (SD) and percentage of hazardous waste, Amhara National Regional State, Ethiopia, 2014.

Code of hospitals	Healthcare waste composition in kg/patient/day						Average Hazardous (%)
	General	Infectious	Sharps	Pharmaceutical	Pathological	Radioactive	
P1	0.06 ±0.01	0.07 ±0.02	0.03 ±0.01	0.03 ±0.01	-	0.002 ±0.001	68.75
P2	0.32 ±0.08	0.18 ±0.06	0.02 ±0.01	0.14 ±0.06	-	0.003 ±0.001	51.73
P2	0.09 ±0.03	0.07 ±0.03	0.03 ±0.01	0.01 ±0.006	0.007 ±0.001	-	56.52
Private	0.16 ±0.13	0.11 ±0.06	0.03 ±0.01	0.06 ±0.01	0.002 ±0.001	0.001 ±0.0001	55.92
D1	0.16 ±0.08	0.05 ±0.01	0.02 ±0.01	0.02 ±0.01	0.009 ±0.001	0.002 ±0.001	38.70
D2	0.25 ±0.02	0.16 ±0.03	0.03 ±0.01	0.05 ±0.01	0.04 ±0.01	0.001 ±0.0008	52.92
D3	0.20 ±0.02	0.13 ±0.08	0.01 ±0.06	0.03 ±0.005	0.02 ±0.004	0.003 ±0.001	50.10
ZH	0.17 ±0.05	0.06 ±0.02	0.01 ±0.004	0.03 ±0.01	0.03 ±0.01	0.0016 ±0.001	43.63
RH	0.22 ±0.04	0.23 ±0.09	0.03 ±0.02	0.05 ±0.03	0.06 ±0.03	0.0005 ±0.0003	62.74
TH	0.32 ±0.11	0.25 ±0.10	0.02 ±0.01	0.07 ±0.03	0.03 ±0.02	0.001 ±0.0005	53.69
Government	0.23 ±0.13	0.17 ±0.11	0.02 ±0.01	0.04 ±0.02	0.03 ±0.01	0.001 ±0.0003	53.16
Government And Private	0.22 ±0.14	0.17 ±0.12	0.02 ±0.01	0.05 ±0.03	0.03 ±0.01	0.001 ±0.0001	55.19

**P1 = Ayu General private hospital, P2 = Selam General private hospital, P3 = IBEX General private hospital, D1 = Boru district hospital, D2 = Enat district hospital, D3 = Mehal Meda district hospital, ZH = Debre Tabor zonal hospital, RH = Debre Birhan referral hospital, TH = Gondar teaching hospital.**

### Hospital healthcare waste composition

Regarding the composition of healthcare waste, almost similar in Public and Private hospitals except pharmaceutical healthcare waste 9 % in Public hospitals, but 17 % in Private hospitals and also pathological waste 6 % in Public whereas while 0.47% in Private hospitals (Figure 10), these proportion variation have a statistical significance with P-value less than 0.05.



1-General, 2- Infectious, 3- Sharps, 4- Pharmaceutical, 5-Pathological and 6-Radioactive waste

**Figure 10:** Composition of healthcare waste in the study public and private hospitals, Amhara National Regional State, Ethiopia, 2014.

### Comparison of private versus governmental hospitals on healthcare waste generation rate:

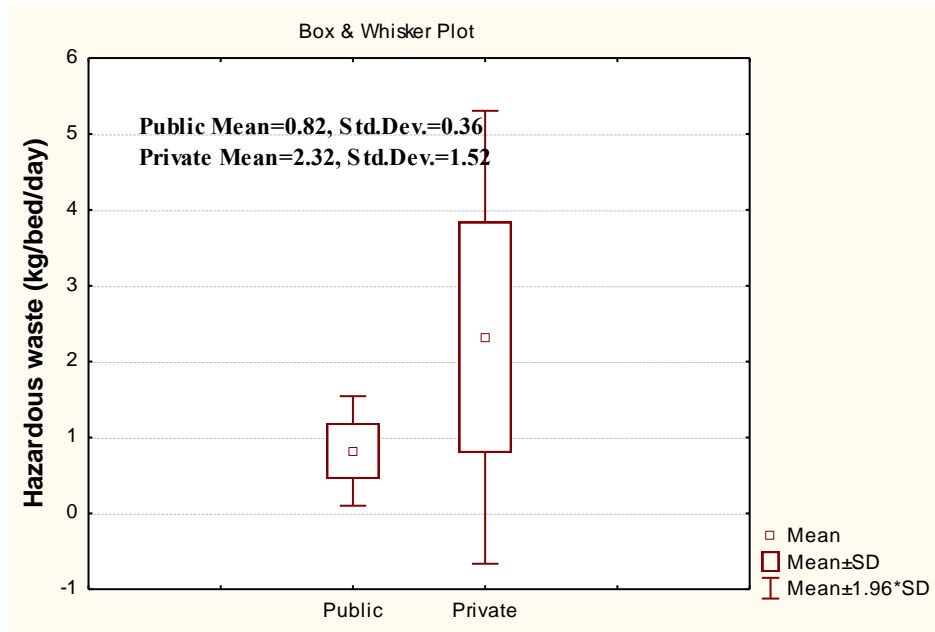
The average hazardous waste that is expressed as a percentage of the total waste generated in private and public hospitals is presented in figure 11. The percentages show that the average value of the hazardous component of the total healthcare waste was > 50% in both private and public hospitals (Table 4 and 5). This pattern was also found in all hospitals except for one district and one zonal hospital in terms of total number of patients (Table 4) and inpatients (Table 5).

**Table 5:** Composition and generation rate of healthcare wastes based on the number of inpatients (kg/bed/day) in nine hospitals, Average with standard deviation (SD) and percentage of hazardous waste, Amhara National Regional State, Ethiopia, 2014.

Code of hospitals	Healthcare waste composition in kg/bed/day						Average Hazardous (%)
	General	Infectious	Sharps	Pharmaceutical	Pathological	Radioactive	
P1	0.42 ±0.13	0.45 ±0.13	0.19 ±0.05	0.23 ±0.08	-	0.02 ±0.003	67.94
P2	2.49 ±0.09	1.42 ±0.5	0.17 ±0.05	0.99 ± 0.4	-	0.02 ± 0.01	51.08
P2	2.63 ± 0.3	1.88 ± 0.2	1.08 ± 0.1	0.4 ± 0.1	0.31 ±0.06	-	58.25
Private	1.85 ±0.4	1.25 ± 0.5	0.48 ±0.07	0.54 ±0.04	0.1 ±0.02	0.01 ± 0.007	56.26
D1	0.82 ± 0.22	0.27 ± 0.06	0.07 ± 0.01	0.09 ± 0.01	0.03 ±0.01	0.01 ± 0.004	36.43
D2	0.96 ± 0.15	0.64 ± 0.19	0.14 ±0.09	0.16 ±0.06	0.18 ±0.05	0.004 ±0.001	53.93
D3	0.79 ± 0.24	0.57 ±0.26	0.07 ± 0.02	0.16 ± 0.05	0.13 ±0.03	0.009 ±0.002	54.25
ZH	0.88 ± 0.31	0.31 ±0.06	0.09 ±0.02	0.15 ±0.05	0.13 ±0.04	0.007 ±0.001	43.84
RH	0.62 ±0.12	0.64 ±0.17	0.07 ±0.03	0.12 ± 0.04	0.14 ±0.05	0.0013 ±0.0002	61.04
TH	0.62 ± 0.14	0.48 ±0.12	0.04 ± 0.01	0.13 ± 0.03	0.07 ±0.02	0.002 ±0.0006	53.80
Government	0.78 ± 0.13	0.48 ± 0.11	0.08 ± 0.01	0.14 ± 0.02	0.11 ± 0.01	0.006 ± 0.0003	51.13
Government And Private	0.67 ± 0.15	0.50 ±0.14	0.05 ± 0.01	0.13 ± 0.03	0.09 ± 0.01	0.003 ± 0.0001	53.57

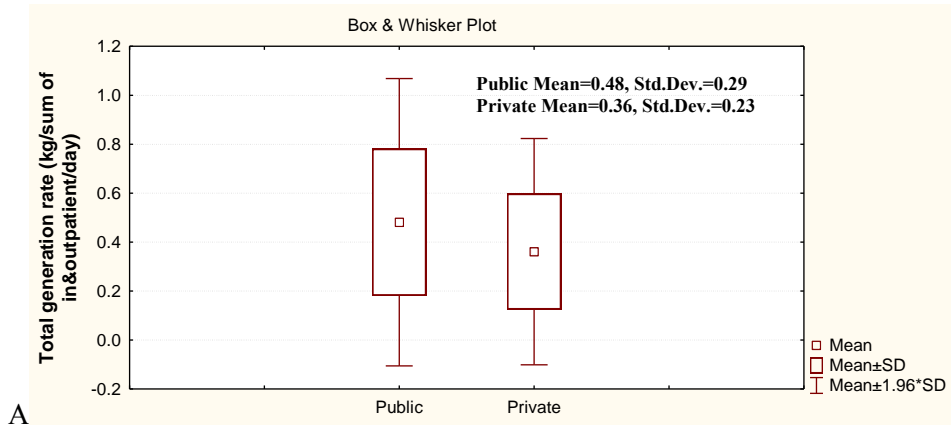
P1 = Ayu General private hospital, P2 = Selam General private hospital, P3 = IBEX General private hospital, D1 = Boru district hospital, D2 = Enat district hospital, D3 = Mehal Meda district hospital, ZH = Debre Tabor zonal hospital, RH = Debre Birhan referral hospital, TH = Gondar teaching hospital.

The generation rate of general healthcare waste in private hospitals was 1.85 kg/bed/day and the public hospitals was 0.78 kg/bed/day, this variation have a statistical significance ( $P < 0.05$ ). Similarly the generation rate of infectious healthcare in private hospitals was 1.25 kg/bed/day and the public hospitals was 0.48 kg/bed/day, this variation also statistical significance ( $P < 0.05$ ).

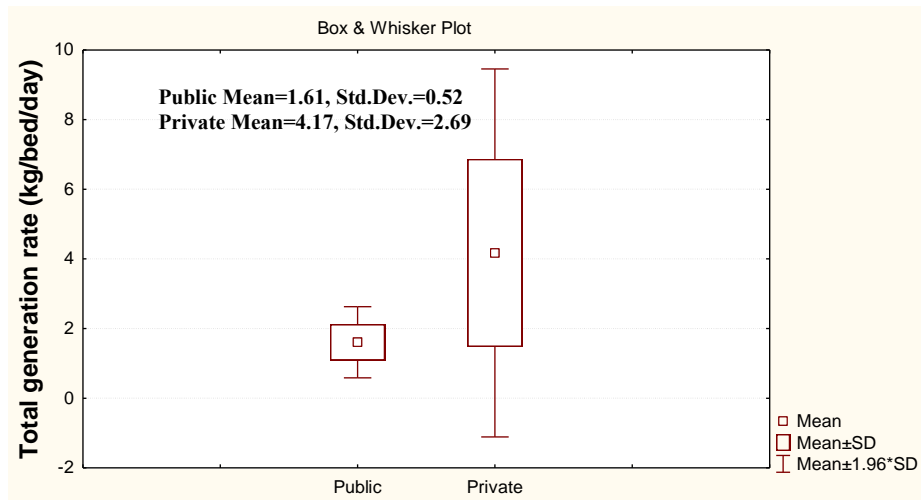


**Figure 11.**Box plot of hazardous healthcare waste generation rate (kg/bed/day) in the study public and private hospitals, average with standard deviation, Amhara National Regional State, Ethiopia, 2014.

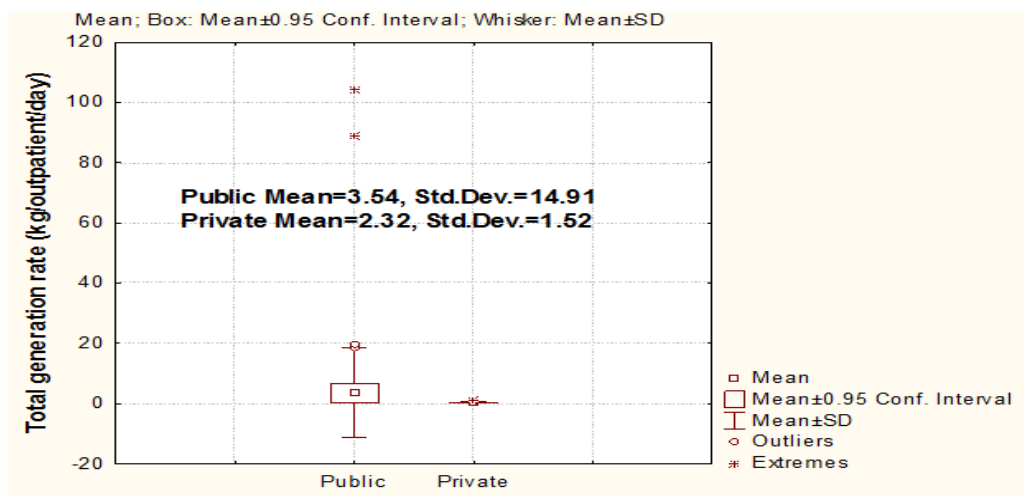
The average hazardous healthcare waste (sum of sharps, pharmaceutical, pathological and radioactive) generation rate in private hospitals was 2.32 kg/bed/day and generation rate in public hospitals was 0.82 kg/bed/day (Figure 11).The one-way between-subjects ANOVA test showed that a significantly higher average value of hazardous waste for private hospitals than in government hospitals ( $P < 0.05$ ).



A



B



C

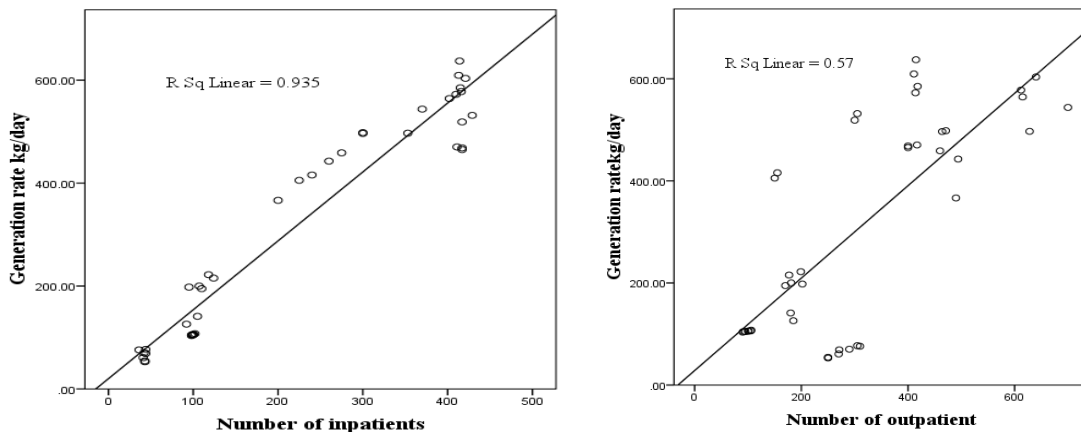
**Figure 12.** Box plots of total healthcare waste (sum of all types) generation rate in the study public and private hospitals, average with a standard deviation in kg/patient (sum of inpatient & outpatient)/day figure A, kg/bed/day figure B, and kg/outpatient/day figure C, Amhara National Regional State, Ethiopia, 2014.

The average total healthcare waste generation rate in terms of kg/sum of inpatient & outpatient/day is higher in public hospitals than in private hospitals. This variation has a statistical significance difference ( $P < 0.05$ ). While the total healthcare waste generation rate in kg/bed/day is higher in private hospitals than public hospitals. This variation also has a statistical significance ( $P < 0.01$ ). The generation rate in kg/outpatient/day in public hospitals is  $3.54 \pm 14.91$  (Figure 12), presenting the generation rate in public hospitals based on the number of outpatients has a higher standard deviation, this implies estimation based on this unit is less accuracy in public hospitals.

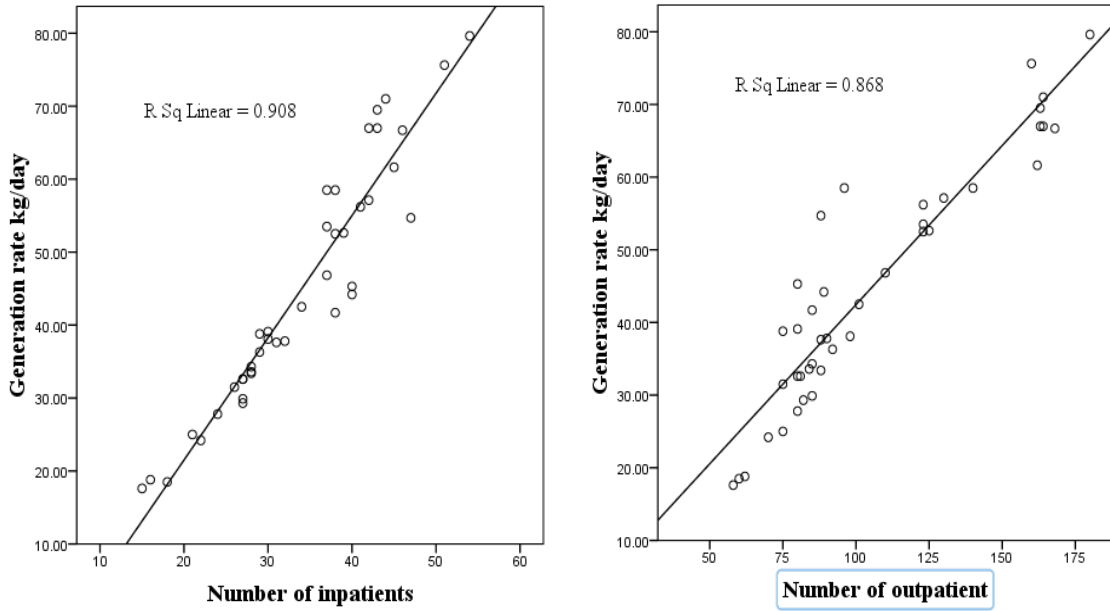
#### 4.3. Selection of the best fit Models for the Prediction of Hospital Healthcare Waste Generation Rate (Paper III)

The important variables (number of inpatients and outpatients) that mainly affect healthcare waste generation rate were identified and linear regression analysis was done in order to select the best fit predictable models used for estimation of healthcare waste generation rate of hospitals.

It was observed that, the amount of healthcare waste generation rate has a strong positively correlated with the number of inpatients  $R^2 = 0.935$  and the number of outpatients  $R^2 = 0.57$  for referral hospitals (Figure 13). In order to investigate the effect of each independent variable on the dependent variable; scatter plots of healthcare waste generation versus the number of inpatients and number of outpatients treated in the hospitals were plotted as shown in figures 13, 14 and 15.

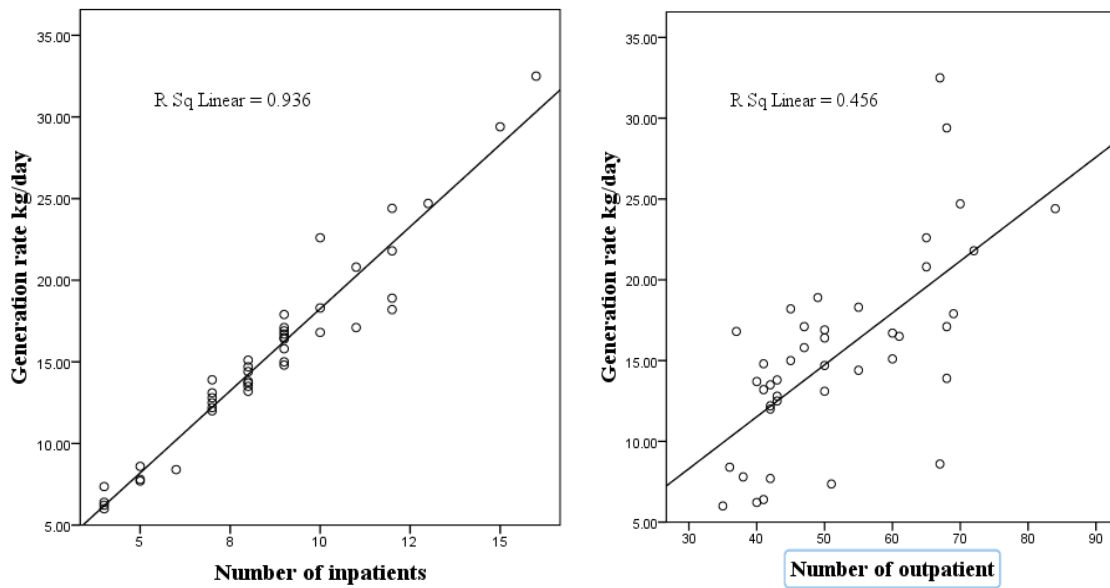


**Figure 13:** Scatter plot, showing the relation between healthcare wastes generated in kg/day with the daily number of inpatients and outpatients for referral hospitals, Amhara National Regional State, Ethiopia, 2014.



**Figure 14:** Scatter plot, showing the relation between healthcare wastes generated in kg/day with the daily number of inpatients and outpatients for district hospitals, Amhara National Regional State, Ethiopia, 2014.

The total healthcare waste generation rate has correlation with the number of inpatients with  $R^2 = 0.908$  and the number of outpatients  $R^2 = 0.868$  for district hospitals (Figure 14).



**Figure 15:** Scatter plot, showing the relation between healthcare wastes generated in kg/day with the daily number of inpatients and outpatients for private hospitals, Amhara National Regional State, Ethiopia, 2014.

Healthcare waste generation rate has correlation with the number of inpatients  $R^2 = 0.936$  and the number of outpatients  $R^2 = 0.456$  for private general hospitals (Figure 15). From the scatter plot figure 13, 14 and 15 observed that the relationship between the number of inpatients and the number of outpatients versus daily generated hospital healthcare waste are linear.

The results of this study revealed that healthcare waste generation rate significantly varies from hospital to hospital based on the operational function of the hospitals. Public referral hospitals were found to be the highest healthcare waste generators followed by public district and private general hospitals in their consecutive order. Hence, to increase the accuracy of prediction, it is required to select separate predictive models for different type of hospitals (Private General, District public and Referral public hospitals). Based on the linear relationship the following predictive models were selected and presented as equations 6, 7 and 8.

**Predictive model for public referral hospitals**

$$\text{Generation rate in kg/day (Y)} = 1.208(\text{NIPT}) + 0.159(\text{NOPT}) \dots \dots \dots \text{Eq.6}$$

Where, NIPT is the number of inpatients and NOPT is the number of outpatients.

**Table 6:** Statistical characteristics of the model for referral public hospitals, Amhara National Regional State, Ethiopia, 2014 (Equation 6)

R	R square	Adjusted R square	Std Error	Change statistics			
				R square change	F change	df	Sig F change
0.971	0.944	0.941	50.68	0.944	327.3	39	0.0001

**Regression parameter estimate**

Variables	Parameter estimate	Standard error	T-value	α-level
Intercept	1.355	16.497	0.08	0.935
Inpatient	1.208	0.075	16.11	0.0001
Outpatient	0.159	0.065	2.45	0.019

**Note:** Acceptable α-level (level of significance) = 0.100; F represents general linearity test;  $R^2$  represents coefficient of multiple determination; df represents degree of freedom; Adjusted  $R^2$  represents adjustment of  $R^2$ ; and T represents - importance of model variables.

**Predictive model for public district hospitals**

Generation rate in kg/day (Y) = - 11.82 + 1.015(NIPT) + 0.211(NOPT).....Eq.7

Where, NIPT is the number of inpatients and NOPT is the number of outpatients

**Table 7:** Statistical characteristics of the model for district public hospitals, Amhara National Regional State, Ethiopia, 2014 (Equation 7)

R	R square	Adjusted R square	Std Error of the Estimate	Change statistics			
				R square change	F change	df	Sig F change
0.984	0.968	0.966	3.04	0.968	574.8	39	0.0001

**Regression parameter estimate**

Variables	Parameter estimate	Standard error	T-value	α-level
Intercept	-11.82	1.795	-6.58	0.0001
Inpatient	1.015	0.093	10.88	0.0001
Outpatient	0.211	0.025	8.46	0.0001

**Note:** Acceptable α-level (level of significance) = 0.100; F represents general linearity test; R<sup>2</sup> represents coefficient of multiple determination; df represents degree of freedom; Adjusted R<sup>2</sup> represents adjustment of R<sup>2</sup>; and T represents - importance of model variables.

### Predictive model for private general hospitals

$$\text{Generation rate in kg/day (Y)} = -4.945 + 1.775(\text{NIPT}) + 0.098(\text{NOPT}) \dots \text{Eq.8}$$

**Table 8:** Statistical characteristics of the model for private general hospitals, Amhara National Regional State, Ethiopia, 2014 (Equation 8)

R	R square	Adjusted R square	Std Error of the Estimate	Change statistics			
				R square change	F change	df	Sig F change
0.983	0.966	0.964	3.04	0.966	550.96	39	0.0001
Regression parameter estimate							
Variables	Parameter estimate		Standard error	T-value	α-level		
Intercept	-4.945		0.768	-6.441	0.0001		
Inpatient	1.775		0.074	24.129	0.0001		
Outpatient	0.098		0.017	5.825	0.0001		

**Note:** Acceptable α-level (level of significance) = 0.100; F represents general linearity test; R<sup>2</sup> represents coefficient of multiple determination; df represents degree of freedom; Adjusted R<sup>2</sup> represents adjustment of R<sup>2</sup>; and T represents - importance of model variables.

#### 4.4. Evaluation of the impact of segregation practice on the generation rate of hazardous healthcare waste

The implementation of healthcare waste segregation practice based on the categories could reduce the hazardous waste generation. In this study, after training given for health professional and waste handlers then with strictly follow up implemented healthcare waste segregation practice. Finally, compare the hazardous healthcare waste generation rate before the implementation of strict segregation practice and after the implementation.

**Table 9:** Composition and generation rate based on the number of inpatient (kg/bed/day) of healthcare waste in Debre Birhan referral hospital before and after the implementation of segregation practice, average with standard deviation (SD) and percentage of hazardous waste, Amhara National Regional State, Ethiopia, 2014.

Segregation practice	Healthcare waste composition in kg/bed/day						Average Hazardous (%)
	General	Infectious	Sharps	Pharmaceutical	Pathological	Radioactive	
Before intervention	0.62 ±0.12	0.64 ±0.17	0.07 ±0.03	0.12 ± 0.04	0.14 ±0.05	0.0013 ±0.0002	61.04
After intervention	1.10 ±0.11	0.45 ±0.12	0.06 ±0.01	0.14 ±0.1	0.22 ±0.11	0.001 ±0.001	44.2

From table 9, observed that the percent hospital hazardous healthcare generation rate reduced about 17%. This reduction of hazardous hospital healthcare is statistical significance (P-value less than 0.0001).

#### **4.5. Healthcare waste management practices: systematic review (Paper IV)**

In this review, examine 360 published literatures addressing healthcare waste management system. The review was limited to, articles published in the year 2003 or later to best illustrate the current state of hospital waste management. Based on the inclusion criteria detailed review involved 28 research papers on healthcare waste management in different regions; this given the varied nature and geographical range of the papers found chosen to provide a relevant level assessment and summary of recurrent themes within this brief report.

### **Reasons for poor waste management**

Many researchers confirmed that, the important reasons for poor healthcare waste management are: lack of awareness, lack of comprehensive staff training, lack of facilities, and absence and/or weak enforcement of rules and regulations (12, 80-84).

### **Approaches for achieving better healthcare waste management**

The research conducted in different areas and time verified that good healthcare waste management achieved by: the presence of responsible waste management team, preparing compressive plan, the waste handlers equipped with the latest information, skill and practices, allocation of adequate financing, the estimation of the amount and type of healthcare waste, use of enforced codes of practice and guidelines, provision of regular training for staffs, and full participation of all staffs (13, 81, 85).

### Review of main findings of manuscripts I-III

**Table 10:** Summary of the main findings, Amhara National Regional State, Ethiopia, 2014.

Paper	Objectives/Research question	Main findings
I	To assess the current practices of solid healthcare waste management systems	In all surveyed hospitals, standard healthcare waste segregation practice was lacking. Consequently hazardous wastes are mixed with the general waste.
II	To determine solid healthcare waste composition and generation rate.	The rate of generation of hazardous healthcare waste in kg/bed/day in private hospitals is greater than the generation rate in public hospitals.
III	To select the best fit predictive models that can be used as a tool precisely estimate solid healthcare waste generation rate.	The influence of number of inpatients and outpatients treated in the hospitals on healthcare waste generation rate varies in different hospitals (private general, public district and public referral hospitals).

## 5. DISCUSSIONS

This study focused on the determination of healthcare waste generation rate, composition and assessment of its management system using mixed study designs. Both quantitative and qualitative data collection techniques were implemented to collect data on healthcare waste generation and its management systems. In addition, a pilot intervention was applied to evaluate the effect of segregation practice on the generation rate of hazardous healthcare waste.

### 5.1. The practice of hospital healthcare waste management systems

Healthcare waste management practice includes all activities of healthcare waste segregation, storage, collection, transportation, treatment, disposal and other safety measures in the health institutions (42).

The first priority among the waste management practices is segregation of waste at the point of generation (40). This research indicated that there was no proper healthcare waste segregation practice using colour code containers and labels (international hazard symbol) in all study hospitals. This finding is similar to the study conducted in Somaliland and Kenya (86, 87). These indicated that the implementation of healthcare waste segregation is a challenge in East Africa Region. The reason was healthcare workers, administrative and waste handler staffs were not adequately perceived the health risk of handling healthcare waste.

Intermediate storage takes place in a specially designed storage area in order to avoid biodegradation, odours, and the attraction of insects and rodents (37). In all study hospitals mixed (hazardous and nonhazardous) healthcare wastes were temporarily stored in open dustbins for about 12 hours that could attract insects, rodents, cat/dogs and they were also prone to spill over; these could potentially contaminate the environment. There is a possibility that such mixed waste can contain harmful agents (microbiological pathogens, sharps, hazardous chemicals, and radioactive substance) that can cause disease and injury to those exposed to them (40, 88). Similar practices of healthcare waste temporary storage practices are also reported in Nigeria, Libya, South Africa, and Ethiopia (31, 33, 37). This implies that in developing countries temporary healthcare waste storage practice creates a health risk to the workers as well as to the public.

In all surveyed hospitals, mixed wastes were collected and transported in a carton or open plastic bins without labelled at the point of generation. The wastes were scattered on the surrounding treatment and disposal sites due to the use of sub-standard waste containers. This will also contribute to the risk of infections for healthcare providers, patients, visitors and the neighbouring community. This finding is different from the study conducted in India (2012), which states that all containers used for collection of hazardous wastes were standard with a proper cover and labelling (89). The difference may be due to the difference on the level of awareness of the healthcare professionals, waste handlers, and decision makers. However, this result is similar to the study conducted in Iran (2011), which reported malpractices of collection and transportation (81).

The most common treatment and disposal methods used by all sampled hospitals were burning in open pit or using faulty design incinerators and pit burial. The dumping and burial sites were in close proximity of the hospital premises. The use of low combustion single-chamber incinerators for the treatment of healthcare waste was against the Stockholm Convention on persistent organic pollutant (90). Since, such incinerators release air pollutants to the environment (17). Therefore, the current practices of healthcare waste treatment in the hospitals could expose the whole community at high risk of accruing chronic and acute health problems. Such malpractices also reported in Jos Metropolis, Nigeria (91).

Furthermore, regular supervision and technical support were not provided routinely in both public and private hospitals. Monitoring by experts at the regional, zonal and district level has a significant role in checking whether all requirements under the law are being met. In addition, the Ethiopian Ministry of Health (MOH) guideline regarding healthcare waste management also recommends that ad hoc committee should be established for monitoring healthcare waste management system at the hospitals (67). However, in all the surveyed hospitals there was no any ad hoc committee established to monitor healthcare waste management. And national healthcare waste management guideline, manual and instructive posters on waste segregations and healthcare waste management strategic plans were not present in all hospitals. This implies that there was no organized structure established to monitor healthcare waste management.

Healthcare waste handling is a hazardous activity; thus, workers should be trained before starting work handling waste, and then on a regular basis (2). Best practices in healthcare management require workers, who receive continuous training (23). This study retrieves that, the public hospitals had organized training related to infection prevention and healthcare waste management to waste handlers, environmental health professionals and heads of departments. However, there was no regular training or on-job orientation for all healthcare workers. All private hospitals had not provided any training related to healthcare waste management and infection prevention to health providers. The study conducted in Nigeria also confirmed that, there were no regular formal training programs on healthcare waste management (92). This might be the main reason for the lack of practice of adequate precautionary measures in handling healthcare waste and exposed themselves as well as the public health risk and pollute the environment.

## **5.2. Composition and generation rate of hospital healthcare wastes**

The average total hospital healthcare waste generation rate estimated in kg/bed/day was  $1.5 \pm 0.6$  kg/ bed/day. The generation rate recorded in this study is smaller compared with the generation rate in Iran (2004) 2.71 kg/bed/day, UK (3.3 kg/bed/day), Norway(3.9 kg/bed/day) and Kuwait (7.0–10.0 kg/bed/day) as it can be seen in Bdour et al. (2007) (37, 54). The reason for this is the higher the per capita gross domestic product (GDP), the higher quantity of hospital healthcare waste which is related to the high supply and provision of healthcare services. The study conducted in Ethiopia (2011) show a higher waste generation rate range (0.75–10.47 kg/bed/day), but the results of this study are comparable with those reported in Turkey (2010) 2.35 kg/bed/day (31, 58). With the exception of this small discrepancy, the findings are in agreement with the fact that in developing countries the overall healthcare waste generation rate is smaller than in developed nations. As the healthcare delivery system of the country is similar across the regional states, the findings of this research may serve for all hospitals in similar settings.

The average hazardous waste generated that is expressed as kg/bed/day in private and public hospitals is presented in Figure 11. The percentage value of the hazardous component of the total healthcare waste is above 50% in both types (private and public) of hospitals. This pattern was also found in all hospitals except for one district (36 %) and one zonal hospital (44 %). However, in all hospitals generated hazardous waste above the

10-25% threshold set by WHO (2013) and WHO (2005) (2, 22). Similarly, the study done in Iran (2004) reported higher proportions of hazardous hospital healthcare waste (29%) were generated, the study conducted in South Africa (2008) reported up to 39% and the study report in Tanzania (2011), the highest percentages of hazardous waste (67%) was recorded (29, 33, 54). All of these reports, the levels above the World Health Organization limit (10-25%), similar to our findings. The major reason for the high percentage of hazardous waste in hospitals of developing countries appears to be the improper segregation of different types of waste materials by health professionals and inadequate education of auxiliary health workers. For example, research carried out on risk perception of healthcare workers towards healthcare waste management in Ethiopia showed that only a small proportion of healthcare workers adequately perceived the health risk of handling waste materials (93). This deficiency is linked with inadequate training and supervision of health workers and, lack of enforceable health regulations aimed at providing a safe working environment at healthcare facilities.

The one-way ANOVA test between-subjects showed that a significantly higher average value of hazardous waste for private hospitals than in government hospitals ( $P < 0.05$ ). This is owing to the fact that, unlike private hospitals, the government has to keep healthcare costs down by controlling supplies and services. As a result, the generation rate of hazardous waste was less than that of private hospitals. This finding contrasts with the study conducted in Hawassa City (2011), which states that the government hospitals produced more hazardous waste than private hospitals. This discrepancy might be due to the differences in the study area, considered only hospitals found in one Town and sample size (31).

The generation rates of total number of patients (in and outpatient) estimated in kg/patient/day was not significantly different when compared between private and government hospitals (Figure 12). On the contrary, the generation rates of inpatients estimated in kg/bed/day were significantly higher in private hospitals than government hospitals (Figure 12). This is owing to the fact that patients who have access to private hospitals have high incomes and can make a significant contribution to the generation rate of healthcare waste. The healthcare waste generation rate is dependent on the socioeconomic status of patients (54). Despite this fact, our finding contradicts with the

report in Bangladesh (2009), which concludes that the generation rate in kg/bed/day is similar for both private and governmental hospitals (49).

The healthcare waste generation rate in public hospitals in terms of kg/outpatient/bed was  $3.54 \pm 14.91$  (Figure 12), the reasons for this higher standard deviation and high estimation is due to the week end days the number of outpatient was less than compared to the regular days in all public hospitals but the number of inpatients were almost similar in all days. However, the healthcare waste generation rate is highly influenced by the number of inpatient due to this fact that the waste generation rate in kg/outpatient/day estimation has high variation compared to the estimation based on the number of inpatients.

### **5.3. Selection of best fit Models for the Prediction of Hospital Healthcare Waste Generation Rate**

The healthcare waste generation rate has a strong correlation with the number of inpatients,  $R^2 = 0.935$ ,  $0.908$  and  $0.936$  for referral, district public and private general hospitals respectively and the number of outpatients,  $R^2 = 0.57$ ,  $0.868$  and  $0.456$  for referral, district public and private general hospitals respectively. The findings of this study indicate that a stronger positive correlation of healthcare waste generation rate with the number of inpatients than the number of outpatients. This is due to longer hospital stays of inpatients with services in hospitals. These findings are almost similar to the study conducted in Greece (2011) and the study conducted in Nigeria (2013) (18, 47). On the contrary, the study conducted by Eker and Bilgili (2011) in Istanbul, Turkey showed that, the evaluation of the waste streams in accordance with the outpatient number gave more appropriate results than other evaluation methods. The observed significant P values ( $P > 0.05$ ) indicate that the evaluation of the waste streams in healthcare services to outpatients does not show any reasonable change associated with service category (58). The reason might due to the aim of the study done by Eker and Bilgili was focusing the waste categories. In fact that waste categories are less likely to be affected by the outpatient (46).

Hospital healthcare waste predictor variables (number of inpatient and outpatient treated in the hospitals) in this study are similar to the study conducted in India (2007), in Jordan

(2007), in Kuwait (2007), in Taiwan (2009) and in Jordan (2004), healthcare waste generation rate affected by the number of inpatient and outpatient treated in the hospital (35-37, 56, 94).

The prediction models described in this research were validated with the comparison between the generation rate reached using the prediction models and the study report conducted in Hawassa City (2011) (31). The result indicated that based on the model (referral hospital healthcare waste generation rate =  $1.208 (\text{number of inpatients}) + 0.159 (\text{number of outpatients})$ ), the generation rate equals 4.36 kg/day, which is within the range of the Army hospital generation rate 7.3 (1.5 to 8.5) actual measurement study result. In addition, the private hospital prediction model (healthcare waste generation rate =  $-4.945 + 1.775 (\text{number of inpatients}) + 0.017 (\text{number of outpatients})$ ) equals 14.1 kg/day, this is also within the range of Asher general private hospital generation rate 11.9 (8 to 16.1) kg/day study report. These shows, the rates are approximately the same between the rate estimated by the prediction models and the actual measurement result.

#### **5.4. The effect of segregation practice on the generation rate of hazardous healthcare waste**

The percentage of hazardous hospital healthcare waste generation rate before the implementation of segregation practice intervention was about 61%, and after application of intervention was about 44 %. This implies that the application of segregation practice able to reduce the hazardous hospital waste generation rate about 17 %. Nevertheless, with this reduction rate, the total percent hazardous waste (44%) is higher than the range of World Health Organization (WHO) report (10-25%). The variation might be due to the health professional had less experience on the segregation practice (2).

## **6. VALIDITY AND GENERALIZABILITY**

The validity of a study is determined by identifying whether the findings reflect the true relationship between exposure and outcome of interest. That is, it is important to find out whether and to what extent alternative explanations, such as chance, bias, or confounding accounted for the observed association. Assuring the validity and generalizability for both the qualitative and quantitative components is mandatory when a mixed method research is conducted.

### **Internal validity**

Internal validity of a research is the ability to measure accurately, what is supposed to measure. The findings of a study could be explained by other facts than the study itself. It could be due to chance, bias and confounding that should be ruled out through closer evaluation of the study design, the selection of study participants and the data analysis. Possible alternative explanations for study results could be:

### **Chance**

Chance refers to the likelihood that sampling variability (random error) explains the observed result. The sources of random error are sampling variability at the selection and use of unreliable measurement instruments at implementation stages. The role of chance in this study was addressed by using adequate and representative samples for each specific objective, measured for seven consecutive days and include wet and dry seasons, performing appropriate statistical tests, estimating the mean with standard deviation; the instrument was designed to measure all components of the variables in question to ensure high content validity and evaluating the reliability of measurement instruments.

### **Selection bias**

This is a systematic sampling error that results from procedures used to select the study participants and from factors that influence study participation. The selection bias was managed in this research by the application of random sampling to select the study hospitals and involved all the department head in the study hospitals for in-depth interview about the current practice of healthcare waste management systems.

### **Information bias**

It is a systematic error that results from systematic differences in the process of measuring the study variables. Various actions were taken, starting from designing data collection tools and materials, were taken to reduce the role of bias as alternative explanations for the research finding. The use of questionnaire adapted from a standard document, calibrating the measuring instrument, recruiting experienced data collectors, provision of training for data collectors and conducting closed supervision during data collection were among the major inputs to reduce information biases during measurement. In addition, to avoid information response bias, the researcher clearly stated about the purpose of the research. An attempt was also made to reduce recall bias by including only staffs currently working the head of the department and directly related to healthcare waste handling.

### **Sources of error**

Errors can overestimate, underestimate or change the direction of the observed association.

### **List of possible Sources of errors**

The following were identified as possible sources of errors: operating times of hospitals, seasons of the year could affect the number and types of patients and economic status of the patients.

Actions taken: Measuring 24 hours waste generated and in all the seven consecutive days, data collected in two main seasons (dry and wet), incorporate both the hospitals found in urban and rural, data collected in both private and public hospitals were possible solutions for control identified confounders. In addition, Applying multilevel modelling was the practical option implementing for controlling the sources of errors in this study.

### **External validity**

External validity (generalizability) refers the finding based on the sample are applicable to other population. In this research, the results from the sample hospitals are applicable for other hospitals. This research investigates different levels of hospital, as well as

private and government hospitals, which means include all types of hospitals found in the healthcare system in Ethiopia. Interviews were conducted in the natural setting of the participants. The models were validated with the comparison between the generation rate reached using the prediction models and those reported in the literature. Therefore, the results may serve as a stepping stone in evaluating the success and failure of pre- and post-intervention projects, and could be useful for the development of operational guidelines for the management of healthcare waste in health facilities nationwide.

## 7. STRENGTHS AND LIMITATIONS

### 7.1. Strengths

One of the major strengths of this research was the use of different methods (measurement, interview and observation) to measure and understand the problem. A mixed method is a programmatic approach to facilitate a comprehensive understanding from a different perspective, produce a clear picture of the problems.

The second strength is incorporating measuring the generation rate of healthcare waste, predicted the generation rate and understands the system applied in handling this hazardous waste. The third strength is included representative sample size in all types of hospitals. Therefore, this research could be useful for the development of operational guidelines for the management of healthcare waste in health facilities nationwide. In addition, this research has added new knowledge in the healthcare waste management system by:

1. Implementing better methodological approaches (measuring 24 hours and all seven days waste generated) for predicting healthcare waste generation rate.
2. Evaluate the contribution of hospitals in public health and environmental pollution.
3. Precisely determine healthcare waste generation rate by measuring at different seasons.
4. Produce a clear picture of healthcare waste generation rate by incorporating all types of hospitals and cover different geographic location found in Ethiopia healthcare systems.

### 7.2. Limitations

#### **The limitations of this research:**

1. Determination and estimation of healthcare waste generation rate based on the two seasons measurement, but for better accuracy it needs to incorporate all the four different seasons that exist in Ethiopia.
2. In this study test only the impact of one component of healthcare waste management practice that is, standard segregation practice (full components are storage, segregation, treatment, collection, transportation, and disposal), but it needs testing both components of healthcare waste management practices.

## 8. CONCLUSIONS

The healthcare waste management requires special attention because of the risk posed by the presence of hazardous substances in the healthcare waste. From the surveyed hospitals, we confirm that, the handling, storage, transport and disposal method of solid wastes practiced by the hospitals in the Region were ineffective to protect the environment from contamination and create public health risks. Hazardous hospital healthcare waste was mixed with the non-hazardous waste. The use of low combustion single-chamber incinerators for the treatment of healthcare waste contributes the release of huge amounts of air pollutants to the environment. Overall, the waste management systems in the Region were poor and create a potential health risk as well as environmental pollution.

Average generation rates of total hospital healthcare wastes in the Public hospitals were  $1.61 \pm 0.52$  kg/bed/day ( $3.54 \pm 1.4$  kg/outpatient/day) and in Private hospitals were  $4.17 \pm 2.69$  kg/bed/day ( $2.32 \pm 1.52$  kg/outpatient/day). The influence of number of inpatients and outpatient treated in the hospitals on healthcare waste generation rate varies in different hospitals (private general, public district and public referral hospitals). The rate also varies by ownership, with private hospitals producing significantly more total hospital healthcare waste (kg/bed/day) than government-run hospitals. These results indicate that both measures of healthcare waste generation (kg/bed/day, kg/outpatient/day and kg/total patient/day) need to be used in combination to reliably quantify the waste generation rates for different types of waste at individual facilities.

The composition of hazardous hospital healthcare wastes were  $0.82 \pm 0.36$  kg/bed/day (53.57 %) in Public hospitals and  $2.32 \pm 1.52$  kg/bed/day (56.26 %) in Private hospitals. This indicates higher hazardous hospital healthcare waste per inpatient generated in Private hospitals.

Statistical analysis revealed that the number of inpatients and outpatients treated in the hospitals were the main significant factors affecting the hospital healthcare waste generation rates. It was found that when the number of inpatients and outpatients increased, the generation rate increased. The models developed in this research are providing for the decision makers with tools to better manage hospital healthcare waste, based on the type of hospitals.

## 9. RECOMMENDATIONS

This research has demonstrated, a number of gaps regarding proper hospital healthcare waste management in the Region. The following are recommendations regarding the different aspects of healthcare waste management that need to be addressed to ensure proper handling and disposal in order to protect the environment and the public

### **Policy makers (Ministry of Health and Regional Health bureau)**

The proper development and implementation of an information-based healthcare waste management strategic plan has significant benefits for hospitals. There is an urgent need for raising awareness and education on healthcare waste issues. This must be supported by a representative and fully functional healthcare waste management structure, which is able to monitor and control all healthcare waste management activities.

Develop rules, regulations and operational guideline for the management of healthcare waste in health facilities nationwide.

### **Program implementers (Zone and District health offices)**

Systematic collection and use of standardized analytical methods of data on healthcare waste among representative hospitals in different administrative regions of Ethiopia may form the basis for the development of feasible, environmentally safe and cost-effective healthcare waste management system.

### **Hospital administrators (service providers)**

Waste generators should play very crucial role to ensure proper handling, transportation, and disposal of the waste they generate. The hospital healthcare waste management emphasises the duty of care as one of the responsibilities of the healthcare waste generator. The employer is entrusted with the responsibility of providing a safe working environment, protection of the environment and public health. Proper education and awareness must be implemented in all hospitals. Adequate budgeting allocation, regular training and investment in HCW management should be implemented by the hospital administrators.

Record keeping is also the responsibility of the waste generator. It is important for a number of reasons, such as being a management tool, providing a baseline for measuring progress in terms of implementing the healthcare waste management plan.

### **Hospital healthcare waste storage area**

There is a need for all hospitals to implement closed and easily cleanable waste container and also identify appropriate area designated as a waste storage area.

### **Hospital healthcare waste segregation**

Before considering waste segregation, healthcare institutions should first consider waste minimization, and must apply the principle of green purchasing. When minimization fails, then proper waste segregation at the source must be implemented, with waste separated into the six relevant categories and not mixed from that point until disposed of. Waste segregation and colour-coding should work jointly. Appropriate colour-coded containers must be used at all times.

### **Hospital healthcare waste transportation**

The healthcare waste generators must practice environmentally safe waste transportation by using structured collection and transportation system for general and hazardous waste.

### **Hospital healthcare waste treatment and disposal**

The incinerators used for the treatment of healthcare wastes should be properly designed and constructed to burn waste completely. Proper landfill principles can be applied in order to dispose of their hospital healthcare waste without compromising the environment and public health.

### **Healthcare waste management plan**

All hospitals must have a waste management plan, drafted after a properly conducted healthcare waste audit. Data on healthcare waste collection, segregation, transportation, storage, disposal, protective equipment, education, training and awareness must be included in the waste management plan.

### **Healthcare waste management team**

All hospitals must have a functional and accountable hospital healthcare waste management structure that meets on a regular basis and which is assigned the responsibility of evaluating progress in terms of the implementation of the healthcare waste management plan.

### **Researchers - Further research**

Further studies should consider four seasonal variations in healthcare waste generation in view of temporal variations in the occurrence of endemic diseases and hospital utilization by the Ethiopian population, especially in rural areas, and make recommendations for improved waste management practices at the regional and national level.

Impact of intervention on healthcare waste management system were not studied; therefore, study should be conducted on the evaluation of the effectiveness of measures taken on healthcare waste storage, collection, transportation, treatment disposal and other intervention for the improvement of healthcare waste management.

## **ACKNOWLEDGMENTS**

I am deeply grateful to my supervisors Dr. Abera Kumie and Dr. Abebe Beyene for their unreserved support, advice and encouragement throughout my PhD study. I am very grateful to Addis Ababa University and School of Public Health for providing me the training opportunity and financial support to accomplish my PhD work. I would like to extend my heartfelt thanks to the Amhara Regional Health Bureau and hospital staff for their support in accessing their documents and support during the data collection preparations and processes. Finally yet importantly, I want to acknowledge the data collectors, supervisors and all of the respondents who participated at different stages of this study.

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## ANNEXES

### **Annex 1: Original papers**

#### **Paper I (Under review on the Journal- International Journal of Occupational and Environmental Health)**

##### **Critical assessment of healthcare waste management practice in Ethiopia**

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## ABSTRACT

**Background:** Despite the high disease burden associated with poor healthcare waste management in developing countries, little is known about the current practices of healthcare waste management system in hospitals of Sub-Saharan Africa where Ethiopia is the case in point.

**Objectives:** The aim of this study is to examine the existing practices in view of developing a standard healthcare waste management intervention strategy in Ethiopia.

**Methods:** A cross sectional descriptive study was conducted in nine randomly selected hospitals from March to April 2014. Data on the practice of healthcare waste management system was collected using semi-structured questionnaire and an observational checklist.

**Results:** All public hospitals used open pits located in their back yard for the final disposal of their untreated healthcare waste. The private hospitals mixed their untreated healthcare waste with the municipal squander. The practice of healthcare waste segregation was found very limited in all hospitals. There was no structured collection, transportation, treatment and disposal system for general and hazardous waste in both private and public hospitals.

**Conclusion:** Overall, the healthcare waste management systems in study hospitals were found to be haphazard and ineffective to tackle environmental contamination and public health risks. Therefore, there is an urgent need to establish environmentally sound healthcare waste management system at all healthcare facilities.

**Key words:** Hazardous waste; Healthcare Waste; Hospital; Waste management; Practice; Ethiopia

### 1. INTRODUCTION

Hospitals are among the complex institutions that provide preventive, curative and rehabilitative services to saving lives and improving the well being of the communities. Different healthcare activities in these health institution lead to the generation of tremendous amount healthcare waste containing a large component (75-90%) of non-risk

or ~~general~~ healthcare waste, which is comparable to municipal solid waste and a smaller component (10-25%) of hazardous waste. The hazardous and toxic parts of waste from healthcare establishments contain infectious, bio-medical, chemical and radioactive material (1). Improper waste management in which the hazardous waste is mixed with the general waste can lead to the entire bulk of the wastes becoming potentially hazardous. If the hazardous wastes are improperly managed, the pathogens and toxic chemicals in the healthcare waste could lead to infections, infertility, hormonally triggered cancers, genital deformities and neurological disorders both in the short and long-term exposure (2-4). In addition, inappropriate management of healthcare waste affects the immediate environment. For example; the indiscriminate burning of wastes containing polyvinylchloride (PVC) produces known human neurotoxins and carcinogens such as dioxin and furan (5). Wrongly buried healthcare wastes could cause surface and ground water pollution, which in turn threatens the human and aquatic life (3-6).

Because of the increasing demand of quality health services and utilization of single use item in hospitals cause the growth of the total quantities of healthcare waste generated from the hospitals (7). Currently, sustainable proper management of healthcare waste attracts public interest because of the increase of health problems associated with exposure of humans to hazardous wastes (8, 9). Based on World Health Organization (WHO) report of 2005, the healthcare waste management practices in developed countries reach higher safety standards (10). While, in developing countries, proper handling and management is substantially undermined (11, 12). In most developing nations, huge amount of healthcare wastes deposited openly in waste dumping site together with municipal domestic non-hazardous solid waste (13). The WHO estimated that injections with contaminated syringes caused 21 million hepatitis B virus (HBV) infections (32% of all new infections), 2 million hepatitis C virus (HCV) infections (40% of all new infections) and 260 000 HIV infections (5% of all new infections) (10). The management of healthcare waste in many developing countries has been often poor and it raises concerns because of the risk to the public health and the environment as a result of the implementation of improper healthcare waste management (14). On the contrary, real gap exist with regard to the assessment of healthcare waste management practices in sub-Saharan Africa countries (15).

Uncontrolled combustion of medical waste in Ethiopia accounted about 26% of the annual total dioxins/ furans release in 2003 (16). Because of the rapid expansion of health related infrastructure in recent times, health care waste generation rate is significantly increased in volume, and diversifying in types. However, healthcare waste management is neglected activities by health service providers and lacked the attention of the decision makers. The daily observation regarding the practices of healthcare waste management indicated that most of the health facilities had not put in place an organized management system to address health care waste management properly (17, 18). This highlight the need for sensitization of the political leaders, health care managers, providers, and their support staff for the development and implementing of guideline, directives, and a strategic plan to establish an effective waste management system in both private and public hospitals.

In developing countries, including Ethiopia, because researches in the area are few in number, and limited in scope, practical information about hospital health care waste management is inadequate, especially for the development of management schemes for hospital wastes (19). This study aimed to investigate the practice of healthcare waste management system and related public health problems in Ethiopia with the view of identifying the gaps in healthcare waste handling that require interventions. The result of this study would serve as a stepping-stone to identify the real gap in the management of healthcare waste and could be the basis for the development of feasible, environmentally safe and cost-effective healthcare waste management in healthcare facilities nationwide.

## **2. METHODS**

### **2.1. Study Design and area**

A cross-sectional descriptive qualitative survey was conducted from March to April 2014 in selected hospitals found in Amhara National Regional State, Ethiopia. Amhara National Regional State has a total of 17 public hospitals (2 Teaching, 3 Referral, 2 Zonal, and 10 District) and 6 General Private Hospitals that are located in 11 different towns. From these hospitals, we proportionally and randomly selected 6 governmental hospitals (1 Teaching, 1 Referral, 1 Zonal, and 3 District Hospitals) and 3 general private

hospitals. The study units were all the different department of the hospitals (outpatient, inpatient, laboratory, pharmacy, X-ray and offices).

## **2.2. Data collection**

Both the key informant interviews and the observations conducted by principal investigators. The data collection tools were pre-tested. The key informant interview was administered by involving one staff from each department/section, the total of 90 hospital staffs (administrator, medical directors, head of all department example Pharmacy, laboratory, pathology, surgery, environmental health, etc. and workers directly involved in waste handling). The main questions were regarding segregation, collection, transportation, storage, treatment, disposal, waste re-cycling and re-use, occupational health and safety, internal policies and administration, training, and budget for health care waste management. In addition, conducted observation in all waste generator sections/site, temporary storage container/area, treatment and transporting equipment and practice, and disposal site for seven consecutive days to show the waste management performance of the hospitals. We used the six characteristics of waste management descriptors and indicators of healthcare waste management, namely: general management strategy, collection, segregation, recycling, storage and disposal of waste to assess the overall performance using the observational checklist.

## **2.3. Data management and analysis**

Data from key informant interviews and observation were analysed by theme. We conducted a content analysis of the data manually, by sorting and organized information according to thematic similarities and differences. Then, we categorized and studied the information to understand relationships in the overall context of the research.

## **2.4. Ethical considerations**

Ethical approval and clearance were obtained from the Institutional Review Board of the College of Health Sciences, Addis Ababa University. Written permission was obtained from Amhara Regional State Health Bureau (ARSHB) and hospitals administration of the study units. All respondents were informed about the study procedures and the interview

was conducted after obtaining their written informed consent. The right of respondents to interrupt or withdraw the interview was duly respected. Privacy and confidentiality were maintained using anonymity.

### **3. RESULTS**

#### **3.1. Healthcare waste segregation practice**

In all public hospitals, only segregation of sharp waste using the safety box was practiced. Segregation of sharp waste was missing in any of the private hospitals. Placentas and blood stained cotton pads were kept in separate containers in all public and private hospitals. The use of waste containers with a colour code and labelling at the point of generation was not implemented in all hospitals. Overall, the practice of healthcare waste segregation was found very limited.

#### **3.2. Temporal storage of healthcare waste practice**

Based on our assessment, all public and private hospitals temporarily stored all wastes in open and substandard dustbins for about 12 hours. Pathological and sharp wastes were stored in a closed plastic container (similar to the container used for water storage in living house).and collected in less than an hour. Public hospitals use standard safety boxes (The box made from carton having a small hole for the insertion of needles and syringes) to store sharp wastes, while private hospitals use non-standard storages, such as carton boxes (the box made from carton used for packing shop materials) that can be easily damaged or torn out.

#### **3.3. Collection and transportation of healthcare waste**

There was no structured collection and transportation system for general and hazardous waste in both private and public hospitals. In four out of six public hospitals, open plastic bins (capacity of contain 25 liters) were used to collect and transport mixed wastes, while two public hospitals used closed plastic container (capacity of 50 liters). Only sharps and pathological wastes were collected and transported separately. Mixed waste was collected and transported in carton or open plastic bins in private hospitals. Almost in all private and public hospitals, healthcare waste was collected and transported to incineration facilities without using wheeled trolleys (leakproof made with stainless steel)

twice a day in the morning before 8:00 am and in the evening after 6:00 pm by cleaning personnel. The waste from delivery, operation and intensive care units was collected less than 2 hours.

#### **3.4. Healthcare waste treatment and disposal practice**

Except in one public hospital (Mehal Meda district hospital), pre-treatment of highly infectious waste was not practiced. The laboratory department in Mehal Meda district hospital treated infectious waste by autoclave machine. A local brick made incinerator (a simple single compartment burning zones, natural-draught air inlet opening, a chimney, top-loading and ash removal doors) was used to burn sharps waste in all hospitals. Nevertheless, the incinerators used for the treatment of healthcare wastes were not proper in design and construction. None of them was able to burn waste completely; consequently they were not reducing waste volume significantly and produced high air pollutant emission. The partial burned healthcare waste was disposed in an open pit. In addition to incinerators, all public hospitals had an open hand dug pit (the simple pit without lined with bricks or concrete and not covered by slab) in their backyard used for the direct dumping and open burning of healthcare wastes. All public and one private hospital had a placenta pit (the hole had two meters deep and one meter wide. The walls and cover on the top were constructed with concrete) for disposal of pathological waste generated from the delivery and operation rooms. Two private hospitals had no placenta pit and these hospitals were disposed pathological waste by burial within the compound.

#### **3.5. Healthcare waste reuse and recycling practice**

Healthcare waste reuse and recycling practice were almost absent in all public and private hospitals, except reusing drug containers (example: cans, plastic and bottles) in all hospitals without any pre-questions and recycling of silver from a radiology waste in one of a public hospital (Gondar Teaching Hospital).

#### **3.6. Training and safety device**

The public hospitals had organized training related to infection prevention and healthcare waste management to few hospital staff members. However, either there was no regular

training or on the job orientation for all healthcare workers. All private hospitals had not provided any training related to healthcare waste management and infection prevention to health providers. Waste handlers had heavy duty gloves, boots, and clothes in all public hospitals, but in private hospitals they had only heavy duty gloves, and clothes. Only two public hospitals (Debre Tabor and Debre Birhan) had a system of treatment support and reporting during the occurrence of injuries in the process of waste handling practices. The report indicated that there were five needle stick injuries within ten months. Vaccination was not provided to healthcare waste handlers in all hospitals. None of the hospitals had formal guidelines and procedures for prevention of occupational injuries. In general, safety guideline for healthcare waste management was not found in any of the hospitals.

#### **4. DISCUSSION**

Healthcare waste management practice includes all activities of waste segregation, storage, collection, transportation, treatment, disposal and other safety measures in the health institutions (20).

Improper healthcare waste management in which the hazardous wastes (10-25%) mixed with the non-hazardous waste (75-90%) can lead to the entire bulk waste becoming potentially hazardous (1). To minimize the percentage of hazardous waste, the hospitals should develop and implement a proper waste management system (10). The first priority among the waste management practices is segregation of waste at the point of generation (21). This research indicated that there was no proper health care waste segregation practice with colour coding of containers and labels (international hazard symbol). This finding is similar to the study conducted in Somaliland and Kenya (22, 23). This indicating that implementation of healthcare waste segregation is a challenge in East Africa Region. . The major reason was healthcare workers, administrative and waste handler staffs were not adequately perceived the health risk of handling healthcare waste.

The place where the healthcare waste is kept before transporting to the final disposal site is termed as a temporary waste storage area (24). Intermediate storage takes place on specially designed storage area in order to avoid biodegradation, odours, and the attraction of insects and rodents (25). Mixed (hazardous and nonhazardous) healthcare

waste temporarily stored in open dustbins for about 12 hours that can attract insects, rodents, cat/dogs and they are also prone for spill over and could potentially contaminate the environment. There is a possibility that such mixed waste can contain harmful agents (microbiological pathogens, sharps, hazardous chemicals, and radioactive substance) that can cause disease and injury to those exposed to them (21, 26). Similar practices of healthcare waste temporary storage practices were also reported in Nigeria, Libya, South Africa, and Ethiopia (25, 27-29). This implies, in developing countries temporary healthcare waste storage practice was created potential health risk to the workers as well as to the public.

In all surveyed hospitals, mixed wastes were collected and transported in a carton or open plastic bins and not labelled at the point of generation. The wastes were scattered on the surrounding treatment and disposal sites due to the use of substandard waste containers. This will also contribute to the risk of infections for health care providers, patients, visitors and the neighbouring community. This finding is different from the study conducted in India by Akansha et al. (2011) which states that all containers used for collection of hazardous wastes were standard with a proper cover and labelling. The difference is on the level of awareness by the healthcare professionals, waste handlers, and decision makers. However, this result is similar to the study conducted in Iran by Hassan Taghipour and Mohammed Mosaferi (2009) which reported that malpractices of collection and transportation of healthcare waste (30, 31).

The use of low combustion single-chamber incinerators for the treatment of healthcare waste was against the Stockholm Convention on persistent organic pollutant (32) since such incinerators release air pollutants to the environment (15). Therefore, the current practices of healthcare waste treatment in the hospitals will expose the whole community at high risk of accruing chronic and acute health problems. Such malpractices are also reported in Jos Metropolis, Nigeria (33).

Handling of healthcare wastes are dangerous activities. Therefore, workers involving in these activities should be trained before starting the practice and on the regular basis (1). The training focus on the safe waste handling procedures, nature of the work in the hospital, the hazards and possibility of worker exposure, and the responsibilities of

individual workers (20). Best practices in healthcare waste management require that workers received regular training (3). This study retrieve that, the public hospitals had organized training but, there was no regular training or on the job orientation for all healthcare workers. The study conducted in Libya and Nigeria also confirmed that there were no regular formal training programs on healthcare waste management (28, 30). This might be the main reason for experiencing lack of adequate precautionary measures during handling of healthcare waste in addition absence of working guidelines.

Generally, in all surveyed hospitals, each component of healthcare waste management practice contradicts with Ethiopia National healthcare waste management guideline. Such practice is similar to the study conducted in Nigeria by Bella et al. (2012), the study done in South Africa by Nemathage et al. (2008) and the survey report on Iran by Titto et al. (2012). This is because healthcare waste handling activities did not receive proper attention in the developing countries.

## **5. CONCLUSIONS**

The finding of this study confirmed that standard healthcare waste segregation was lacking in all hospitals. Consequently, all healthcare wastes were mixed with the general waste that leads to the total healthcare waste generated to be considered both infectious and hazardous. The wastes were collected and transported using a non-standard encoded container and hence both the collection and transportation systems were ineffective to protect the environment from contamination. The use of low combustion single-chamber incinerators for the treatment of healthcare waste contributes the release of huge amounts of air pollutants to the environment. Overall, the waste management systems in Ethiopia were almost not yet installed and create an environmental pollution and potential health risk. There is an urgent need to establish standard healthcare waste management at all healthcare facilities in developing countries.

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## Assessment of composition and generation rate of healthcare wastes in selected public and private hospitals of Ethiopia

Waste Management & Research  
2014, Vol. 32(3) 215–220  
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sagepub.co.uk/journalsPermissions.nav  
DOI: 10.1177/0734242X14521683  
wmr.sagepub.com  
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### Abstract

In many developing countries, the inadequacy of data regarding the quantity and composition of healthcare waste is one of the major reasons for improper healthcare waste management. We investigated the generation rate and composition of healthcare wastes in six public and three private hospitals. We conducted healthcare waste composition and characterization measurements for seven consecutive days in the selected hospitals following the protocol described by the World Health Organization (WHO). The results revealed that the total generation rate of healthcare wastes of hospitals ranged from 0.25 to 2.77 kg/bed/day with a median value of 1.67 kg/bed/day for inpatients to 0.21–0.65 in kg/patient/day with a median value of 0.31 kg/patient/day for outpatients. The waste generation rate in private hospitals (median 3.9 kg/bed/day) was significantly greater (Kruskal–Wallis test,  $P < 0.05$ ) than in government hospitals (median 1.5 kg/bed/day). The median values of percent hazardous waste estimated for private and government hospitals were 63.4% and 52.2%, respectively. These figures are about three times greater than the threshold values recommended by the WHO. This situation might be attributed to the improper practice of healthcare waste segregation by health professionals and auxiliary health workers due to inadequate risk perception and lack of enforced public health regulations. The study revealed that the generation rate and proportion of hazardous waste significantly varies between public and private hospitals and number of patients treated per day.

### Keywords

Hospitals, healthcare waste, generation rate, waste composition, Ethiopia

### Introduction

Waste produced in the course of healthcare activities entails a higher risk of infection and injuries than municipal waste. Hence, the management of healthcare waste requires special attention and needs to be assigned a high priority. Healthcare waste management is a current issue in many developing countries, including Ethiopia. In developing countries, the quantity of healthcare waste has sharply risen in recent years as a result of rapid population growth, thus increasing the demand for health services. Despite large investment in expanding public and private healthcare facilities in most developing nations (GEF, 2009), healthcare wastes are usually rampantly disposed of in the environment without any treatment (Diaz et al., 2005; Idowu et al., 2013). In this situation, healthcare waste management is the most neglected activity of most health services providers, resulting in significant exposure to occupational risks among healthcare workers (Goodnough et al., 2001), high incidence and prevalence of nosocomial infections (Allegranzi et al., 2011), and environmental contamination (Satterthwaite, 2003; Hossain et al., 2011).

In many developing countries, the unavailability and inadequacy of data about the quantity and composition of healthcare waste is one of the major reasons for inadequate and improper

healthcare waste management (WHO, 2004). Thus, it is crucial that the composition and generation rates of each component of healthcare wastes be known for the planning and implementation of healthcare waste management programs.

Only a few case studies have been conducted on the generation rate and composition of healthcare waste in Africa. In these case studies, a wide range of variation of generation rate and percent composition are reported. For instance, healthcare waste generation rates in kg/bed/day were 0.01–3.98 in Nigeria (Idowu et al., 2013), 7.0–8.0 in Tanzania (Kagonji and Manye, 2011) and

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0.95–8.20 (Engdaw et al., 2009; Haylamicheal et al., 2011) in Ethiopia. The percentage composition of hazardous waste reported is 28% in Libya (Sawalem et al., 2009), 39.3% in South Africa (Nemathaga et al., 2008) and 20–63% in Ethiopia (Engdaw et al., 2009; Haylamicheal et al., 2011; Mesfin et al., 2013). These variations were associated with healthcare facilities (HCFs) with different levels of specialization, the proportion of patients treated daily, ownership and waste management approaches (GEF, 2009). Therefore, the generation rate and composition should be estimated separately considering all these different factors.

All the healthcare waste studies conducted in Ethiopia (Engdaw et al., 2009; Haylamicheal et al., 2011) and other African countries (e.g. Idowu et al., 2013) did not consider different levels of hospitals (teaching, referral, district) and ownership (private and government). They are all case studies in one or more hospitals of similar type within the same city. This research is the most extensive study in Africa to date, investigating different levels of hospital, as well as private and government hospitals.

This study was designed to estimate the generation rate and composition of healthcare wastes in nine hospitals with different levels of specialization, capacity and ownership (private and government) in seven towns of Amhara National Regional State in Ethiopia. The results may serve as a stepping stone in evaluating the success and failure of pre- and post-intervention projects, and could be useful for the development of operational guidelines for the management of healthcare waste in health facilities nationwide.

## Methods and materials

### Study area

Amhara National Regional State has a total of 17 public hospitals (two teaching, three referral, two zonal and 10 District) and six general private hospitals, all of them located in 11 towns in the Ethiopian Highlands. From these hospitals, we proportionally and randomly selected six governmental hospitals (one teaching, one referral, one zonal and three district hospitals) and three general private hospitals. The towns vary in size from small to medium (Debre Birhan) and large (Gondar), which correspond with the size and functionality of the study hospitals. The total number of beds per hospital varied considerably, particularly between private and public hospitals and among public hospitals: Ayu private hospital (64 beds), Selam private hospital (62), IBEX private hospital (32), Boru district hospital (80), Enat district hospital (54), Mehal Meda district hospital (41), Debre Tabor zonal hospital (89), Debre Birhan referral hospital (135) and Gondar teaching hospital (512).

### Data collection, characterization and estimation of generation rate

We conducted a cross-sectional survey in all selected hospitals from November to December 2012. We recruited data collectors,

who have secondary school certificates, and supervisors, who have BSc degrees in Environmental Health. We gave 1-day training about data collection, and demonstrated data collection tools and protocols for data collectors and supervisors. All waste collection buckets, safety boxes and plastic bags obtained for the study were labeled to indicate the different categories of healthcare waste, date of collection and sample number. The quantity of waste generated was estimated by collecting and weighting healthcare waste from all departments of the study hospitals using a calibrated sensitive weight scale every day at 12:00 PM for seven consecutive days (Monday–Sunday). The waste characterization was conducted in accordance with World Health Organization (WHO) guidelines (Prüss et al., 1999). The daily generation of waste together with the number of beds occupied and patients treated in outpatient departments were recorded daily. The healthcare waste generation rates were estimated on the basis of kg/bed/day, kg/patient/day and kg/outpatient/day, as described by Awad et al. (2004) and Engdaw et al. (2009).

### Statistical analysis

We used EPI-INFO 7 for data entry and STATISTICA version 8.0. for data analysis. The analysis was performed separately for each of the nine hospitals, grouped by public and private hospitals, and by category of healthcare waste. First, we explored the distribution of the data, including normality using a normality test, which showed that the data were not normally distributed. Therefore, we used Spearman's rank correlation test for the bivariate associations and Kruskal–Wallis test to compare the independent groups (type of hospitals and categories of waste). We also used median and interquartile range (IQR) as a measure of central tendency to summarize the data in tables and graphs.

## Result and discussion

### Healthcare waste generation rate

Data collected from the three private and six government hospitals showed that the median total healthcare waste generation rate estimated in kg/patient/day (sum of inpatient and outpatient) for all nine hospitals was 0.31, with an IQR of 0.21–0.65 (Table 1). The median generation rate for outpatients was 0.34 kg/outpatient/day (IQR = 0.21–1.09), and for inpatients it was 1.67 kg/bed/day (IQR = 1.25–2.77) (Table 2). These data show that the median generation rate in kg/bed/day was about five times greater than the generation rate estimated in kg/outpatient/day. The generation rate recorded in this study is much smaller when compared with the generation rate in Iran (2.71 kg/bed/day) as reported by Askarian et al. (2004), UK (3.3 kg/bed/day), Norway (3.9 kg/bed/day) and Kuwait (7.0–10.0 kg/bed/day) as it can be seen in Bdour et al. (2007). The reason for this is the higher the per capita gross domestic product (GDP), the higher quantity of healthcare waste which is related to the high supply and provision of healthcare services.

**Table 1.** Composition and generation rate using the total number of patients (kg/patient/day) of healthcare waste in six public and three private hospitals, median with interquartile range and percentage of hazardous waste.

Codes of hospitals <sup>a</sup>	Healthcare waste composition in kg/patient/day						Median hazardous (%)
	General	Infectious	Sharps	Pharmaceutical	Pathological	Radioactive	
P1	0.06 (0.05–0.07)	0.07 (0.06–0.09)	0.04 (0.03–0.05)	0.04 (0.03–0.05)	–	0.003 (0.002–0.003)	71.8
P2	0.32 (0.26–0.45)	0.20 (0.16–21.00)	0.02 (0.01–0.04)	0.15 (0.11–21.00)	–	0.003 (0.003–0.004)	53.8
P3	0.07 (0.04–0.10)	0.05 (0.03–0.08)	0.03 (0.02–0.05)	0.01 (0.008–0.010)	–	–	56.2
Private	0.09 (0.06–0.24)	0.10 (0.06–0.16)	0.03 (0.01–0.05)	0.04 (0.01–0.10)	–	0.003 (0.001–0.003)	65.7
D1	0.12 (0.11–0.21)	0.03 (0.03–0.07)	0.01 (0.004–0.010)	0.01 (0.005–0.010)	–	0.001 (0.001–0.004)	29.8
D2	0.15 (0.13–0.30)	0.11 (0.09–0.20)	0.03 (0.02–0.04)	0.02 (0.02–0.06)	0.03 (0.02–0.06)	0.0007 (0.0006–0.0010)	55.9
D3	0.1 (0.07–0.20)	0.09 (0.06–0.14)	0.01 (0.09–0.02)	0.03 (0.02–0.04)	0.02 (0.01–0.04)	0.001 (0.001–0.004)	60.1
ZH	0.12 (0.09–0.21)	0.04 (0.03–0.09)	0.01 (0.004–0.020)	0.02 (0.01–0.04)	0.02 (0.01–0.02)	0.0008 (0.0008–0.0020)	47.8
RH	0.10 (0.08–0.16)	0.13 (0.11–0.20)	0.02 (0.01–0.04)	0.02 (0.01–0.03)	0.02 (0.01–0.06)	0.0002 (0.0002–0.0006)	65.5
TH	0.31 (0.29–0.40)	0.28 (0.22–0.32)	0.009 (0.003–0.010)	0.09 (0.07–0.12)	0.04 (0.02–0.04)	0.001 (0.001–0.002)	57.5
Government	0.14 (0.10–0.29)	0.10 (0.05–0.21)	0.01 (0.009–0.030)	0.02 (0.01–0.06)	0.02 (0.01–0.04)	0.001 (0.0007–0.001)	51.9
Private and government	0.12 (0.08–0.28)	0.10 (0.05–0.20)	0.02 (.009–0.040)	0.03 (0.01–0.08)	0.01 (0.001–0.020)	0.001 (0.006–0.003)	57.3

<sup>a</sup>P1 = Ayu General private hospital, P2 = Selam General private hospital, P3 = IBEX General private hospital, D1 = Boru district hospital, D2 = Enat district hospital, D3 = Mehal Meda district hospital, ZH = Debre Tabor zonal hospital, RH = Debre Birhan referral hospital, TH = Gondar teaching hospital.

Reports from Ethiopia show a higher waste generation range (0.75–10.47 kg/bed/day) as reported by Haylamicheal et al. (2011), but the results of this study are comparable with those reported in Turkey (2.35 kg/bed/day) by Eker et al. (2010). With the exception of this small discrepancy, the findings are in agreement with the fact that in developing countries the overall healthcare waste generation rate is smaller than in developed nations. As the healthcare delivery system of the country is similar across the regional states, the findings of this research may serve for all hospitals in similar settings.

The results indicate a stronger positive correlation of healthcare waste generation rate with the number of inpatients ( $r = 0.842$ ,  $P < 0.0001$ ) than with the number of outpatients ( $r = 0.538$ ,  $P < 0.0001$ ). This is owing to the longer hospital stays of inpatients with services in hospitals.

#### *Comparison of private versus governmental hospitals on healthcare waste generation rate*

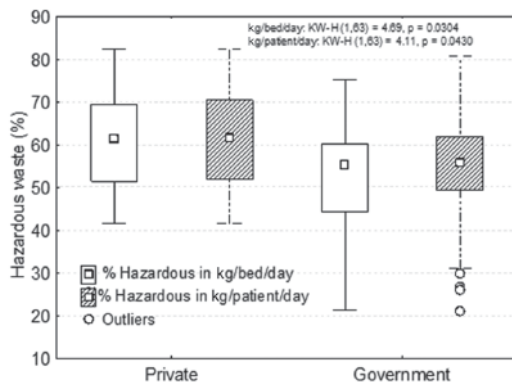
The median hazardous waste that is expressed as a percentage of the total waste generated in private and public hospitals is presented in Figure 1. The percentages show that the median value of the hazardous component of the total healthcare waste

is > 50% in both types of hospitals (Figure 1). This pattern was also found for all hospitals except for one district and one zonal hospital in terms of total number of patients (Table 1) and inpatients (Table 2), which generated hazardous waste above the 10–25% threshold set by Prüss et al. (1999) and WHO (2005). The research conducted in hospitals of Nigeria reported hazardous waste levels of 9–15% (Bassey et al., 2006). Similarly, higher proportions of hazardous (29%) waste were reported from hospitals in Iran (Askarian et al., 2004), and South Africa reported up to 39% (Nemathaga et al., 2008); one of the highest percentages of hazardous waste (67%) was recorded in hospitals of Tanzania (Kagonji and Manyele, 2011), a level similar to our findings. A major reason for the high percentage of hazardous waste in hospitals of developing countries appears to be the improper segregation of different types of waste materials by health professionals and inadequate education of auxiliary health workers. For example, research carried out on risk perception of healthcare workers towards healthcare waste management in Ethiopia shows that only a small proportion of healthcare workers adequately perceived the health risk of handling waste materials (Yenesew et al., 2012). This deficiency is linked with inadequate training and supervision of health workers, and lack of enforceable health regulations aimed at providing safe working environments in HCFs.

**Table 2.** Composition and generation rate based on the number of inpatient (kg/bed/day) of healthcare waste in the nine study hospitals, median with interquartile range and percentage of hazardous waste.

Hospital code <sup>a</sup>	Composition of waste in kg/bed/day						Average hazardous (%)
	General	Infectious	Sharps	Pharmacy	Pathological	Radioactive	
P1	0.37 (0.31–0.40)	0.37 (0.37–0.54)	0.21 (0.18–0.23)	0.25 (0.19–0.26)	–	0.01 (0.01–0.02)	69.4
P2	2.77 (2.12–3.66)	1.55 (1.25–1.70)	0.09 (0.01–0.33)	1.16 (0.95–1.69)	–	0.02 (0.02–0.03)	50.4
P3	1.66 (1.50–2.62)	1.33 (1.00–2.67)	1.0 (0.75–1.65)	0.50 (0.21–0.50)	–	–	63.0
Private	1.50 (0.43–2.77)	1.00 (0.50–1.62)	0.25 (0.17–0.50)	0.45 (0.25–0.80)	–	0.01 (0.001–0.020)	63.4
D1	0.83 (0.66–0.96)	0.23 (0.21–0.25)	0.08 (0.03–0.10)	0.09 (0.04–0.13)	–	0.010 (0.010–0.011)	33.1
D2	0.92 (0.75–1.01)	0.64 (0.54–0.81)	0.20 (0.10–0.26)	0.15 (0.13–0.19)	0.16 (0.14–0.21)	0.004 (0.003–0.004)	56.6
D3	0.71 (0.59–1.13)	0.66 (0.50–0.91)	0.11 (0.08–0.15)	0.18 (0.13–0.38)	0.18 (0.12–0.28)	0.01	61.6
ZH	0.71 (0.67–0.95)	0.27 (0.25–0.33)	0.06 (0.03–0.11)	0.14 (0.10–0.18)	0.11 (0.09–0.14)	0.007 (0.006–0.007)	45.2
RH	0.44 (0.32–0.56)	0.61 (0.46–0.79)	0.09 (0.07–0.17)	0.08 (0.06–0.10)	0.13 (0.10–0.16)	0.001	67.4
TH	0.56 (0.50–0.62)	0.46 (0.42–0.51)	0.01 (0.007–0.030)	0.15 (0.14–0.17)	0.07 (0.04–0.08)	0.002	59.7
Government	0.69 (0.54–0.98)	0.43 (0.30–0.63)	0.08 (0.03–0.13)	0.14 (0.09–0.18)	0.10 (0.04–0.16)	0.005 (0.002–0.010)	52.2
Government and private	0.71 (0.52–0.12)	0.54 (0.36–0.63)	0.11 (0.04–0.22)	0.16 (0.10–0.30)	0.04 (0.01–0.14)	0.007 (0.002–0.010)	54.7

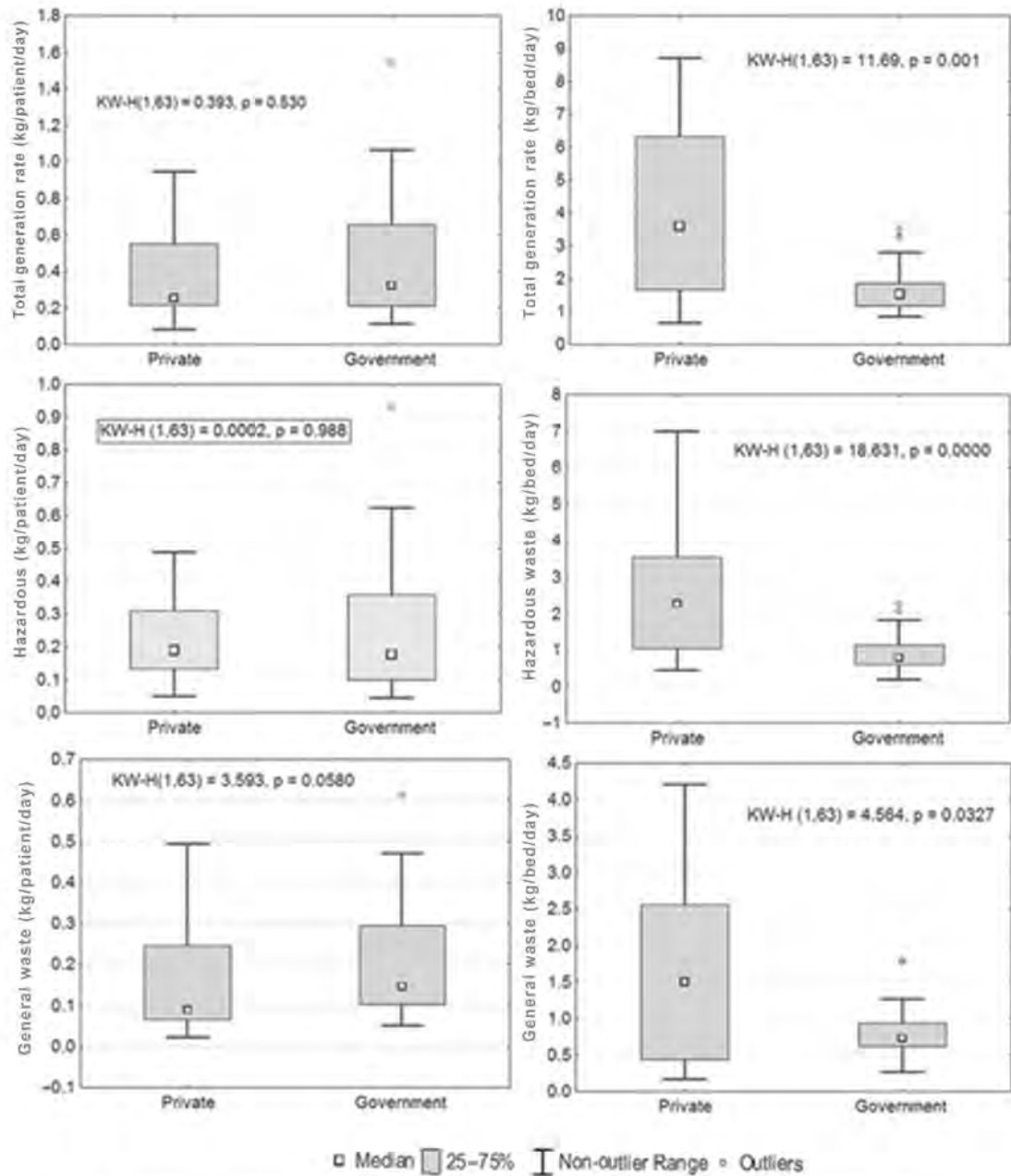
<sup>a</sup>P1 = Ayu General private hospital, P2 = Selam General private hospital, P3 = IBEX General private hospital, D1 = Boru district hospital, D2 = Enat district hospital, D3 = Mehal Meda district hospital, ZH = Debre Tabor zonal hospital, RH = Debre Birhan referral hospital, TH = Gondar teaching hospital.

**Figure 1.** Box plot of percent of hazardous waste generation among six public and three private hospitals in Amhara National Regional State, Ethiopia.

The Kruskal–Wallis test (Figure 1) showed a significantly higher median percentage value of hazardous waste for private hospitals than for government hospitals ( $P < 0.05$ ). This is owing to the fact that, unlike private hospitals, the government has to keep healthcare costs down by controlling supplies and services. As a result, the generation rate of hazardous waste

will be less than that of private hospitals. This finding contrasts with the study conducted in Hawassa city by Haylamicheal et al. (2011), which states the government hospitals produced more hazardous waste than private hospitals. This discrepancy might be owing to the differences in study area and sample size, as Haylamicheal et al. (2011) considered only hospitals found in one town. Nevertheless, the median percentage values of both generation rate units (kg/bed/day and kg/patient/day) were found to be the same within a group (private or government).

The generation rates of total number of patients (in- and out-patient) estimated in kg/patient/day was not significantly different when compared between private and government hospitals (Figure 2). On the contrary, the generation rates of inpatients estimated in kg/bed/day were significantly higher in private hospitals than government hospitals (Figure 2). This is owing to the fact that patients who have access to private hospitals have high incomes and can make a significant contribution to the generation rate of healthcare waste. The healthcare waste generation rate is dependent on the socioeconomic status of patients (Askarian et al., 2004). Despite this fact, our finding contradicts the report by Patwary et al. (2009), which concludes that the generation rate in kg/bed/day is similar for both private and governmental hospitals.



**Figure 2.** Box plots of median hazardous and general healthcare waste generation rates in kg/bed/day and kg/patient/day for three private and six government hospitals.

### Healthcare waste composition

There was no difference between private and government hospitals in the composition of healthcare waste, with the exception of pathological waste, which was nearly absent in private hospitals. The percentage of hazardous waste is above 50 percent (kg/

patient/day and kg/bed/day) in all private and in four government hospitals, which accounts for 77.8% of hospitals. The overall percentage of hazardous waste represented 56.4% of the total healthcare waste generated in all hospitals. The reasons for the high percentages are the absence of segregation and a proper healthcare waste management system.

## Conclusion

The rate of generation of healthcare waste in kg/bed/day is about five times greater than the generation rate estimated in kg/outpatient/day in the nine hospitals studied. The rate also varies by ownership, with private hospitals producing significantly more total and hazardous waste than government-run hospitals. These results indicate that both measures of healthcare waste generation need to be used in combination to reliably quantify the waste generation rates for different types of waste at individual facilities. Systematic collection and the use of standardized analytical methods of data on healthcare waste among representative hospitals in different administrative regions of Ethiopia may form the basis for the development of feasible, environmentally safe and cost-effective healthcare waste management in the study communities. Additional studies should consider seasonal variations in healthcare waste generation in view of temporal variations in the occurrence of endemic diseases and hospital utilization by the Ethiopian population, especially in rural areas, and make recommendations for improved waste management practices at regional and national level.

## Acknowledgement

We would like to thank the Amhara Regional State Hospital staff and administrators for their collaboration and unreserved help during data collection.

## Declaration of conflicting interests

The authors do not have any potential conflicts of interest to declare.

## Funding

We are also grateful to Addis Ababa University for financial and logistic support.

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**Paper III (Under review process on the Journal-Waste management and research)**

**Developing models for the prediction of hospital healthcare waste generation rate**

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## ABSTRACT

An increase in the number of health institutions along with frequent use of disposable medical products has contributed to the increase of healthcare waste generation rate. For proper handling of healthcare waste, it is crucial to predict the amount of waste generation beforehand. Predictive models can help to optimize healthcare waste management systems, set guidelines and evaluate the prevailing strategies for healthcare waste handling and disposal. However, there is no, mathematical model developed for Ethiopian hospitals to predict healthcare waste generation rate. Therefore, the objective of this research was to develop models for the prediction of healthcare waste generation rate. A longitudinal study design was used to generate long-term data on solid healthcare waste composition, generation rate and develop predictive models. The results revealed that, the healthcare waste generation rate has a strong linear correlation with the number of inpatients ( $R^2 = 0.965$ ), and a weak one with the number of outpatients ( $R^2 = 0.424$ ). Statistical analysis was carried out to develop models for the prediction of the quantity of waste generated at each hospital (public, teaching and private). In these models, the number of inpatients and outpatients were revealed to be significant factors on the quantity of waste generated. The influence of the number of inpatients and outpatients treated varies at different hospitals. Therefore, different models were developed based on the types of hospitals.

**Key words:** Healthcare waste, generation rate, hospitals, prediction, models, Ethiopia

### 1. Introduction

All over the world, there is a continued growth in the number of hospitals and other health facilities in relation to meet the healthcare demand of the alarming population growth. An increase in number of health institutions combined with an increase in the use of disposable medical products has contributed to the large amount of healthcare waste being generated (1, 2). The high generation rate compounded by poor handling and disposal practices (3) increased the risk of environmental pollution and diseases transmission (4). Due to these facts, installation of integrated healthcare waste management system for health institutions is becoming a crosscutting issue (5).

Many researchers have argued that, the availability of enough information about the amount and composition of the healthcare waste generated are the first steps for the implementation of sound waste management systems (6, 7, 8). In addition, healthcare waste should be characterized by source, generation rates, types of waste produced, and composition in order to monitor and control the existing healthcare waste management systems (7). Therefore, development of models is not only a necessity, but millstones for proper healthcare waste management system.

The generation rate of healthcare waste varies among the type of hospitals (government, private and teaching hospitals) (9). Hence, the development of predictive models should consider the type of hospitals. The amount of different kinds of healthcare waste generated at hospitals can be determined by identifying the relationship between the weight of the healthcare waste generated and main important factors that affect healthcare waste generation rate such as type of hospital, hospital specialization, hospital size, and proportion of patients treated on a daily basis (10-14). Statistical analysis is one option to evaluate the relationship between these important factors and the amount of healthcare waste generated (15), in each type of hospital that most predictive models lack.

The study conducted by Bdour et al. (2007) in Jordan confirmed that, high statistically significant (linear) correlation exists between the number of patients ( $R^2= 0.945$ ) and the number of beds ( $R^2= 0.905$ ) with the amount of daily healthcare waste generated (4, 16). The study done in Irbid, Jordan by Awad, et al (2004) indicated that the quantity of healthcare waste generation rate has strong correlation with the number of patients, number of beds, and type of hospital at  $R^2= 0.973$ ,  $R^2 = 0.956$  and  $R^2 = 0.368$  respectively (4). Similarly, the study conducted by Komilis and Kasafaros (2011) indicated a linear statistically significant correlation at  $p < 0.05$  with  $R^2 = 0.43$  between daily healthcare waste generation rate and the number of beds occupied (17). The study done by Katoch and Kumar (2007) in India confirmed that the seasonal variation in the biomedical waste production rate remained nearly the same (4).

Determining in advance healthcare waste generation rate using mathematical predictive models can help to optimize healthcare waste management systems, to set guidelines and to evaluate the prevailing strategies for healthcare waste handling as well as proper

disposal. From the review of available literatures, we confirmed that only few predictive models are available. The available models are presented in equations 1 up to 4.

$$\text{Generation rate in kg/day} = -17.77 + 1.049(\text{PAT}) + 0.818(\text{BED}) + 12.22(\text{Type}) \dots \text{Eq.1}$$

Where, PAT= the number of patients, BED= the number of beds and TYPE= the type of hospital (4).

**Monthly average biomedical waste generation rate (Wo) of hospitals** in kg/day in terms of average bed occupancy rate, B (beds/day) equals:

$$W_o = K_1 + K_2 \cdot B + K_3 \cdot B^2 \dots \text{Eq. 2}$$

Where, coefficients  $K_1$ ,  $K_2$  and  $K_3$  are constants for a particular type of hospital (18).

$$\text{Generation rate in kg/day} = -21.7 + 0.06(\text{PAT}) + 0.372(\text{CAP}) \dots \text{Eq.3}$$

Where, PAT is the number of inpatients and CAP is the number of beds (19).

$$Y = (T_{hb} \cdot W_{hb}) + (T_{cb} \cdot W_{cb}) + (T_{dt} \cdot W_{dt}) \dots \text{Eq.4}$$

Where,  $Y$ =total healthcare waste generated per day in kg/day,  $T_{hb}$  = total number of hospital beds in sampled facilities,  $W_{hb}$ = average waste per hospital bed per day in sampled hospitals;  $T_{cb}$  = total number of clinic beds in sampled facilities,  $W_{cb}$  = average waste per clinic bed per day in sampled clinics;  $T_{dt}$  = total number of diagnostic centres tests per day in sampled facilities and  $W_{dt}$  = average waste per diagnostic test in sampled diagnostic centres (20).

All the equations (Eq.1 to 4) shows that the healthcare waste generation rate predictive models varied based on the difference of the study area. This indicates, estimating the generation rate of healthcare wastes in developing countries should consider the local determinant factors. Nevertheless, there is no any predictive model available in Ethiopia that can be used for predicting healthcare waste generation rate. Therefore, this research has a paramount importance for improving healthcare waste management system at local and national level.

## **1. Methods and materials**

### **Study area**

The Amhara National, Regional State has a total of 18 public hospitals (two teaching, three referrals, two zonals and 11 districts) and six general private hospitals, all of them located in 11 towns. From these hospitals, we proportionally and randomly selected six governmental hospitals (one teaching, one referral, one zonal and three district hospitals) and three general private hospitals. The towns vary in size from small (Boru media) to medium (Debre Birhan) and large (Gondar), which correspond to the size and functionality of the study hospitals. The total number of beds per hospital varied considerably, particularly between private and public hospitals and among public hospitals: Ayu private hospital (64 beds), Selam private hospital (62), IBEX private hospital (32), Boru district hospital (80), Enat district hospital (54), Mehal Meda district hospital (41), Debre Tabor zonal hospital (89), Debre Birhan referral hospital (135) and Gondar teaching hospital (512).

### **Study design**

A longitudinal study design was done to generate solid healthcare waste composition, generation rate, and develop predictive models based on seasonal variability data that can precisely estimate the generation rates of hospital healthcare waste. This study design allows capturing variations and composition of healthcare waste generation.

### **Data collection**

Out of the total 24 hospitals, the data was collected from nine proportionally allocated with different levels of specialization, capacity and ownership (private and government) and randomly selected hospitals. The data collection was conducted in two rounds. The first round was conducted from November to December 2013 (dry season) and in the second round from June to July 2014 (wet season). The data collectors had secondary school certificates, and supervisors had BSc degrees in Environmental Health. In both the first and second round of data collection, one day training was given about data collection, demonstration of data collection tools and protocols for data collectors and supervisors. All waste collection buckets (black, yellow, red and blue colour for general, infectious, pathological and pharmaceutical healthcare waste respectively), safety boxes

and plastic bags were labelled to indicate the different categories of healthcare waste, date of collection and sample number. The quantity of waste generated was estimated by collecting and weighing healthcare waste from all departments of the study hospitals using a calibrated sensitive weight scale  $\text{R}\cap\text{C}$  model made in India every day at 12:00 pm for seven consecutive days (Monday–Sunday) during both rounds. The waste characterization was done in accordance with World Health Organization (WHO) guidelines (21). The daily generation of waste together with the number of beds occupied and patients treated in outpatient departments were recorded daily. As described by different authors, the healthcare waste generation rates were estimated on the basis of kg/bed/day and kg/outpatient/day (4, 22).

### **Statistical analysis**

We used EPI-INFO 7 for data entry and SPSS version 16 for data analysis. The analysis was performed separately for each of the nine hospitals, grouped by public and private hospitals, and by category of healthcare waste. First, we explored the distribution of the healthcare waste generation data, including normality using a normality test, which showed that the data were normally distributed. Therefore, we used Pearson correlation test for the bivariate associations.

In this study, the important variables that affect the quantity of wastes generate from the hospitals were identified, then multivariate linear regression analysis was applied in order to develop predictable models that can be used in estimating or predicting the waste generation rate in sampled hospitals. Establishing the simple correlation matrices between different variables was the first step in model development. This step was helpful to investigate the strength and form of the relationship between the variables included in the analysis. In order to see the effect of the parameters and their confidence levels on the waste generation rate in healthcare services, analysis of variance (ANOVA) was performed to compare the rate by the type of hospitals. The F-test was a tool to see which parameters had a significant effect on the removal efficiency. The data quality was ensured by using calibrated instruments, experienced professional supervisors, training of supervisors and data collectors and daily on-site supervision was made by the investigator during the actual measurements.

## 2. RESULTS AND DISCUSSION

The two round data collected from the sampled hospitals showed that the mean generation rates in kg/bed/day were 1.14, 0.74, 0.21, 0.27, 0.09, and 0.02 for general, infectious, sharps, pharmaceutical, pathological and radioactive healthcare waste respectively. The percentage compositions were 46.32%, 33.95%, 4.04%, 9.67%, 5.78% and 0.24% for general, infectious, sharps, pharmaceutical, pathological and radioactive healthcare waste respectively. These results have significant difference compared with World Health Organization (WHO) reports of 80%, 15%, 1%, 3% and less than 1% for general, pathological and infectious, sharps, pharmaceutical and radioactive healthcare waste (21, 23). The reason might be the absence of segregation practices in the sample hospitals.

In this study, the important variables (number of inpatients and outpatients) that mainly affect healthcare waste generation rate were identified using correlation. Linear regression analysis was done in order to develop predictable models. It was observed that healthcare waste generation rate has a strong correlation with the number of inpatients ( $R^2 = 0.965$ ,  $P < 0.0001$ ), the number of outpatients ( $R^2 = 0.424$ ,  $P < 0.0001$ ) and number of total patients ( $R^2 = 0.802$ ,  $P < 0.0001$ ). The results showed a stronger positive correlation of healthcare waste generation rate with the number of inpatients than with the number of outpatients. This is owing to longer hospital stays of inpatients with services in the hospitals. Such positive correlations are also reported by Komilis and Katsafaros (2011) in Greece and th Idowu, et al. (2013) in Nigeria (17, 19).

The bed occupancy rates were 78.3%, 69.6%, 55.5%, 41.6%, 39.0%, 28.8%, 17.7%, 12.5% and 3.1% for Gondar teaching, Debre Birhan referral, Enat district, Debre Tabor zonal, Mehal Meda district, Boru district, Selam private, Ayu private and IBEX private hospitals respectively. The waste generation rates in kg/day were 689.5, 140.2, 62.7, 56.9, 34.3, 28.4, 25.4, 10.3 and 7.6 in row of the bed occupancy rates of the hospitals.

The relation between bed occupancy rate and healthcare waste generation rate have linear relationship ( $R^2 = 0.5$ ). In order to investigate the effect of each independent variable on

the dependent variable; scatter plots of healthcare waste generation versus the number of inpatients, number of outpatients and total number of patients were plotted (Figures 1, 2 and 3).

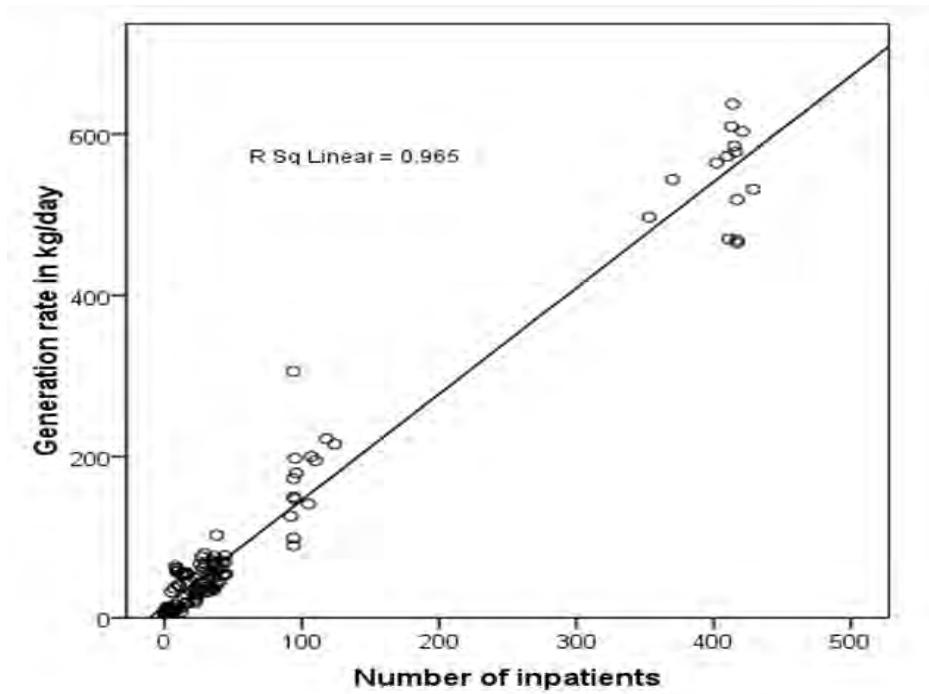


Figure 1: Daily healthcare waste generation versus number of inpatients in all hospitals.

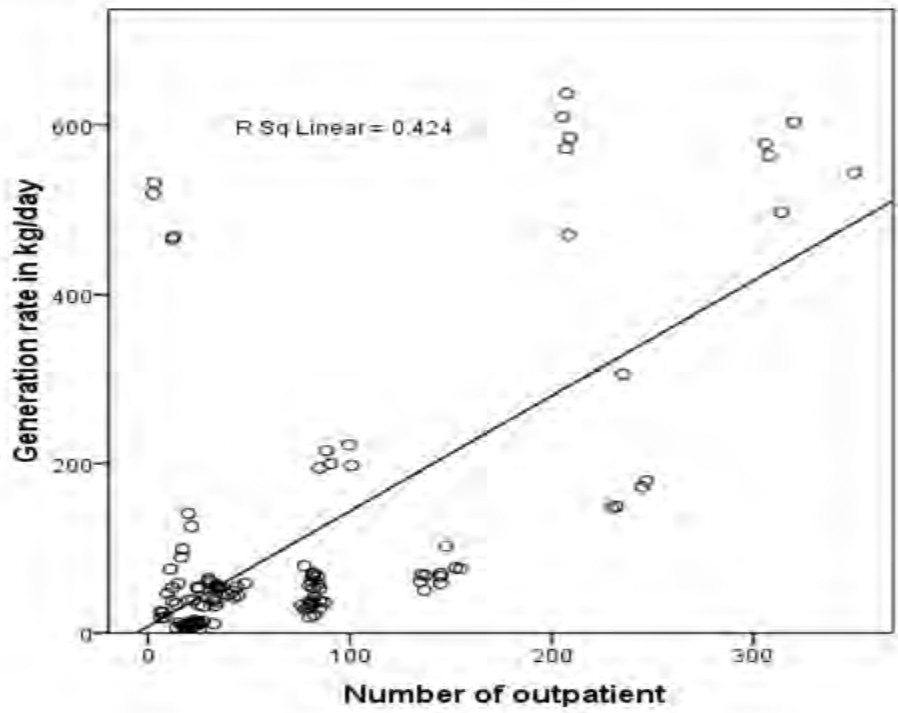


Figure 2: Daily healthcare waste generation versus number of outpatients in all hospitals.

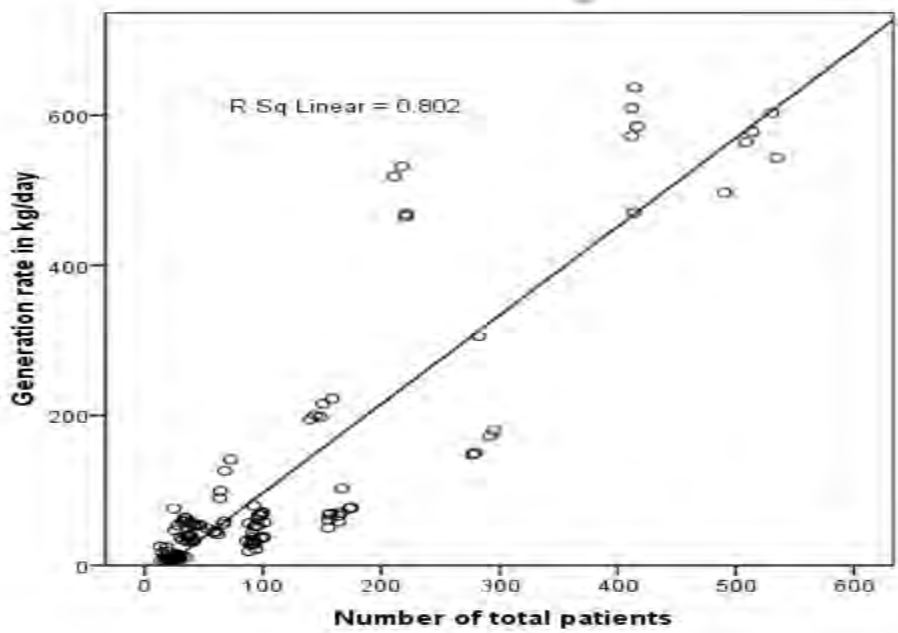


Figure 3: Daily healthcare waste generation versus number of total patients in all hospitals.

As shown in figures 1, 2 and 3, the relationship of healthcare waste generation rate among the number of inpatients, the number of outpatients and total number of patients is linear. Based on the linear relationship the following predictive models were developed and presented as equations 5, 6, 7 and 8.

The predictive model developed for total healthcare waste generation rate derived from inpatients and outpatients is given in Equation 5.

$$\text{Generation rate in kg/day (Y)} = 1.26(\text{NIPT}) + 0.135(\text{NOPT}) \dots \text{Eq.5}$$

Where, NIPT is the number of inpatients and NOPT is the number of outpatients.

**Table 1: Statistical characteristics of the model (Equation 5)**

<b>Analysis of variance</b>					
Model	df	Sum of square	Mean of square	F- value	$\alpha$ -level
Regression	2	3281691.925	1640845.963	2.559E3	0.0001
Residual	123	78880.206	641.302		
Total	125	3360572.131			
$R^2 = 0.927$ , Adjusted $R^2 = 0.926$					
<b>Regression parameter estimate</b>					
Variables	Parameter estimate	Standard error	T-value	$\alpha$ -level	
Intercept	1.629	3.125	0.521	0.603	
Inpatient	1.216	0.023	53.824	0.0001	
Outpatient	0.135	0.018	7.635	0.0001	

**Note:** Acceptable  $\alpha$ -level (level of significance) = 0.100; F represents general linearity test;  $R^2$  represents coefficient of multiple determination; df represents degree of freedom; Adjusted  $R^2$  represents adjustment of  $R^2$ ; and T represents - importance of model variables.

### **Healthcare waste generation rate predictive models by hospital type**

The results of this study revealed that healthcare waste generation rate significantly varies based on the types of hospitals. Public referral hospitals were found to be the highest

healthcare waste generators followed by public district and private general hospitals in their order. This finding is also in agreement with the research reports of Awad et al. (2004). Hence, to increase the accuracy of prediction, it is required to develop separate predictive models for different type of hospitals (Private General, District public and Referral public hospitals). The predictive models for three categories of hospitals are presented in equations 6, 7 and 8.

**Predictive model for private general hospitals**

$$\text{Generation rate in kg/day (Y)} = -4.945 + 1.775(\text{NIPT}) + 0.098(\text{NOPT}) \dots \text{Eq.6}$$

Where, NIPT is the number of inpatients and NOPT is the number of outpatients.

**Predictive model for public district hospitals**

$$\text{Generation rate in kg/day (Y)} = -11.82 + 1.015(\text{NIPT}) + 0.211(\text{NOPT}) \dots \text{Eq.7}$$

Where, NIPT is the number of inpatients and NOPT is the number of outpatients

**Predictive model for public referral hospitals**

$$\text{Generation rate in kg/day (Y)} = 1.208(\text{NIPT}) + 0.159(\text{NOPT}) \dots \text{Eq.8}$$

Where, NIPT is the number of inpatients and NOPT is the number of outpatients

**Table 2: Model summary of three types of sampled hospitals**

Hospital type	R square	Adjusted R square	Std Error of the Estimate	Change statistics			
				R square change	F change	df	Sig F change
Private general	0.966	0.964	0.768	0.966	550.9	39	0.0001
Public district	0.968	0.966	3.04	0.968	574.8	39	0.0001
Public referral	0.944	0.941	50.68	0.943	327.3	39	0.0001

The healthcare waste generation rate also positively correlated to the number of inpatients ( $R^2 = 0.657$ ), ( $R^2 = 0.468$ ) and ( $R^2 = 0.976$ ) for Private General, Public District and Public

Referral Hospitals respectively. The generation rate is also positively correlated with the number of outpatients ( $R^2 = 0.817$ ), ( $R^2 = 0.210$ ) and ( $R^2 = 0.699$ ) for Private General, Public District and Public Referral Hospitals respectively. All independent variables used for the prediction of healthcare waste generation rate were found to be statistically significant. The linear regression based on the number of outpatients and healthcare waste generation rate in district hospitals is only explained 21% of the number of outpatient variables. The healthcare waste generation rate predictor variables (number of inpatient and number of outpatient treated in the hospitals) that are identified and used for the development of the predictive models in this study are similar to the research findings reported elsewhere. For instance, the studies conducted in India, Jordan, Kuwait, Greece, and Taiwan confirmed that healthcare waste generation rate is affected by the number of inpatients and outpatients in the hospital (11, 16, 18, and 24).

This research included different type of hospitals such as private and government hospitals and also different levels of hospitals, which included teaching, referral, zonal, district and general that can represent all types of hospitals found in the healthcare system of Ethiopia. Therefore, the results may serve as a stepping stone in evaluating the success and failure of pre- and post-intervention projects, and could be useful for the development of operational guidelines for the management of healthcare waste in health facilities nationwide.

## **CONCLUSION**

From the total healthcare waste, the major components were general and infectious wastes, which account 80.27%. Our finding proved that both measurement units (kg/inpatient/day, kg/outpatient/day, kg/sum of inpatient and outpatient/day) of healthcare waste generation rate need to be used in combination to reliably quantify the healthcare waste generation rates. As the number of inpatients and outpatients variables were found to be the main predictors of the healthcare waste generation rate. The healthcare waste generation rate were also dependent on the type and level of hospitals, therefore, to formulate precise predictive model for the estimation healthcare waste generation rate, it required to be analysed separately in accordance with the types and

level of hospitals. The models developed in this study can assist to develop a strategic plan for the implementation of appropriate healthcare waste management system.

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## **ACKNOWLEDGEMENT**

We would like to thank the Amhara Regional State Hospital staff and administrators for their collaboration and unreserved help during data collection.

## **Declaration of conflicting interests**

The authors do not have any potential conflicts of interest to declare.

## **Funding**

We are also grateful to Addis Ababa University for financial and logistic support.

**Paper IV (Under review on Journal- International Journal of Environment and Waste Management)**

**Healthcare waste management practices: systematic review**

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## 1. INTRODUCTION

Hospitals are among the complex institution, which generated a broad range of hazardous waste materials in the course of healthcare activities (1). The hazardous waste has a small portion of healthcare waste, the absence of appropriate waste segregation practices mixing hazardous waste with general (non-hazardous) waste, can lead to the entire bulk of waste becoming potentially hazardous (2). Healthcare waste should be segregated for collection by using colour bags and containers (plastic, metal or paper) (3).

Because of exponential population growth; the need for new hospitals establishment is being felt increase. As a result of this, the healthcare waste generation rate significantly increases in volume and diversifying in type of waste that requires proper handling and disposal (4).

Healthcare waste management includes all activities of waste segregation, temporary storage, transportation, treatment and final disposal of all types of waste generated in the health institutions (5). Globally, healthcare waste management is an important public health and environmental issue because healthcare waste contains infectious materials, sharps, hazardous chemicals, and radioactive (6). In many developing countries healthcare wastes have not received sufficient attention; hazardous and general waste is still handled and disposed together, these pose hazardous to the environment and subsequently for human (7).

In developing countries, the most common healthcare waste treatment facility is incinerators. These incinerators have deficiencies in the construction, site, operation and management (8). These defects can result in emit a wide range of pollutants, such as mercury, dioxin, and furans (9). The long-term low-level exposure of humans to dioxins and furans may lead to impairment of the immune system, impaired development of the nervous system, the endocrine system and the reproductive functions (8). The problems of healthcare waste incineration on human health and environmental degradation eventually were recognized. International organizations such as Environmental Protection Agency (EPA), Hospitals for a healthy Environment (HHE) and Health Care without Harm (HCWH) have looked for ways to reduce the negative effects of healthcare practices on human health and the environment (10).

The study conducted in Gondar hospitals, Ethiopia by Anagaw et al. (2012) showed that the prevalence of Hepatitis B Virus (HBV) and Hepatitis C Virus (HCV) were higher in those handlers clinical waste compared to non-clinical waste handlers. There was poor waste management system which contributed to the occurrence of higher degree of sharps injury and blood and fluids splash (11).

**Based on World Health Organization (13) the minimum standard of each component of healthcare waste management systems is described below:**

#### **Segregation of health care waste**

Healthcare waste should be segregated based on their potential hazard characteristics, treatment requirement, and disposal route, by the person who produces each waste item. Separate labelled colour code containers (infectious waste yellow, chemical and pharmaceutical waste brown, general waste black) should be available for each medical area for each category of healthcare waste.

#### **Healthcare waste storage**

Closed colour-coded labelled containers are kept away from patient indoors for interim or short-term storage (depending up on the type of waste not more than 12 hours) of healthcare waste in each medical rooms. Waste bags and sharps containers should be filled to no more than three quarters full.

The central storage area should be hard-standing impermeable easily cleanable floor with good drainage (away from watercourses), fenced, lockable, inaccessible to insects animals, and isolated from patients and the public.

#### **Collection and transportation of healthcare waste**

The Collection should be fixed and appropriate to the quantity of waste, but not more than a day. The collection of healthcare waste must follow specific routes through the hospitals in order to reduce the passage of loaded carts through wards and other clean area. Waste transport trolleys are closed with lids to isolate the wastes from patients and the public. The internal transport of waste should use separate floors, stairways or elevators as far as possible. Transport staff should wear adequate personal protective equipment, gloves, strong and closed shoes, overalls and masks.

### **Treatment of healthcare waste**

The unusable waste materials should preferably be treated to reduce their potential health or environmental hazard and volume, with remaining residues sent for land disposal to a suitably constructed site. Treatment technologies employ thermal, chemical, irradiative, biological or mechanical processes. These technologies could be supplemented by post-treatment shredders, grinders and compactors.

Incinerators should have flue gas cleaning systems to minimize pollutant releases and meet national or international emission limits. The thermal process should be reach more than 800 °C.

### **Disposal of healthcare waste**

In all healthcare waste systems, the removal of the remaining healthcare waste materials after minimization or treatment will require access to land for final disposal. Desirable features of a landfill are restricted access to prevent scavenging, daily soil cover to prevent odours and regular compaction and isolation of waste to prevent contamination of groundwater and surrounding areas.

### **Training**

Healthcare waste handlers and all health professionals should be trained before starting work and then on a routine basis. The training should include awareness rising about the potential hazards from waste, the purpose of immunization, safe healthcare waste handling procedures, reporting of exposures and injuries, preventing infection following an exposure, and the use of protective equipments.

There was inadequate information on the implementation of healthcare waste management system at the hospital level. Therefore, this paper reviews different practical experience applied in the management of health care waste at hospital level and identify the best appropriate practices applied to the safe handling, treatment and disposal of healthcare waste.

### **Segregation of health care waste**

Healthcare waste should be segregated based on their potential hazard characteristics, treatment requirement, and disposal route, by the person who produces each waste item. Separate labelled colour code containers (infectious waste yellow, chemical and

pharmaceutical waste brown, general waste black) should be available for each medical area for each category of healthcare waste.

### **Healthcare waste storage**

Closed colour-coded labelled containers are kept away from patient indoors for interim or short-term storage (depending up on the type of waste not more than 12 hours) of healthcare waste in each medical rooms. Waste bags and sharps containers should be filled to no more than three quarters full.

The central storage area should be hard-standing impermeable easily cleanable floor with good drainage (away from watercourses), fenced, lockable, inaccessible to insects animals, and isolated from patients and the public.

### **Collection and transportation of healthcare waste**

The Collection should be fixed and appropriate to the quantity of waste, but not more than a day. The collection of healthcare waste must follow specific routes through the hospitals in order to reduce the passage of loaded carts through wards and other clean area. Waste transport trolleys are closed with lids to isolate the wastes from patients and the public. The internal transport of waste should use separate floors, stairways or elevators as far as possible. Transport staff should wear adequate personal protective equipment, gloves, strong and closed shoes, overalls and masks.

### **Treatment of healthcare waste**

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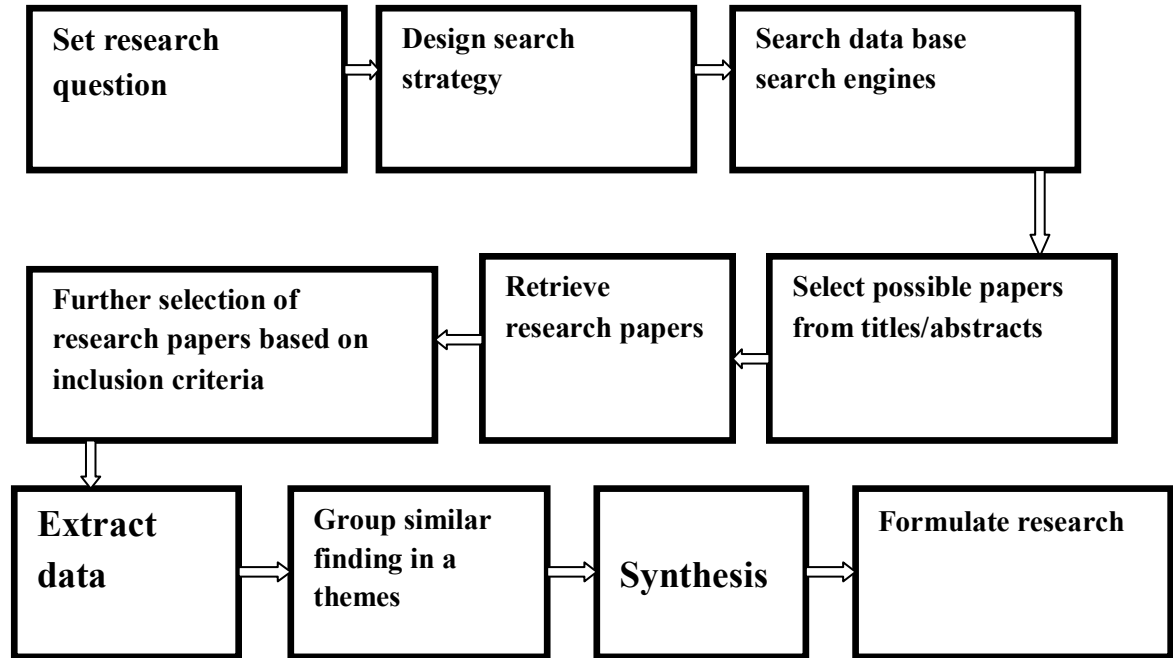
There was inadequate information on the implementation of healthcare waste management system at the hospital level. Therefore, this paper reviews different practical experience applied in the management of health care waste at hospital level and identify the best appropriate practices applied to the safe handling, treatment and disposal of healthcare waste.

## **Key questions**

Is there a practice difference in the management of healthcare waste in different countries experience?

## 2. METHODOLOGY

To assess the different practices of healthcare waste management systems applied in different countries a descriptive review was done using the following steps



**Figure 1: The systematic literature review process applied in healthcare waste management practices review, 2014**

### Search strategy and search engines

Initially, the DARE data base (<http://www.library.ucsf.edu>) was explored in an attempt to confirm whether systematic review or Meta-analysis or availability of ongoing project related to the topic. We undertook a literature search and review process according to a plan prepared before data collection. We considered studies conducted on the health care waste management. Relevant papers were found through computerized literature search engines of scholarly articles. They were MEDLINE <http://www.ncbi.nlm.nih.gov/sites/entrez?db=pubmed>, EMBASE, <http://www.embase.com>, and Science Direct <http://www.sciencedirect.com/>. It is designed for providing access to multiple databases, cross-disciplinary research, and in-depth exploration of specialized subfields within an academic or scientific discipline using the queried for the terms “healthcare waste” OR “ medical waste” OR “ bio-

**medical waste” OR “ clinical waste” OR “hospital waste” OR “ infectious waste” OR “ pathological waste” OR “ pharmaceutical waste” OR “ radioactive waste” OR “sharp waste”** all fields. The review was limited to article published in the year between 2003 through 2013 to best illustrate the current state of affairs and to reflect possible changes.

### **Selection criteria and procedures**

Study designs included in this review were interventional and observational studies. We aimed to identify studies on the management of healthcare waste management system using inclusion and exclusion criteria. Research articles deal about healthcare waste management system in hospitals used as inclusion criteria. If the research papers are repetition in one country, I selected the recent research paper. The research which are discussed only about healthcare waste generation rate, the research article published before 2003 and research that are not related with waste management system were excluded from this review.

### **Stage 1: Title and abstract screens**

After the literature search the titles, all articles titles were examined, then irrelevant articles were discarded. In the title screening process, elements considered of relevance were:

- ❖ The study conducted at hospital level
- ❖ Healthcare waste management system

Eligible studies were then selected. Subsequently, all abstracts were critically examined for relevance.

### **Stage 2: Data extraction**

For each paper, we examined year of publication, counties where the study was done, methodological approaches, the scope of the study, sample size, the main finding of the study.

Whether they meet the eligibility criteria or not each paper were assesses based on the following criteria (Table 1).

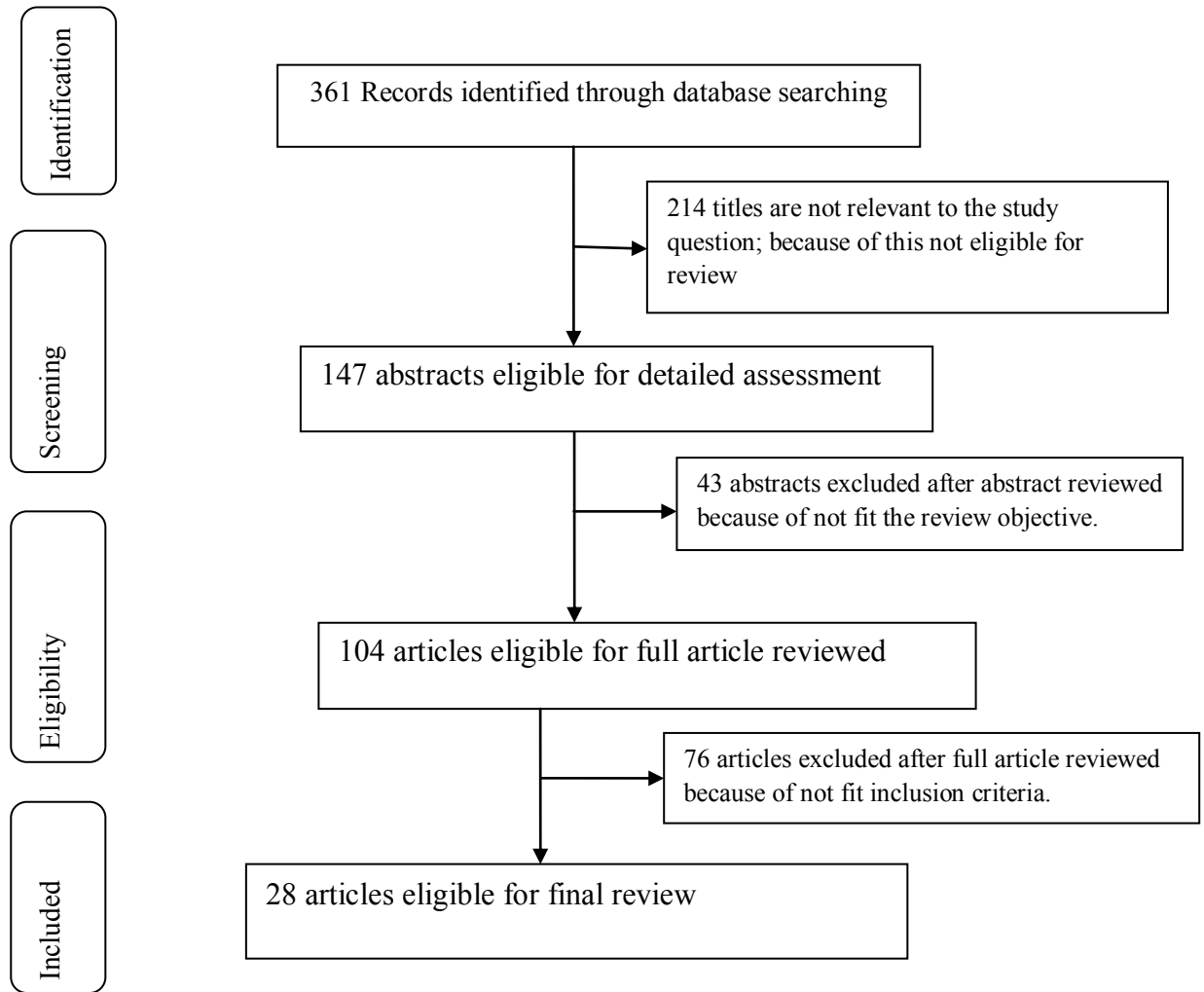
**Table 1:** Inclusion and exclusion criteria used for the selection of healthcare waste management practice in this review, 2014

<b>Inclusion criteria</b>	<b>Exclusion criteria</b>
Healthcare waste management at hospital level	Healthcare waste management at health centre and health post level.
The main findings are clearly stated themes of the components of healthcare waste management (generation, storage, treatment, collection, transportation, disposal and safety measures)	Only healthcare waste generation rate
Objectives are clearly formulated	Ambiguous result
The data based on the actual measurement	Non English literatures
Conclusion and Recommendations are based on study findings	

## **Analysis**

The extracted data were analyzed by theme. We conducted content analysis of the data manually, by sorting and organized according to thematic similarities and differences. Then, we categorized and studied the information to understand the relationships in the overall context of the review.

The overall flow diagram of the review process described by the following diagram:



**Figure 2: Flow diagram of the systematic review process, healthcare waste management system, 2014.**

**Information was grouped according to the following themes:**

- Information focused on the healthcare waste generation, storage, treatment, collection, transportation, disposal and safety measures.
- Problems/obstacles related to healthcare waste management
- Factors contribute to the healthcare waste management

### **3. RESULTS AND DISCUSSIONS**

In this review, examine 360 published literatures addressing healthcare waste management system. The review was limited to, articles published in the year 2003 or later to best illustrate the current state of hospitals waste management. Based on the inclusion criteria detailed reviewed involved 28 research papers on healthcare waste management in different regions; this given the varied nature and geographical range of the papers found chosen to provide a relevant level assessment and summary of recurrent themes within this brief report.

#### **Healthcare waste segregation**

The segregation consists in separating of different waste based on the hazardous characteristics of waste. Based on the world health organization assessment only about 10-25% of healthcare wastes are hazardous, the management of healthcare waste costs could be greatly reduces if a proper segregation were implemented. Segregation of healthcare waste also decreases the risk of infecting workers handling waste (12). The healthcare waste should be segregated by using colour containers (13).

The research conducted in different countries revealed that healthcare waste segregation practices varies in different countries; such as the study conducted in Libya, Brazil, Nigeria, Iran, Ghana, South Africa, and Ethiopia confirmed that, hazardous healthcare wastes were stored in the same containers as domestic waste (13-21). These creating a great risk to the hospitals staffs, the public, and the environment (14). Whereas the study conducted in Greece, Mongolia, Portugal, China and India showed healthcare waste were segregated according to the characteristics using colour coding and/or labelling of waste containers (1, 22-26).

#### **Temporal storage of healthcare waste**

The place where the healthcare waste is kept before transporting to the final disposal site is termed as a temporary waste storage area (13). Intermediate storage takes place in a specially designed storage area in order to avoid biodegradation, odours, and the

attraction of insects and rodents (7). The common practices in Jordan, Nigeria, Libya, South Africa, and Ethiopia were no special storage area/room for healthcare waste, wastes store temporary in open containers which creates potential threat (7, 16, 19, 21, and 27). On the other hand, in Greece, Mongolia, and Portugal the healthcare waste stored in a room equipped with screen for flies and rodent protection, clearing facilities and well ventilated (22, 24, 26).

### **Collection and transportation of healthcare waste**

Healthcare waste should be collected and transported in a regular base. The collection of healthcare waste must follow specific routes through the hospitals in order to reduce the passage of loaded carts through wards and other clean area. The carts should be easy to load and unload, free from sharp edges that could damage waste containers, and easy to clean (6). The study conducted in many developing countries showed healthcare waste collected and transported in open plastic containers; this was possibly due to lack of awareness which could lead to direct exposure to hazardous substance for waste handler (4,5, and 28). Whereas in developed countries healthcare wastes were collected and transported by different closed containers with specific colour codes through pre-established routes, which include specific corridors and elevators on each floor (22, 26, 29 and 30).

### **Treatment of healthcare waste**

The purpose of healthcare waste treatment is to decrease the potential hazard posed by waste, while endeavouring to protect the environment (12). The study conducted in developing countries revealed that the commonest method of healthcare waste treatment was done by poor design and construction incinerators have low combustion capacity (19, 31 and 32). Such types of incinerators have public health risk from incinerator emissions are driven largely dioxin, furan and A high amount of ash are generated because of the incomplete burning of healthcare waste (8). Pre-treatment of highly infectious lab waste was not done in many hospitals found in developing countries like Ethiopia, Ghana, Nigeria, and South Africa (15, 16, 19, and 20).

## **Disposal of healthcare waste**

Healthcare waste disposal is an important problem for public health and the environment (33). Because healthcare waste contains infectious materials, genotoxic chemicals, heavy metals like mercury, Poly Vinyl Chloride (PVC), and radioactive substance (6). Many researches confirmed that, the problems were higher in developing countries for example, the study conducted in Libya, Ghana, Iran, and Nigeria showed that, hospitals disposed of their waste , along with general domestic waste , in an open dumping site outside of their compounds (13, 19, 20, and 34). Other countries like Ethiopia, South Africa, Tanzania, and Botswana untreated healthcare waste and the waste from incineration residues openly dumped on-site (18-19, and 35-37). These lead to environmental pollution problems, fires, higher risk of diseases transmission and open access to scavengers and animals (12). Whereas, the healthcare waste disposal within the countries of the European Union (EU) and China were strictly control by law in order to prevent the negative consequence of hazardous healthcare waste on the human health and the environment (38).

## **Healthcare waste management training**

Healthcare waste handling is a hazardous activities; workers should be trained before starting work handling waste, and then on a regular basis (12). The training focus on the safe waste handling procedures, nature of the work in the hospital, the hazards and possibility of worker exposure, and the responsibilities of individual workers (5). Best practices in healthcare waste management require that workers received repeated training (8). In some countries like Libya, Nigeria, and Ethiopia there were no regular formal training program on healthcare waste management (18, 21, and 39). While others such as India, Iran and Uganda; have repeated training and instruction about appropriate healthcare waste management to take adequate precautionary measures in handling healthcare waste (1, 32, and 40).

**Table 2:** The most common practices of healthcare waste management (segregation, storage, treatment, collection and transportation, and disposal) in hospitals of different countries, 2014

<b>Components of healthcare waste management</b>	<b>Countries &amp; year of study</b>	<b>Practices</b>	<b>Comparison with WHO minimum standards</b>	<b>References</b>
Healthcare waste segregation	Greece-2007, Mongolia-2008, Portugal-2010, China-2009 and India-2008.	Healthcare wastes were segregated according to the characteristics using color coding and/or labeling of waste containers.	Fulfill the WHO minimum standard of healthcare waste segregation.	Tsakona et al., 2007; Shinee et al., 2008; Ferreira & Teixeira, 2010; Ruoyan et al., 2009; & Rao, 2009.
	Libya-2009, Brazil-2005, Nigeria-2009, Iran-2004, Ghana-2012, South Africa-2008 Ethiopia-2011&13	Hazardous healthcare wastes were stored in the same containers as domestic waste	Not fulfill the WHO minimum standard.	Sawalem et al., 2009; Silva et al., 2005; Coker et al., 2009; Askarian et al., 2004; Sasu et al., 2012; Nemathage et al., 2008; Debere et al., 2012; Haylamicheal et al., 2011.
Healthcare waste storage	Greece-2007, Mongolia-2008, Portugal-2010.	Healthcare waste stored in a room equipped with screen for fillies and rodent protection, clearing facilities and well ventilated.	According to the WHO minimum standard.	Tsakona et al., 2007; Shinee et al., 2008; Ferreira & Teixeira, 2010.
	Jordan-2007, Nigeria-2009 Libya-2009, South Africa-2008, Ethiopia-2013.	No special storage area/room for healthcare waste	Violate WHO minimum requirement.	Bdour et al., 2007; Ngwuluka et al., 2009; Sawalem et al., 2009; Nemathage et al., 2008; Debere et al., 2013.

Collection & transportation of healthcare waste	Greece-2007, Mongolia-2008, Turkey-2010.	Healthcare wastes were collected and transported by different closed containers with specific color codes through pre-established routes.	Within the WHO minimum standard.	Tsakona et al., 2007; Shinee et al., 2008; Eker et al., 2010.
Treatment of healthcare waste	Ghana-2012, Nigeria-2009, Ethiopia-2013, South Africa-2008.	The commonest method of healthcare waste treatment was done by poor design and construction incinerators have low combustion capacity	Not achieve the WHO minimum standard	<b>Sasu et al., 2012; Coker et al., 2009; Debere et al., 2013; Nemathage et al., 2008.</b>
Disposal of healthcare waste	China-2010	The final disposal of treated healthcare waste using standard sanitary landfill.	According to the WHO standard.	Ruoyan et al., 2010.
	Libya-2009, Iran-2002, Ghana-2012, Nigeria-2006, Ethiopia-2011, South Africa-2008, Tanzania- 2006, Botswana- 2008.	Open dumping outside/ on-site.	Not fulfill the WHO minimum standard	<b>Sawalem et al., 2009; Askarian et al., 2004; Sasu et al., 2012; Bassey et al., 2006; Deneke et al., 2011; Nemathage et al., 2008, Manyele &amp; Anicetus 2006; Mbongwe et al., 2008.</b>

### Reasons for poor waste management

Many researchers confirmed that, the important reasons for poor healthcare waste management are: lack of awareness, lack of comprehensive staff training, lack of facilities, and absence and/or weak enforcement of rules and regulations (3, 13, 30, 36, and 41-43).

### Approaches for achieving good healthcare waste management

The research conducted in different area and time indicated that, good healthcare waste management achieved by: the presence of responsible waste management team, preparing

compressive plan, the waste handlers equipped with the latest information, skill and practices, allocation of adequate financing, the estimation of the amount and type of healthcare waste, use of enforced codes of practice and guidelines, provision of regular training for staffs, and full participation of all staffs (6, 13, 14, 22, 23, 26, and 44).

## **5. CONCLUSIONS AND RECOMMENDATION**

Healthcare waste management requires special attention because of the risk posed by the presence of hazardous substances in the healthcare waste. Improper storage, collection, transportation, treatment and disposal practices in the management of healthcare waste were common; especially in developing countries. In many countries, there was no standard segregations practices; hazardous and general (non-hazardous) healthcare waste still handled and disposed together. Low level of awareness about the importance of implementing appropriate healthcare waste management systems are predominant in many developing countries. There is an urgent need for raising awareness and education on healthcare waste issues. Proper healthcare waste management strategy is needed to prevent public health risk and environmental pollution related to hazardous healthcare waste.

### **Gaps for further study**

Impact of intervention on healthcare waste management system were not studies, there for study should be conducted on the evaluation of the effectiveness of measures taken for the improvement of healthcare waste management.

### **Limitation of the systematic literature review**

Literatures written other than English language were not included in this study. Though language restrictions is not recommended because literature from all languages maximise data retrieval and minimises bias but, unavoidable constraints such as a lack of access to translation services and funds to pay for these makes it necessary to restrict the systematic review to only English language publications.

### **Declaration of conflicting interests**

The authors do not have any potential conflicts of interest to declare.

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## Annex 2. Data Collection tools

### 2.1. Tools for observational checklist for assessing healthcare waste management practice

#### 1. for waste storage and waste segregation:

S.No.	Activities/facilities	Yes	No
1	Does wastes are segregate at the generation point?		
	If yes:		
2	Is for general health care waste black bin?		
3	Is for optionally infectious health care waste yellow bin?		
4	Is for used sharp, including broken glass yellow containers?		
5	Is the facility used, another option?  If yes, specify: _____		
6	Is the temporary waste storage bin having cover?		
7	Is the temporary waste storage bin easily cleanable?		

**2. For waste collection and transportation:**

<b>S.No.</b>	<b>Activities/facilities</b>	<b>Yes</b>	<b>No</b>
1	Does the facility have waste collection point?		
2	Is the waste collection do with time table of the frequency of collection?		
3	Is the worker having duty glove?		
4	Are the workers having boots?		
5	Does hazardous / infectious HCW and non-risk HCW are collected on a separate trolley?		
6	Are the workers having a prone for waste collectors?		
7	Does waste containers are appropriately sealed?		
8	Does waste removed and replaced immediately when they are no more than three-quarters full?		

**3) For on-site health care waste storage:**

<b>S.No.</b>	<b>Activities/facilities</b>	<b>Yes</b>	<b>No</b>
1	Does the facility have dedicated place?		
2	Does possibility for animal/insects to have access is designed to store hazardous /infectious waste?		
3	Is the health care waste store for more than 24 hours? Before being treated / disposed of?		

**4) For waste treatment and disposal:**

S.No.	Activities/facilities	Yes	No
1	Does the facility have on-site Sterilization / disinfection equipment?  If yes, what type? _____		
2	Do existing facilities provide adequate capacity?		
3	Are existing facilities in compliance with applicable regulation? That is?  -Is open burning is prohibited at disposal site?  - Is cover is applied at the required interval?  - Is access to the disposal site is controlled with signs?  -Fencing?		

Other observations

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**2.2. Tools for in depth interview questionnaire for assessing healthcare waste management practice**

Name of hospital \_\_\_\_\_

Name of collector \_\_\_\_\_

**1. PROFILE**

S.NO.	Question	Response Code	Skip to	Code
1	Does the facility have an on-site incineration?	1.Yes 0.No		
2	How many beds?			
3	How many patient days?			
4	How many employees?			
5	Is health care waste generation rate assessment done last year?  If yes, how much the total health care waste?			
6	How much waste was recycled? Types?			
7	Is there a waste segregation practices?			
8	Does the facility have on-site sterilization/ disinfection equipment? What type?			

## 2. MANAGEMENT

S.No.	Question and filters	Response		Skip to	Code
		Yes	No		
1	Does the facility have a mercury (Hg) elimination policy/program?				
2	Does the facility have a program for purchasing Hg alternative materials				
3	Does the facility have a recycling program?  What are they? (I.e. Paper, plastic, aluminium, steel, Cardboard, pallet, and food waste,).				
3	Are waste volumes tracked? If so, how? (i.e. by dept, floor)				
4	Has the facility performed a waste audit in the last 3 years				
5	Has a committee been formed to investigate waste reduction? Efforts, If so , what Department is on the committee				
6	Does the facility have a written: operational standard of the waste management plan for potentially infectious waste?				
7	Staff trained in waste management?				

### 3. PATIENT CARE.

S.No.	Question and filters	Response		Skip to	Code
		Yes	No		
1	Does the room have a red bag and general waste container?				
2	Are visual aids or instructions present near the waste receptacles to help in Proper segregation? What used?				
3	Is patient kits (bed pans, pitchers, e.t.c.) reusable?				
4	Are chemotherapy wastes collected separately?				
5	Are Hg thermometers sent home with patients and/or new mother?				
6	Does a red bag waste contain non-infectious materials? If so, list examples				
7	Are reusable under pads, linens, gowns, and bedpans used?				
8	Are sharps containers reusable				
9	Is waste dental amalgam from lab and drain traps collected for off-sit recycling/retort?				

## 1. LABORATORY

S.No.	Question and filter	Response Code		Skip to	Code
		Yes	No		
1	Are solvents recycled (i.e. xylene, alcohol)? Volumes?				
2	Are formaldehyde/formalin and glutaraldehyde recycled? Volumes?				
3	Does lab contain both red bag and general waste containers?				
4	Does the red bag waste contain non-infectious material? If so, list examples.				

## 5. PHARMACY.

S.No.	Question and filter	Response Code		Skip to	Code
		Yes	No		
1	Are drugs supplied in reusable shipping containers?				
2	Is inventory maintained as first-in/first-out?				

3	Is expired drug sent back to the supplier /manufacturer?				
4	Are non-PVC IV bags used?				
5	Is reusable container used for in-house distribution?				
6	Are compounding methods performed using secondary containment?				

#### 6-FOOD SERVICE

- 1- Is food waste used for compost or recycled?
- 2- Do refrigerators use mercury thermometers?

#### 7. GENERAL FACILITIES

S.No.	question and filter	response		skip to	code
		yes	no		
1	Are fluorescent lamps recycled?				
2	Is there a program to collect and recycled batteries?				
3	Has the facility investigated using non-toxic x-ray developing solutions or digital imaging system?				

4	Do you have a solid waste reduction strategy?				
5	If you incinerate your solid waste, is there a plan to try to eliminate Incineration as a disposal method?				
6	Do you have a waste management policy that includes:  - Hierarchy of waste management.  - Goals of waste management program.  - Handling and disposal procedures for all waste streams.  - Pollution prevention.				
7	Does your hospital provide waste management education or training?				
8	Do you communicate your environmental successes with the community?				
9	Do you have an environmental preferable purchasing policy to encourage waste reduction?				
10	Do you practice waste segregation?				
11	Do you reduce / eliminate chlorine-containing supplies, reduce the amount discarded that goes to medical waste incineration?				
12	Do you have a procedure for the safe handling and disposal of Cytotoxic				

	drug?				
13	Are chemotherapy waste containers strategically placed to collect only Chemo waste and not other regulated medical waste or trash?				
14	Are material safety data sheets maintained and made readily available to all employees?				
15	Do you have a written spill privation plan and are spill kit available and accessible?				
16	Do you capture and recycle the silver and x-ray film from radiology?				

### **Annex-3: Participant's Consent Information Sheet**

#### **a. Participant's information sheet**

**Title of the project: Determining Generation rate of Healthcare Solid Waste,**

**Composition**

**and Evaluation of its Management in Amhara National Regional**

**State,**

**Ethiopia.**

**Principal Investigator: Esubalew Tesfahun**

**Advisor:** 1. Dr. Abera Kumie

2. Dr. Abebe Beyene

**Coordinating office:** Addis Ababa University, School of Public Health

**Introduction:** Health care service is vital for our life, health and well being. But the waste generated from health care activities can be hazardous, toxic and even lethal because of their high potential for disease transmission. The hazardous and toxic parts of waste from health care establishments comprising infectious, bio-medical and radioactive material as well as sharps constitute a grave environmental and public health risk, if these are not properly treated. **Purpose:** This study aimed to determine health care waste generation rate and develop mathematical model that can be used to estimate generation rate by investigating in detail the generation and composition trends for planning appropriate waste management system. **Procedure and Participation:** The method of the research is a descriptive cross sectional study. The expected duration of the participant's contact with the interviewer will be not more than fifty minutes. You asked to participate in this research because the trustful information which you will provide is important for the understanding of the proposed subject matter. You will be asked about solid health care waste management system is based on four environmental factors: sanitation, safety, security, and aesthetic conditions.

**Confidentiality:** to establish secured safeguards of the confidentiality of research data, the PI will use codes during the data collection period instead of using names. The original data will be locked in cabinets until the data analysis carryout and no person shall access except the PI and the advisor for data checking and cleaning purpose. The

use of information for any purpose other than that to which participants consented is unethical to the participants. The information you provide is not disclosed in the way it identified your personal characteristics and privacy. After the research defence and final work is approved by the school of public health and academic commission and university senate, the original data questionnaire will be incinerated in a secure manner.

**Benefit:** The research does not have a short term financial, health care and capacity building benefit to the research participant as an individual or as a group, but in the long run it will help the concerned organization and policy makers to have a policy consideration and direction and formulation of strategy and design of sound health care waste management system based on the recommendations and the findings. Moreover the research work will help as a baseline data in the field. If any environmental health associated health threats are identified, the principal investigator will inform the Regional health bureau and local health administrators to provide the necessary interventions.

**Risk:** The proposed research does not have any inhumane treatment of research participants and any physical harm, social discrimination, psychological trauma and economic loss.

**Inducement, incentive and Compensation:** This study process has no any form of inducement, coercion and the study does not bring any risks that incur compensation.

**Results Dissemination:** The researcher is responsible for dissemination of findings moreover fully accountable to provide feedback to the hospital administration and to the policy makers. Maximum effort will be done to publish the finding in the scientific reputable journal.

**Freedom to withdraw:** If you want to participant in the study, you have full right to withdraw from the study any time you wish. This would have no effect at all on your health benefit or other administrative effect that you get from the hospital as routine moreover; nobody will enforce you to explain the reason of withdrawal.

**Person to Contact:** The participant has the right to ask information that is not clear about the research context and content before and or during the research work. You can contact the principal investigator and his advisor. Moreover, this research undergone ethically reviewed and approved by Addis Ababa University, College of Health Sciences IRB. The

main task of this board is to make sure that the ethical principles is adhered or not and the research participants are protected from harm.

If you want more information and check about this project you can contact the following people

**Addis Ababa University College of Health Sciences IRB Secretary Office Tel.**  
0115512876

**Principal Investigator name and address:** Esubalew Tesfahun Tel: 0911917860

**Supervisor name and address:** Dr. Abera Kumie, School of Public Health, College of Health Science, Addis Ababa University; Mobile:0911882912

**b. Informed consent form**

**Title of the project: Determining Generation rate of Healthcare Solid Waste, Composition and Evaluation of its Management in Amhara National, Regional State, Ethiopia.**

I have been well aware that this research undertaking is a post graduate degree partial fulfilment of research thesis which is fully supported and coordinated by AAU School of Public Health and the designate principal investigator is Esubalew Tesfahun. I have been fully informed in the language I understand about the research project objectives that are to understand the health care waste management systems.

I have been informed that all the information I shall provide to the interviewer will be kept confidential. I understood that the research has no any risk and no composition. I also knew that I have the right to withhold information, skip questions to answer or to withdraw from the study any time I have acquainted nobody will impose me to explain the reason of withdrawal. It is also enlighten there would have no effect at all on my health benefit or other administrative effect that I get from the hospital.

I have assured that the right to ask information that is not clear about the research before and or during the research work and to contact

Addis Ababa University College of Health Sciences IRB Secretary Office Tel.  
0115512876

**Principal Investigator's Name:** Esubalew Tesfahun Tel: 0911917860.

**Supervisor's Name and Address:** 1. Dr. Abera Kumie Tel: 0911882912. Addis Ababa  
University College of Health Sciences

2. Dr. Abebe Beyene Tel: 0912888500

I have read this form, or it has been read to me in the language I comprehend and understood the condition stated above, therefore, I am willing and confirm my participation by signing the consent.

Name of the participant \_\_\_\_\_

Agreed to participate in the study: Yes /No (mark one of them for verbal consent)

Signature \_\_\_\_\_ (if written consent)

Name of witness signature \_\_\_\_\_ (Data collector, supervisor, any third person)

Signature \_\_\_\_\_

Date \_\_\_\_\_

**Annex 4: Declaration**

**Letter of declaration**

I, the undersigned, declared that this is my original work, has never been presented in this or any other University, and that all the resources and materials used for the dissertation, have been fully acknowledged.

Name: Esubalew Tesfahun

Date: \_\_\_\_\_

Signature: \_\_\_\_\_

Place: School of Public Health

This dissertation has been submitted for examination with my approval as supervisor

Name: Dr. Abera Kumie

Date: \_\_\_\_\_

Signature: \_\_\_\_\_