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URBAN SOLID WASTE MANAGEMENT: PERSPECTIVE FROM DILLA TOWN, SOUTHERN ETHIOPIA

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Abstract

This article aims to examine solid waste management practices in Dilla town, Southern Ethiopia. The empirical data is gathered through repeated fieldwork carried out in 2017 with 120 households in Dilla town. Observation, questionnaires, interviews, and focus group discussions were used to obtain the primary data. This study has also benefited from various secondary sources. As the study shows, in Dilla, there is a paucity of basic infrastructure to collect and safely dispose solid wastes. As a result, scenes of scattered wastes, the heap of wastes, and overflowing containers are common in the town. These problems are linked to lack of containers, improper use of transfer stations, limited municipal waste collection service, apathy towards environmental sanitation, a gap in law enforcement, low municipal budgets for the sector, and lack of strategic planning. Thus, the existing rules and regulations of solid waste management have to be strengthened and enforced. There have to be mechanisms by which the government and private sectors work together to ensure sustainable solid waste management.

Keywords: Dilla, Environmental education, Solid waste, Solid waste management, Solid waste sorting

1 Introduction

Managing solid waste is a major challenge for countries worldwide. This problem is often magnified in cities where a dense concentration of people leads to a substantial amount of waste generation. The implementation of effective waste management practices has been identified as essential for economic development in low-income countries in particular. The solid waste management problem is an issue mostly witnessed in urban areas. Urban areas are usually the hardest hit as efforts to develop and grow lead to an influx of economic opportunities and people (UNEP, 2007; Shafiul and Mansoor, 2003). Over recent decades one of the characteristics manifest in the developing countries has been the disparity between urban population growth and sanitation infrastructure provision. This disparity is being worsened by the challenges of poor waste management practices impacting on the public health and environment of the rapidly transforming cities (Chatterjee, 2010). Today, dealing with the environmental costs in rapidly growing economic development, urbanization, and improving living standards in cities have led to an increase in the quantity and complexity of generated waste, representing a phenomenal challenge (UNDP, 2004). Consequently, it has put human life and the environment at stake.

It is commonly agreed that managing solid waste in an environmentally sustainable manner is essential for keeping cities healthy and livable. In light of this, solid waste management remains an integral

part of basic urban services. The health implications of poor waste management are negative to the people exposed to unsanitary conditions. Diseases such as cholera, typhoid, dysentery and malaria are all related to the practice of poor waste management. This can result in the loss of human resources needed for development. Despite the fact that developing countries do spend about 20 to 40 percent of municipal revenues on waste management, they are unable to keep pace with the scope of the problem (Zerbock, 2003). This is particularly the case in the developing world where poor infrastructure, bureaucratic competence and limited institutional capacity impede the effectiveness of solid waste management (Yohanis and Genemo, 2015). In fact, calls have been made to prioritize environmental and public health concerns (UNDP 2004), but solid wastes continue to be one of the major problems in African. Like the other cities of developing countries, due to failure to effectively implement waste management systems, most urban areas of Ethiopia are suffering from the adverse effects of solid wastes thrown away everywhere.

Dilla town started its solid waste management some three decades back. The service cannot meet changing demands. As the estimate of the municipality shows, only 65 percent of the waste generated in the town is collected, having the rest being carelessly disposed of. The residents in the town to same extent are mobilized from time to time to clean their immediate neighborhoods. Nevertheless, all these efforts ended up with limited success. The solid waste management service is inadequate, and scenes of scattered waste are common in most part of the town. The piles of wastes dumped illegally in open places, roadsides, sewerage courses and drainage channels are shreds of evidence of the poor waste management system of the town. Poor solid waste management affects the life of people living in towns, particularly those who live in overcrowded areas. The solid wastes left uncollected everywhere are causing the closing up of sewerage canals leading to spillage, and creating odors, (identified as one of the health threats) and in general, make areas filthy and unattractive for a living. Poor solid waste management has remained one of the problems Dilla continues to face. This paper attempts to bring to fore the status of solid waste management in Dilla town. First, the paper outlines the research methodology and fieldwork context. This is accompanied by the presentation of empirical findings focusing on the practices and challenges of solid waste management. Finally, the paper highlights the implications of the research for solid waste management practice.

2 Solid Waste Management System

Waste is often found as a liquid or solid form. Rouse (2008) considers solid waste as material that no longer has any value to its original owner, and is discarded. Waste also refers to "an item, material or substances that are considered useless at a given time and place" (Mugambwa, 2009). In Ethiopia, according to the Federal Democratic Republic of Ethiopia Solid Waste Management Proclamation (Proclamation No. 513/2007), "Solid Waste" means anything that is neither liquid nor gas and is discarded as unwanted. Solid wastes are wastes arise from human and animal activities, including the heterogeneous mass of garbage from the urban community as well as more homogenous accumulation comprising of countless different materials such as food wastes, packaging material such as paper, metals, plastic, glass, construction wastes, pathological wastes, and hazardous wastes. Rapid population growth and urbanization in developing countries have led to the generation of enormous quantities of solid wastes (Yohanis and Genemo, 2015). If it not disposed of safely and appropriately, solid waste can create significant health problems and unpleasant living environments (Endrias and Solomon, 2017). The primary objective of waste management is thus to give adequate protection to the general public and environment from the harmful effects of waste.

The term solid waste management has been viewed differently by various authors. Kumah (2007) defines solid waste management as “the administration of activities that provide for the collection, source separation, storage, transportation, transfer, processing, treatment, and disposal of waste”. Solid Waste Management (SWM) could be defined as the art of

managing garbage in a specific location which may include; waste collection, recycling, treating and disposing of in accordance with the agreed national or international standards such as the best principles of public health, conservation, aesthetics and other environmental considerations (Nathanson, 2000, the emphasis is mine). The functional element in solid waste management includes waste generation (the stage at which materials are identified as no longer being of value (materials become valueless) and are either thrown away or gathered together for disposal), storage (a system for keeping materials after they have been discarded and prior to collection), collection (how waste is collected for transportation to the final disposal site), transportation (the stage when solid waste is transported to the final disposal site), and finally disposal of solid waste in an environmentally sustainable manner (safe disposal where associated risks are minimized) (see Momoh and Oladebeye, 2010; Kreith, 1994; Coffey and Coad, 2010; Momoh and Oladebeye, 2010). All these activities combine to minimize the health, environmental and aesthetic impacts of solid waste.

3 Materials and Methods

3.1 Study Design and Sampling Technique

Since the intention was to assess the solid waste management practices in Dilla town, the author selected all three sub-cities for the study (Figure 1). Then, three kebeles were randomly selected to represent the respective sub-cities: Weldina kebele from Badcha sub-city, Bereda kebele from Sessa sub-city and Buno kebele from Haro Wollabu sub-city). The sample size for the survey was 120 households; determined at a 5% margin of error using Yamane's method. These households were selected using proportional simple random sampling method. Accordingly, the required 44 sample households were selected for Weldina kebele (Badcha sub-city), 36 from Bereda kebele (Sessa sub-city) and 40 from Buno kebele (Haro Wollabu sub-city).

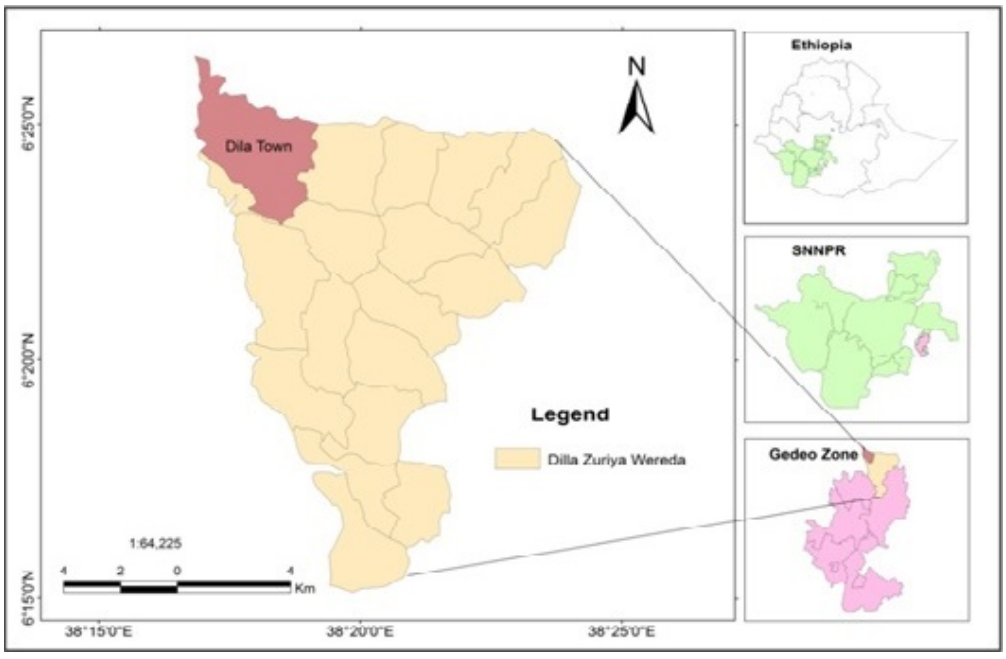

Fig. 1 Location map of the Study Area. Source: Daniel (2015).

The empirical data upon which the author draws is gathered through repeated periods of fieldwork carried out in 2017 in Dilla town, Southern Ethiopia. Using a descriptive cross-sectional research design, the study has adopted a mixed research approach to assess the current solid waste management practices in the study town. The purpose of the study and the selected methodology for addressing the problem have played a significant role in the decision as to whether the author should concentrate on one sub-city or consider all sub-cities of the town.

Purposive sampling was applied to select key informants which include government officials from Dilla Municipality, Environmental Protection and Land Administration Bureau, workers of Micro and Small Enterprises (MSEs), and community representatives. These individuals were selected based on length of experience in solid waste management and their life experience. Questionnaire survey (120 households), in-depth interviews (8 key informants which include government officials/officers and experts), and focus group discussions (24 participants which include MSE workers, municipal workers, community representatives, traders and market/street vendors in 4 groups) were used to solicit the required data. Being inspired by phenomenology, the author conducted field observation to have a first-hand view of solid waste management practices. Waste weight measurement (at source) and characterization (at the dumpsite) were done for seven days, and the waste generation rate and composition were presented in tables in the text. A combination of descriptive statistics and qualitative (thematic) analysis methods were employed to analyze the data gathered.

4 Results and Discussions

4.1 Solid Waste Management Practices

Solid Waste Composition

An attempt was made to know the types of wastes the study households generate. The result of the survey in the study town shows that residential waste is an aggregate of all materials or a heterogeneous mass of discarded materials ready for disposal. According to the survey data (based on seven sampling days), the waste generation rate was found to be 0.39kg/cap/day. As can be seen from Table 1, the household covered by the study generates different types of wastes. The bulk of solid waste from households in Dilla was found to be dominated by organics (35.8%). This was followed by ash and dust, with an overall average of 15%, plastic materials (14%), and papers and cardboard (10.8%). The other components (scrap metals, glass, and textiles/ worn-out clothes) generally have proportions between 5% and 9%, which are the least abundant waste items generated. Ashes are common types of wastes, particularly among poor households due to excessive use of biomass fuels. The waste aggregate more frequent in the whole mass of household waste was sticks and leaves. Dilla is a cash crop area and sticks and leaves of the chat are more in quantity than other wastes (see also Regassa, Sundaraa, and Bogale, 2011). This indicates that waste composition is geography-specific.

Table 1 Household solid waste composition.

Types of Waste	Frequency	Percent
Organics	43	35.8
Inert materials	18	15.0
Plastics	17	14.0
Paper /Cardboard	13	10.8
Textiles/ worn-out clothes	11	9.1
Glass	11	9.1
Metals	7	5.8
Total	120	100.0

Data source: 2017 baseline survey

Waste composition is also influenced by the economic context of households. 'Greater affluence leads to higher consumption levels, thus generating more waste amidst changes in waste composition' (UNEP, 2007). As populations become wealthier, the consumption of inorganic materials increases, while the relative organic fraction decreases. As observed during the fieldwork, low-income households have a high percentage of organic matter in the household waste stream like food left-over, vegetable and fruit peelings, onion seed coats, papers, cardboards soon. However, other component wastes show a reverse trend. Paper, plastic, glass, and metal fractions increase in the waste stream of middle- and high-income households. This pattern in the waste composition is attributed to high spending among better-off people on packaging materials and much disposed, while low-income households spend most of their disposable income for purchase of food items most of which are consumed (less wasteful in consumption), and a relatively high level of recovery of 'valuable' components such as scrap metals, plastics, card boxes and bottles for sale. Recovered/separated wastes are either reutilized at source or sold to itinerant buyers, locally known as korale (Daniel, 2015).

Solid Waste Sorting

Sorting of solid waste at the source (point of generation) is an essential component of solid waste management. Waste sorting is the process by which waste is separated into different elements. The purpose is to make waste management easy and simple. Waste sorting is an activity that aims at generating benefits out of waste. An attempt was made to assess to what extent households covered by the study practice waste segregation (sorting). In Dilla, solid waste sorting at the source is a relatively new activity, which has not yet become a common practice. As the data show, the majority (70%) of the households covered by the study do not separate waste at the household level or stored their waste without separation. Only 30% of the households practice waste sorting (Table 2); waste is separated at the household level into organic and inorganic. Nigatu et al (2011) also found the same result in their study of the challenges and opportunities of solid waste management in Addis Ababa City in that part of households covered by the study short wastes into organic and inorganic.

Communities understood reusable materials very differently essentially depending on the type of reuse mechanisms prevailing in their locality. As the interviews and discussions disclose, cans, and scrap metals are stored for sale; sorted and sold by weight to people, locally known as korale who export the collected materials to the capital, Addis Ababa and sold to factories for recycling. Organic wastes like plant origin are sorted for reuse in gardens and as fuel after the waste gets dried (common in low-income households). Animal source (meat and bone) is used to feed domestic animals like dogs. Some households give the waste away to their neighbors who use it

for animal feed. The manure is used to plaster walls and floors and for fuel when dried up whereas grass is fed to domestic animals. Chatt leaves can also be used for fuel when dried up. In some households, vegetable and fruit peelings are used as manure in the back yard gardens or used for animal feeds. As indicated by participants during focus group discussions, 'metals, plastic materials, worn-out clothes, and shoes are potentially reusable materials'. Recyclables are removed by some households before collection. It is also removed by waste pickers during the collection process and at disposal sites.

Table 2 Practice of waste sorting.

Practice of waste sorting		Frequency	Percent
Practice of sorting	Yes	36	30.0
	No	84	70.0
	Total	120	100
The reason for not sorting	Lack of understanding	29	34.5
	Lack of sensitivity	23	27.3
	Little practical value	17	20.2
	Difficult and time taking	15	17.8
	Total	84	100

Data source: 2017 baseline survey

In Dilla, sorting is relatively set to increase. However, the practice is far from expected. The households gave the reason why they failed to practice sorting. These include a lack of awareness regarding the importance of waste sorting (34.5%), lack of sensitivity (27.3%), and little practical value (20.2%). For 17.8% of surveyed households, waste sorting is difficult and time-taking activity. As the interviews and discussions disclose, 'some households are not familiar with waste sorting; others are familiar with waste sorting but do not have the willingness to source separate waste materials or do not agree on the importance of waste sorting due to the belief that separation of solid waste is of limited practical value because all types of waste will eventually mix. Some people believe that sorting of waste materials is the responsibility of the municipality or waste collection crew'. Key informants considered 'lack of attention and sensitivity to waste segregation' as barriers to proper management. They mentioned that 'households may be aware of the importance of segregation but they are sometimes careless and mix all types of wastes as one'. This indicated an attitudinal problem existing among the households. As one community leader put it; "there are factors that shape the willingness to source separate waste materials: (1) it consumes too much time, (2) it needs more containers and this has a cost implication, and (3) it requires more space in households. These factors combine to impede waste sorting at household level", which Regassa, Sundaraa, and Bogale (2011) confirmed.

Solid Waste Storage

Storage of waste at the source is the first essential step of Solid Waste Management. The waste should normally be stored at the source of waste generation till collected for its disposal. During the fieldwork, the author tried to know what materials the households used for storing solid wastes. Table 3 shows that 49.2% of the total 120 respondent households store their solid waste in sacks, 25% deposited in plastic bags (use hard festal or small plastic bags locally known as *Madaberia*. As focus group discussions disclose, households use sack and plastic bags to store solid waste because of the cost-effectiveness of sacks and plastic bags, their availability in the

market, and suitability for holding and transporting large amounts of solid wastes. As Table 3 further shows, 19.2% households store their solid wastes in homestead yard, open spaces, near roadsides and vacant areas, in open sewers, banks of rivers and around buildings close to their homes. Others use carton box (5%) and metallic barrel (1.6%) to store the solid waste they generate. Obviously, the use of open places within the compound to dispose of solid wastes creates sanitary problems which in itself could lead members of the household to face serious health problems. In addition to it, it makes waste collection difficult.

Table 3 Materials used for collecting household waste in Dilla town.

SN.	Waste item generated	Frequency	Percent
1	Sack	59	49.2
2	Plastic bags	30	25.0
3	Homestead yard	23	19.2
4	Carton box	6	5.0
5	Metallic barrel	2	1.6
	Total	120	100

Data source: 2017 baseline survey

A huge amount of organic materials comes from the rural areas depraving nutrients from the rural soil to feed the urban population, the leftovers after consumption have no way to return to the source to build the soil, rather lost and create problems to human health and the surrounding environment in the town due to mismanagement. Different studies described that this waste is creating health and environmental problems (Tamiru, 2004). The study households dispose of solid wastes in uncontrolled and unplanned dumps (some of these storage areas are street sides and pedestrian walkways), which sprawls over a large area and this affects the surrounding scenery or makes the environment filthy. As one key informant puts it, 'in some households, there is no habit of waste storage. In the absence of a system of storage of waste at the source, the wastes are thrown on the streets, treating streets as the receptacle of waste'. Open transfer stations are major problems to the environment, especially on air that the people inhale and on the water runoff that results in the water supply.

Solid Waste Collection

Waste collection service is one of the components of solid waste management. It contains the process of gathering of waste from place of generation and taking it to transfer stations (UNEP, 1996). As can be seen from Table 4, the majority (68.3%) of use communal collection system where waste generators bring their waste to collection points which could be containers or open places including roadsides, 45% use block collection where waste generators are responsible for bringing their waste to collection vehicles and the rest 25% the households use door to door collection service. In the town, two basic types of solid waste collection system (human-powered and animal-powered) are used. Concerning the human-powered collection, transportation of wastes to the collection points (transfer stations) or collection vehicles is made using human labor. This is common among residents who cannot afford to pay for a door to door collection services. In addition to communal and block collection, households use door-to-door service provided by two-wheeler carts. Workers inform households to get their solid waste ready for the collection service and then workers collect the waste using two-wheeler carts, with

a donkey in front pulling the cart. Since municipality collection vehicles cannot reach all the areas, households living around roadsides were the only beneficiaries of the block collection service. As Table 6 shows, waste collection method Dilla is mostly self–delivered (82.5%); waste generators deliver their waste directly to collection points or collection vehicles.

Table 4 Types of solid waste collection system in Dilla.

SN.	Waste collection system	Frequency	Percent
1	Communal collection	54	45.0
2	Block collection	45	37.5
3	Door to door collection	21	17.5
	Total	120	100.0

Data source: 2017 baseline survey

As one community representative disclosed, 'municipal waste collection system has only one route and the truck makes one trip per day to the final disposal site. It is also unable to adhere to its collection schedule'. Carts provide the door-to-door solid waste collection services to the households, but it is not as they wish. As the discussions held with cart drivers disclosed, 'most of the carts are old and cannot travel at expected speed and delay in collection and disposal process is common.' The problem is particularly serious during rainy seasons. During the interview, some respondents stated that there is no door to door collection service in their area due to inaccessibility (unreasonable road surfaces and topography). This study further identified that high-income residential areas have more access to collection services than low-income residential areas. In areas where motorized collection service does not reach, an animal-powered collection system is mostly used. But, as study households indicated, 'there is still a lack of patronage in low-income residential areas as animal-driven carts do not regularly collect wastes as required and people forced to use human labor'. Variability in waste collection frequency reduces confidence in the waste collection service (Coffey and Coad, 2010). As observed during fieldwork, the number of waste containers is not enough, and sections of the neighborhoods are obliged to throw their garbage in open areas.

Solid Waste Disposal at Transfer Stations

The availability of waste transfer stations is a matter of concern in the solid waste disposal and management system of urban areas. The number and location of transfer stations have a direct impact on solid waste management service. There are communal containers in the town but in a few areas. In areas where there are no communal containers, residents use open places as transfer stations. As one of the key informants pointed out, 'disposing of solid wastes in open places, and drainage systems is a common practice in the town. There is punishment on individuals who dispose of waste in an unauthorized place. However, regulations are not obeyed by the households as desired.' The communities dump wastes in open places, and drainage systems indiscriminately and some transfer stations (places) are often overflowing with uncollected wastes. There is improper use of transfer stations because the stinky smell of the waste has forced dwellers not to reach transfer places to dispose of wastes properly. Some households resort to burning at pre-collection sites. The burning of waste produces toxic gases as well as smoke and these have been shown to have serious effects on the health of people (UN-Habitat, 2012:16). Households burn biodegradable organic wastes (that should be composted) together with other solid wastes. But, as MSE workers indicated, 'the problem with compost is that there is generally low demand for the product'.

During the focus group discussion, the people indicated that the frequency solid collection service provided by MSEs (the municipality) is very low given the large size of solid wastes that come from the households. As one of the key informants indicated, 'parts of the household wastes are carelessly dumped in open places before it reaches to transfer stations'. On the other hand, wastes that are collected in different containers (transfer stations) are not timely transported to endpoints. The problems related to limited carrying capacity the municipality tracks and downtime frequently caused by vehicle problem'. One street vendor noted the following: 'limited number of communal containers and low frequency of waste collection brought about heaping of waste in open space, sewers and other places particularly close to residential areas. These conditions create problems for the households, calling for the more efficient arrangement of transfer stations'. The long-distance covered or time spent to dispose of wastes goes to add up the dumping of wastes in illegal conditions. The uncollected solid waste has often the common cause of blocked sewerage which increases the risk of flooding and vector-borne diseases and reduces the aesthetic value of green areas.

Fig. 2 (a) Overflowing of uncollected wastes. (b) Waste dumped over open sewers.

Final Disposal

Waste management is dependent on a safe and reliable disposal system. Wastes that have different origins have to be collected in disposal sites. Safe disposal of waste material is very important if a clean and human-friendly environment is to be kept. Waste collected at transfer stations needs to be transported to the location of final disposal. Common transport mode in the study town is open and general-purpose trucks that transport and dump all types of waste materials together. Besides, the trucks are not convenient for workers during loading. Lifting of wastes is done manually. As one community representative put it, 'most often workers are not provided with protective materials which expose workers to various diseases.' Wastes on transit are often uncovered causing littering, odor, and aesthetics problems. The municipality is responsible for transporting wastes to the final dump site, locally known as *Walleme* by means of trucks. According to the interview held with one of the key informants, 'the main challenge in the transportation of solid wastes includes a few trucks, trucks that are very old, maintenance difficulties, and negligence of drivers'. *Walleme* dumpsite is located in an environmentally sensitive area; close to a valley that is not prioritized for other uses. As observed, *Walleme* receives mixed wastes of various origins. The waste dumps pose real hazards to workers, waste pickers, and stray animals that visit the sites. Most of the waste workers and scavengers do not wear proper protective gears which protect them from serious health risks.

Fig. 3 (a) Waste transport using open truck. (b) Expanded waste in dumping site.

Urban areas are supposed to have designated landfill sites. However, in Dilla, such terminal end sites are non-existent. Dilla's dumpsite is a natural valley. This site is on the outskirt of the city where poorly maintained roads present significant risks to waste transport. The trouble with this landfill is that there is little capacity to protect the surrounding environment from the hazardous chemicals and leachants (seriously polluting black liquid formed by the decomposition of organic wastes) that is released into the dumpsites. Leachants from these dumps can flow into lakes and drainage channels as runoff water and pose human health threats. Presently, waste management disposal is underdeveloped. This landfill operates near or beyond maximum capacity. Waste is not subject to compaction. The existence of plastic waste in the upper layer reduces the biological degradation of organic waste which reduces the life span of dumpsites and decomposition of the waste. Valleys are often the worst places for an environment-friendly waste disposal operation, because of difficulties in preventing the long-term contamination of water resources (UN-HABITAT, 2012). Wastes that are tipped down slopes into galleys or valleys tend to pollute or block watercourses, and offer very little opportunity for rehabilitation at a later date. To make matters worse, landfill sites are not fenced. This condition increases the impact of waste on the surrounding environment as a whole.

4.2 Challenge to Solid Waste Management

In Dilla, well trained human resources for solid waste management are scarce. People without or with limited technical training in waste management are simply assigned to handle it. There are limited numbers of service providers. The solid waste management department uses different types of equipment (vehicles, waste containers, dust bin) for solid waste management service. But the problem is associated with inadequacy and improper use of these materials. One serious problem that affected the solid waste management system is the problem of vehicles. The town has a limited number of municipal trucks and some of these trucks served for many years. Because of this, most of the vehicles are currently inefficient (they are not working with their standard capacity). The demand does not be timely addressed, resulting in a growing problem of waste management in the town. The people are unable to use the existing containers as they wish. Placing containers has problems. Containers are few in number and not evenly distributed. Besides, some of the containers are placed very close to residential houses and those residents living near the containers complain about the stinking smell. In addition, the filthy areas where the containers are placed continue to affect the public health and the beauty of the town. As one of the key informants put it, 'people continue to use containers improperly because of the stinky smell of the wastes that are left uncollected for long'.

The reasons why waste disposal is often so unsatisfactory, and why so little is being done to improve the situation are generally not only technical. As one of the experts put it, 'the reasons for the problems solid waste management are linked to legislation and its enforcement, the low priority given to waste disposal and environmental protection in municipal budgets, the lack of strategic planning, and the failure to develop the necessary human resources'. An important aspect that can play a significant role in the process of waste management is the issue of law enforcement. Of course, the municipality of the town is responsible for the enforcement of rules and regulations. The Constitution of the Federal Democratic Republic of Ethiopia (Article 92.2) indicates that "Government and citizens shall have the duty to protect the environment". But, in Dilla, there is no continuous education on solid waste management and the legal system that governs it to the residents. Even those who know the law, they never act accordingly (violate existing regulations). This affected the management system and created a negative impact on the performance of waste management. There is a problem of vehicles to dump the waste in due course. This problem is grave, especially during rainy seasons. Carts and municipal trucks cannot move as they want (the carts are old and road surfaces are not reasonable). This in turn takes much time hence the waste that is expected to be disposed of is not taken to the dumping site at the fixed time frame. There is improper use of transfer stations by some households. There is a lack of willingness from the beneficiaries' side to pay the fee the collection service deserves. Lack of community participation is also a challenge.

5 Conclusion

Solid Waste Management is one of the important obligatory functions of not only urban local bodies but also of rural local bodies. But this essential service is not efficiently and properly performed by the concerned bodies of Dilla resulting in sanitation, social, and environmental problems. The waste management problem is complex because it involves a multitude of scientific, technical, economic and social factors. In Dilla, there is a paucity of basic infrastructure to collect solid wastes and safely dispose of them. Lack of or limited number containers (compared to the demand of the community), in the proper use of transfer stations (due to overflowing and the stinky smell of the waste), limited waste collection service form the municipality side, (due to of vehicles problems and lack of motivation form workers side), resulting in a heap of wastes and overflowing containers, and stinking smell that pollutes the environment. It is observed that social problems associated with apathy towards waste segregation, environmental cleanliness and sanitation have made solid waste management service unsatisfactory in the study area. Extensive environmental education should be given for the public not only about the importance of creating a healthy environment but also about the mechanisms of controlling wastes generated. Besides, the existing rules and regulations of solid waste management have to be strengthened and enforced. Priority should be given to waste disposal and environmental protection in municipal budgets. It is necessary to have capacity building programs to develop the necessary human resources. There have to be mechanisms by which the government and private sector work together and continuous follow up and supervision to ensure sustainable solid waste management. The sector needs to have a well-defined strategic plan.

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ANTIBACTERIAL ACTIVITIES OF CRUDE EXTRACT OF *CROTON MACROSTACHYUS* LEAVES AND PURE COMPOUND (METHYL LAURATE) ISOLATED FROM IT

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Abstract

Croton macrostachyus Delil belongs to one of the largest genera of the family Euphorbiaceae, called Croton under the subfamily Crotonoideae. The genus Croton is ecologically prominent, and an important source of secondary metabolites with antimicrobial properties in tropics and subtropics. The objective of this study was to test the antibacterial property of the leaf extract of Croton macrostachyus and a lauric acid derivative, Methyl Laurate, isolated from it. Crude extract was obtained through phytochemical screening using the solvent acetone. The pure compound Methyl Laurate was isolated by a combined application of column chromatography, gel filtration using Sephadex LH-20 and preparative thin layer chromatography (prep-TLC) following crude extraction. Disk diffusion method was employed to assess antibacterial activities of both the crude and the pure compound on four bacterial strains viz Staphylococcus aureus, Escherichia coli, Salmonella typhi and Shigella boydii. MIC values were also determined for each. NMR data has confirmed that the isolated compound is a lauric acid derivative called methyl laurate. The crude extract, Croton Ethyl-acetate Extract (CEaE) showed strong antibacterial activities against Staphylococcus aureus and Shigella boydii with an MIC value of 6.25 mg/ml. However, the isolated compound, methyl laurate showed strong activities against all tested bacterial species with an MIC of 0.156 mg/ml (156 µl/ml) for Staphylococcus aureus, Salmonella typhi and Shigella boydii while 0.312 mg/ml (312 µg/ml) for Escherichia coli. Results suggest that this plant contains phytochemicals that can combat pathogenic bacteria that might be the rationale for its traditional use in the external wound healing process.

Keywords: Antibacterial, *Croton macrostachyus*, Disk diffusion, Methyl Laurate , MIC

1 Introduction

Croton macrostachyus Delil belongs to one of the largest genera of the family Euphorbiaceae, called Croton under the subfamily Crotonoideae. *Croton* is an ecologically prominent and important source of secondary metabolites with antimicrobial properties in the tropics and subtropics. *C. macrostachyus* is reported to have ethnomedical uses concerning reproductive biology such as stopping bleeding in childbirth, inducing abortion, and serving as a purgative.

The genus *Croton* is used for treatment of several human health problems including diabetes, malaria, dysentery, stomachache, ascariasis, and taeniasis in different areas (Kasa, 1991; Giday *et al*., 2007; Mesfin *et a*l., 2009). Abdominal pain, gonorrhea, wounds, ringworm infestation, hemorrhoids, venereal diseases, cough, rheumatism and as a purga-

tive in cases of ascariasis are also among diseases traditionally treated by different species of *Croton* (Abebe, 1986; Mazzanti *et al*., 1987; Yirga *et al*., 2011). There are also reports for the analgesic, anti-inflammatory, mitogenic, molluscicidal, and larvicidal activities of extracts from different species of *Croton* (Tachibana *et al*., 1993; Karunamoorthi and Ilango, 2010).

Different reports have been made available for some compounds isolated from Genus *Croton* for their *in vitro* antimicrobial activities. Antimicrobial compounds isolated from Croton include flavonoids, alkaloids, and terpenes (Junior *et al*., 2011). Sesquiterpene oxide obtained from the bark *C. stellulifer* has been reported to possess antimicrobial property against some bacterial strains such as *Escherichia coli, Staphylococcus aureus, S. epidermidis, Proteus vulgaris*, and fungal species *Candida albicans* and *Aspergillus fumigatus* (Martins *et al*., 2000).

Bioactive compounds isolated from genus *Croton* include terpenes/terpenoids (monoterpenes, sesquiterpenes, diterpenes and triterpens), alkaloids and flavonoids. For instance, lupeol, a triterpene, is one of a bioactive compound isolated from the genus Croton. Other bioactive compounds such as crotin (a chalcone), crotepoxide (a cyclohexane diepoxide), fatty acids and saponins are also reported from *Croton* (Salatino *et al*., 2007; Schmelzer and Gurib-Fakim, 2008). In Ethiopia, *C. macrostachyus* has folk medicinal uses as purgative and vermifuge, treatment of various skin infections, management of helminthes and venereal diseases and induce abortion (Abate, 1989 in Giday *et al*., 2007; Schmelzer and Gurib-Fakim, 2008). The objective of this study was to test the antibacterial property of the leaf extract of *C. macrostachyus* and a lauric acid derivative, *Methyl Laurate*, isolated from it.

2 Materials and Methods

2.1 Plant Materials Collection

Fresh leaves of *C. macrostachyus* were collected from Dilla, Gedeo Zone, 360 km from Addis Ababa, Ethiopia, in November 2013 at altitude of about 1550 m a.s.l and then identified by the help of botanists. Sample specimens were kept in the Herbarium of Addis Ababa University under voucher number GT 006/2013. Leaves were cleaned of any external contaminants and then dried under shade for about 15 days with a careful and continuous follow up to avoid any contamination. Leaves were then grounded using a general purpose blender to an appropriate size for extraction with the help of mesh (0.5 mm).

2.2 Crude Extraction

The subsequent extraction method was employed to get crude extracts from the plant sample using four different solvents with increasing polarity according to the methods in Rimando et al. (2001) and Sigh, (2008). About 1 kg of *C. macrostachyus* leaves powder was macerated for 24 hours in n-hexane with the ratio of 1:7 and 1:5 (w/v) respectively. After 24 hours filtration was made using a double layer filter paper (Whatmann No. 1) giving filtrates and residues. Residues were then macerated in ethyl acetate with a similar ratio as of n-hexane for another 24 hours. These processes were repeated using ethanol and methanol for two subsequent days (24 hours each). All filtrates were concentrated using Rota-vapor to obtain crude extracts and named as shown in figure 1.

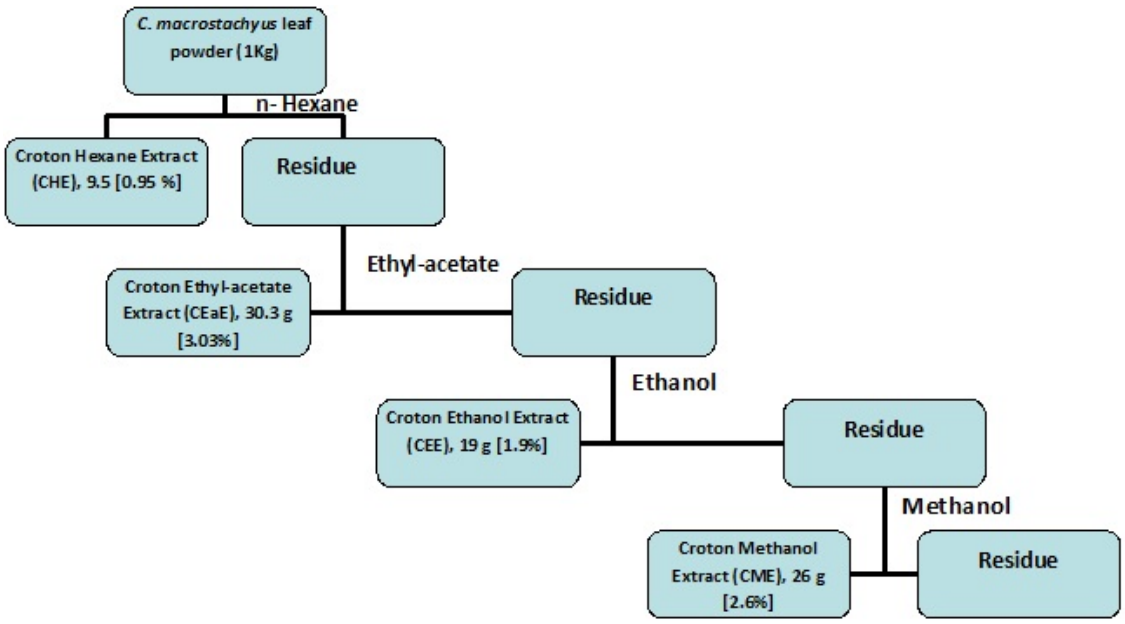

Fig. 1 Flow chart of crude extraction of the leaves of *C. macrostachyus*.

Preliminary antibacterial tests were made for each crude extract to select the most active ones. Based on the preliminary test CEaE (Croton Ethyl-acetate Extract) was selected and then subjected to fractionation according to methods in Shahverdi *et al*. (2005) and Erasto *et al*. (2006) with slight modifications. Fractionation was done for each using flash column chromatography that was packed with silica gel 60 F_{254}. Samples were adsorbed on silica gel 100 (1:2) and then applied to the column followed by the addition of solvents with increasing polarity (100% n-hexane to 100% chloroform then to 100% ethyl acetate ending with methanol:ethyl acetate [1:3]). Fractions of similar profiles on the TLC were combined together and prep-TLC was made for each using an appropriate solvent system to get bands. Prep-TLC was examined under UV light of 254/365 nm wavelength and then each band was carefully cut out and dissolved separately in chloroform and then filtered using a 9 mm Whatmann NO 1 filter paper to separate from the silica gel. The obtained filtrate was left to dry until the solvent completely evaporates, which was then weighed and subjected to NMR analysis (Rimando *et al*., 2001).

2.3 Antibacterial Susceptibility Test

Four bacterial species selected on the bases of their pathogenicity to cause frequent and series infections in human were used. Standard bacterial strains *S. aureus* (ATCC25223), *S. typhi* (ATCC13311), *Escherichia coli* (ATCC23923) and *S. boydii* (ATCC9207) were obtained from Ethiopian Health and Nutrition Research Institute (EHNRI), Addis Ababa, Ethiopia.

The disk diffusion method was employed for the antibacterial sensitivity tests according to methods of Onyeagba *et al*. (2004) and Taiwo *et al*. (2007) with some modification. The absorbent filter paper was used to prepare disks with a diameter of 6 mm each. The paper disks were dispensed in batches in a screwed capped bottle and sterilized at 160 ^{o}C for an hour. The four bacterial strains were made to grow and activated on their selective media: S.S agar for *S. typhi* and *S. boydii*, Malliton-Salt agar for *S. aureus* and Mackonkey agar for *Escherichia coli*. These plates were incubated at 37 ^{o}C for 24 hours.

Few colonies of each strain were transferred with a sterile inoculating loop to a liquid medium (nutrient broth) until turbidity was adjusted to that of McFar-

land 0.5 turbidity standard. Four plates containing Muller-Hinton agar were prepared where the four bacterial strains were streaked using sterile cotton swabs (Tadeg *et al*. 2005; Taiwo *et al*., 2007). The crude extract (CEaE) was dissolved in 3% Tween 80 at concentrations of 50 mg/ml whereas the pure compound, methyl laurate was dissolved at 1 mg/ml in the same solvent. Four disks were impregnated with 30 μ of the crude extract and another 4 with 30 μL of the pure compound and all left to dry. Four plates each with a specific test bacterium were divided into four quadrants. On the first quadrant a disk impregnated with crude extract and on the second a disk impregnated with the pure compound was kept. A stock solution of standard antibiotics (CAF for *S. typhi*; ERY for *S. aureus*; AMP for *E. coli* and CIP for *S. boydii*) were prepared at a concentration of 2.5mg/ml each). A 30 μL of each was loaded on a disk and kept on the 3rd quadrant to serve as a positive control, and a disk immersed in 1ml of 3% Tween 80 was kept on the rest serving as a negative control. All plates were then incubated at 37 ^{o}C for 24 hours after which zone of inhibition was measured. All tests were conducted in triplicate to confirm results.

2.4 Determination of Minimum Inhibitory Concentration

Minimum Inhibitory Concentration (MIC) of the crude extract (CEaE) and the pure compound (methyl laurate) was determined according to methods in Adebolu and Oladimeji (2005) and Doughari *et al*. (2008). The disk diffusion method was employed as in the susceptibility tests except that disks were impregnated with 50 μL of each prepared concentration of the samples. The crude extract was tested at concentrations of 50 mg/ml, 25 mg/ml, 12.5 mg/ml, 6.25 mg/ml, 3.125 mg/ml and 1.56 mg/ml. The MIC value of methyl laurate was tested at concentrations of 1 mg/ml, 0.5 mg/ml, 0.25 mg/ml, 0.125 mg/ml, 0.0625 mg/ml and 0.03125 mg/ml.

2.5 Data Presentation and Analysis

1D spectrum (^{1}H NMR and ^{13}C NMR) was used to get the number of proton and carbon respectively while 2D spectrum (DEPT, HMBC, HMQC, and COSY) to confirm and plot results for each compound. The structure of each compound was identified based on available literature and constructed using Chem-Draw® software. Results of antibacterial tests were recorded by measuring (in mm) zones of growth inhibition by the controls. The presence/absence of growth was recorded for MIC values. The average (Mean $\pm$ SEM) value of three tests was taken for all results. One way ANOVA (Tukey) was used to compare results with 95% confidence intervals where P-value less than 0.05 showing significant difference.

3 Results and Discussions

3.1 Isolated Compound

The result of 1D spectrum (^{1}H NMR and ^{13}C NMR) and 2D spectrum (DEPT, HMBC, HMQC, and COSY) had confirmed that the pure compound isolated from the crude extract (CEaE) was a 13-C compound, with a formula of $C_{13}H_{26}O_2$ and Mol. Wt. 214.3 (Riháková *et al*., 2001). It is a lauric acid derivative named as methyl laurate or methyl dodecanoate (Figure 2). Although other compounds were also been isolated methyl laurate has been selected for the fact that it had shown strong antibacterial activities at a concentration of 16 mg/ml with the MIC value of 0.3 mg/ml as reported by the same author (data not shown).

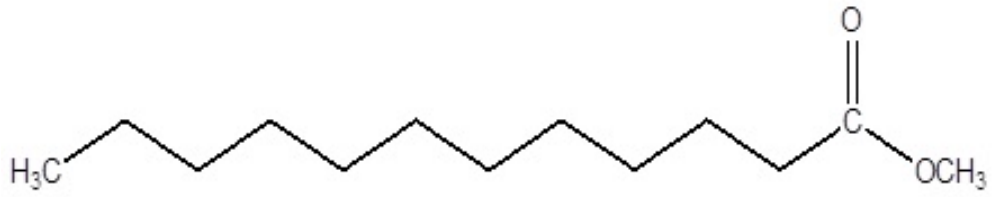

Fig. 2 The proposed structure of methyl laurate isolated from *C. macrostachyus* leaf extract (CEaE).

3.2 Antibacterial Activities

The ethyl acetate crude extract of *C. macrostachyus* leaves (CEaE) showed antibacterial activities against all tested bacterial strains at the concentrations of 50 mg/ml. The mean zones of growth inhibitions of CEaE were 23.67±0.6, 19.3±1.6, 20±1.0, and 26.6±1.1 against *S. aureus, E. coli, S. typhi* and *S. boydii* respectively (Table 1). As shown in Table 1, the mean zones of growth inhibitions recorded by the isolated compound, methyl laurate were 25.67±1.2, 22±1.0, 25.5±0.58 and 26±2.0 for *S. aureus, E. coli, S. typhi* and *S. boydii* respectively. Though significant difference to the negative control (P = 0.00), both the crude extract and methyl laurate have antibacterial activities against all tested bacteria without significant differences with the respective standard drug (P > 0.05)

Table 1 Growth inhibition (Mean ± SEM) of the four bacterial strains by crude ethyl acetate extract (CEaE) of *C. macrostachyus* leaves and the isolated compound, Methyl laurate.

Test Material	Conc.	*S. aureus*		*E. coli*		*S. typhi*		*S. boydii*	
		Mean± SEM	P- value	Mean± SEM	P- value	Mean± SEM	P- value	Mean± SEM	P- value
Tween 80	1ml	0±0.0	0.00	0±0.0	0.00	0±0.0	0.00	0±0.0	0.00
Drug*	2.5mg/ml	27±1.3		24±1.0		28±1.0		28±1.0	
CEaE	50mg/ml	23.67±0.6	0.39	19.3±1.6	0.01	20±1.0	0.00	26.6±1.1	0.61
Methyl laurate	1mg/ml	25.67±1.2	0.40	22±1.0	0.85	25.5±0.58	0.10	26±2.0	0.43

*Drugs Used: Erytromycin (for *S. aureus*), Ampicilin (for *E. coli*), Chloramphenicol (for *S. typhi*) and Ciproflaxin (for *S. boydii*)

3.3 Minimum Inhibitory Concentration

The MIC of this extract was 6.25 mg/ml to all bacterial strains tested (Table 2). The isolated compound, methyl laurate has shown similar MIC values (0.156 mg/ml) for all tested bacterial strains except *E. coli* that was 0.312 mg/ml (Table 3)

The finding of the present study is in agreement with many other works. Crude extracts obtained from the leaves and stem of *C. macrostachyus* had been reported to show effective inhibitory activities against both Gram negative and Gram positive bacteria (Taniguchi and Kubo, 1993). The crude hydro-alcoholic extract of *C. campestris* leaf has been reported to show antibacterial activities on *S. aureus* and *E. coli* (Junior *et al*., 2011). Martins *et al*. (2000) had reported that essential oil from *C. stellulifer* have growth inhibitory activities against *E. coli*, *S. aureus*, *S. epidermidis* and *Streptococcus faecalis*. The crude methanol extract from *C. pullei* has also shown inhibitory activity of *S. aureus* (Peixoto *et al*., 2013). In the present study, the crude extract of *C. macrostachyus* leaves has the least activity against *E. coli* which can be supported by Panda *et al*. (2010a) that had reported similar results for the aqueous and alcoholic extracts of *C. roxburghii* having a higher antibacterial against *S. aureus* than *E. coli*. The present work, therefore, convinces that this plant has antibacterial phytochemicals.

In the present study methyl laurate showed the best antibacterial activities in this study as other lauric

acid derivatives such as lauric acid carbohydrate esters do in the previous study (Nobmann *et al*., 2009). In addition, many other lauric acid derivatives such as D-laurate A, T-laurate and lauro-sucrose have been reported for their effective antimicrobial activities (Riháková *et al*., 2001). Moreover, lauric acid derivatives such as methyl caprate and methyl laurate have been reported to involve in the manufacturing of detergents and surfactants (Thompson *et al*., 1990; Cermak and Isbel, 2004) due to their ability to fight microbes. These could support the positive result of antibacterial activity observed for methyl laurate in the present work, which might go with its ability to treat such diseases and asserts the traditional use of this plant for skin infection.

Table 2 Minimum Inhibitory Concentration (MIC) of crude ethyl acetate extract (CEaE) of *C. macrostachyus* leaves.

Test Bacteria	Activity					
	50 mg/ml	25 mg/ml	12.5 mg/ml	6.25 mg/ml	3.125 mg/ml	1.563 mg/ml
S. typhi	++	+	+	+	-	-
S. boydii	+++	++	+	+	-	-
S. aureus	+++	++	+	+	-	-
E. coli	++	+	+	+	-	-

Table 3 Minimum Inhibitory Concentration (MIC) of methyl laurate isolated *C. macrostachyus* leaves.

Test Bacteria	Activity							
	1 mg/ml	0.5 mg/ml	0.25 mg/ml	0.125 mg/ml	0.625 mg/ml	0.312 mg/ml	0.156 mg/ml	0.078 mg/ml
S. typhi	+++	++	++	++	+	+	+	-
S. boydii	+++	++	++	++	+	+	-+	-
S. aureus	+++	+++	+++	++	+	+	-+	-
E. coli	+++	+++	++	+	+	+	-	-

4 Conclusion and Recommendations

People, especially those living in developing nations like Ethiopia have used and are still using medicinal plants designing their own methods of applications. Scientific proof is, then, crucial to validate the traditional application of such plants along with suggesting the possibility of developing drugs from them. In Ethiopia, this plant is used to heal wounds and get rid of intestinal worms in different rural and suburban areas. The findings of the present study might give an insight that this plant contains secondary metabolites that could combat infectious agents like bacteria. Since the present study focused only on the antibacterial activities of leaf extract and active compound similar studies need to be performed on other parts of the plant. Great effort and attention should be given to conserving this plant by confirming and educating people about its medicinal values. It is also recommendable to check the toxicity profile of the plant using other animal models along with in-vivo tests for drug development from this plant.

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Conflict of interest

The author declare that no conflict of interest.

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E J E D

THE ROLE OF PARTICIPATORY FOREST MANAGEMENT IN SUSTAINING RURAL LIVELIHOOD AND FOREST CONDITIONS IN SHEKO FOREST, SOUTHWESTERN ETHIOPIA

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Abstract

Different arrangements of decentralized forest management highlighting the inclusion of communities have been promoted to halt deforestation and environmental degradation. The participatory Forest Management (PFM) scheme was introduced as an alternative tool to enhance sustainable forest management through community participation during the early 1990s. This study was conducted in the Sheko forest to examine the role of PFM on the livelihoods of rural community and forest conditions. Forest inventory and socioeconomic surveys were conducted to collect data through involving 95 households and 27 sample plots. The data were analyzed by descriptive and inferential statistical tools. The result indicated that PFM has positive impacts on both forest conditions and rural livelihoods. Income derived from forest products was 89.06%. Of this71.76% was obtained from forest coffee collection while the remaining was shared between honey production and wild spice collections. A total of 55 woody plant species belonging to 34 families were recorded from the three forest zones. Of this, 45 were found within unmanaged dense forest zone, 41 in semi-forest coffee-based agroforestry zone and, 21 in the open zone agroforestry. Overall Shannon diversity index was 3.25 in unmanaged dense forest, 2.89 in semi-forest coffee-based agroforestry and, 1.9 in open zone agroforestry. Higher seedling and sapling densities were recorded under unmanaged forest followed by open zone agroforestry and semi-forest coffee-based agroforestry. The lower number of seedling and sapling under semi-forest coffee-based agroforestry could be attributed to frequent weeding and thinning activities. Concerning the diameter distribution, the unmanaged forest zone displayed uniform distribution and semi-forest coffee-based agroforestry zones displayed a J shaped distribution while the open zone displayed an inverted J shaped distribution suggesting a better regeneration of tree in the unmanaged forest and open zone agroforestry while in semi-forest coffee-based agroforestry zones intervention was required to improve poor regeneration of tree species.

Keywords: Forest income, forest status, forest products, Livelihoods, Participatory Forest Management

1 Introduction

Forests constitute about 90% of terrestrial biodiversity and play a critical role in supporting the livelihoods of over 1.2 billion people worldwide (World Bank, 2002).In developing countries, forest-based enterprises provide about 13–35% of all rural non-farm employment, equivalent to 17 million formal sectors and 30 million informal sector jobs (An-

gelsen and Wunder, 2003). Ethiopia possesses a wide variety of forest resources such as high forests, woodlands, bushlands, plantations, and trees outside forests with varying ecological and livelihood significance (Aklilu *et al*., 2016; Gashu and Aminu, 2019; Limenih and Temesgen 2011; Tesfaye *et al*., 2012;). Sustainable forest management can contribute to economic development by providing income, employment, food security, and shelter where it is most urgently needed (Agrawal and Chhatre, 2006; Chirenje *et al*., 2013).

The livelihoods of rural and even of some urban people in Ethiopia are closely linked to the forests that provide a range of benefits from energy and construction materials, to grazing, medicinal plants, ritual, and spiritual activities and sources of foods (Ameha *et al*., 2014; Tadesse *et al*., 2017). Forested landscapes also provide a range of environmental services, including watershed protection, biodiversity conservation, carbon sequestration, and landscape preservation. These services are highly valuable to both forest dependent households and off-site beneficiaries whose activities depend on the continued production of these services (Amanda *et al*., 2017; Temesgen and Wu, 2018). Despite these multiple benefits, Ethiopian forests have been considerably declining both in size and quality (Dessie and Christiansson, 2008; FAO, 2011). For example, the deforestation rate in the highlands of Ethiopia is estimated to be 14,000 million hectares per year (FAO, 2010). The decline is mainly due to the massive removal of forest or vegetation cover to meet the fast-growing population and their increasing demand (Getacher and Tafere, 2013; Kassa *et al*., 2009; UNDP, 2012). Given the continued population growth and declining agricultural productivity, the pressure on forests will continue unabated. Hence, managing forest resources is essential to ensure forest-based ecosystem services and improve the rural livelihood (Tadesse *et al*., 2014; Temesgen and Wu, 2018; Tolessa *et al*., 2017).

Ethiopian has been made several efforts in managing and developing forest resources through conventional forest management approaches by declaring forests as state forests or protected forests (FAO, 2010). However, forests depletion reduction outcome is minimal, as the resources have been suffered from mismanagement mainly due to loosely defined property relations (Gobeze *et al*., 2009). The conventional forest management has alienated local communities from participating in forest conservation and protection in Ethiopia, which has led to illegal and unsustainable resource utilization (Farm Africa, 2002). This requires a paradigm shift from conventional forest management to PFM that promotes the participation of the local community in the management and development of forest resources.

Participatory Forest Management (PFM) is a management tool that involves mobilizing local people for group action in managing specific forest areas adjacent to their settlement to ensure socio-economic development of community and reduce pressure on forests (Ahmid and O'Hara, 2010; Schreckenberg and Luttrell, 2009). This involves sharing responsibilities and benefits according to a well-defined and mutually agreed rules and regulations. The agreed rules and regulations are planned, implemented, maintained, and monitored by the village institutions (Mbuvi *et al*., 2009).

Several cases in Ethiopia cases showed a positive impact of PFM on forest and livelihood status. In fact, in some cases, the impacts of PFM may be varied depending on local conditions (Ahmid and O'Hara, 2010; Tesfaye *et al*., 2011). That is why site-specific research required among which Sheko woreda is the one that pursuing PFM since 2010. Before the introduction of PFM, poaching of forest products, encroachment, and charcoaling were alarming illegal activities taking place in the Sheko forest (Plan, 2014). Nowadays, due to PFM intervention, the communities are carrying out protection and rehabilitation of catchment areas (Ahmid and O'Hara, 2010; Aklilu *et al*., 2016) which are causing positive changes in the forest conditions and livelihood of local communities. However, there were few studied that gives account on the performance of the scheme. Thus, this study aims to investigate the role of Participatory Forest Management arrange-

ment in sustaining the rural community's livelihood and improving forest conditions in Sheko forest.

2 Materials and Methods

2.1 Description of the Study Area

Our study area, Sheko district, is located in Southern Nations Nationalities and People Regional State of Ethiopia at about 600 km from regional city Hawasa (Figure 1). It lies between latitude and longitude of 6^o58'N and 35^o45'E, respectively, and at an altitude that ranges from 900 to 1850 m.a.s.l. (Ayalew *et al*., 2015). The mean annual temperature is 22.6^{o}C and the annual rainfall ranges from 1200 to 2200 mm.

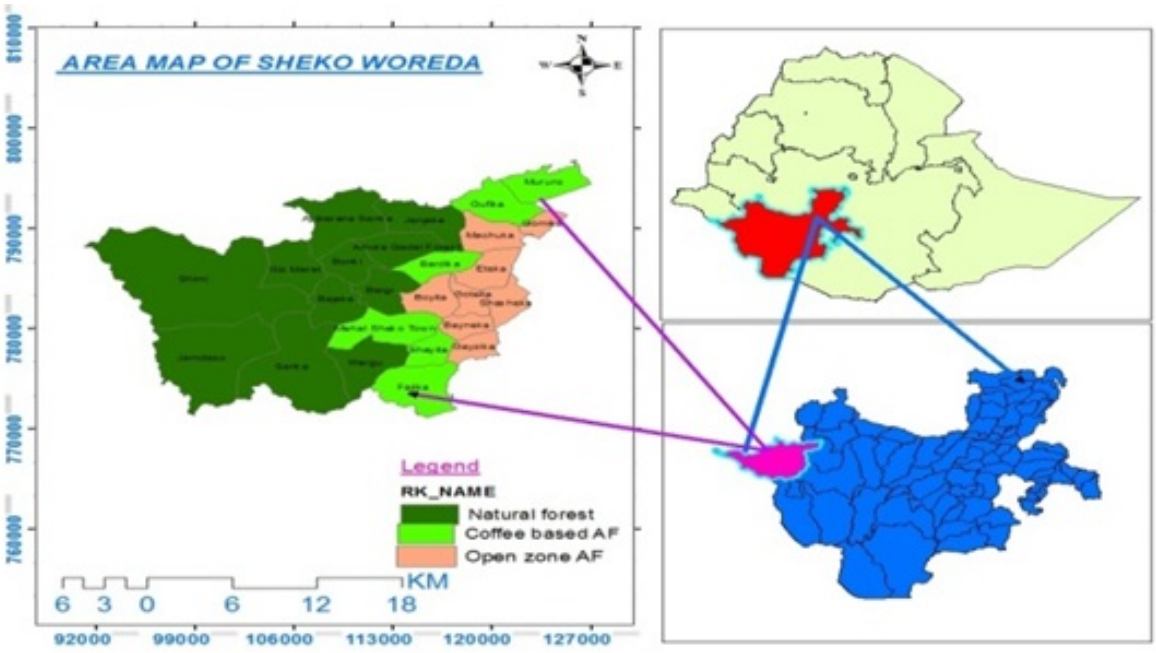

Fig. 1 Location map of the study area.

The area is endowed with large areas of natural vegetation and having a total human population of 64,661(Ayalew *et al*., 2015). As considered by the same author, the dominant land use system of the study area is a mixed farming system with various types of coffee exploitation like wild coffee extraction, garden coffee cultivation, coffee plantations, and small scale agriculture, with some locally marketable products and the major cereal crops are maize and sorghum.

2.2 Data sources and analysis

Socio-economic data was collected through direct interview with the forest users, specifically heads of households and village leaders in the selected association using structured questionnaires which aimed at capturing both qualitative and quantitative information. Secondary data that could support primary sources were collected from published and unpublished documents. The population sample was determined according to Yamane's (1967) formula that recommended at least 10% of households could participate in the research in each of the selected PFM association. From thirty-eight associations practic-

ing in PFM, six (two from each of the three forest zone) were randomly selected and the questionnaire was administered on 95 households reached through a simple random sampling approach.

Forest in the study area is comprised of (1) unmanaged natural forest – UNF (vegetation of >3 ha with trees above 5 m in height and canopy cover of more than 10%); (2) semi- forests coffee-based agroforestry – SFCBAf where coffee is cultivated under native forest canopies through planting coffee seedlings and allowing natural regeneration of coffee plants and by clearing the understory vegetation (Senbeta and Denich, 2006); and (3) garden coffee systems (open zones agroforestry – OZAf) where naturally regenerating and nursery coffee plants are grown with other crops under native shade tree species (Wiersum *et al*., 2008). Vegetation sampling quadrants were based on line transects. A total of six line transects were laid out across the contour at a regular interval of 300m from the three forest zones. Vegetation samples were collected from 27 plots (9 plots from each forest zone in $900m^2$ at the interval of 200m which belongs to the three forest zones. In each plot, parameters such as abundance (individuals) and tree diameter at breast height (cm) was collected. To ensure that all vegetation types are visited, the population of the forests were further stratified into individual plants with the diameter at breast height (DBH) > 5 cm and height > 1.3 m were classified as trees, individuals with a DBH < 5 cm but height > 1.3 m were classified as saplings and individuals with height < 1.3 m were classified as seedlings (Omoro *et al*, 2010).

The obtained data were analyzed statistically using the SPSS and GraphPad Prism statistical packages. Therefore, frequencies, descriptive, bivariate correlational analysis, and cross-tabulation techniques were employed. Several bivariate statistical analyses were made to explore the correlations between different socioeconomic variables. The density of woody plant species per hectare among the three forest zone was derived from the number of individuals recorded in the sampled plots. Different diversity indices such as species richness, species abundance, and Shannon index. One way ANOVA analysis at a 10% level of significance was used to test differences in woody species richness, abundance, and diversity indices among the three forest Zones.

3 Results

3.1 Socio-Economic Characteristics and Forest Resources

The majority of the sample respondent households were men headed (77%) and with an average family size of six members. The sample respondents were, on average, 36 years of age, and their holding size ranges from 0.25 ha to 8 ha with an average of 2.5 ha. Their livelihood mainly depended on crop production, forest coffee collection, wild spice collection, fuel wood collection, honey production and off-farm activities (petty trade and wage employment). The mean annual income of the sampled households in the study area for the year 2017/18 was 58983.45 ETB with minimum and maximum income ranged between 1760 and 140,800 ETB (Table 1). Much of the income from the forest products go to household subsistence as they purchase most cereals which are not grown in the study area. From the total annual income of the household, about 71.76% income is derived from the coffee collection, 5.2%, from honey production, 12.1% from wild spice collection, 10.2% from crop production, and 0.74%, from off-farm activities.

Table 1 Growth inhibition (Mean ± SEM) of the four bacterial strains by crude ethyl acetate extract (CEaE) of *C. macrostachyus* leaves and the isolated compound, Methyl laurate.

Income Sources	Mean	Std. Deviation	Minimum	Maximum
Coffee	42328.89	26481.736	1760	140800
Honey	3063.43	7024.940	0	38400
Spices	7144.90	7551.884	0	36000
Crop production	6018.37	9504.989	0	39000
Off-farm activities	427.86	766.670	0	3311
Total	58983.45	20459.326	1760	140800

The most important forest products on which most livelihoods-based in Sheko forest include forest coffee harvesting, fuelwood collection, honey production, wild spice harvesting and timber and construction materials were identified as the preferred and major sources of income. Interviews indicated that the communities' did not allow extracting the forest products like charcoal and timber freely from the forest. Of the sampled household almost all were engaged in forest product collection for their income source even though the types of forest product preference varied among the studied households. Forest coffee harvesting was the most important and valuable commercial forest product in which about 66% of the sampled households were engaged in wild coffee collection, while the remaining shared among different forest products like spice with coffee production (12%), fuelwood and timber harvesting (8%) and integrating honey with coffee production (13%), and construction material (1%) (Figure 2). As a result, there has been increasing interest in forests as a source of local rural employment and income, particularly through non-farm activities (trade, own small business, daily labour). The interview showed that the average production of coffee was 24.86 quintal ha-1yr-1 and 92.4% of the products were for sale and the remaining 7.4% were used for home consumption. Regardless of its eminence, the survey showed that wild coffee varieties have been nowadays attacked by Gibrilla diseases especially in the semi-forest coffee-based agroforestry system.

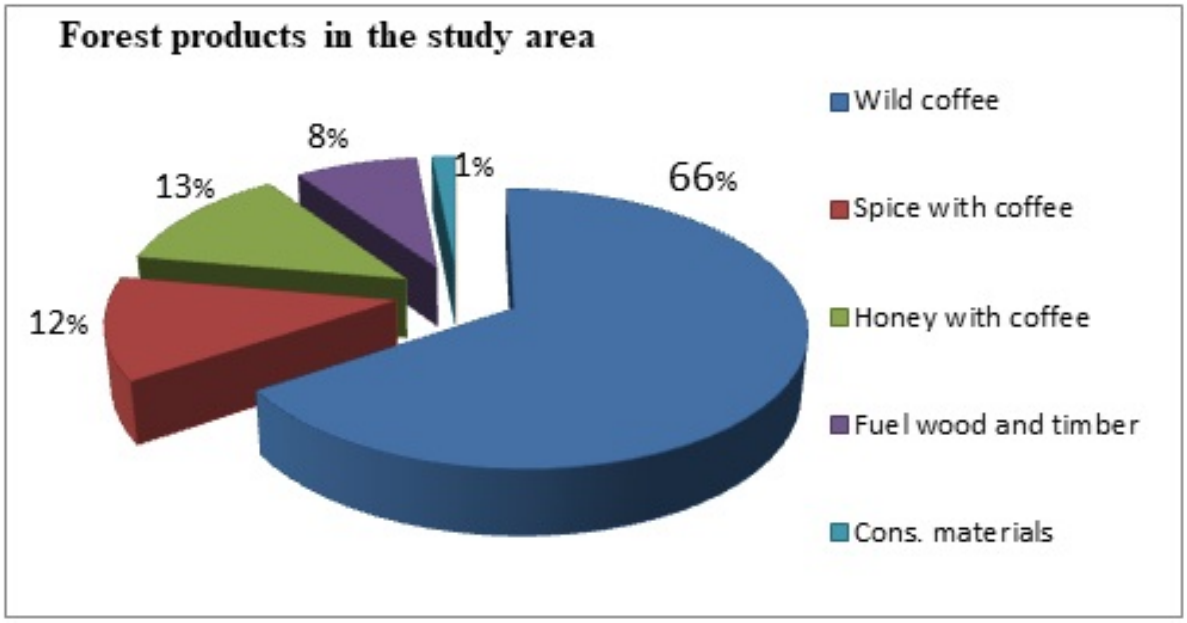

Fig. 2 Forest products collected by studied households in study area.

The most important wild spices grown in Sheko were Korerima (*Aframomum corrorima*), Turmeric (*Curcuma domestica*), ginger (*Zinigiber officinale*), Mitmita (Chilies) and black paper, (*piper nigrun*) (Figure 3). These spices are used for several purposes including medicinal values, traditional food processing (e.g., butter, oil) and as a flavour for food. Even though spices are highly demanded, and have the potential to improve local livelihood, the dependence of mode of production on the wild population and traditional production system have caused in low yield, poor quality and unreliable supply. Moreover, lack of market linkage and governmental support for the promotion of wild spice make their sustainability questionable.

Fig. 3 Wild spices in the study area – (a) turmeric plant, (b) black pepper and (c) wild coffee harvesting (All photos by the researcher, 2018).

Flora diversity (Appendix) is one of the opportunities for honey production and it has been an encouraging natural endowment for the long-standing traditional bee-keeping activity, which is one of the sources of livelihood for the local communities and developed over years to meet household honey con-

sumption or sale requirements. The most widely used tree and shrub species for bee-keeping in the study area include *Croton macrostachyus*, *Cordia africana*, *Lecaniodiscus fraxinifolius*, and *Vernonia amygadlina*. The honey production system in the study area was the traditional system and the farmers were not yet transformed into modern beehive system and this leads to a low level of honey production and quality.

3.2 Community Participation on PFM

Regarding the extent of community participation in PFM, apparently, 96.5% of the respondents confirmed their active participation for more than 3 years while 3.5% did not. The non-participating individuals are not permanent residents and hence the rule forbids them to join the association. The level of gender-based community participation and decision making in the three PFM stages (conservation, development, and utilization stages) were also evaluated. Accordingly, about 84.7% of the respondents replied that both men and women have equal rights of voting and participation in decision making and equitably shared responsibilities of managing the forest. However, the remaining 14.3% revealed that there is no equal participation in all PFM stages especially in forest patrolling. This unequal participation is mainly attributed to women's home related burden and topographical difficulties to regularly engage in forest patrol.

3.3 PFM vs. Trends in Forest Products Utilization

The result showed that both non-timber (wild coffee, spice, medicine, and honey) and woody (fuelwood, timber, and construction material) forest products played an important role in household needs. Before the PFM introduction, 53.1% of the respondents replied as they have had a high level of utilization, while 27.6% medium and 19.4% replied low utilization level. After PFM implementation, 52% of the respondents replied as they have had a low level of forest product utilization, 27.6% medium and 20.4% replied high utilization level. This utilization level reversal is attributed to the introduction of community agreed management and utilization plan of PFM that specifies restrictions and rights of forest product utilization for the members. More specifically, PFM intervention strictly limited some destructive utilization types, namely: timber, charcoal, and fuel wood products which had been the most important source of income. Thus, the new PFM plan generally regulates extraction levels and period in cases where the extraction is not prohibited. In both cases, before and after PFM, the community has been allowed to access forest products for their household needs.

Regarding the collection and sale of different forest products, results of household inventory showed that before the introduction of PFM, the average production rate of coffee was 11.43 quintal $ha^{-1}yr^{-1}$, honey 6.3Kg per beehive and spice 18 quintal $ha^{-1}yr^{-1}$ with a mean market price of 16.12, 13.57 and 18.25 Birr per Kg for coffee, honey, and spice products, respectively. While after the introduction of PFM, the average production rate was changed to 12.82 quintal $ha^{-1}yr^{-1}$ for coffee and 10kg per hive of honey production, and the market price was changed to 24.02 per kg for coffee and 76.42 birr per Kg for honey. But, the production for spice before and after the introduction of PFM remains the same while the price changed from 18.25birr to 34 birr after PFM introduced (Figure 4).

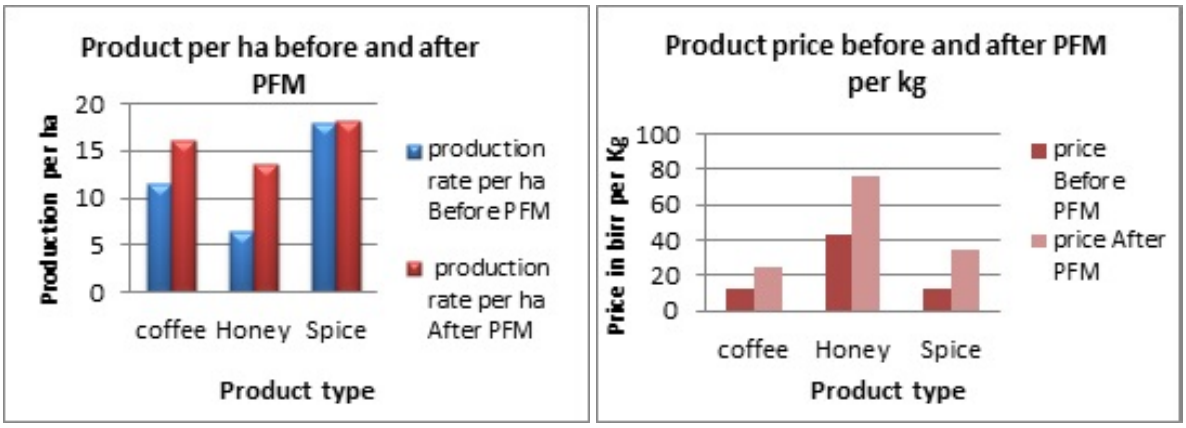

Fig. 4 Production and marketing price changes before and after PFM.

3.4 PFM vs. Trend of forest conditions

Tree inventory, stem density, and species composition were assessed in three forest zones of Sheko district to detect trends of forest conditions. In the unmanaged natural forest (UNF) the diameter at breast height (DBH) class of the tree species was evenly distributed as no management interventions undertaken (Figure 5a). In the semi-forest coffee-based agroforestry (SFCBAf), shrubs and emerging tree seedlings are annually removed with exception for coffee where coffee saplings were planted as enrichment planting. Field measurement result showed that the SFCBAf is dominated by higher-level diameter class trees with little or almost no seedlings and sapling because farmers open up the canopy by thinning shade trees and clear the understorey vegetation to increase coffee yield. In SFCBAf zone, the overall individual tree distribution in DBH classes displayed J-shape (Figure 5b) and showed the limited number of saplings and seedlings with a higher number of big trees. In contrast to SFCBAf, the individual DBH classes in open zone agroforestry (OZAf) displayed an inverted J-shaped which were dominated by seedling and saplings and with a little number of big trees (Figure 5c) as forest clearance and agricultural land expansion was high before PFM introduction.

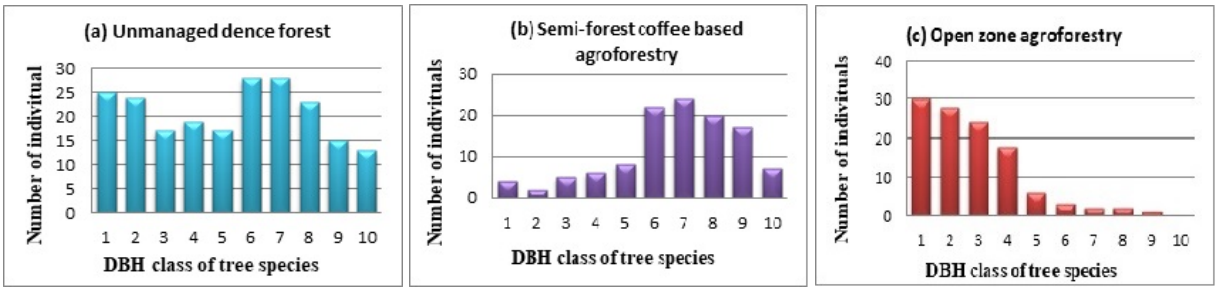

Fig. 5 Diameter classes of the individual trees in three forest zones: where 1- seedlings, 2- saplings, 3= 10-20cm, 4-=21-30cm, 5= 31-40cm. 6= 41-50cm, 7=51-60cm, 8= 61-70cm, 9= 71-80cm and 10= above 81cm.

Species distribution of the forest zones is heterogeneous, with most species observed only in few plots and with low average densities. Most species abundant in the forest were *Albizia gummifera*, *Cordia africana*, *Croton macrostachyus*, *Ehretia cymosa*, *Graville robusta*, *Leucaenea leucocenhala*, and *Militia ferruginea*. These species constituted 76% of the abundance. A total of 55 woody species in

34 families were recorded in the three forest zones (Appendix), of which 45 were found in the UNF zone while 41 were found in SFCBAf zone and 21 species found in OZAf. From the total woody species recorded, tree density was 1765, 902, and 378 individuals' ha^{-1} in UMF, SFCBAf, and OZAf, respectively. A comparison between the three land use systems showed that the UNF zone had higher stem density as their relative ecological stability enhance growing ability. Economically responsive trees like Eucalyptus species and G. Robusta were common in OZAf, while indigenous tree species like *F. vasta*, *C. macrostachyus*, *M. ferruginea*, and *C. africana* are more common in SFCBAf and UNF as community prefers them for coffee shed and soil fertility improvement.

The mean values of Shannon diversity indices are very high in UNF and SFCBAf as compared to OZAf. Diversity indices of SFCBAf are close to those of UNF. A one way ANOVA and Turkey's test showed significant differences in the diversity indices between the OZAf and UNF (p=004). A similar significant difference was found between the SFCBAf and UNF (p=0.027). A comparison between the different locations (plots) established that UNF accounts for higher tree diversity in comparison to any of the two other sites 2.89 and 1.9 in SFCBAf and OZAf, respectively. From the researchers' field observation, the variations of the three land use systems were judged to be from human and animal frequent interference in OZAf and SFCBAf land use systems.

4 Discussion

4.1 The Role of PFM in Sustaining the Rural Livelihood of the Community

From the findings of this study, it is evident that the majority of the respondents embraced the role of PFM on the sustaining of rural livelihood and forest conservation. The study results indicated that approximately 96.5% of respondents participated in PFM. A similar study conducted in Kenya reported that 95.2% of the respondents supported involvement in forest management and conservation program (Musyoki *et al*., 2016). Responsibility sharing is also well-practiced and both men and women had equal rights in decision making and equitably shared responsibilities of managing the forest and forest-based products in the study area. This result is in line with the findings of Gobeze *et al*. (2009).

Wild coffee, spice, honey, fuelwood, timber, construction materials, and medicinal values were identified as the major types of community preferred forest products extracted from Sheko forests and played an important role in income generation and other household needs. Studies conducted in Kenya (Matiku *et al*., 2011), northwestern Ethiopia (Gashu and Aminu, 2019), and Bonga forest (Gobeze *et al*., 2009) reached similar findings. In Sheko district, forest coffee is the most important and high-value commercial forest product reported by the sampled households followed by spice with coffee production, fuelwood, and timber harvesting, integrating honey with coffee production and construction material, as Jose (2002) conclusion also indicated the high dependence of rural households on forest products.

In the Sheko district, recently, there has been an increasing interest in forests as a source of local rural employment and income, particularly through non-farm activities. After PFM has been introduced with schemes of the management agreement, specific restrictions and rights of forest utilization were imposed. As a result, the extractions of destructive (woody) forest products like timber, charcoaling, and construction materials was controlled with some ease for income generation and home consumption. Our result revealed that, in the year 2017/18, the maximum total annual income of households was 140,800 ETB with mean and minimum income 58983.45 and 1760 ETB, respectively. About 89.6% of sampled households were involved in the sale of forest products and 10.94% from crop production and off-farm activities.

A study in the Bale Mountains of Ethiopia showed that forest products are important sources of income contributing to 34% and 53% of household per capita income and per capita cash income, respectively (Yemiru, 2011). Non-timber forest products including butterfly pupae sold at the Kipepeo market place,

additional honey from the forest or modern beehives placed in the forest, and fruits collected for domestic consumption accounts 39 USD for each household per year (Matiku *et al*, 2013).

4.2 The role of PFM on forest improvement

From the three forest zones of the study area, a total of 55 woody species representing 34 families were recorded. The higher tree species diversity and the highest Shannon index of 3.25 were recorded in UNF than OZAf. A study reported from south-eastern Rift Valley escarpment (Gedeo agroforestry) of Ethiopia, revealed a total of 58 woody species, belonging to 49 genera and 30 families (Negash, 2013). The highest overall tree density of 1765 individuals ha-1 was recorded in Shako UNF, which is 902 and 378 individuals ha^{-1} in SFCBAf and OZAf, respectively. This is in concurrent with findings of Gobeze et al. (2009) whereby a total of 52 woody species, representing 30 families, were recorded in the forest blocks under PFM and non-PFM with a tree density of 1756 individuals' ha^{-1}.

The higher species diversity and abundance exists in UNF than SFCBAf and OZAf which suggests better protection of the forest conditions in UNF than other forest zones. This is reflected by the observed variation in the abundance of seedling and sapling population among the three forest zones. For instance, in the SFCBAf the individual distribution in diameter classes displayed J-shape which shows a limited number of saplings and seedlings with a higher number of big trees. While in UNF the forest condition is apparently in uniform condition due to no management interventions. In contrast to SFCBAf, the diameter classes in OZAf displayed an inverted J-shape which was dominated by seedling and saplings trees with a little number of big trees. These findings are in conformity with several similar studies (Ameha, 2013; Farm Africa, 2015; Gobeze *et al*, 2009). For instance, Plano (2014) reported a better forest structure that shows a healthy tree population distribution across diameter classes in PFM than non-PFM forest. In Adaba-Dodolla, Ethiopia, total stem density (a measure of forest growth) of four selected species were higher in forests under PFM (Ameha *et al*., 2014) as compared to forests not adopted PFM. The study from Bonga area also showed a healthy vegetation structure with higher seedling, sapling, and mature trees in PFM than in adjacent non-PFM forests (Gobeze *et al*, 2009). According to Gobeze *et al*. (2009), PFM improved forest conditions such as seedling and sapling densities and capacitate the local community to form new institutional arrangement that increased their participation in forest management. A comprehensive review of previous studies on PFM in Ethiopia also confirmed the positive contribution of PFM on forest conditions and livelihood (Siraji, 2018).

5 Conclusion

In general, the results of the study reconfirmed the potential of PFM for improving forest conditions and sustaining the livelihood of rural peoples. The introduction of PFM to the area achieved the dual purposes of improving forest conditions and of positively affecting the livelihoods of participant local communities. PFM in Ethiopia has shown good signs of successfully reducing an 'open access' mentality to natural forest and has demonstrated the benefits of increasing the value of forests for local people through increased local control and user rights, as opposed to trying to delink people and forests (O'Hara, 2013). With regard to the forest condition seedling and sapling, populations were observed in UNF and OZAf compared to SFCBAf within PFM. PFM also increased income sources diversify for the rural community in order to reduce the influence on the forest. Hence, improvements in income sources from forest products continue to play an important role in household livelihoods and in poverty alleviation in the study areas where other income opportunities are limited.

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Conflict of interest

The author declare that no conflict of interest.

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Appendix

List of species encountered in three land use under PFM

Species scientific name	Local name	Family name	Local use*
Albizia gummifera	Sessa	Fabaceae	FU, CO,SH
Annona senegalensis	Giishta	Annonaceae	FU, TI,CO
Antiaris toxicaria	Tengi	Moraceae	FI, FO, ME, FR
Baphia abyssinica	Shiffo	Fabaceae	FU, CU
Bersama abyssinica	Booqqoo	Francoaceae	FU, CU, SH
Blighia unijugata	Banga	Sapindaceae	FU, HO , SH
Cajanus cajan	Yergibater	Fabaceae	FD , FU
Carica papaya	Papaya	Caricaceae	FO FD WB, MU
Cinnamomum verum	Kerefa	Lauraceae	FU, TI, SH
Clausena anisata	Limich	Rutaceae	FU, CO, SH
Clematis semensis	Azohareg	Ranunculaceae	FU, CO, TI
Cordia Africana	Wanza	Boraginaceae	FU, CO
Croton macrostachyus	Bisana	Euphorbiaceae	FU,CO
Cupressus lusitanica	Yeferenjitid	Cupressaceae	FE
Diospyros abyssinica	Kuri	Ebenaceae	FU,CO, SH
Dracaena fragrans	Wago	Asparagaceae	SH
Ehretia cymosa	Sertte	Boraginaceae	FU,CO
Erythrina abyssinica	Korch	Fabaceae	FE
Eucalipttus glublus	Bahirzaf	Myrtaceae	FU,CO SH
Euphorbia abyssinica	Kulkual	Euphorbiaceae	FU, CO, SH
Ficus sur	Warka	Moraceae	FU,CO SH
Ficus vasta	Shola	Moraceae	FU,CO SH
Garcinia buchananii	Chachu	Clusiaceae	FU,CO SH, HO
Gravilea robusta	Gravilea	Proteaceae	FU,CO SH
Hallea rubrostipulata	Mety	Rubiaceae	FU
Hippocratea africana	Harge	Celastraceae	FO,FU
Lecaniodiscus fraxinifolius	Sember	Sapindaceae	FU,CO SH
Leucaenea leucocenhala	Lusniea	Fabaceae	FU,CO SH
Macaranga capensis	Balantine	Euphorbiaceae	FU,CO SH
Maesa lanceolata	Kelewa	Primulaceae	SHAND ME
Mangifera indica	Mango	Anacardiaceae	FU,CO SH
Manilkara butugi	Butigi	Sapotaceae	FU,CO SH
Millettia ferruginea	Birbira	Fabaceae	FO and FU
Mimusops kummel	Gojbaro	Sapotaceae	FU, CO

Moringa oleifera	Shiferaw	Moringaceae	FU,CO SH
Ocimum lamiilifolium	Demakesse	Lamiaceae	FU,CO SH
Olea capensis	Kerewayu	Oleaceae	FU,CO SH
Olea welwitschii	Baha	Oleaceae	FU,CO SH,TI
Persea Americana	Avocado	Lauraceae	FU,CO SH,TI
Phoenix reclinata	Zembaba	Arecaceae	SH
Phytolacca dodecandra	Endod	Phytolaccaceae	FU,CO SH
Polyscias fulva	Gomu	Araliaceae	FU,CO SH
Pouteria adolfi-friderici	Kerero	Sapotaceae	FU,CO SH
Prunus africanus	Tikurinchet	Rosaceae	FU,CO SH
Ricinus communis	Gulo	Euphorbiaceae	FU,CO SH
Sapium ellipticum	Bosoka	Euphorbiaceae	SH and HO
Schefflera abyssinica	Getema	Araliaceae	FU, CO, SH
Sesbania sesban	Sesbania	Fabaceae	FO and FU
Spathodea campanulata	Chaka admik	Bignoniaceae	FU,CO SH
Trichilia dregeana	Luiya	Meliaceae	FO and FU
Trilepisium madagascariense	Gebo	Moraceae	FU,CO SH
Vepris dainellii	Tossa/megeto	Rutaceae	FU, CO, SH
Vernonia amygadlina	Girawa	Asteraceae	FU,CO SH, HO

* CO – Construction, SH – Shade, FE – Fence, FO – Food, FU – Fuel wood, TI – Timber, ME – Medicine, FR – Fodder, HO – Honey, WB – Wind break, MU- Mulch

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E J E D

SELECTING SOLID WASTE SITES USING INTEGRATED FUZZY LOGIC MODEL AND MULTI CRITERIA APPROACH IN SHASHEMENE TOWN: OROMIA REGIONAL STATE, ETHIOPIA

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Abstract

Solid waste is unwanted material generated from combined residential, industrial, and commercial activities in a given area. Since landfills are permanent sites, they need special attention in selecting the location by applying an efficient method. This study employed the Fuzzy logic in combination with Weighted Linear Combination (WLC) methods for the selection of solid waste landfill site in Shashemene town. Moreover, the study used multi-criteria decision-making integrated with Geographic Information System (GIS) to evaluate solid waste site. The results show that the most considerable factors in site selection are the distance from road, river, residential areas, and commercial areas with weights of 0.242, 0.194, 0.134, and 0.119 respectively. However, slope and height are not significant criteria. Overall, the final capability map generated by the weighted linear combination method represents 41.5% of the study area is not suitable for landfill setting, whereas low, moderate, high, and the most suitable classes cover 30.7%, 16.4%, 7.5 and 3.9% of Shashemene town, respectively. The study also identified three best (3) sites of 25.9ha, 205.19ha, and 268.75ha for the landfill in the town.

Keywords: Analytical Hierarchy Process (AHP), Fuzzy logic, landfill site selection, multi-criteria, solid waste, Weighted Linear Combination (WLC)

1 Introduction

Solid waste is unwanted material that is generated from combined residential, industrial, and commercial activities in a given area. Most urban areas in the country plagued by acute problems related to solid waste due to the continuous migration of people from rural and semi-urban areas to towns and cities (Shukla, 2000). It is also a global environmental problem in today's world both in developing, and developed countries. Increasing population growth, rapid economic growth and the rise in the community's living standard accelerated solid waste generation in the world (Elmira *et al*., 2010).

Many of urban local bodies dispose of solid waste in open land, vacant areas and by roadsides which creates unhygienic condition and in many seasons those wastes degraded and emits CO^2, methane, other toxic gases which in turn toxicants water bodies which cause Jaundice, nausea, asthma (Nishanth *et al*., 2010). Solid waste dumping site selection is difficult because of its requirement to consider environmental and other factors that can be easily and significantly affected (Sumathi *et al*., 2008).

Recently, there is an increasing and complexity of solid waste production in the world mainly because of growing developments, urbanization, and improv-

ing living standards in cities, which intern at expense of the environmental cost (Smit *et al*., 1996). To solve all problems of solid waste disposal, having a properly planned waste dumping site is one of the most important management activities, which need to be carefully planned (Regassa *et al*., 2011). The disposal sites must consider all the socio-economic, environmental, land use factors and peoples" safety within the cities/towns. The study area is no exception from these problems like many towns and cities in Ethiopia. Recently, to investigate the capability of the land and public acceptance, economic development and environmental impact assessment of landfill, GIS has a greater ability in data analysis, effective database establishment, and flexibility of applying models such as WLC, Fuzzy and Boolean logic and Multi-criteria decision method (Sordoud *et al*., 2017). Moeinaddini *et al*. (2010) applied Weight Linear Combination (WLC) and Analytical Heirarchy Process (AHP) focused on hydrology, wind orientation, slope, distance from the road and residential areas as significant parameters to carry out landfill site selection in the two Iranian metropolitan areas of Gorgan and Karaj respectively. Seners *et al*. (2010) applied AHP and GIS were combined for landfill site selection in Konya, Turkey. The distance from transport routes and rail, the distance from archaeological sites, urban areas, land use/land cover, and slope were taken as factors in the investigation. Considering the relative priority of all criteria in comparison with others, a specific weight was designated to each criterion according to their total influence overall process of decision making. Furthermore, Zeinhom *et al*. (2009) used integration of GIS and Multi-Criteria Decision Making (MCDM) to locate landfill sites in Mansoura city, Egypt. In their research, eight criteria were used. They used both Weighted Linear Combination (WLC) and Analytical Hierarchy Process (AHP) in a GIS environment. The study was intended to assess the existing site and identify a suitable site for solid waste disposal of Shashemene town with implemented WLC in a GIS-Fuzzy Logic environment to locate the site for a landfill.

2 Materials and Methods

2.1 Description of the study area

Shashemene is located in West Arsi Zone of the Oromia National Regional State, with a distance of about 251 kilometers to the south of the capital city of Ethiopia Addis Ababa. Geographically, the town located is at 7^o12'00"N – 7^o13'57"N latitude and 38^o36'00"E – 42^o00'16"E longitude in the Ethiopian rift valley region (Figure 1). The 2007 national census reported a total population of the town 100,454, of whom 50,654 were men and 49,800 were women.

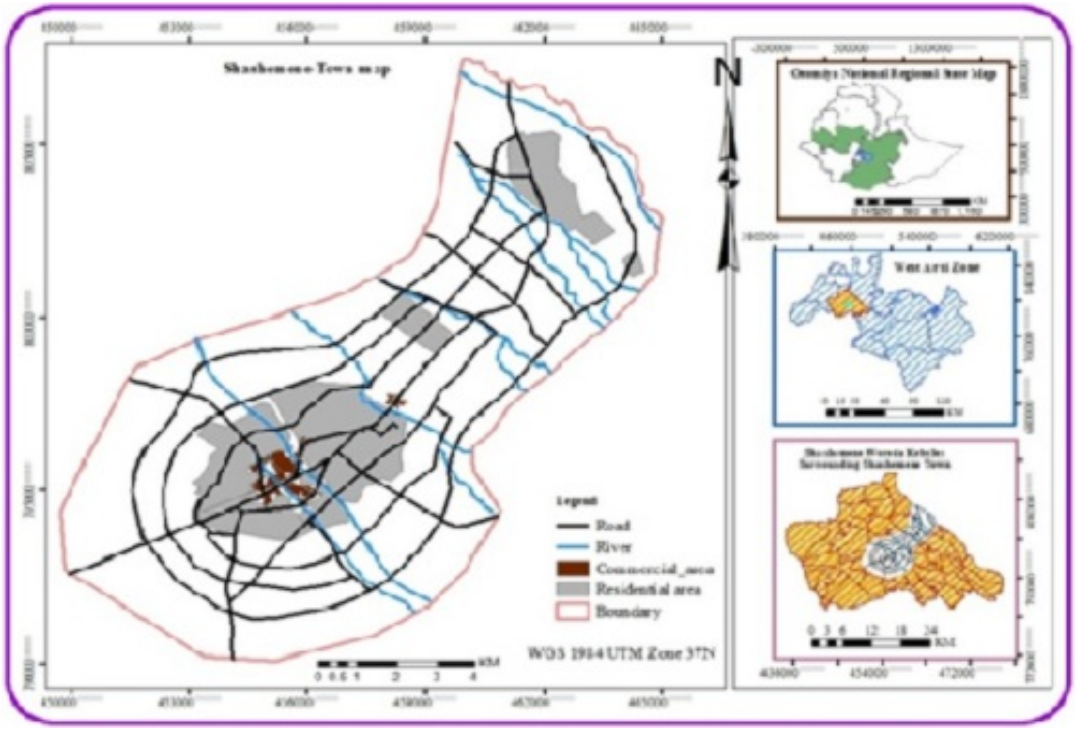


Fig. 1 Map of the study area

2.2 Materials

Several datasets, both vector and raster at different scales were used.

Table 1 Input data sources and description.

Input data	Entity	Sources
Spot 5	Tiff	Ethiopia Geospatial Agency
SRTM (ShuttleRadarTopographicMission)	Digital Elevation Model (DEM)	http://srtm.csi.cgiar.org/.
Topographic map sheet	Tiff	Ethiopia Geospatial Agency
Structural plan	Vector	Office of Land Development Agency, Shashemene town
Soil map	Vector/shape file	http://www.fao.org
GPS readings	Point data	Field surveyed

2.3 Methods

Digitization: to convert base map to digital maps, thirteen (13'n) criteria features such as roads, environmentally sensitive areas, cemetery areas, residential and mixed-use, planned social services, and Land Use have been obtained through digitized structural plan of the town. River, commercial area, military area and existing social services were digitized from a topographic map and the soil type was digitized from soil map that was downloaded.

Fuzzy logic: It was introduced by Zadeh in 1965 and permits the notion of nuance. Apart from true, a proposition may also be anything from almost true to hardly true. The fuzzy theory, which is a gener-

alization of classic set theory, allows a membership function to operate over the range of real numbers (0, 1). To convert criteria maps to fuzzy layers, equation 1 is used.

$$X_i = \frac{R_i - R_{min}}{R_{max} - R_{min}} * Standardized\ range \quad (1)$$

Where, the **standardized range** represents the range of changes in standardization, X = the cell's value following standardization, R_i = the cell's value before standardization, R_{min} = the minimum value in the factor, and R_{max} = the maximum value in the factor.

Boolean logic: It was used to standardized constraint maps to fuzzy layers. In standardizing constraints, Boolean logic based on the value of 0, 1 was used, where constrains take zero and other parts take 1 (Aliani *et al*,. 2016; Gemitzia *et al*., 2007) so, land use/cover and soil type were standardized using Boolean logic for a solid waste suitable site.

Analytical Hierarchy Process (AHP): The AHP is a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales, which will then measure intangibles in relative terms. It assists to establish priorities among the elements within each stratum of the hierarchy. After that, a consistency Index (CI) computed using the following formula.

$$CI = \frac{\lambda_{maxn}}{n} \quad (2)$$

Where, n is the number of criteria and λ_{max} is the biggest eigenvalue (Malczewski, 1999).

To determine if the comparisons are consistent or not, the Consistency Ratio (CR) calculated using the formula:

$$CR = \frac{CI}{RI} \quad (3)$$

Where, RI is the Random Inconsistency index that is dependent on the sample size, a reasonable level of consistency in the pairwise comparisons is assumed if $CR < 0.10$, while $CR \geq 0.10$ indicates inconsistent judgments (Saaty, 2008).

The consistency ratio of this study indicated that 0.08 which was acceptable as given in table 3.

Table 2 Determined relative criterion weights

Criteria/parameters	EIGENVECTOR	Percentage
River	0.194	19.4
Commercial area	0.119	11.9
Residential area	0.138	13.8
Social service	0.080	8.0
Water well/Reservoir	0.064	6.4
Environmentally sensitive area	0.044	4.4
Cemetery	0.028	2.8
DEM	0.013	1.3
Slope	0.012	1.2
Military area	0.015	1.5
Road	0.242	24.2
Land use land cover	0.029	2.9
Soil type	0.024	2.4
Total	1	100

2.4 Evaluation criteria

River: Since major rivers have a higher discharge and greater downstream influence, no solid waste disposal should be sited within the floodplains of major rivers. Based on Soroudi *et al*. (2017), 2000 and 4000 meters were decided 'a' and 'b' control points for rivers with linear and monotonically increasing fuzzy membership function used.

Cemetery sites: According to Nas *et al*. (2010), cemetery areas were standardized using control points (1500m) and b(4500m) with linear and monotonically increasing fuzzy membership type and shapes respectively because it causes problems and complaints about the residents. Environmentally sensitive areas: The environmentally sensitive area in this study is faults that cause limitation for setting a landfill. Environmental sensitive areas were standardized using control points 'a' 1000(m) and 'b' 5000(m) with linear and monotonically increasing fuzzy membership types and shapes respectively.

Commercial area: Commercial areas include highly building areas, business centers, and area developed by many infrastructures. Based on Foomani *et al*. (2017) control points of 3000, 4000, 5000 and 6000 meter was chosen considering the commercial area as one source of hazardous waste with sigmoidal fuzzy function type and symmetric membership shape was chosen due to it causes bad odors and depreciation of land in the surrounding area. The sufficient landfill capacity for the city's long-term requirements should be considered and the landfill site should not be affected by the development plans of the city.

Residential area: Landfill sites should be located away and far from populated areas. Otherwise, it causes bad odors and depreciation of land in the surrounding area (MET *et al*., 2008). Based on the methodology described in Babalola and Basu (2011), 500(m) and 3000(m) of 'a' and 'b' control points and linear and moronically increasing fuzzy function was considered for this factor.

Slope: Slope is an important factor in the suitability site selection because it determines the amount of surface runoff produced by the precipitation rate and displacement velocity of water to the potential site in addition to the construction cost (Tsegaye, 2006). According to the study of Foomani *et al*. (2017), 5% and 15% were chosen as 'c' and had control points with monotonically decreasing shape and linear fuzzy membership function type was considered.

Water well/reservoir area: Nas *et al*. (2010) have recommended a minimum distance of 2000m off from wells and reservoirs for locating a dumping site due to pollution-related problems. Therefore, 2000m and 6000m control points of 'a' and 'b' with linear fuzzy function type and monotonically increasing fuzzy function shape was considered.

Military area: According to Alfy *et al*. (2010), solid waste disposal must be 3000m far from the military area. For this study, fuzzy standardized using 3000m and 6000m control points of 'a' and 'b' with sigmoidal fuzzy function type and monotonically increasing fuzzy function shape was considered because of areas used for the testing of military equipment or training of military personnel are not open for public usage.

Social service area: Social service places, where people gather and do their day-to-day activities are also among the sensitive sites that need careful planning in waste disposal process. Social services in this article are two types of existing places and future planned areas. Existing places area (schools, mosques, hospitals, and church and market areas) and future planned areas according to the structural plan of the town were identified. As described in the methodology Semaw (2018), 1000m and 4000m control points of 'a' and 'b' with linear and monotonically increasing fuzzy membership function was used.

Road: Road is one of the criteria that should be considered in solid waste dumping site suitability analysis. Based on Demesoukad *et al*. (2013), control points of 500, 1000, 1500, and 2000 meters with J-shape type and symmetrical fuzzy membership function shape was considered.

DEM: Hilly landscapes not only increase construction costs but also become a burden to vehicles transporting waste to landfill locations since a number of highlands will be difficult to negotiate if proper leveling is not done (Foomani *et al*., 2017). Based on the study of Soroud *et al*.(2017), 1600 - 2000m equal to between 0 - 1, more than 2000m equal to 0 with user-specified fuzzy membership function was considered.

Land Use/land cover: Land use/Land cover map of the study area is one of the criteria used to select potential sites for solid waste disposal in Shashemene town. Forest areas are not suitable for landfills, but agriculture areas are suitable because they are suitable for landfill facilities (Guler and Yomraholu 2017). According to the study of Ebistu and Minale (2013), land use/land cover of Open space equal to 1, Agriculture equal to 0.6 and Forest area equal to 0 was considered with User specified fuzzy membership function type as shown on figure 4A.

Soil type: Soil characteristics promote safe and economic feasible impletion and operation of a dumpsite for site selection. Based on the study of Soroud *et al*. (2017), nitosols equal to 1 and xerosols equal to 0.8 with discrete fuzzy membership function were concerned as shown in figure 3K.

Weighted Linear Combination (WLC): This method is used to combine and generate a single map, showing areas of different suitability levels for setting a landfill within the study area. It is simple and most widely applied method (Rafiee *et al*., 2011). Using WLC method, the Suitability Index was calculated by summing the product of each weight of each criterion with its standard score and it is the method of evaluation that represented cell suitability by weighting and combining factor map layers using equation 4 as follows:

$$S_f = \sum_{i}^{N} = 1 W_i X_i \tag{4}$$

Where, S_f stands for total suitability index value (0-1) of factor maps, W_i = Weight, X_i indicate criterion score factor i and N = Total number of factor criterion. In considering constraints based Boolean logic, constraints with the value of 0 should multiplied by suitability as calculated from the factor using equation 5 as follows.

$$S_c = \sum_{i}^{K} =_i b_j \tag{5}$$

Where S_c totals suitability index value, (0), k, and b_j show total number of constraints and suitability index value for each constraint (0) respectively. Final suitability index

The final suitability index (S_t) was computed by integrating total factor suitability (S_f) and the total constraints suitability (S_c) index using equation 6 as follows.

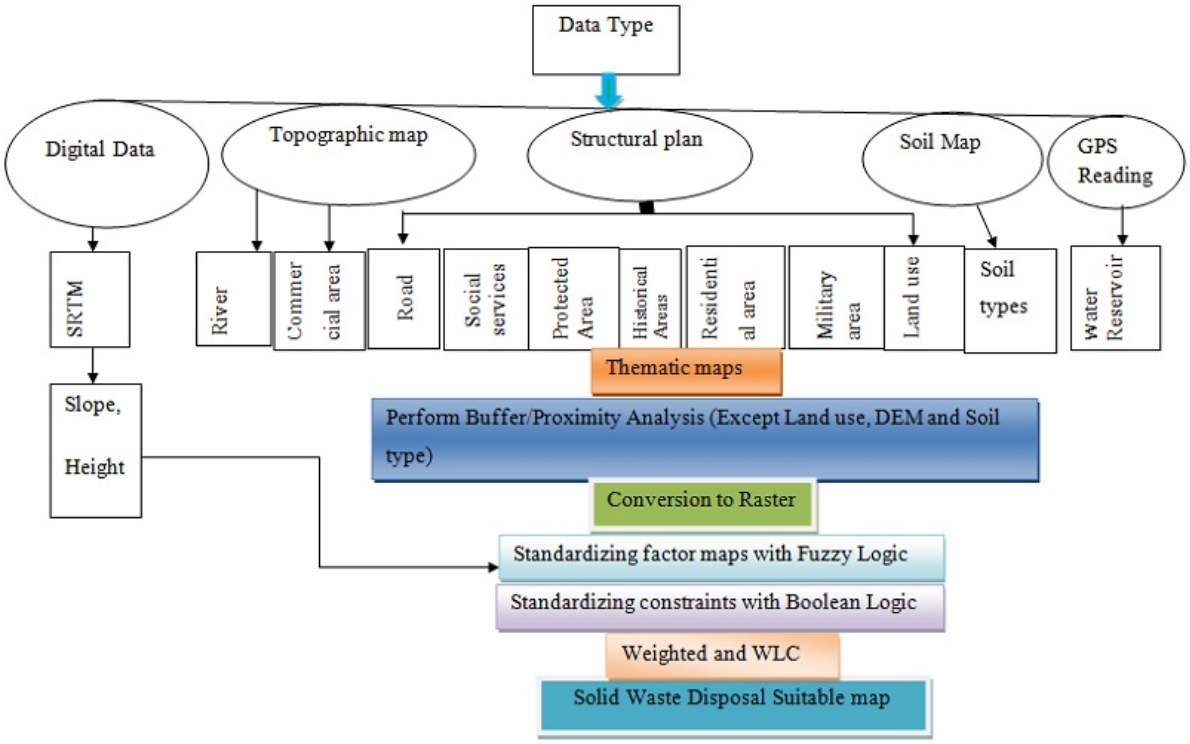
$$S_t = S_f{}^* S_c \tag{6}$$

Where S_f = Integrated total factor, S_c = Total constraint suitability. Based on Soroud *et al*. (2017), the final suitability of each criterion suitability and combined WLC results of solid waste dumping site was reclassified as described in Table 2 below.

Table 3 Classification for Solid Waste disposal sitting of final WLC

Class number	Land capability	Final value of each pixel
1	Not suitable	0 – 0.2
2	Low suitable	0.2 – 0.4
3	Moderate suitable	0.4 – 0.6
4	Highly suitable	0.6 – 0.8
5	Extremely suitable	0.8 - 1

Methodological Flow Chart of the Study



3 Results and Discussions

3.1 Results

River suitability map: The result of fuzzy standardized map of figure 2A showed that within 2000m distance from the river, the area was unsuitable and it was showed by red color or (0) value on the map. The green and yellow colors showed suitable area above 2000m distance from river and far distance from river respectively and the suitability level increases by (1) value. The result of river suitability map in figure 2B showed that out of the total area, 10861.74ha (84.25%) was unsuitable for solid waste disposal site and area which is 311.4ha (2.42%) was evaluated as highly suitable and the rest area 1039.77ha (8.06%) was evaluated as the most suitable for solid waste disposal site for river criteria.

Cemetery sites suitability map: According to Nas, *et al*. (2010) distance from Cultural Heritage Sites should not be within 1500m because it causes problems and complaints of the residents. The result of fuzzy standardized map of figure 2C showed that within 1500m distance from cemetery, the area was unsuitable and it was showed by red color or (0) value on the map. The blue color or (1) value showed suitable area, which was above 4500m far away from cemetery area. When the distance of solid waste disposal site increases from cemetery, the suitability level increases by (1) value.

Environmentally sensitive areas suitability map: Value 0 indicated that unsuitable area within 1000m distance and value 1 showed suitable area near 5000m distance from the site as showed in figure 2E. The results of figure 2F showed that out of the total area, 2437.83 ha (18.91%) was unsuitable for solid waste disposal site, which was found in the area of 1000m.

Commercial area: The areas of town nearer to the site had less distance, which were 3000m far and less standardized fuzzy value near to 0. Medium distance, which was 4500m, has high value near to

1 and it was highly suitable for solid waste disposal site. Selection and high distance more than 6000m has fuzzy standardized value near 0 as showed on figure 2G. The suitability level of commercial area in figure 2H showed that out of the total area, 9949.86 ha (77.17%) was unsuitable for solid waste disposal site because it was found in the 3000m and 6000m distance from commercial areas.

Residential areas suitability map: The fuzzy standardized map of residential area in figure 2I showed that near distance, which was 500m, has fuzzy value near 0 of red color on map and it was unsuitable area. On the other hand, areas that were 3000m faraway have 1 fuzzy value and indicated in green color on the map showed suitable area. The results of suitability map on figure 2J showed that out of the total area, 7473.4ha (57.96%), which was found in 500m was unsuitable area for solid waste disposal site.

Slope suitability map: The slopes greater than 15% and less than 5% have 0 value and they were unsuitable area for solid waste site selection and value 1 of slopes between 5% and 15% were considered highly suitable area as showed in figure 2K. The result on figure 2L showed that majority of the study area falls of the slope class that covered 75% of the area (slope between 5% and 15%), which was extremely suitable for solid waste dumping.

Water well/reservoir areas suitability map: The fuzzy standardized map in figure 3A showed that value 1indicated suitable areas, which were about 6000m far from the water well and 0 value showed unsuitable area, which was about 2000m distance from water well/reservoir area. The results of suitability map in figure 3B showed that out of the total area, 3152.34 ha (24.45%), was found about 2000m far from the water well and it was unsuitable for solid waste disposal site.

Military area: The fuzzy standardized map on figure 3C showed that about 3000m distance had fuzzy value 0, which indicated unsuitable area in red color on the map and far distance about 6000m had fuzzy 1 value, which indicated suitable area of green color on the map. The suitability results on figure 3D showed that out of the total area, 5426.55 ha (42.09%) was unsuitable for solid waste disposal site.

Social service area: Fuzzy standardized map in figure 3E indicated that about 1000m had a fuzzy value 0 and red color on map, which showed unsuitable area and near 4000m have fuzzy value 1 and green color on map, which indicated suitable area. The suitability map results in figure 3F showed that out of the total area, 8856.7 ha cover highest area about 68.69% was found near 1000m from social service, and it was unsuitable for solid waste disposal site.

Road suitability map: The fuzzy standardized map in figure 3G showed that the area near 500m to the road and 2000m far from the road had a fuzzy value near 0 that indicated the area was unsuitable. The area near 1000m to the road had a high pixel value of 1 and it was a suitable area indicated in figure 3G. The suitability map results of figure 3H showed that out of the total area, the highest area of about 85% (10949.49 ha) was found near 500m to the road was unsuitable. Only 5.6% of this area was suitable for the solid waste disposal site. Generally, the road was the most determining criteria for the solid waste disposal among the thirteen criteria since 85% of the area was unsuitable under this factor.

DEM: The result of the fuzzy standardized map in figure 3I showed that height of 2000m had fuzzy value 0, which indicated an unsuitable area with red color on the map, and height of between 1800m of the town DEM had fuzzy value 1 that was indicated suitable area as shown by green color on the map in figure 3I. In this criterion, the suitability map showed three suitability levels of unsuitable, high suitable and the most suitable. The area under this factor did not fulfill less suitable of fuzzy value 0.2-0.4 and moderate suitable of fuzzy value 0.4-0.6 as shown on figure 3J. The suitability map results in figure 3J showed that out of the total area, about 29.19% (3762.99ha) were found at 2000m height and they were unsuitable for solid waste disposal site

Land Use Land Cover: The result showed that agricultural area had moderate suitable (value 0.6), open space area had the most suitable (value 1), and for-

est area had unsuitable (value 0) as shown in figure 4A. In this criteria, the suitability map in figure 4B has three suitability level of unsuitable, less suitable and high suitable because of the area under the factor did not fulfill the most suitable, and moderate suitable that means no fuzzy standardized value of between 0.4 - 0.6 (moderate suitable) and 0.8 – 1 (extremely high suitable). The suitability map results in figure 4B showed that, out of the total area, about 2164.14ha (65.19%) was unsuitable for solid waste disposal site. Generally, only 205.02ha and 950.40ha, which were 6.18% and 28.63%, were evaluated as less and highly suitable for the solid waste disposal site respectively as showed in figure 4B.

Soil type suitability map: The study area has soil type showed in figure 3L and largely dominated by Eutric Nitosols, which covered 49.52% and found in the north-east, east and east- south part of the study areas. The second type of soil is Haplic xerosols, which constitutes 31.6% dominated the western and northern parts of the study area.

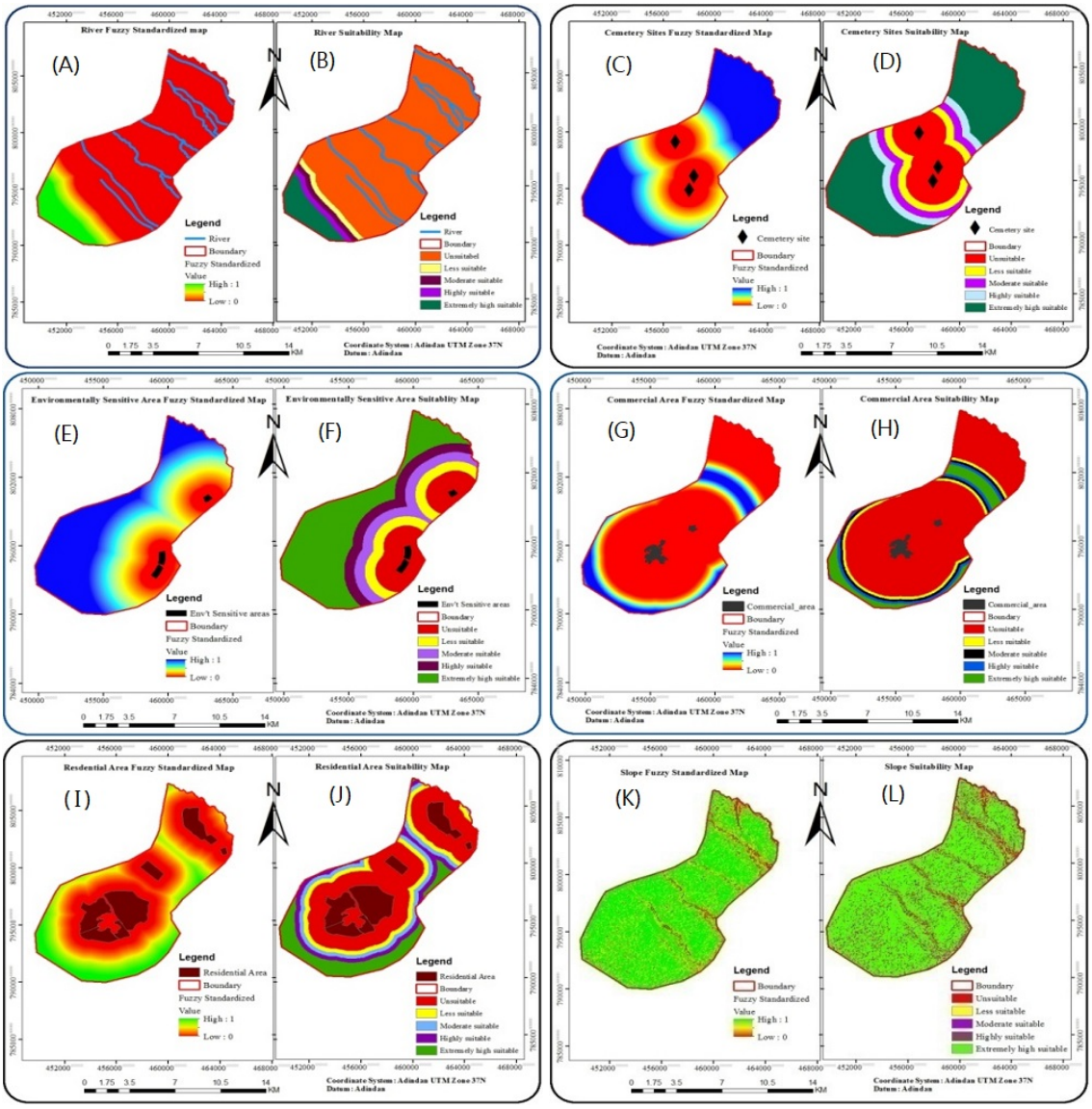
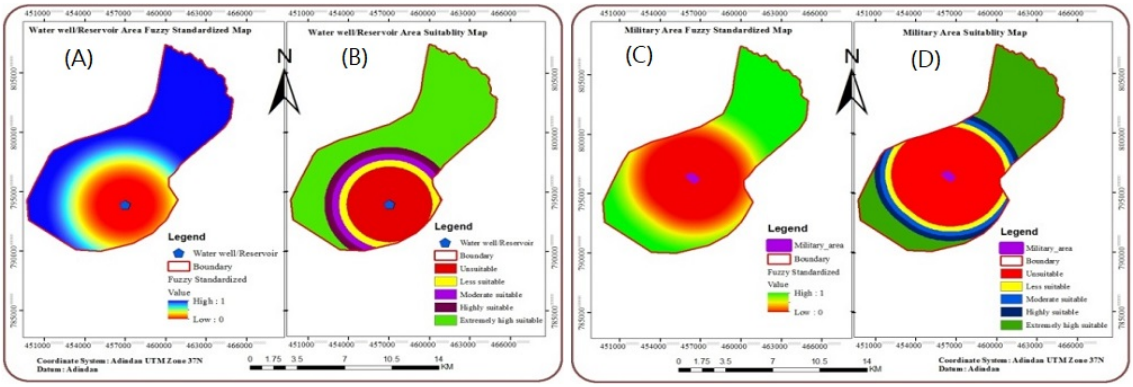


Fig. 2 (A) Land use/Cover fuzzy standardized map (B) Land use/land Cover suitability map.

3.2 Discussion

The present study represents an important step in addressing a critical gap in the selection of solid waste disposal site and enhances environmental acceptability. Solid waste dumpsite should be located at a suitable distance from roads to reduce the relative cost for transportation. According to Demesoukal *et al*. (2013), a minimum distance of 500m buffer should be maintained for road suitability location. The river was also a factor due to pollution problems and contamination by leach so, no solid waste disposal should be sited within the floodplain of the rivers and a minimum distance of 2000m should be maintained (Gemitzi *et al*., 2007; Soroudi *et al*., 2017). The cemetery area is cultural heritage sites and distance of 1500m used with linear and monotonically increasing fuzzy type and shape due to problems and complaints about the residents (Nas *et al*., 2010). Areas found within 1000-meter buffer distance from environmentally sensitive areas were considered unsuitable for solid waste disposal sites due to the high permeability of soil near the fault and keep groundwater contamination (Rafiee *et al*., 2011; Foomani *et al*., 2017). Water well is an important environmental criterion for the landfill site selections process and according to Nas *et al*. (2010), a minimum distance of 300m off from wells and reservoirs for locating a dumping site should be used. and areas located within this distance are unsuitable, and the more the long distance a landfill moves the more the suitability is due to less exposure to pollution and contamination.

Commercial areas include building areas such as business centers, areas developed by many infrastructures, and it is a source of hazardous wastes. Therefore, during site selection, minimum distances of 3000 meters need to be considered since it causes bad odors and depreciation of land in the surrounding areas (Foomani *et al*., 2017). Solid waste disposal must be 3000m far away from the military area since areas used for testing military equipment's or training military personnel are not open for public usage (Alfy *et al*., 2010). Social service sites should consider landfill planning to avoid possible interventions and risk against human health; we need to consider a minimum distance of 500 meters (Hasan *et al*., 2009; Semaw, 2018). The interpretation of the final WLC suitable shows there are five categories of suitability levels. The final WLC map generated showed in figure 5 and table 4 indicated that unsuitable, less suitable, moderately suitable, highly suitable, and extremely highly suitable areas respectively for solid waste dumping sites.



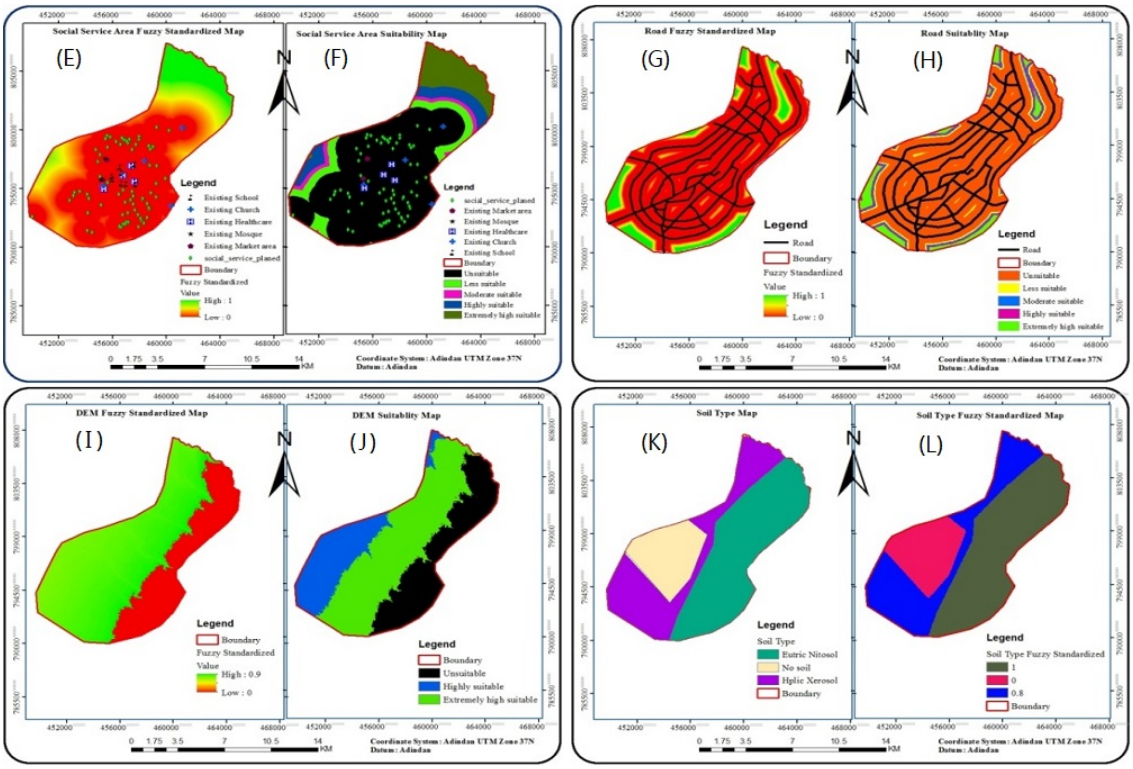


Fig. 3 Map showing Fuzzy Standardized and Suitability of each criterion (A & B: River, C & D: Cemetery area, E & F: Environmental sensitive area, G & H: Commercial area, I & J: Residential area, K & L: Slope in percent).

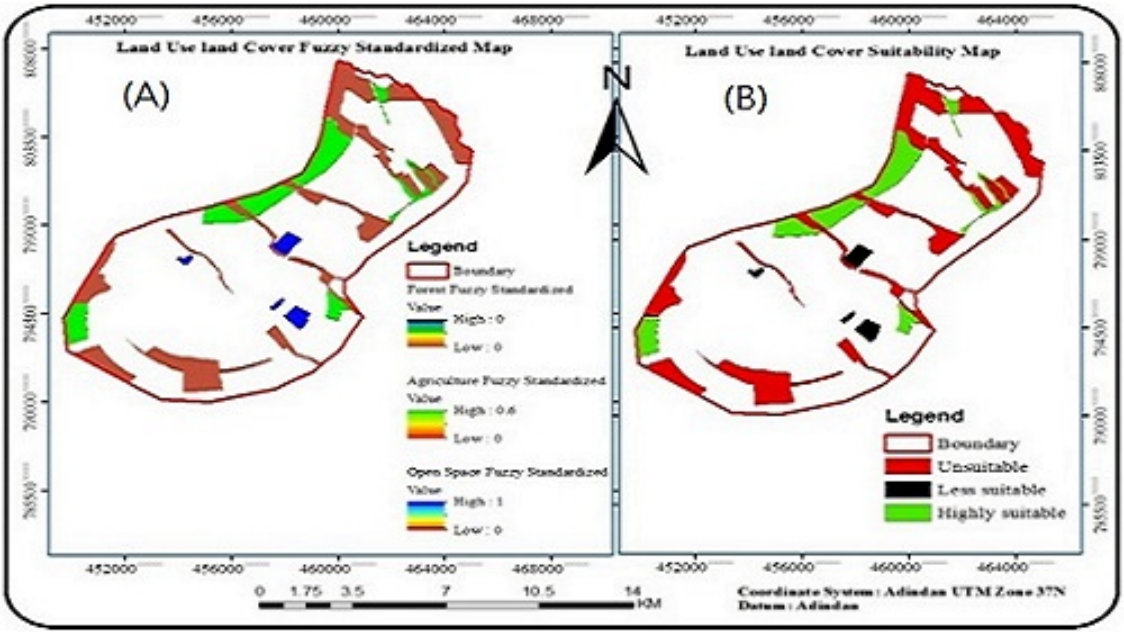


Fig. 4 Map showing Fuzzy Standardized and Suitability of each criterion (A & B: Water well/reservoir, C & D: Military area, E & F: Social services, G & H: Road, I & J: DEM in meter, K & L: Soil type).

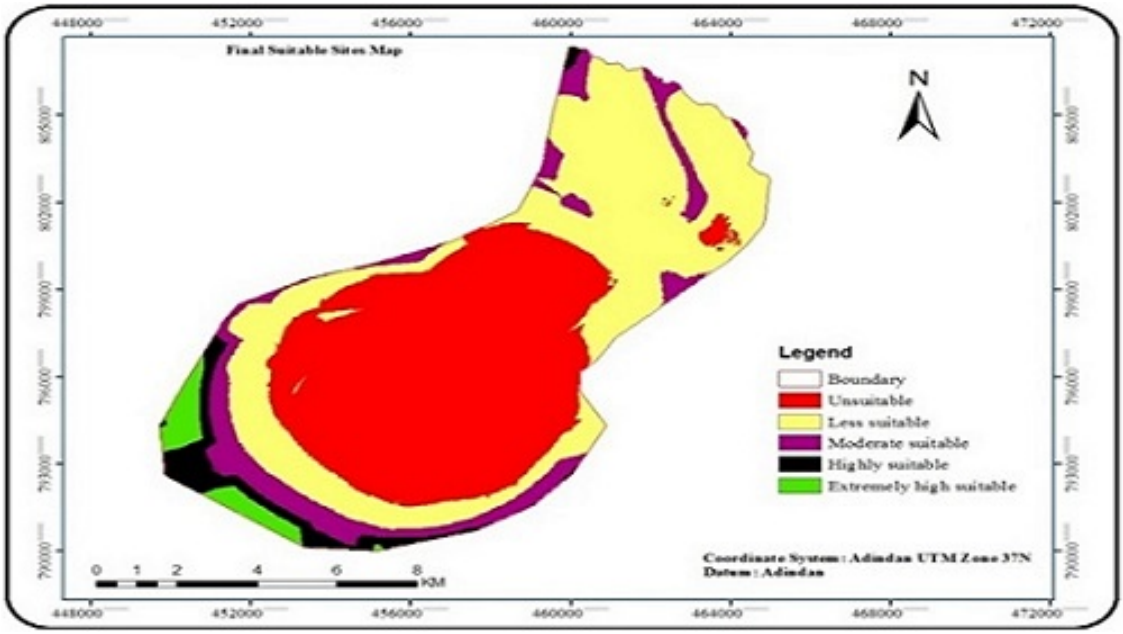


Fig. 5 Final WLC suitable sites.

Table 4 Weighted linear combination of Solid waste disposal Site Suitability Area.

Suitability Level	Value	Area (ha)	Percent
Unsuitable	1	5356.5	41.5
Less suitable	2	3959.0	30.7
Moderate suitable	3	2110.1	16.4
High suitable	4	966.8	7.5
Extremely suitable	5	500.8	3.9
Total		12893.2	100.0

By using the stated criteria, suitable areas for solid waste dumping sites potential were on the southwestern parts of the town. To evaluate the solid waste disposal sites, criteria such as distance from the road, the river, the residential areas, and the commercial areas were used. Finally, as showed in figure 6A, class site 3 (rank 1) is selected as the most suitable site for municipal solid waste disposal. This is because it is (0.9km) far away from the road, (2.653km) far away from the river, (3.17km) far away from residences, and (4.132km) far away from commercial areas. The other sites are site 1 (rank 2) and site 2 (rank 3) respectively. Generally, six final evaluated candidates of the solid waste disposal sites for Shashemene town were put in table 5, and presented with their area and geographical location and in figure 6B.

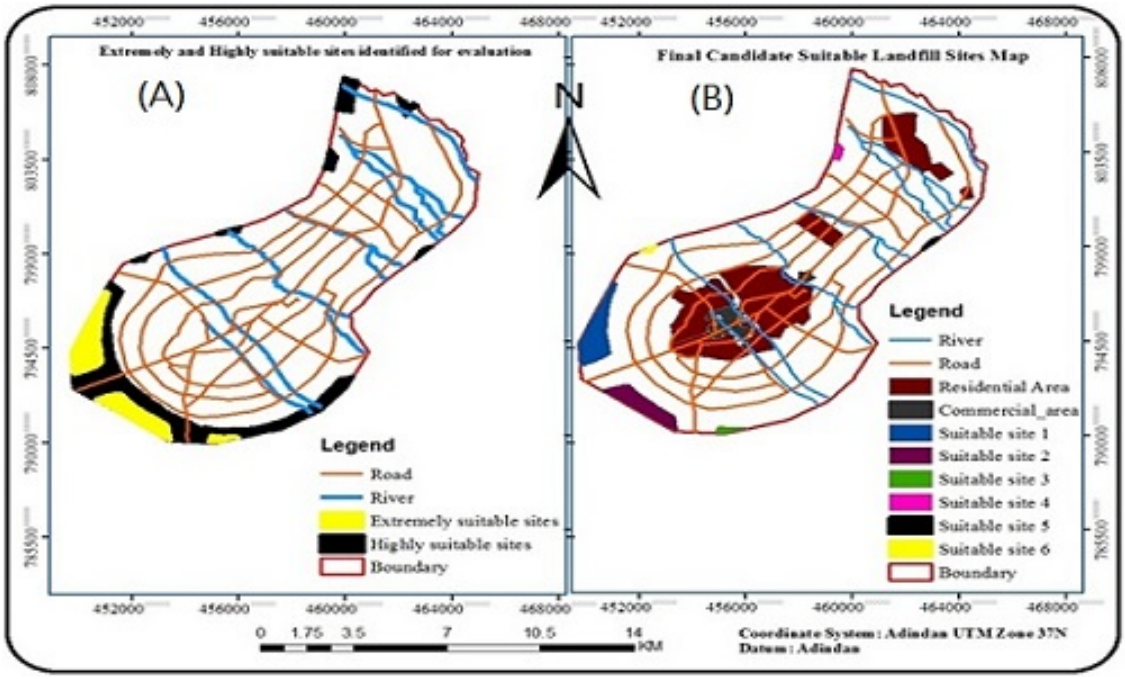


Fig. 6 (A) Extremely and Highly suitable sites identified for evaluation map (B) Final evaluated suitable landfill candidate sites map

Table 5 Final candidates of suitable sites.

Final class of suitability	Geographical location		Area (ha)
	Latitude	Longitude	
Suitable 1	38^{o}35’38.59"N	7^{o}08’58.30"E	25.9
Suitable 2	38^{o}32’58.77"N	7^{o}11’13.57"E	205.2
Suitable 3	38^{o}33’59.44"N	7^{o}09’37.50"E	268.8
Suitable 4	38^{o}37’56.98"N	7^{o}16’06.82"E	24.4
Suitable 5	38^{o}34’07.01"N	7^{o}13’35.95"E	7.6
Suitable 6	38^{o}39’50.79"N	7^{o}13’49.00"E	6.8

4 Conclusions

Since the landfill is a fundamental step in waste management strategy, the landfill site selection demands in-depth consideration. Setting of the landfill sites is a multidisciplinary and a very complex process, therefore, careful consideration of all factors ranging from environmental to economic is required. In the present study, the flexibility to apply such models as WLC, the combination of GIS, fuzzy logic (for standardization of factor maps), Boolean logic (for standardization of constrain maps), and multi-criteria assessment methods (MCDM) was used for MSW landfill sitting. Although a weighted value was assigned to factors in fuzzy theory by applying the Analytical Hierarchy Process (AHP) method according to their importance for the suitability and consistency ration indicated 0.08.

The four sub criteria of road, river, residential area and commercial area are the most determinant sub main criteria used to evaluate the potential of solid waste disposal site so as to choose the final best

suitable site. Finally as shown on figure 6A, the most suitable site suggested in this study was about 25.9 hector with geographical coordinate of the selected site is 07^{o}8'58.304"N and 38^{o}35'38.59"E. In addition, the distance from nearest road, river, residences and commercial area is (0.9km), (2.653km), (3.17km) and (4.132km) respectively. Overall, the final capability map generated by the weighted linear combination method represents that 41.5% of the study area is not suitable for landfill sitting, while low, moderate, high and extremely high suitable classes cover 30.7%, 16.4%, 7.5% and 3.9% respectively of Shashemenetown. Finally, six most highly suitable solid waste disposal sites were identified for Shashemene town but the final decision may be influenced by political opinion, public opinion, economic studies, land ownership, and other field studies should be considered for final decision.

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Conflict of interest

The author declare that no conflict of interest.

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E J E D

COFFEE RESEARCH ACHIEVEMENTS, THEIR BACKSTOPPING TO THE DEVELOPMENT OF THE SUB-SECTOR IN ETHIOPIA AND PRODUCTIVITY GAP BETWEEN FARM AND RESEARCH: A Review

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Abstract

Literature shows more of the world population turns to coffee consumption particularly Latin America, India and China. Demand for the beverage is estimated to increase by nearly 25% over the coming five years. On the other hand, global coffee production and supply is very unlikely to increase due to many factors. To fill the expected gap between production and consumption, Ethiopia has a better opportunity. Current productivity per hectare is about 647 kg which is lower than in many growing countries. Eventually, the research developed 42 coffee verities among which 35 are selections and seven of them are hybrids. As different coffee husbandry technologies enable to boost coffee production and productivity many agronomic practices are generated and recommended along with coffee varieties. Major coffee diseases like (Coffee Berry Disease, Coffee Wilt Disease and Coffee Leaf Rust) management options are also the knowledge developed by research. Integrated weed management practice developed to mitigate weed infestation from coffee farms enables us to reduce 65% yield loss. Among coffee quality maintenance technologies developed is altitude based fermentation time. For altitudes ≤1200, 1200-1500, and >1800 meter above sea level recommended 24, 24-48 and 48-72 hours fermentation period respectively. Improved coffee seed production also remains the responsibility of the research. In this regard, until now, about 300,000 kg of improved seed supplied in which estimated to cover about 300,000 hectares of land. Despite these all technologies, there is a wide productivity gap among the research, modern plantation, and the national average productivity. Even though developed technologies made considerable contributions to coffee production, productivity, and quality improvement in Ethiopia a lot is remaining. The national average productivity only reached 30% of the research results. This big gap in productivity range requires a wide utilization of research output by development is crucial. Actually, this demands: (1) Aggressive scaling-up of proven technologies (2) Managing coffee stands through mobilizing coffee sector rehabilitation and wide utilization of technologies (3) Addressing research in unaddressed areas (4) Establish & support sustainable coffee seed system (5) Establish viable extension system and consolidate the relationship of research and extension so that existing technology can be disseminated. In general, the major interest of this review paper is to bold out the outputs of existing national coffee research and to clearly show the gap between research results and development wing. On the other hand, it will try to show how concerted efforts should be made to improve both the volume and quality of coffee to the expected result to increased export revenue to the country.

Keywords: Coffee productivity; Coffee technology

1 Introduction

Coffee is at the center of Ethiopian culture and economy, which contributes for 29 – 31% of export earnings of the nation, 4.7 million small-holders directly involved in producing coffee and about 25 million people directly or indirectly depend on the coffee sector for their livelihoods (CSA, 2015; Taye Kufa *et al*., 2016). Despite the natural endowment of the country and the economic importance of the crop to Ethiopia, both the value and the volume of coffee exported from the country do not show a substantial increase in the past few decades. An improvement in coffee productivity and quality has a direct impact on the livelihoods of a large number of resource-poor people. Appropriate management practices along with a better understanding of the crop behavior are important requirements for improving the growth, productivity, and bean qualities of coffee trees (Adugna, 2016). Thus, research on this commodity is crucial for the country.

The national coffee research in Ethiopia was established in late 1967. The ultimate goal of the coffee commodity research is to provide all the relevant technologies that are essential to revamp the Ethiopian coffee industry and thereby maximize the country's foreign exchange earnings from coffee and improve the livelihoods of the resource-poor smallholder coffee farmers and that of all other actors in the value chain. With this general objective, the research system tried to develop different coffee production technologies. Developed technologies revolve around variety improvement, coffee processing and quality maintenance, entomological, pathological and weed studies, the advance of agronomic practices (spacing, hole size, weed control, fertilizer rate, etc.).

The current productivity per hectare is about 647 kg (CSA, 2018/19) which is lower than in many growing countries. The government targeted to reach the productivity of 990-1080 kg/ha at the end of Growth and Transformation Period (GTP-II). Aligning with the national coffee sector development plan the national coffee research strategy is also designed to enhance coffee production and productivity by generating appropriate coffee technologies with its full packages. Since the establishment of national coffee research ample coffee production technologies were generated. The prominent are the development of 42 coffee varieties among which 35 are selections and seven of them are hybrid varieties (Bayetta and Labouse, 2006; Fekadu *et al*., 2008; Tadesse, 2017; MOALR, 2017; Ashenafi, *et al*., 2017).

Coffee Berry Disease (CBD) is one of the biggest challenges before the release of these varieties. The change that these varieties brought to the coffee sector are one of the glorious results in the coffee subsector especially gave relief for high CBD prone areas. To generate high yielder, disease resistant, and quality varieties, it is important to collect, evaluate and maintain coffee germplasm. In this regard, to maintain arabica coffee germplasm and utilize for further research program accessions are maintained at nationally coordinated coffee research centers (Fekadu *et al*., 2008; Tadesse, 2017). On the other hand, to overcome the coffee variety adaptation problems, different varieties across different coffee growing environments were studied and well-adapted varieties recommended for respective coffee growing areas.

As different coffee husbandry technology enables to boost coffee production and productivity, many agronomic practices are generated and recommended along with coffee varieties. Coffee nursery management practices, coffee seedling planting, young coffee management, old coffee management, cycle changing, appropriate shed tree identification, organic and inorganic fertilizer application practices are to be mentioned.

Major coffee diseases like [(Coffee Berry Disease (CBD), coffee wilt disease (CWD), and coffee leaf rust (CLR)] management options are also the knowledge developed at the research centers (Taye, *et al*., 2016; IAR/JARC, 1996; EIAR, 2017). Weed is also one of the big challenges in coffee production. Integrated weed management practice developed to mitigate weed infestation from coffee farms enables to reduction of 65% yield loss (Tadesse and Getachew, 2008). Arabica coffee grown in Ethiopian is in gen-

eral quite good quality. Most of the time quality maintenance is the biggest challenge apart from coffee production. The national coffee research program developed different coffee quality maintenance technologies to advise coffee producers. Among quality maintaining recommendations given were, coffee fermented under shade takes more time, yet, using shaded fermentation tanks help to achieve a uniform fermentation process and better quality coffee (Behailu and Solomon, 2006). Parchment coffee drying also studied and recommended drying depths of 3 to 4 cm by covering during very strong sunshine hours gave better values of cup quality (Solomon and Behailu, 2006). Describing of the quality status of released coffee varieties were also conducted to provide information for growers (Behailu *et al*., 2008). Improved coffee seed production also remains the responsibility of the research centers. Due to the perennial nature of the crop no commercial seed producer engaged, yet the research centers shouldered the responsibility to disseminate.

Despite these all production technologies developed; there is still a wide gap among the productivity achieved at research the center and national average productivity. The national average productivity per ha is 647 kg per ha (CSA 2018/19) while that of the research ranges 1500-2600 kg per ha. It is believed that productivity can be doubled by using the technology at hand.

The current coffee demand scenario shows, more of the world population turns to coffee consumption particularly Latin America and the populous nations like India and China. Demand for the beverage is estimated to increase by nearly 25% over the coming five years (Sabrina, 2015). On the other hand, global coffee production and supply are very unlikely to increase since the world's largest producer, Brazil, is frequently facing recurrent drought, frost, and other climatic problems. Other coffee growing Latin American countries are not also expected to produce much because of the devastating coffee leaf rust disease which remains to be a persistent problem in this part of the world. Asian Countries like Vietnam, India, and Indonesia are not also expected to produce enough that can stabilize the market because of various internal factors such as land shortage, input supply, and high production cost, etc (ICO, 2013).

In order to fill the expected gap between production and consumption and stabilize the international coffee market, the world is eying at Africa to see other many countries to emerge. The continent also owes wide ranges of agro-ecologies and incredible landmass suitable for coffee production in all the 25 coffee growing countries of Africa. However, except Ethiopia, Uganda, and Cote d'Ivoire, all the rest countries are producing very small amounts and are not still ready to transform their coffee sub-sector. Currently, Ethiopia is the leading coffee producer in African and the world's fifth-largest producer. And it is likely to say Ethiopia can take this opportunity as coffee is highly related to the economy and social integration of the people.

So, the major interest of this review paper is to highlight the research outputs of existing national coffee research. Concurrently, support the reader to ultimately understand multi disciplinary research activity towards the technology development to the users working on coffee. On top of this readers can get a clue on how the coffee research in Ethiopia supports the development and indicate a lack of correspondence among them. It also shows the productivity gap between research results and farmers/growers. Finally, it will try to show how concerted efforts should be made to narrow down the productivity gap by forwarding possible recommendations.

2 Coffee Variety Development

The major thrusts of this research discipline are (a) collection and selection of Arabica coffee germplasm in Ethiopia; (b) selection scheme for specific purposes (CBD resistance); and (c) hybridization scheme. At present, a total of 6721 indigenous and exotic coffee accessions are collected and conserved at field gene bank (Table 1). A large number of these accessions were evaluated for yield, disease and insect pest resistance/tolerance, overall quality, and other traits of breeding interest while the remain-

ing are currently under evaluation. Accordingly, a large number of promising accessions were selected and utilized in the breeding program for variety development (Tadesse, 2017; Fikadu *et al*., 2008).

Table 1 Summary of Arabica coffee germplasm collections maintained at field gene bank of JARC.

Batch of collection	Year of collection	Number of accessions
French mission collections and SN series	1966	73
CBD resistant selections	1973-1975	696
CBD resistant selections	1981-1987	568
National coffee collections	1970-1990	554
National coffee collections	2004-2009	941
Sub-total		2832
International coffee collection	1968-1984	190
Local landrace coffee collections	1994-2013	3699
Total coffee genetic resource		6721

source: Tadesse, (2017).

Accordingly from the existing vast coffee accessions the national coffee research program released 42 Arabica coffee varieties out of which seven are F1 hybrids that are currently under production at diverse agro-ecologies of the country (MOALR, 2017; Ashenafi, *et al*., 2017; Tadesse, 2017; Bayetta and Labouse, 2006; Fekadu *et al*., 2008). The release of these varieties has contributed to increasing production and productivity of coffee at the national level as well as in the reduction of production costs such as expenditure for chemical purchase for controlling major fungal diseases commonly attacking the crop. And the release of these coffee varieties gave chance to have an adaptable variety to many of the coffee growing agro-ecologies of the country. The summary of coffee varieties released depicted in Table 2 and 3.

Table 2 Summary of pure-line coffee varieties released from coffee breeding program in Ethiopia.

Year of release	Number of varieties	Clean coffee yield (kg/ha)	textArea of recommendation Altitude range (masl.)*
1978-1981	13	1220-1970	Low to high
1997	3	1660-1940	Low to medium
2002	2	2140-2540	Low to medium
2006	5	1540-2350	Medium to high
2010	11	1190-2120	Medium to high
2018	1	1980	Medium
Total	35	11.9-25.4	Low to high

Key*: Low=(1000- 1550), Medium=(1550-1750), High=(1750-2100). Source: Extracted from variety release data of coffee breeding at JARC.

Table 3 Summary of hybrid coffee varieties released from coffee breeding program in Ethiopia.

No.	Variety name	Year of release	Yield(kg/ha)	Production area (Altitude range)
1	Ababuna	1997	2380	1500-1750
2	Melko CH2	1997	2400	1500-1750
3	Gawe	2002	2610	1500-1750
4	EIAR50-CH	2016	2650	1000-1750
5	Melko-Ibsitu	2016	2490	1000-1750
6	Tepi-CH5	2016	2340	1000-1750
7	Gera 1	2018	2346	1800-2100

Source: Extracted from variety release data of coffee breeding at JARC.

On the other hand, the released varieties lack stable performance across wide environments (Yonas, *et al*., 2008). In order to solve such a problem conducting adaptation trials across different research centers and respective stakeholders are underway. Especially, this activity is implemented mainly in accordance with the landrace variety development program (Bayetta, and Jean Pierre, 2006). By now for most of the released varieties, the specific places where suitably grown is already identified. The adaptation work mainly focuses on areas that are not well identified for adaptation of each variety.

3 Disease and Pest Resistance Development and Prevention

Coffee Berry Diseases (*Colletotrichum kahawae*), Coffee leaf rust (*Hemileia vastatrix*), Coffee Wilt Diseases (*Gibberella xylarioides*), bean discoloration (*Pseudomonas syringae*), leaf blight (*Ascochyta tarda*), root-rot (*Armillaria mellea*), brown-eyespot (*Cercospora coffeicola*), and damping-off diseases of seedlings (*Rhizoctonia* spp., and *Pythium* spp.), Fruit-rot (*Fusarium* spp.), and thread-blight (*Corticium kolleorega*) were recorded associated with coffee in Ethiopia (Eshetu *et al*., 2000).

However, the three major coffee diseases namely are coffee berry diseases (*Colletotrichum kahawae*), coffee wilt disease (*Gibberella xylarioides*) and coffee leaf rust (*Hemileia vastatrix*) in this order. With the review study made by Kifle and Demelash (2015), it is reported that CBD is a major problem still in the coffee production of Ethiopia. Even for the rest of Arabica coffee producing African countries, its harvest loss may reach 60% (Mouen *et al*., 2008). Whereas, in Ethiopia, the overall national average loss due to coffee berry disease is estimated to range 25-30%, (Eshetu, 1997; Eshetu *et al*., 2000). In the recent survey study made by (Kumlachew *et al*., 2016) nearly sixty per cent of the surveyed districts had significantly higher levels of CBD incidence that ranged from 50 to 80%. In this study observed increased severity of CBD as compared to results of previous surveys in major coffee-growing regions of Ethiopia, with respective mean per cent values of 28.8 in Oromia and 36.0% in Southern Nations Nationalities and Peoples Region (SNNPR). The severity result is a bit higher than the previous estimate. Despite its good resistance to improved varieties in the survey study areas, it was observed only 7.2% coffee farm with resistant varieties planted. The majority of the surveyed farmers (nearly 70%) were found to grow a mixture of the local cultivars with the improved coffee varieties as the later ones are mostly preferred for their resistance to CBD and giving more yield. Extensive planting of susceptible local coffee landraces might be the reason for high incidence and severity. Another study showed that recent climatic changes like increased amount and duration of rainfall have reasonably predisposed and favored the coffee berries to infection by CBD pathogen (Kifle and Demelash, 2015). From these observations, it can be concluded that the dissemination of improved and resistant coffee varieties has to

get due attention. To overcome this problem CBD resistant coffee varieties are developed for many CBD prone areas. As a result, this enables no fungicide application and greatly contributed to organic coffee production.

It is also tried to develop many coffee disease prevention and control technologies developed for CWD and CLR diseases (Demelash and Kifle, 2015; Girma *et al*., 2009; Kifle *et al*., 2016). Current Crop protection activities are conducted mainly to develop appropriate methods of controlling diseases, insect pests, and weeds with special emphasis on developing integrated disease and pest management practices which is cost-effective and efficient.

In Ethiopia out of 47 insect spp. attacking coffee identified. Out of the identified insect pest species; Antestia bug (*Antestiopsis* spp.) and Coffee blotch leaf miner (Leucoptera spp.) are considered as a major pest (Essayas *et al*., 2008). The control and prevention method also developed by researchers apart from categorizing as major, potential and minor insect pest problems (Essayas *et al*., 2008; Million and Bayissa, 1986). Currently, some of the minor problems are also becoming major. Periodical assessment and surveillance study undergo by the national coffee research team. Some of common insect pest species in Ethiopian coffee production and their problem status are depicted in Table 4.

Table 4 List of insect pest species and their problem status.

Scientific Name	Common Name	Order	Family	Pest Status
Antestiopsis facetoides (Greathead)	Anthestia bug	Hemi.	Pentatomidae	Major
Antestiopsis intricata (Gquiere and caryon)	Anthestia bug	Hemi.	Pentatomidae	Major
Lecoptera coffeina Washboum	Coffee blotch miner	Lep.	Lyonetidae	Major
Ceroplastates bravicauda Hall	White waxy scale	Homo.	Coccidae	Potentially Important
Coccus allipinus De Lotto	Green scale	Homo.	Coccidae	Potentially Important
Diathrothrips coffea Williams	Coffee thrips	Thys.	Thripdae	Potentially Important
Hypothenemus hampei (Ferriere)	Coffee berry borrer	Coleo.	Scolytidae	Potentially Important
Selenothrips rubrocinctus (Giard)	Coffee thrips	Thysano.	Tripidae	Potentially Important
Stictococcus fomicarious (Newselead)	Coffee coushion scale	Homo.	stictoccocidae	Potentially Important
Antestiopsis orbitalis qhesquieri Caryon	Anthestia bug	Hemi.	Pentatomidae	Minor
Leucoplema dohertyl (Warren)	Coffee leaf skeletonizer	Lep.	Epiplemeidae	Minor
Toxoptra aurantil (Boyer de fanscol)	Coffee aphids	Homo.	Aphidedae	Minor

source: Essayas *et al*., 2008; Million and Bayissa, 1986.

On the other hand, weed is a very serious production problem in the coffee production corridors of Ethiopia. Many of coffee production areas being high rainfall areas, weeding is considered as the major production cost. Some of the weed species affecting coffee production in Ethiopia are identified and listed out as noxious and minor (Tadesse and Getachew, 2008; Demelash, 2018).

It strongly affects the coffee production due to competition and may reach 65% loss when severely affected (Tadesse and Getachew, 2008). Integrated weed management (IWM) uses all available knowledge to manage weeds and prevent them from causing economic loss without adversely affecting the environment (Opile, 1995). Cover cropping, mulching, slashing and digging, shading, land preparation methods and herbicides can be logically integrated depending on the environmental situation where the coffee is growing to obtain maximum benefits from IWM program. In this regard, the national coffee research developed prevention and control of weeds known as integrated weed management practice which is eco-friendly and cost-effective (Tadesse and Getachew, 2008; Tadesse, 1998; Demelash, 2018;). The relative merits of different weed control methods as evaluated in different measures presented in Table 5.

Table 5 Relative merits of the different weed control methods.

Measures	Different weed control Methods				
	Slashing and digging	Mulching	Cover cropping	Herbicide	Integrated control
Cost	+	+++	++++	++	++++
Time	+	++	+++	++++	++++
Yield benefit	+	++	+++	+++	++++
Crop safety	+	+++	+++	+++	++++
Soil moisture	+	+++	+++	+	++++
Soil erosion	+	++++	++++	+	++++
Soil nutrient benefit	++	++++	++++	+	++++
Weed flora change to undesirable types	+	++	+++	+	++++
Overall sustainability	+	+	++	+	++++

Key: *+=Low merit ++=Fair merit +++= Medium merit ++++= High merit. Source: Demelash, 2018.*

4 Agronomic Technologies Development

Agronomy and physiology discipline research focused to solve the bottleneck agronomic constraints and challenges in the areas of nursery and field management and processing (pre- and post-harvest) technologies or practices that would increase production, productivity and quality of coffee products and thereby contribute to increased income of the growers. Developed variety can give enough production if and only if it is managed well. Contextually, it can be said the poor agronomic practice can be a killer or best practice is an enhancer of productivity of a given germplasm. The national coffee research system developed different agronomic practices that start from nursery to cycle changing.

4.1 Nursery Management

Pre-sowing seed management is one of the critical technical issues in nursery management. Stages of the harvest of the cherries, the condition of processing and drying affect the germination of coffee seeds. In studies conducted by the national coffee research, results revealed that seeds sown immediately after harvesting and processing were found to be the best option for higher germination rate and better seedling growth (Anteneh, 2015). With prolonged storage the seed viability decreases (Figure 1).

Figure 1. Effect of time of storage on germination of coffee seed. Source: Tesfaye *et al*. (1998)

The development partners usually use the pre-germination of coffee seeds. This practice is implemented to get enough time for nursery preparation. Yet, it is at the expense of coffee seed viability reduction. On the other hand, pre-germination is the primary cause of multiple and crooked tap roots and eventual tree death in the field (Bayetta and Mesfin, 2005; Anteneh, 2015). Hence, coffee seeds should be seeded directly in seedbeds or polythene tubes for the production of seedlings with a normal root system than following the pre-germination techniques.

Thus, to overcome this practical problem and support smallholder farmers' research work conducted to use different seed storage conditions and material (locally available) rather than using pre-germination. Among locally available storage materials earthen pot stored seed & seeds stored under grass hut storage condition showed better germination (Table 6). While sowing, if seed viability is doubtful, two seeds per hole should be seeded and then thinned to one plant. Furthermore, coffee seeds should be sown after removing the hard seed cover (parchment) and soaking the seeds in cold water for 24 hours as the practices enhance germination and seedling growth (Anteneh, 2015).

Table 6 Percentage coffee seed Germination under Different storage condition and Storage materials.

Storage condition	Storage Material	Germination%	Rank
Seeds stored under concrete building on the wooden table	Earthen pot	63.94	1
	Tin	53.58	4
	Glass jar	31.89	6
	Paper bag	63.57	2
	Polythene bag	52.29	5
	Sacks	62.2	3
	Mean	54.59	
Seeds stored on the ground under grass hut	Earthen pot	62.77	2
	Tin	65.82	1
	Glass jar	45.23	6
	Paper bag	53.68	5
	Polythene bag	55.27	4
	Sacks	85.5	3
	Mean	56.96	
Seeds buried in the ground under grass hut	Earthen pot	59.8	1
	Tin	38.26	2
	Glass jar	29.53	4
	Paper bag	36.88	3
	Mean	41.12	
Mean of storage materials	Earthen pot	62.17	1
	Tin	52.55	4
	Glass jar	35.54	6
	Paper bag	51.37	5
	Polythene bag	53.77	3
	Sacks	59.59	2
	Grand Mean	52.4	

Source: IAR progress report of the coffee department, 1988.

With regard to nursery soil, coffee seedlings can be grown on raised beds (15 cm height) or in polythene tube (10 - 12 cm diameter and 22-25 cm height) filled with forest soil collected from the top 5 - 10 cm depth. However, in the absence of forest soil (FS), it was recommended to use blends of topsoil (TS) and compost (C) only or TS, C and sand (S) following the order of 3TS:1C:0S > 2TS:1C:1S > 2TS:1C:0S > 6TS:3C:2S. Likewise, Taye (1998) and Taye *et al*. (1999) revealed that a mixture of locally available organic manure and TS in 1:4, 2:4 and 3:4 ratios had promoted both shoot and root growth of coffee seedlings. However, if this media blend is suspected to be low in plant nutrients, the addition of 2 g DAP/seedling after the seedling attain two pairs of true leaves would improved seedling growth (Taye *et al*., 1999). For maximum germination, sowing coffee seeds at a depth of 1 cm with the grooved side placed down and embryo tip-up had improved germination (Yacob, 1986).

After sowing the seed, mulching and watering are the subsequent activities. It was observed that coffee seed beds covered with 3 - 5 cm thick mulch need to be watered at 2 days interval until seedling emergence during the dry season. After emergence by removing mulch and providing moderate overhead shade, watering seedbeds twice a week until seedlings attain 2 to 4 pairs of true leaves and then after, at a week interval produced vigorous seedlings for field planting (Tesfaye *et al*., 2005; Anteneh and Taye, 2015).

Methods of transplanting had substantial influences on the percent survival rate of coffee seedlings. Polythene pot raised (ball root transplanted) coffee seedlings showed 92.92% field survival as compared to those raised on seedbed (bare root transplanted) seedlings with a mean value of 62.44% (Figure 2). Thus researcher advises growers to use polythene raised seedlings.

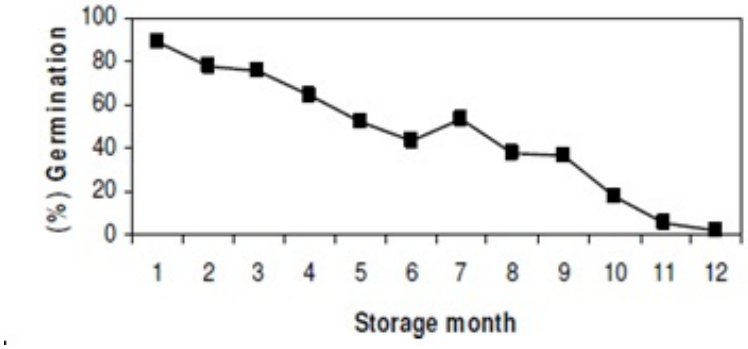

Fig. 1 The effects of transplanting method. Source: Taye *et al*. (2001); Anteneh, *et al*. (2015)

The survival rate of coffee seedlings also increased with increasing hole size; though, the response varies among ecological conditions (Figure 3a). Moreover, appropriate time of transplanting is also important to ensure better survival of coffee seedlings; although proper planting time has to be best predicted and modeled using several years' weather data (Anteneh *et al*., 2015). May/June and July/August transplanting resulted in better field survival rates of coffee seedlings in most of the study sites (Figure 3b). This is mainly related to the onset of rain.

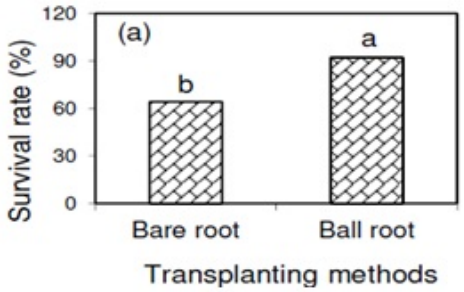

Fig. 2 The effects of transplanting method. Source: Taye *et al*. (2001); Anteneh, *et al*. (2015).

4.2 Field Management

In the center of origin, Ethiopia, Arabica coffee has been found growing naturally under the canopy strata of various shade tree species and, thus, it flourishes best when grown under shade than open sun condition (Yacob *et al*., 1996). In addition to their apparent roles in soil fertility enhancement, moisture conservation, weed suppression and modulation of light, leguminous shade trees have tremendous use in promoting organic coffee production in the country (Yacob *et al*., 1996; Taye and Tesfaye, 2001). Accordingly, *Millettia ferruginea*, *Acacia abyssinica*, *Albizia* sp., *Erythrinia abyssinica*, *Calpurinea subdecondra* and *Cordia african* were found to be suitable shade tree species for coffee production (Table 7) as most of them have wider canopies and feathery leaves to provide coffee plant beneath with moderate light regime and replenish organic matter through decomposition litter fall.

Table 7 The influenced by planting patterns on coffee yield and some desirable traits of the prominent shade tree species.

Strip planting		Intercropping		Characteristics of shade trees		
Shade tree species	Yield (kg ha_{-1})	Shade tree species	Yield (kg ha_{-1})	% light interception	Litter fall (kg $ha_{-1}yr_{-1}$)	Canopy diameter (m x m)
Milletia + *Albizia*	2158^{a}	*Milletia ferruginea*	1809^{a}	40	4271.34	8 x 8
Leucaena + *Acacia*	1896^{b}	*Albizia* spp.	1521^{bc}	26	1240.00	18 x 18
Milletia + *Gravillea*	1343^{d}	*Acacia abyssinica*	1534^{bc}	30	2167.00	20 x 20
Calpurnea + *Acacia*	1693^{c}	*Erythrina abyssinica*	1485^{c}	19	1022.33	16 x 16
Albizia + *Acacia*	1255^{de}	*Calpurnea subdecondra*	1467^{c}	-	452.33	6 x 6
Tephrosia + *Erythrina*	1136^{def}	*Cordia africana*	1204^{d}	36	4511.67	16 x 16

Means with in a column followed by the same superscript letter(s) is not significant at 0.05 probability levels.
Source: Yacob *et al*. (1996), Tesfaye *et al*. (1998) and Endale *et al*. (2008).

Canopy volume, which is dictated by the number of bearing heads, branch angle, and plant height, determines spatial arrangement and optimum spacing in coffee (Yacob *et al*., 1996). It is a strong genetic trait that can be used to group coffee into three broad canopy classes identified as open, intermediate, and compact types, each of which requires its own spacing (Yacob *et al*., 1996). In support of this (Tesfaye *et al*., 1998) suggest, taking into account the morphological nature of coffee trees and pruning systems to be used, optimum spacing, and the corresponding population density has been recommended for each canopy classes. For modern coffee plantation the density/spacing recommendation for single and multiple stem pruning (Table 8).

Table 8 Density/spacing Recommendation for Single and Multiple Stem Pruning.

Canopy class	Spacing (m)	Trees/ha
Single stem		
Open	1.8-2.20	3068-2066
Intermediate	1.70-2.00	3460-2500
Compact	1.60-1.80	3906-3086
Multiple stem		
Open	2.00-2.50	2500-1600
Intermediate	1.80-2.20	3086-2066
Compact	1.60-2.15	3906-2163

Source: IAR/JARC. 1996.

Field trial results showed that coffee yield linearly increased with increasing population density or close spacing under open sun conditions probably because of mutual shading. However, the efficiency of close spacing varied among agro-ecologies (Figure 4b). For instance, in low altitude areas like Tepi, the efficiency of close spacing declined after four crop harvests (Figure 4a). An increase in the proportion of dead primary branches and a decline in crop bearing surface, which is directly associated with the increased level of mutual shading or reduction in light interception by the individual tree, could be accounted for the early exhaustion and decline in coffee yield at Tepi. On the other hand, significantly high yield gain (Figure 4b) and long-lasting efficiency of close spacing were evidenced at Gera and Wenago (both high altitude areas) (Figure 4a). Furthermore, results obtained at Metu (mid-altitude area) had revealed the increased efficiency of close spacing in enhancing the yield performance of compact Arabica coffee (Endale *et al*., 2008).

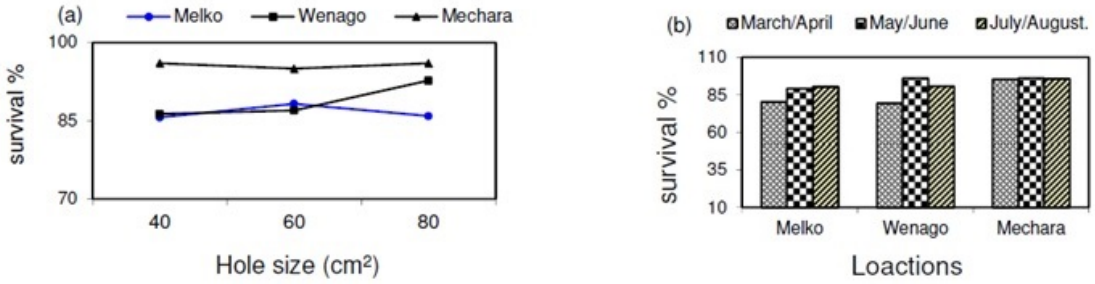

Fig. 3 The influence of crop season (a) and population density (b) on mean clean coffee yield at Tepi, Gera and Wenago.Source: Taye *et al*., (2001) and Endale *et al*., (2008).

After coffee trees being exhausted due to various environmental factors or aging, it needs to be rejuvenated. Although the conventional practice in Ethiopia is stumping, old and exhausted coffee trees can also be renovated during cycle conversion and become productive by different rejuvenation practices, *viz*. agobiado, topping, decote and eskeltamento (Yilma, 1986). It has been reported that stumping coffee trees in a slant position (45^o angel) at 30 - 45 cm height above the ground renovate old coffee orchards and make it productive (Paulos, 1997).

5 Soil Nutrition Technologies

In Ethiopia, Arabica coffee is predominantly grown on highly weathered and leached *Nitosols* which is deficient in nitrogen and phosphorus. Coffee is a heavy nutrient feeder. It has been documented that more nutrients are removed annually by the harvested products in comparison to other tree crops like Cocoa and Tea (Coste, 1992). However, the nutrient requirements by the crop may vary among the coffee varieties, age of the tree, crop load, type of production (forest, garden, plantation, and open and low shade), soil fertility status, soil reaction, and plant population.

The use of decomposed coffee husk compost at a rate of 10 ton ha^{-1} (4 kg $tree^{-1}$ on a dry weight basis) with 50% soil incorporation and the remaining half surface application was found to be superior in terms of yield performance of coffee trees. Hence, it can be concluded that depending on the availability of organic inputs and plant ecological factors, the use of organic inputs at the rate of 5 to 10 t ha^{-1} (2 to 4 kg $tree^{-1}$) is advisable for Arabica coffee production (Taye, 1998; Taye and Tesfaye, 2001). In other studies carried out at Jimma and its sub-center that represent the major coffee growing agro-ecologies of the country Paulos (1994) come out with a set of recommendations (Table 9) that are of immense value to the grower. Accordingly, forest coffee, low yielding, and young trees (less than three years) and rich soil (fertile soil) should be applied low amount than the recommended full dose. On the other hand, open and low shaded coffee plantations, high yielding varieties, and mature trees on poor soils should be given the full dose of the recommended fertilizers (IAR, 1996).

Table 9 Location specific NPK fertilizer recommendation for coffee.

Location	Recommendation domain	Recommendation rate (kg $ha^{-}1$)		
		N	P	K
Melko	Jimma,Maa, Seka, Gomma and Kossa	150-172	63	0
Gera	Gera	No fertilizer	No fertilizer	No fertilizer
Metu	Metu, Hurumu, Yayou and Chora	172	77	0
Tepi	Tepi	172	77	0
Bebeka	Bebeka	172	77	0
Wonago	Wonago, Dale, Aleta Wondo and Fiseha Genet	170-200	33-77	0
Bedessa	Habro, Kui and Darelebu	150-235	33-77	62

Source: IAR (1996).

6 Soil and Water Conservation Technologies

Coffee husk, grasses as mulch material, and cover crops such as desmodium are found to be important in minimizing soil and moisture loss, suppression of weed seed germination, and smothering of its growth in plantation coffee (Anteneh *et al*., 2015). Soil and moisture conservation techniques such as ridging (tied and untied ridges) enhanced yields of CBD resistant coffee cultivars in coffee plantation over the control plot, and flat land (Figure 5).

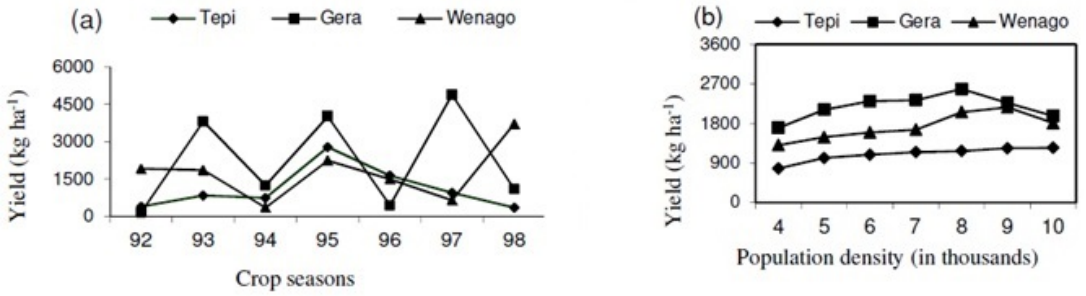

Fig. 4 The influence of soil and moisture conservation techniques on yield of modern Arabica coffee cultivars.
Source: Tesfaye *et al*. (1998); Endale *et al*. (2008).

7 Coffee Quality Management Technologies

Quality is critically important to the coffee industry. Coffee that has good inherent quality may be rejected unless good processing practices are strictly followed. Developing and promoting improved pre- and post-harvest processing technologies that enhance the quality and productivity of coffee for different agro-ecologies throughout the country are key study areas of quality section.

Coffee plays a dominant role in the Ethiopian national economy (Davis *et al*., 2012) but, it is generally characterized by low productivity and low quality (Alemayehu *et al*., 2008). Strengthening the position and price of Ethiopian coffee on the world market requires a systematic analysis of the impacts of practices and procedures on coffee quality throughout the value chain, from farm to the point of delivery of green beans to the exporters.

The quality of coffee consists of (i) physical attributes: length, size or weight of coffee beans (ii) organoleptic characteristics: acidity, aroma, body, aftertaste, flavor, overall preference and balance and (iii) chemical constituents such as caffeine, trigonelline, chlorogenic acid (Agwanda *et al*., 2003; Behailu *et al*., 2008). The national coffee research tried to develop different coffee quality maintenance and quality enhancer technologies.

It was confirmed that there is a long fermentation time difference for washed coffee processing. Optimum quality was achieved at 64 hours at Melko, 78 hours at Limu Kosa and total fermentation time of about 48 hours at Bebeka. Based on the altitude, fermentation time in the range of 24 hours for $\leq$1200 masl; 24 to 48 hours for 1200-1500 masl; 48 to 72 hours for 1500-1800 masl and above 72 hours for above 1800 masl were preferable to have coffee with superior cup quality in all aspects (Woelore, 1993; Behailu *et al*., 2008).

In the washed coffee production, final quality, among other factors is greatly dependent upon the fermentation process (Woelore, 1993). It has been confirmed that under-water soaking following "dry" fermentation, i.e., two-stage fermentation enhances the appearance of both raw and, particularly and consistently, the roast of coffees compared to 'dry' fermentation only (IAR, 1969). On the other study, it was confirmed that, although coffee fermented under shade takes more time, using shaded fermentation tanks help to achieve uniform fermentation process and better quality coffee (Behailu and Solomon, 2006). With regard to washed coffee drying, parchment coffee drying depths 3 to 4 cm and covering during very strong sunshine hours gave better values of cup quality and recommended (Solomon and Behailu, 2006). In addition quality status of released coffee varieties were described (Behailu *et al*., 2008). This result enables to know the quality status of each variety released.

8 Environmental Protection

Growing coffee is protecting the environment. While we grow coffee we maintain the shade trees and if we maintain the tree by implication we conserve the soil and water. On the other hand, the byproduct of coffee processing subjects the environment for pollution if proper management is not implemented. There are research results that enable us to offer proper advice for producers. One of the issues of pollution is coffee washing station effluent management. Failure of monitoring and evaluation activities of the existing processing stations has resulted in the generation of huge amounts of processing byproducts that have the potential of polluting the environment. In general, water pollution is a pressing problem in developing countries, particularly, where there is high population growth, great development demands, high waste production without well-developed waste treatment technologies, and a lack of comprehensive environmental policies and water quality monitoring systems and standards (Yared, 2008). In his study, the negative impacts in terms of river pollution, health risks both to humans and livestock and other effects were well understood.

For effluent treatment, many technologies were adopted and vetiver is the one. It is reported that using vitiver grass for successfully treating the effluent. In Ethiopia, different coffee farms are thriving to adopt the technology for treating the effluent discharged from coffee pulpery (Ashenafi, 2015).

The significance of shade tree and vetivar plant in Ethiopian coffee-growing agriculture can benefit not only for conservation purposes and have multiple use apart from environmental protection. So, farmers and growers have a chance to use the research recommendations.

9 Seed Provision, Hybrid coffee Multiplication through cuttings and Biotechnology

Even though there is no formal coffee seed system in Ethiopia, the coffee research centers shouldered responsibility for the production and supply of improved coffee seeds from the released and adaptable coffee verities. According to informal information, the contributions of farmers' coffee seed system in the major coffee-growing areas of the Oromia and SNNP regional states is immense, though comprehensive results are inadequate and await investigations (Taye *et al*., 2011). This includes the production of uncertified coffee seeds from the released and adaptable coffee varieties by small-scale farmers, private investors and privatized state coffee farms, which produce and use for themselves, on top of transferring to other users in their vicinities.

Though the data need updating, demand shares in most years is more than 80%, indicating the untapped opportunities for the interested private and public institutions to involve in the coffee seed business. As described by Negusie *et al*., (2008) the research centers cannot meet the rapidly growing demand for improved coffee varieties in the country. Yet with the existing capacity research centers are providing seeds of improved varieties which give chance to growers. In this regard, the national coffee research centers produced about 270,000 Kg of seed which is expected to cover about 270,000 ha of land (Ashenafi *et al*., 2017) up to 2017. Up until now reach 300,000 kg and cover equivalent amount hectare.

With the attempt of exploiting heterosis from hybrid coffee; Ethiopian coffee breeders developed seven hybrid varieties (Table 3). The hybrid varieties developed can be propagated sexually (direct hand pollination and crossing of the two parents to get F1 seed) or by asexually taking orthotropic stem cuttings. Seed propagation, which is associated with hand pollination to get F_1 seed, requires a large number of skilled labors. Consequently, using F_2 leads to a lack of uniformity as a result of segregation. Propagation of coffee by vegetative cuttings guarantees uniformity.

Research results showed that a combination of a single node with softwood cuttings with one pair of leaves taken from the orthotropic shoot and rooting media composed of topsoil, sand, and manure in 2:2:1 ratio were recommended for propagation of

hybrid coffee. It was observed that this practice resulted in the highest rooting ability of stem cuttings (89.2%) and survival rate (63.3%) at hardening off stage (Behailu *et al*., 2006). With this procedure, the researchers are disseminating hybrid coffee varieties and offering training for subject matter specialists and farmers.

Cuttings generate relatively low multiplication rates as they can only be obtained from orthotropic branches. Plant tissue culture is a form of vegetative propagation used for the large-scale production of plants known as micro propagation (Ahloowalia *et al*., 2004). Multiplication by tissue culture techniques could provide the best alternative than the former two methods of coffee propagation especially in terms of getting high number of planting materials of hybrid coffee. Biotechnologists over the world and in our country made much effort (Wondyifraw *et al*., 2008; Elias, 2017) and started to propagate hybrid coffee in different approaches. Apart from optimizing the tissue culture protocol coffee research biotechnology lab is propagating and disseminating just to familiarize growers with seedlings prepared through tissue culture.

10 Economics of Coffee Production and Technology Popularization

Existing national coffee research has generated a number of technologies that were disseminated to the users. These coffee technologies include varieties, agronomic, protection, harvesting, and post-harvesting management. In this regard, there are questions like how strategic is the system in exploiting the potential gains from the utilization of the available technology, knowledge and information, in general, and queries on the content of the production technology package, the scale of extending/promoting the technologies and the linkages among different institutions, in particular (Admasu and Zekarias, 2008).

In coffee, parallel to generating various technology transfer mechanisms were employed to promote the wide use of improved technologies across the country rapidly. Various attempts to introduce and accelerate the dissemination of improved coffee technologies were made. These include pre-scaling of improved technologies, supplying production sources-improved seeds and seedlings, training and advisory services, field-days, farmers' research group, partners' council forums, publication distribution services, communication media-on-air, etc. There is a great need of capacitating small-scale farmers, cooperatives and unions, private investors and others involved in the value-chains through training services and knowledge sharing events (Negusie *et al*., 2008).

Lack of strong extension service on coffee and the absence of commercial coffee seed multiplying agency necessitated the research centers' involvement in the production and distribution of seeds of improved varieties and other related technologies. A variety of approaches and mechanisms were employed by the Research-Extension department to trigger of dissemination and diffusion of improved coffee technologies. These include among others: on-farm and on-station demonstrations, hands-on training, workshops and conferences, field/open days and visits, written extension materials, exhibitions and displays, video, seed and seedling dissemination (Negusie *et al*., 2008). As coffee-growing farmers are numerous and vast production area coverage is in place there is a high need to strengthen the extension system and consolidate the relationship of research and extension so that existing technology can be disseminated. Based on coffee technology adoption studies, there exist gaps between the available levels of knowledge, information and technology, and the existing system of coffee production (Admasu and Zekarias, 2008).

11 Gap Analysis

In Ethiopia, more than 90% of the total volume of coffee production comes from small-scale farms, whose average land size is less than one hectare with low average yields ranging from 200-250 kg /ha (Workafes and Kassu 2000). Small-scale growers have not fairly benefited and remain more vulnera-

ble to risks related to volatile coffee prices and climate change. To support these resource-poor farmers and growers the existing research system developed many technologies per-se varieties, agronomic practices, crop protection, nutrition, harvesting and the like. Despite these all production technologies developed; there is still a wide gap among the productivity achieved at the research center and national average productivity. The national average productivity per ha is quite less than the research results (Figure 6). The country has not fully exploited existing research technologies and its vast natural endowment of genetic and unique natural coffee forest environments due to several factors, including insufficient access to finance and poor input distribution mechanisms for small-scale coffee farmers, the predominant use of local landrace coffee types, traditional management, harvesting and post-processing practices as well as lack of quality differentiated marketing system and in general lacking strong institution which leads the sub-sector development.

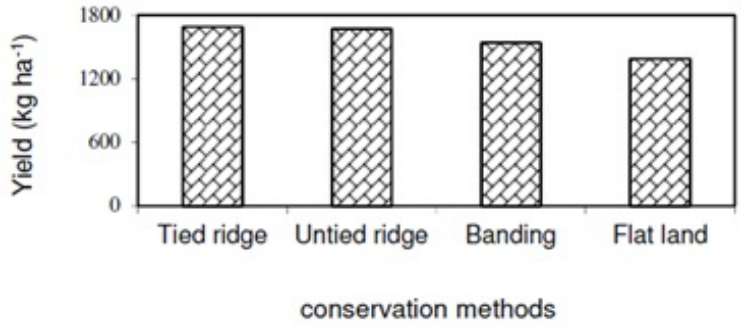

Fig. 5 The productivity gaps between Research and Different Farming Systems of Ethiopia.
Source: Taye Kufa. 2018.

The Ethiopian government is successively targeting to increase the productivity of coffee per unit area. Aligning with the national coffee sector development plan the national coffee research strategy is also designed to enhance coffee production and productivity by generating appropriate coffee technologies and disseminating existing once with its full packages. The national average productivity is nearly 30% of the research results. The big gap in productivity range requires a wide utilization of research output by the development wing. This could be possible if concerted effort make in place. From existing information, it can be estimated that by narrowing the gap between research achievements and the national average much increment on national average production can be made.

12 Conclusion

Ethiopia has a goal to become the second leading arabica coffee producer and exporter in the world. To this end, the national coffee strategy plan has been developed with ambitious targets for coffee production and export earnings. First, it needs to see that; is it really possible that the country has a competitive advantage than other producing counties over the world? As more of the world population turns to coffee consumption demand for the beverage is estimated to increase. On the other hand, global coffee production and supply are very unlikely to increase since the world's largest producer countries are frequently facing different challenges and some of them are also shifting due to various internal factors such as land shortage, input supply, and high production cost, etc. So, they are not expected to produce enough production that can stabilize the market. Ethiopia can take this threat as an opportunity and produce more coffee production and quality. In or-

der to fill the expected gap between production and consumption over the world and stabilize the international coffee market, Ethiopia does have a better chance as the country laid better ground. There is also the greatest opportunity, in many ways, than any other producing countries to exploit the opportunity from this rising world coffee consumption. This is due to the predominant role of coffee (*Coffea arabica* L.) in the Ethiopian economic, social and cultural dimensions dates back to several centuries the large population involvement, favorable environment, different coffee quality types and long experience in the sub-sector are some reasons among others. Cognizant of the deep-rooted attachment of coffee to the Ethiopian community and its multitude of importance to Ethiopia it is possible to make a difference.

In the body of this write-up, a lot has been discussed on existing research technologies. Yet, there is a wide productivity gap among the research, modern plantation farmers practice. Coffee technologies developed by the research different disciplines is much encouraging. Even though developed technologies made considerable contributions to coffee production, productivity, and quality improvement in Ethiopia a lot is still remaining to address a number of challenges facing the Ethiopian coffee industry. This big gap in productivity range requires a wide utilization of research output by development is crucial. Actually, this demands: (1) Aggressive scaling-up of proven technologies (2) Managing coffee stands through mobilizing coffee sector rehabilitation and wide utilization of technologies (3) Addressing research in unaddressed areas (4) Establish & support sustainable coffee seed system (5) Establish viable extension system and consolidate the relationship of research and extension so that existing technology can be disseminated.There is also a great need of capacitating small-scale farmers, cooperatives, unions and private investors by access to finance.

This requires strong national coffee institutions and creating synergy among existing institutions viz research, higher learning institutions, extension, and other key actors in the coffee value-chains. As marketing is the driver for production, it has to be more modernized and farmers are able to get better prices in continuously searching better market. This may demand supporting farmers' organizations, cooperatives, and unions to sustain their power in creating ideal environments and supporting capacity development. If this happens; possible to double the current production and productivity through wise utilization of existing technologies.

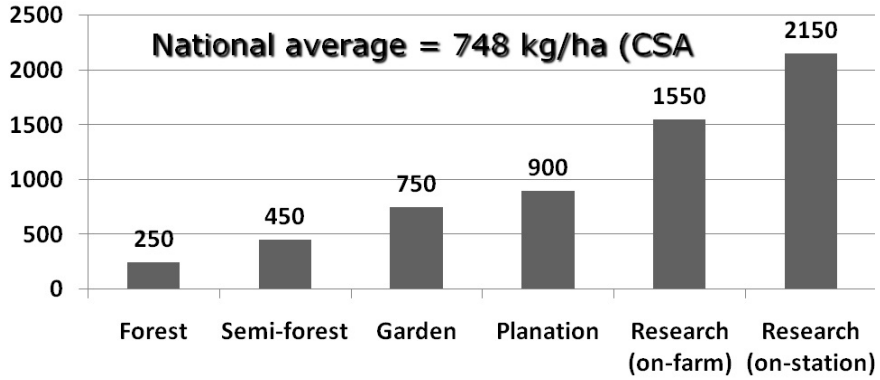

Fig. 6 Flow chart of crude extraction of the leaves of *C. macrostachyus*.

Conflict of interest

The author declare that no conflict of interest.

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