Investigation of Potential Environmental Impacts and Sustainable Management of Municipal Solid Waste using the Driving force-Pressure-State-Impact-Response-Outcome (DPSIRO) framework: Case of Bahir Dar, Ethiopia

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Title: Investigation of potential environmental impacts and sustainable management of municipal solid waste using the Driving force-Pressure-State-Impact-Response-Outcome (DPSIRO) framework: Case of Bahir Dar, Ethiopia

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Posta 272

Abstract

The generation of MSW in urban areas in Ethiopia and elsewhere continues to increase and poses a challenge to city governments and citizens if the wastes are not properly managed. Applying an integrated system for managing MSW and recovering the material for use in new products can reduce the negative impacts on the environment. The purpose of this study is to apply the DPSIRO framework to develop a system that reduces the negative impacts of MSW in Bahir Dar city in a sustainable way. The research started by identifying the main driving forces that lead to the generation of MSW. Then, states because of pressures and the consequent impacts were investigated. Finally, the appropriate responses and outcomes obtained from the responses were dealt with. Methods used to quantify GHG emissions, leachate, and eutrophication potential were applied. According to the findings, the waste disposal site emits an

estimated 46Gg of greenhouse gases per year in 2020. The eutrophication capacity of organic waste generated in the city was 0.0594 Kg N-equivalent or 59.4g N-equivalent. The waste also contains an average of 1,112mm of leachate per day on an annual basis. The state of the environment has an impact on human health and the ecosystem. Applying the circular economic system, knowledge transfer, and waste management fees are the main responses suggested to decision and policy makers. The responses correspond with balanced economic, social and environmental situations. Outcomes were quantified in terms of organic fertilizer, income and renewable energy (briquette) when the actions were taken.

Keywords: Sustainable management, Eutrophication potential, Greenhouse gas emission, Municipal solid waste, Framework, Ethiopia

1. Introduction

Citizens and businesses in most of the world's cities consume a great deal of materials and produce a great deal of waste (Makarichi et al., 2018). With rapid population and economic growth and urbanization, solid waste output is increasing in urban areas around the world (Farzadkia et al., 2020; Singh, 2019). According to a World Bank report (Franco et al., 2021; Kaza et al., 2018) cities around the world generate roughly 2.01 billion tons of MSW per year, and that number is projected to increase to 3.40 billion tons by 2050. Clearly the solid waste problem is a major concern for national and local authorities in many cities throughout developing and developed countries (Inghels et al., 2016; Noufal et al., 2020). Especially in developing countries, the common solid waste management system that they use is landfill because it is relatively less costly to implement and operate than other options. However, landfills are widely regarded as the least preferable municipal solid waste management system due to its high contamination potential, including water and soil pollution due to the leachate

seepage and greenhouse gases (GHGs) emissions resulting from the decomposition of biodegradable waste (Adeleke et al., 2021; Wang et al., 2020), and the sequestration of potentially reusable materials in lieu of recycling.

The negative impact of municipal solid waste due to its mismanagement in the cities covers from local to global level. The release of odorous compounds from landfill has a very local (micro-) impact as it affects the surrounding population. Discharge of pollutants into ground or surface water due to landfilling can have an impact on the regional (meso-) scale, as eutrophication can occur tens of kilometers away from disposal facilities unless fugitive leachate is collected and properly treated. Emissions of greenhouse gases such as methane contribute to global warming, which has an impact on the global population (macro impact) (Ellen et al., 2018; Matheus, 2018; Mattos et al., 2020). The increasing demand for goods due to increased urbanization and population is causing solid waste generation in Bahir Dar city to steadily increase. Currently, the majority of solid waste produced in the city is dumped into open dumpsites without any processing and uncontrolled emissions lead to negative impacts on soil, water and air environment; these emissions are expected to continue in the future until MSW management systems are improved.

Sustainable MSW management necessitates a multifaceted approach including a wide range of stakeholders (Salem et al., 2020). The aim of the study was to apply the Driving force-Pressure-State-Impact-Response-Outcome (DPSIRO) framework to study the potential impact of municipal solid waste on air, soil and water quality and develop sustainable indicators to reduce the impact. The DPSIRO framework is an extension of the DPSIR framework and it is a cycle which relates to a particular human need and accompanying activities (Misganaw & Teffera, 2021). The DPSIRO framework analysis describes that economic and social development, which

are common driving force (D), exert pressure (P) on the environment, and, as a result, the state (S) of the environment such as depletion of natural resources and degradation of environmental quality changes. These changes then have an impact (I) on the environment and human health. Due to these impacts, society responds (R) to the driving force, the pressure, state or impact, and then when society gives the response, the outcome (O) shows the expected result at each response of the impact.

2. Methodology

2.1. Overview of study area

The city of Bahir Dar was chosen for investigation of the possible negative impacts of MSW and the development of sustainable indicators to reduce the impacts using the DPSIRO framework. Bahir Dar is a town in Ethiopia's northwestern region, near the southern end of Lake Tana, at the headwaters of the Blue Nile River that then flows through Sudan and Egypt. The city is located at an elevation of approximately 1,820 meters above sea level, with geographic coordinates of 11°36'N and 37° 25' E. The establishment of Bahir Dar can be traced back to the fourteenth century, when Saint Kidane Miheret Church was built on the current site of Saint Giorgis Church (Biruk, 2017; Kassie, 2016; Tirusew et al., 2013). The city evolved from a monastery administration site as well as a market place to a rapidly growing urban center. The Amhara National Regional State's administrative seat is now located there. The city is made up of five sub-cities that share a common geographical location and people's living habits. With the range of attractions on the nearby Lake Tana (Ethiopia's largest lake and popular for churches and monasteries on the lake's 37 islands), it has become one of the country's main tourist destinations. Currently, the city consists of more than 415,000 peoples.

2.2. Research Method

In this study, the DPSIRO framework has been applied to assess the impact of municipal solid waste on soil, water and the air environment in Bahir Dar city. Figure 1 illustrates the cause and effect relation between factors of the DPSIRO framework. During the time of study, initially the driving forces which lead to the generation of municipal solid waste as pressure were determined. Second, the environmental change that results from pressure has been investigated. The state change of the environment was quantified in terms of greenhouse gas emission, eutrophication potential and leachate using mathematical models. Using an intergovernmental panel on climate change (IPCC) model, the total amount of CO₂ and CH₄ emitted from Bahir Dar city waste was estimated (Misganaw & Teffera, 2021). According to IPCC guidelines, the equation for measuring methane emissions from waste disposal sites was calculated using equation 1.

$$\text{Methane emission } \left(\frac{\text{Gg}}{\text{yr}} \right) = \frac{\text{MSW}_T \times \text{MSW}_F \times \text{MCF} \times \text{DOC} \times \text{DOC}_F \times F \times (1 - \text{OX})}{\frac{16}{(12 - R)}} \dots\dots\dots 1$$

The abbreviations in the above equation represent, MSW_T is total municipal solid waste generated (Gg/yr.), MSW_F represents the fraction of MSW disposed of in one or more solid waste disposal sites, MCF is methane correction factor (fraction), DOC indicates degradable organic carbon (fraction) (kg C/kg SW), DOC_F illustrate fraction DOC dissimilated, F is fraction of methane in waste dump gas, 16/12 is the conversion of carbon to methane, R represents recovered methane (Gg/yr.) and OX is oxidation factor (fraction-IPCC default is 0).

The approach assumes that all future methane emissions occur in the same year that the waste is discarded. The method is straightforward, and calculating emissions needs only the input of a small number of parameters, for which the IPCC guidelines provide default values in cases where country or city-specific quantities and data are unavailable. The amount of methane gas

released from the disposal site was estimated using the recommended degradable organic carbon and decay rate value for waste disposal site.

The emissions of carbon dioxide from municipal solid waste disposal sites without gas collection systems were calculated using $B = A \times \left(\frac{1-F}{F} + OX \right) \times \frac{44}{16} \dots \dots \dots 2$.

In equation 2 the variable B is CO₂ emission (Gg/yr.), A represents the quantity of CH₄ calculated from equation 1 above (Gg CH₄/yr.), F is fraction by volume of CH₄ in landfill gas, generally assumed to be 0.5, OX illustrates soil oxidation fraction, typically 0.1 (fraction) and the numerical values 44 and 16 represent molecular weight of CO₂ (kg/kg-mol) and molecular weight of CH₄ (kg/kg-mol) respectively.

The eutrophication capacity of organic waste was calculated using equation 3, 4 and 5 after the molecular formula of organic waste of Bahir Dar city determined.

$$EP = \frac{V/MW}{V_{ref}/MW_{ref}} \dots \dots \dots 3,$$

$$V = P + \frac{N}{16} + \frac{ThOD}{138} \dots \dots \dots 4 \text{ and}$$

$$ThOD = C + \frac{H-3N}{4} + \frac{O}{2} \dots \dots \dots 5.$$

The variables in the above three consecutive equations represent, EP is eutrophication potential, P indicates the number of phosphorus atoms in the molecule equals to 0 for all of our compounds, N is the number of nitrogen atoms in the molecule, O illustrates the number of oxygen atoms in the molecule, C is number of carbon atoms in the molecule, H represent number of hydrogen atoms in the molecule, V ref is the V for phosphate anion, [PO₄]³⁻ and V ref equals to 1, MW ref indicate the MW for phosphate anion, [PO₄]³⁻ and MW ref equals to 94.97 g/mol, MW is the MW of the compound and ThOD represent theoretical oxygen demand. The volume of leachate resulting from municipal solid waste in Bahir Dar city were quantified by using the

relation $L=R-E_a$ 6.

The symbols in equation 6 represented as, L is the volume of leachate, R is the volume of rainfall and E_a is the volume of real evapotranspiration (or simpler evaporation from the earth level).

Third, the impact that results from the change of soil, water and air quality was determined. Next to the impact, the recommended responses and expected outcomes obtained from the possible actions were determined. The responses and outcomes form a balanced relationship with economic, social and environmental situations. Finally, the overall scenario of the DPSIRO framework was conceptualized holistically by forming a balanced relation between economic, social and environmental situation. [Figure 1]

2.3. Data Collection, Data Source and Data Type

All of the data needed to complete the DPSIRO framework analysis for this study was gathered at the same time from both primary and secondary data sources. The five cases found in the city were grouped into three major groups once the analysis was completed. The three major classes were: inner, middle, and outer. A grouping technique based on population density, geographical location, population settlement, and land use pattern was employed to make data gathering from sample sites homogeneous. Data was randomly collected from the inner, middle, and outer classrooms to make the data representative at the time.

There are around seventeen Keble's in the city's five Kefleketema. The core (inner) part includes Keble 01, 02, 03, 04, 05, 06, and 12. 07, 08, 09, 10, 15, and 17 are the Keble's who belong to the middle part. The remaining Keble numbers 11, 13, 14, and 16 make up the outer group. This data was obtained from the Bahir Dar city administration office, which falls under the Keble's level category for 2016. From those categories, three Keble examples were chosen. Keble 05, Keble 10, and Keble 11 came from the center, middle, and peripheral, respectively. A total of 65, 96,

and 62 households were chosen at random to be sampled. The total number of households taken from both groups was 223.

The number of samples collected from sampling households was 33, 36, and 27 for the central, middle, and inner regions, respectively, with a total weight of 646.215kg from residential. The events took place between January 18 and March 23, 2020. The data for this approach was primarily gathered through solid waste characterization, focus group discussions, and face-to-face interviews with responsible persons regarding solid waste management, industry availability, and the population of Bahir Dar. Land observation was the other technique used. It was carried out to determine the actual capacity of municipal solid waste collected in the area, as well as their solid waste collection and sorting methods. Secondary data was gathered from both existing and unpublished sources for the study.

3. Result and Discussion

3.1. Deriving Force and Pressure

Three main driving forces: natural population growth rate, economic growth and rapid urbanization are led to generation of municipal solid waste in case of Bahir Dar city. With a waste generation rate of 0.223kg per capita per day, the municipal solid waste produced in Bahir Dar city increased from 73.05 tons per day in 2007 to 148.13 tons per day in 2020 (Misganaw & Teffera, 2021). The average annual population growth rate of 6.6 percent is one of the key factors that determines the shift in urban solid waste generation rate (Biruk, 2017; Tirusew et al., 2013). The study of municipal solid waste in Bahir Dar city revealed that as the city's population grows, the amount of municipal solid waste generated grows as well. As shown in table 1 below, solid waste production is rising in all waste generation sources. Depending on the result and from

the total waste generated, only 58% was properly collected and disposed of and 86% of the total waste generated is degradable (Asmare & Alelign, 2019; Wegedie, 2018). [Table 1]

Based on the analysis of environmental sustainability of the DPSIRO model, the pressure of municipal solid waste generation (P) is initiated by the driving force of municipal solid waste generation (D) and can block the action of the responsible community®. A large quantity of solid waste is generated in residential areas. It covers around 55% of the total waste. Rapid urbanization and technology used for production process are also considered as driving forces leading to waste generation in the city. Production, consumption and land use for solid waste disposal sites are pressures in addition to waste generation.

3.2. State

The pressure resulting from the driving force leads to changes in the state of environmental components, such as water, air and soil quality. This environmental degradation creates an elevated threat to economic growth and development (Chapagain et al., 2020). Change in environmental quality is a combination of physical, chemical and biological conditions.

3.2.1. Greenhouse Gas Emission (GHGs)

Air pollution is one of the world's most important challenges, with long- and short-term health consequences in countries of all socioeconomic levels (Luiz et al., 2020; Maroosi et al., 2019). GHGs, such as CH₄ and CO₂, are produced from the aerobic and anaerobic biodegradation of municipal solid waste (Zhang et al., 2019). The amount of CH₄ and CO₂ emitted from Bahir Dar city dump site was determined using the IPCC model. In this paper, municipal solid waste equals the amount of urban waste transported to the disposal site, then the MSW_F is equal to 58% and the remaining 42% is assumed to be lost due to recycling, waste burning at source, waste thrown

in to the drains and waste not reaching in to dump site due to insufficient solid waste management system. This insufficient management increases the transmission of diseases, causes contamination of surface and ground water, greenhouse gas emissions, and ecosystem damage. The total GHG emissions from dumpsite are calculated as the sum of the CO₂ emissions and the CH₄ emissions (converted to CO_{2eq}) (Misganaw & Teffera, 2021). The result obtained by using this relation was 23.112Gg in 2007 and reached 46.873Gg in 2020. As the result indicated in figure 2 the emission of greenhouse gases is increasing from time to time from 2007 to 2020. [Figure 2]

3.2.2. Eutrophication Potential

Another state condition that occurs in a water body when the composition of organic waste rises during the generation of municipal solid waste is eutrophication. The chemical formula of organic waste produced in Bahir Dar city was determined to calculate the EP (excessive biological activity of organisms due to over-nitrification) of municipal solid waste generated in the area. The organic waste generated in the city with percentage coverage was indicated in table 2. [Table 2]

Table 3 indicates the percentage chemical composition of organic wastes in terms of carbon, hydrogen, oxygen, and nitrogen. The weight of carbon (C), hydrogen (H), oxygen (O), and nitrogen (N) for each portion of organic waste was determined using the data in table 3. The aim of determining the weight of elements found in organic waste was to determine the waste's chemical molecular formula in terms of carbon, hydrogen, oxygen, and nitrogen to determine eutrophication potential. [Table 3]

The chemical composition of organic wastes was determined based on the composition in the table above. The total percentage composition calculated in the organic part of municipal solid waste of Bahir Dar city is indicated in table 4. [Table 4]

The eutrophication potential (EP) can be calculated for any compound that contains only C, H, N and O. In order to determine the eutrophication potential of organic waste generated in Bahir Dar city, obtaining the molecular formula of the organic waste is required. Then the molecular formula of the waste can be obtained by dividing each component by its molecular weight by excluding sulfur and ash. To obtain the general chemical formula that is present in organic municipal solid waste of Bahir Dar city, use the lowest represented element nitrogen as the base. After taking nitrogen as the base, then dividing each value of the element by the number of moles of nitrogen and the result is indicated in table 5. [Table 5]

As indicated in table 5, the organic waste produced in the city has the chemical formula $C_{24}H_{36}O_{13}N$. The calculated value of ThOD and V were 38.75 and 0.343 respectively by using the molecular formula of organic waste of the city and mathematical equations in the material and method part. The eutrophication potential of organic waste produced in Bahir Dar city was 0.0594 Kg N-equivalent or 59.4g N-equivalent.

3.2.3. Leachate

Like greenhouse gas emission and eutrophication, leachate is another factor which changes the state of a given environment. A number of factors influence the proportion of leachate generated, including waste characteristics, structure, and compressed congestion; weather conditions, average annual temperature, cell size, and gradual processing of the disposal region; and ground water impacts.

Generally, leachate quantity is patterned or specified through an easy water equilibrium method, considering the amount of water reaching the landfill and the level of water departing from the landfill (that is water used in biochemical processes and evaporation). The average annual evapotranspiration of Bahir Dar city is 307mm per day and the average annual temperature and rainfall is 19.6⁰C and 1419mm per day respectively (source: national metrology agency). Then the average amount of leachate that is found from municipal solid waste of Bahir Dar became 1,112mm per day.

3.3. Impact

In the DPSIRO framework, impacts are expressed in terms of the effect of change in the quality of the environment (soil, air and water) on social and ecological systems. Ecosystem and human welfare effects are both included in the impacts, however the former is focused on ecosystem problems such as reducing water, soil and air quality (Cooper, 2013). Indicators in the impact component of the DPSIRO framework are used to measure the change in state of air, soil and water due to the pressure and the driving force caused by the state of air, soil and water environment change. As indicated in figure 2, the emission of greenhouse gases increased from 23.112Gg to 46.873Gg in the years between 2007 and 2020 (Misganaw & Teffera, 2021). By trapping heat, this rise contributes to climate change, as well as respiratory problems caused by smog and pollution. The increment of GHG emissions induces genetic damage in animals, plants and bacteria in addition to human health impact (Mussury & Rocha, 2020). Other implications of climate change produced by greenhouse gases include extreme weather, food supply shortages, and increasing wildfires.

The eutrophication potential of municipal solid waste in the city is high and this leads to toxic poisons for human health that can be produced by harmful algal bloom species. Algal toxins can

build in shellfish and, more broadly, seafood, reaching harmful levels for human and animal health. Shellfish poisoning can result in paralysis, neurotoxicity, or diarrhea. Eutrophication has high ecological impact in addition to human health impact. Lake Tana water, which is the largest lake in Ethiopia, is found in Bahir Dar city and has high fish products for the community. Increased turbidity or reduced light penetrations into the lower depths of the water column are both caused by phytoplankton development. This can stifle the growth of submerged aquatic plants in lakes, affecting species that rely on them.

Leachate also leads to various human health impacts like greenhouse gas emission and eutrophication. Sweating, bleeding, and stomach ailments can all be induced by drinking contaminated leachate water, according to medical literature, as can blood disorders, congenital defects, and even cancer. Solid wastes generate organic pollutants and taken by agricultural plants and their accumulation in edible parts cause serious health problems to animals and humans (Parlavecchia & Loffredo, 2020).

3.4. Responses

There are various groups of responses in order to protect the resulting impact by municipal solid waste generation on water, air and soil environment. This response is taken by society to environmental situation and an initiative intended in order to reduce at least one impact (Cooper, 2013; Neves et al., 2008). Accordingly, the responses that given during the time of study are: sustainable with environment (i.e. friendly with nature in current time and future), technologically feasible with adequate method and equipment, economically feasible, wanted by the society live in the city, legally much with national as well as international legislations and also administratively attainable. The responsible parties either individuals or groups present in Bahir Dar could consider the following responses: shifting the policy from a linear to a circular

economy (i.e. applied the wastes produced from one sector to as an input for another one). There are several studies that can be used as inputs to convert Bahir Dar's policy from a linear to a circular economy system (Asmare & Alelign, 2019; Biruk, 2017). According to (Asmare & Alelign, 2019), more than 74 percent of Bahir Dar City's municipal solid waste can be used to make briquettes, and over 86 percent of the waste can be composted into organic fertilizer.

The application of user fees for waste management services is the next possible action. Because it imposes fees on waste generators, this reaction is a very essential policy for reducing the city's garbage creation from various sources. The goal of imposing trash charges is to reduce waste generation both in terms of quantity and risk, as well as to improve waste recovery (Michel et al., 2018; Sanjeevi & Shahabudeen, 2015). Transportation and garbage treatment fees are included in the prices, which should be lower for separated waste than for mixed waste. The purpose of the trash tax is to promote garbage recovery and reduce waste on the land (Misganaw & Teffera, 2021). Create awareness for community regarding with reducing, reusing and recycling should be increased; suitable policies and frameworks regarding to solid waste management should implement and monitor properly; built the ability of municipality in terms of economic, personnel and technical aspects and transfer information for community regarding to health, socio-economic and other harmful impacts of improper solid waste management of the city are important responses to reduce the generation and impact of waste.

3.5. Outcome

The reaction to the DPSIRO model resulted in high efficiency in research to assist decision makers in developing and executing policies in favor of the city's municipal solid waste management system (Misganaw & Teffera, 2021). The strategic actions taken by responsible parties at various level of DPSIRO framework (driver, pressure, state and impact) leads to

significant outputs with related to social, environmental and economic sustainability. The possible responses dealt in this research leads to various outcomes. From those out comes, the three basic states that identified in soil, water and air (leachate, eutrophication and greenhouse gas emission) can be reduced due to waste quantity reduction in waste disposal site. Currently the waste disposal site of Bahir Dar city consumes around 22 hectare (Asmare & Alelign, 2019). So, implementation of 3R policy in municipal solid waste management of Bahir Dar city results in creating of lands for construction, farming and other purposes from waste disposal site. The impacts resulting from inorganic fertilizer also can be reduced by substituting it by organic fertilizer (compost) using compostable wastes as raw material. The city now produces 148.12 tons of municipal solid trash each day. With a waste density of 162.3 kg/m^3 , the annual volume of waste is $333,291.6 \text{ m}^3$ per year. A maximum of 0.6 m^3 of solid waste is required for the creation of one quintal (100kg) of compost, according to Dream Light PLC's expertise. This indicates that 47,772 ton of compost can be made from 86 percent of biodegradable garbage per year. The average total amount of money produced per year, according to this product, is around 1,313,724 Birr (Misganaw & Teffera, 2021).

In addition to the financial benefits, the environmental consequences of municipal solid waste mishandling are mitigated. Knowledge transmission regarding municipal solid waste management and the use of waste taxes and levies in society in the context of a circular economy raises public awareness about trash income production and protects people's economy, environment, and health. Figure 3 uses the DPSIRO framework to summarize the result of better knowledge of the overarching concept of the research. [Figure 3]

4. Conclusion on Research Findings

338 The DPSIRO framework indicated the overall scenario of impact of municipal solid waste on air,
339 water and soil impacts. The generation of municipal solid waste in Bahir Dar city is increasing
340 from time to time due to population growth and economic transformation as a driving force. This
341 leads to a change in the quality of the given environment by mismanagement of municipal solid
342 waste. Currently, a large portion of the waste that is generated in Bahir Dar city is disposed
343 directly into an open dumpsite without any sorting activity. The amount of greenhouse estimated
344 from waste disposal sites reaches 46Gg per year in terms of carbon dioxide equivalent. Most of
345 the waste generated in the city is organic with the molecular formula $C_{24}H_{36}O_{13}N$. This waste
346 increases the eutrophication in the water body with the potential of 0.0594 Kg N-equivalent. The
347 average amount of leachate that is found from municipal solid waste of Bahir Dar is 1,112mm
348 per day with an average annual temperature and rainfall is 19.6⁰C and 1419mm per day
349 respectively.

350 These greenhouse gas emissions, eutrophication potential and leachate are considered under state
351 factors of the DPSIRO framework. The waste generated in the city poses various impacts on
352 human health and wildlife. The scenario of the response indicated that Bahir Dar city should start
353 to implement reduction, reuse and recycling solid management options in order to reduce
354 potential environmental and human health impacts with economic benefits. The waste
355 composition is also used as an input in order to implement those management options. As the
356 output obtained indicates, if Bahir Dar city implements reduction, reuse and recycling, it is
357 possible to produce 47,772 ton of compost from 86 percent of biodegradable garbage per year.
358 The average total amount of money produced per year, according to this product also around
359 1,313,724 Birr. The responses identified in this study leads to environmental, social and

economic balance. For more investigation, quantification of the other impacts associated with municipal solid waste is recommended.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author's contribution

Awoke Misganaw: Conceptualization, Methodology, and Software, Data curation, Writing- Original draft preparation: Visualization, Investigation, Supervision, and Validation.

Banchamlak Akenaw: Methodology, Data curation, Visualization, Writing- Reviewing and Editing.

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Figures

Figure 1

The DPSIRO conceptual framework developed by authors

Figure 2

Net annual GHGs emission (Gg per year) from 2007 to 2020

Figure 3

Scenario of DPSIRO framework for municipal solid waste management system of Bahir Dar city