Coffee Processing Risk Assessment:

Waste Management

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Introduction

Coffee is one of the most important agricultural commodities traded worldwide. The two primary species are *Coffea arabica* and *Coffea robusta* which are grown in many locations globally. Ethiopia is the original location for coffee and was found initially by the Oromo people in Kafa province. *Coffea arabica* is the primary species grown in Ethiopia and represents one of the largest, if not the largest source of revenue for the nation. The processed and roasted bean is brewed with water and is consumed worldwide.

Prior to final consumption, the coffee berry must undergo several processing steps to remove the bean from other parts of the fruit and prepare the beans for sale. The two methods for coffee processing are wet and dry methods; wet method processing accounts for most of the coffee processed worldwide. An abundance of surface water sources throughout the Yirga Chefe/Dila region support numerous wet processing facilities. There are fewer facilities using the dry processing technique.

As is the case in other coffee producing regions worldwide, wet and dry processing facilities in the study region generate significant quantities of solid and liquid wastes, much of which is not managed properly. As a result, much of the surface water observed during this study showed significant degradation with high potential for increasing contamination by coffee processing wastes.

Coffea arabica is a relatively small woody shrub with glossy leaves and fragrant white flowers. Beans from this species often receives a premium price as a result of its excellent flavor and aroma. The species grows best at altitudes between 3000 and 6500 feet. Each plant yields approximately 0.5 – 0.8 kg per year and contains approximately 1.0% caffeine. It comprises nearly 75% of all production worldwide.

The coffee berry is the fruit of the plant with four distinct anatomical fractions: 1) coffee been or endosperm; 2) hull or endocarp; 3) mesocarp layer or mucilage, and; 4) pulp or esocarp. Each bean is surrounded by delicate tissue with structure maintained by the endocarp (referred to commonly as parchment or hull). The endocarp surrounds the bean and becomes brittle when dry. Coffee pulp is a primary byproduct of wet processed coffee and comprises approximately 40% wet weight of the ripe coffee berry. Pulp contains carbohydrates, proteins, minerals and smaller quantities of tannins, caffeine and potassium. Similarly, processing waste water contains a variety of organic materials including pectins, proteins, sugars and other materials.

Coffee pulp contains many organic components:

- Tannins
- Pectic substances
- Sugars
- Caffeine
- Chlorogenic acid
- Caffeic acid.

Micronutrients and ash (carbon) are also present in coffee pulp:

- Boron (B)
- Calcium (Ca)
- Copper (Cu)
- Iron (Fe)
- Manganese (Mn)
- Phosphorus (P)
- Potassium (K)
- Sodium (Na)
- Zinc (Zn)
- Magnesium (Mg)

General Processing

The predominant method of coffee cultivation in the study area includes garden and shade-grown methods with most production coming from small-scale farmers located near individual processing facilities. Following harvesting by hand and transportation to processing facilities, ripe coffee berries are immersed in water for removal of unripe or otherwise compromised berries and/or other undesirable materials (dirt, stems, etc.). Pulp is removed from the ripe coffee cherry to give coffee cherry pulp plus mucilage-coated parchment (hull-covered green beans). The mucilage-coated parchment is then fermented in a tank of water, whereby the mucilage loosens from the parchment, and the mucilage-containing water is then drained. The parchment is dried in the sun or with a mechanical dryer, and after drying parchment is passed through a huller that removes the hull from the green beans. Mucilage removal may also be accomplished in a single step by use of a demucilaging pulper. In a final step, the green beans are sorted by size and low quality beans are removed.

Water is also used as the primary transport mechanism for beans prior to drying. The three primary fractions resulting from processing are ripe coffee berries, coffee pulp, and coffee hulls. As a general rule and on a dry weight basis, from 1000 g (1 kg) of harvested coffee berries, pulp, hulls, mucilage and beans comprise approximately 26%, 10%, 14%, and 50%, respectively. Mucilage is the component of the coffee berry attached to the hull and consists of approximately 82% water, 9 % protein, 4% sugar and pectic acids plus ash in small quantities. Green coffee, the end product of the overall processing chain, is roasted prior to consumption with an approximate weight loss of 16%.

General Coffee Processing Chain (with by-products)

I. Coffee Bean Harvested (Small Farmers/Plantations etc.)

II. Coffee Berries Transported to Processing Facility

   a. Wet Processing

      i. Pulping ------------------------------------→ Coffee Pulp

      ii. Fermentation/Chemical/Physical -----→ Mucilage (Liquid)

      iii. Washing ------------------------------------→ Waste Water

      iv. Solar drying (or other)

   b. Dry Processing

      i. Hulling --------------------------------------→ Hulls

III. Commercial Coffee Beans Ready for Sale/Distribution

Waste Management for Coffee Processing

Disposal of coffee wastewater and pulp poses a significant challenge worldwide. Improper disposal methods often result in significant pollution of surface and groundwater as well as posing a threat to human health, livestock health and overall environmental quality. Wastewater from wet processing contain significant concentrations of organic pollutants while improper pulp and husk disposal creates additional problems with odors, toxic substances, and leachate creation. The majority of solid wastes in the study area are deposited in shallow excavated unlined pits while liquid wastes are disposed of or stored in retention basins or lagoons. Similarly, both liquid and solid waste basins were often located in lowland areas with shallow groundwater and/or near surface waterways thereby increasing the risk to water quality.

The high concentration of organic constituents in liquid and solid waste creates significant environmental and human health problems throughout coffee producing areas worldwide. Wastewater entering surface streams can result in direct toxicity to aquatic organisms while causing longer-term adverse effects created by decomposition of organic pollutants. During fermentation, sugars in wastewater are acidified and this, in turn, can reduce the pH of liquid wastes to near 4. Digested mucilage then precipitates out of solution and can form thick crusts on the surface of liquid waste basins/lagoons. These crusts create barriers to full oxygenation of liquid wastes and prolong the decomposition process. As the pH rises, liquid wastes turn a dark green to black color creating additional problems in surface waterways.

Solid waste from processing is often saturated with water and piles begin to decompose quickly in the presence of molds, fungi, and other microorganisms. Because these solid wastes are often stored in basins or in large piles, anaerobic conditions are present and odors increase. Some species of molds and other decomposers can produce potentially toxic mycotoxins such as Ochratoxin-A and others.[1] These and other pollutants are then transported to surface waters by overland runoff, leachates, and/or leakage to groundwater from percolation through basin/lagoon soils. In some cases, waste lagoons are in direct contact with shallow groundwater sources raising risks to both humans and the environment.

This project focused on risk evaluations for waste management methods at a selected wet and dry method coffee processing facilities in the Dila, Ethiopia region. The Dila region has very high human population densities with corresponding pressures on natural resources. Surface waterways (rivers and streams) in the region are contaminated by human waste, land conversion (heating of water following loss of vegetative cover), road construction and maintenance (erosion, etc.) as well as other human activities. Together, these impacts create significant cumulative effects to water quality and, in turn, affect adversely all users of these water sources. For example, excessive erosion and soil movement into surface waterways alters stream morphology and reduces natural cleansing processes normally present in flowing waters. As a result, area waterways are less able to process effectively wastes coming from coffee processing activities. Overall, cumulative impacts to these aquatic ecosystems are already significant and increasing as production increases and human populations grow.

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[1] See e.g., Pittet, A., Tornare, D., Huggett, A., Viani, R. Liquid Chromatographic Determination of Ochratoxin A in Pure and Adulterated Soluble Coffee Using anf Immunoaffinity Column Cleanup Procedure. *J. Agric. Food Chem.* 1996, 44, 3564-3569; or Bucheli, P., Kanchanomai, C., Meyer I., Pittet, A. Development of Ochratoxin A during Robusta (*Coffea canephora*) Coffee Cherry Drying. *J. Agric. Food Chem.*2000, 48, 1358-1362).

Methods

We evaluated 15 coffee processing facilities in the Dilla region including cooperatives and privately-owned operations. Sites were visited in January and February 2015 after the processing season had ended. This period also corresponded to the short dry season allowing access to waterways, disposal lagoons, and nearby communities. The majority of the facilities visited used wet processing methods while two operations utilized dry processing. Facilities were located adjacent to surface waters and were accessed by a poorly-maintained system of dirt roads.

Four (4) focus group discussions (FGD) were conducted with community members living near wet processing facilities and using waterways affected by coffee wastes. Average group size exceeded 30 individuals with additional participants joining the discussions as they progressed. One FGD included over 50 individuals. Focus group discussions were well received by community members and many participants raised issues.

Focus Group Findings

High human population density in the region results in large numbers of community members living near processing facilities and using waterways that receive processing waste water and leachate. Moreover, these waterways are often polluted with human wastes and other materials creating significant ecological and human health challenges. In many instances, pulp waste is also disposed of along roadways in piles several square meters in size. While some of this material is used as a soil amendment by local residents, much of the waste has not been composted properly and carry some of the same risks presented by large disposal piles on facility properties. These piles or rotting pulp can also contribute polluted leachate to waterways and continue to release noxious odors as decomposition proceeds.

Human exposure to wastes can occur throughout the year with highest risks occurring during the rainy season/processing season. Exposures to toxic and nuisance by-products of coffee processing wastes occurs via inhalation of vapors and particulates and through ingestion via contaminated water and foodstuffs. Dermal exposure occurs during bathing, recreation, clothes washing and during other activities with direct contact with waste water. The highest risk of exposure to wastes and waste by-products for workers occurs during processing periods while local residents' risks are prolonged as collected wastes are distributed in the environment by both natural processes and human activities.

Both male and female participants in these informal discussions listed a wide-range of adverse health effects on themselves, their families and livestock from exposure to waste-contaminated waters, direct contact with non-composted solid wastes and exposure to noxious odors from improper waste disposal pits and piles.

- Observed problems are worse during processing activities but remain throughout much of the year.
- Problems appear to be worsening over time as production increases.
- Adverse health effects experienced include headaches, nausea, gastrointestinal issues, skin irritation, eye irritation, skin lesions.
- Disposal of solid wastes along roadways created hazards for children and waterways (leachate). These wastes are used directly on individual properties in some cases. Many roadside waste piles are not utilized effectively and create longer-term hazards for surface waters and human/livestock health.
- Livestock meat and milk tainted. Participants indicated that off-tastes were present in livestock products drinking from polluted surface waters.

Risk Assessment: Findings

Surface waters in the region range from slightly to severely polluted. Shallow groundwater contamination in vicinity of processing waste pits is at risk from some waste basins/lagoons. Cumulative impacts from human use, waste disposal, erosion, and coffee processing wastes can overwhelm assimilative capacity of surface waters.

Use of surface waters without proper treatment poses significant threats to human health, livestock and environmental quality.

Use of contaminated surface waters for coffee processing may result in contamination of product and human exposure.

Economic development may be affected as surface waters (and groundwater) are subject to increasing contamination levels and natural cleansing processes (e.g. denitrification, oxygenation, vegetative filtration, etc.) are overwhelmed or lost.

- Liquid waste retention basin/lagoon capacity varies among sites. Many facilities had basins/lagoons that were inadequate for high volumes of liquid and/or solid wastes particularly during periods of high precipitation. Basin/Lagoon capacity are likely to be exceeded during production season, and this period corresponds to rainy season in Dilla region. Capacity of retention basins/lagoons is slowly reduced from non-waste materials (e.g. erosion from waste flumes, cultivation along waterways, etc.)
- Overflow from waste basins/lagoons enters surface waters during rainy season.
- Intentional discharge of liquid wastes may occur at night (as per FGD and local knowledge)
- Groundwater contamination is likely in areas close to waste basins/lagoons.
- Most retention basins located too close to surface waters. This increases the risk of contamination and prevents natural processes (e.g. vegetative filtration) from taking place.

- Lack of multi-stage liquid retention basins/lagoons at most facilities reduces natural aeration within basins/lagoons.
- Anaerobic conditions are present in most waste retention basins/lagoons adding to odor problems.
- Drying of basins during non-processing periods results in compromised retention ability. Cracks may form in basin/lagoon walls allowing for focused leakage and discharge to environment.
- Livestock grazing removes essential vegetation within and around basins/lagoons and berms adding to erosion risk during processing periods.
- Tree growth on basin/lagoon sides compromises basins via root infiltration and subsequent death. Holes that result allow for focused discharge of wastes to the environment.

Anticipated Impacts: Summary

Short-term: Improve awareness of decision-makers regarding risks from current coffee production waste management and disposal methods. Educate local residents on construction of low-tech water filtration methods. Educate local residents on health threats from exposure to solid waste piles/liquid wastes.

Medium-term: Provide technical input for future proposals addressing identified risks. Implement low-capital improvements and management changes. Facilitate waste water chemical analysis and receiving water analysis.

Long-term: Reduce waste generated, water usage, and impacts to local communities. Implement capital improvements. Ensure safe processing methods for sustainable production.

Short-Term Recommendations: Specifics

Host organization in conjunction with other relevant organizations should develop printed materials for distribution to processing facilities and local communities. These should be used to reinforce direct trainings covering safe handling of waste waters, solid wastes, non-process runoff water, composting methods, non-composted application of solid waste (pulps/husks). Goal: Improve overall management operations via standardized knowledge base. Improve community residents' knowledge of low-tech water filtration and health risks from exposure to contaminated surface waters.

Other items that may be covered in printed educational materials include, but are not limited to:

- Instructions and visual examples for adopting process changes to conserve process water or reuse wastewater for solid waste transport.
- Diversion of non-process water runoff from basins/lagoons during rainy season/processing periods when basin/lagoon capacity is limited. Goal:

Reduce non-process runoff draining to wastewater retention basins to maintain capacity for wastes.

- Installation of ladders in basins/lagoons for escape purposes in the event a person falls into a basin/lagoon.

Medium-Term Recommendations

- Insure proper separation of solid from liquid wastes prior to release.
- Increase aeration of both liquid and solid waste storage sites.
- Physical manipulation. Gas and/or electric-powered aeration for liquid waste pits.
- Gravity-based manipulation. For sites with multiple stage liquid waste retention basins, use overflows to increase aeration.
- Natural manipulation: Utilize algal and emergent macrophyte photosynthesis for oxygenation.
- Create "buffer" strips along all waterways and un-lined waste flumes.
- Spread solids to increase aeration and solar drying.
- Maintain vegetation in dry retention basins.
- Recover vegetation in coffee drying areas.
- Line waste flumes with impermeables (e.g. rocks, concrete)
- Perform routine maintenance of flumes and production grounds. No additional organic and/or inorganic (soils) materials to waste streams. Excavate retention basins during dry season.

Long-Term Recommendations

- Investigate use of biomass (pulps/husks) for waste-to-energy purposes on site. Coffee wastes are amenable to small-scale anaerobic biomass methane production for electricity or coffee drying purposes. Digested materials can then be utilized for land spreading purposes (fertilization, etc.). [2]
- Increase use of pulps/husks for local and regional-use charcoal production.[3] Current pressures on local forests for fuelwood is posing increasing threats to local ecosystems, including waterways. Current conditions contribute to high breeding bird diversity as well as overall biological diversity. Providing a substitute for burning wood would contribute to increasing resilience in the face of climate changes.

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[2] Sugitha, T.C.K. et al. 2013.
Development of anaerobic consortia and its invitro evaluation for biomethanation potential of coffee processing wastes. African Journal of Microbiology Research 7(45), pp. 5137-5147.

[3] Cubero-Abarca, R. et. al. 2014. Use of coffee (Coffea arabica) pulp for the production of briquettes and pellets for heat generation. Cienc.Agrotec. 38(5). http://www.scielo.br/scielo.php?pid=S1413-70542014000500005&script=sci_arttext

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- Construction of on-site water wells for human consumption and coffee processing
- Reduce permeability of retention basins using constructed materials (e.g. concrete, etc.).
- Development of "Treatment Trains" for improved wastewater treatment prior to discharge to receiving waters.
- Construct vegetated wetlands (Vetiver grass) for final water treatment purposes prior to discharge to waterways.
- Establish "no-use" stream zones for recovery. Identify sources of erosion into local waterways for remediation.
- Identify and implement water-recycling mechanisms for waste water reuse.
- Establish safe locations for composting of pulps/husks. Distribute compost to local farmers.
- Utilize rainwater harvesting during processing season for processing water.

Conclusions

This risk assessment identified numerous threats to public health and environmental quality resulting from improper coffee processing waste disposal methods. Current waste management practices are a result of numerous interacting economic, social, geographical, and environmental forces many of which are outside the control of individual processors or affected communities. Solutions to these challenges are available but costs can be limiting for many operators.

At the same time, numerous management changes coupled with modest investments in capital improvements over time can address many of the issues identified in this report. Education of processors, local communities, and governmental authorities is critical to developing low-cost sustainable and site-specific solutions for individual operations. Developing an accurate geospatial map of focus areas is a low-cost first step towards understanding the extent and magnitude of the issues and will help to identify sites for active intervention.

At the same time, developing working relationships with experts at local universities offers a potentially-rewarding long-term relationship with Ethiopia's growing higher education sector. Dila University is located in Dila and offers natural resource and geographic information system (GIS) programs for local coordination and initiatives.

Figures.

Figure 1. Typical coffee processing (wet) facility, Yirga Chefe, Ethiopia. Water is pumped from surface streams at base of slope for processing. Liquid and solid wastes are placed in excavated lagoons near waterways down slope of processing operation.

Figure 2. Focus group participants, Yirga Chefe, Ethiopia. Families living near coffee processing facilities experience a range of health problems associated with improper management of coffee processing wastes.

Figure 3. Liquid waste lagoon with processing wastes, Yirga Chefe region, Ethiopia. Poorly constructed waste lagoons threaten surface waters and nearby communities.

Figure 4. Multi-stage liquid waste lagoons can utilize photosynthesizing plants and gravity-based methods to oxygenate waste waters.