# Prioritization of sludge management alternatives in the Philippines using Calibrated Fuzzy ANP

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## Abstract

Proper and sustainable sludge management and treatment is always associated with solids by-product generated by sewage treatment plants (STP). The water utilities in the Philippines, particularly in Metro Manila, need to look for an alternative sludge treatment method since the quantity of sludge is expected to increase significantly as the number of STPs increases in order to attain the 100% sewerage coverage by year 2037. The options considered in this study are composting, anaerobic digestion, thermal treatment, and alkaline stabilization. The selection process by decision makers should be robust, thus this study presents a concrete assessment using calibrated fuzzy Analytic Network Process (ANP), as a decision-making tool for determining the most appropriate alternative for sludge treatment in the Philippines. Calibrated fuzzy ANP address the ambiguity involved in giving judgments which provides a decision framework that allows interdependencies among criteria or between criteria and alternatives, the factors that affects the decision making are considered with a proper evaluation. The four sludge treatment alternatives presented above are assessed based on three main criteria: (a) economic viability, (b) socio-environmental concerns, and (c) implementability. The sub-criteria for economic viability include investment cost, operating cost and energy cost. Socio-environmental criterion on the other hand considered sub-criteria like carbon footprint, pathogens and bacteria reduction and environmental risk. Implementability criterion includes the following sub-criteria: process safety, system complexity and market viability. Results from the decision model after value judgment elicitation indicates composting was the most preferred alternative, Anaerobic Digestion ranks second while Alkaline stabilization ranks third. It showed that the most important criteria was Socio-Environment with 0.407 priority weight, and the most important sub-criteria was Process Safety with a weight of 0.157.

## Keywords

sludge, composting, analytic hierarchy process, fuzzy ANP

## Introduction

There is an increasing number of sewage treatment plants (STPs) being constructed in developing countries like the Philippines, Vietnam, Indonesia to treat domestic wastewater discharges prior to their ultimate disposal to bodies of water. In the Philippines in particular, the two water concessionaires in Metro Manila aim to increase the sewage collection and treatment coverage to 100% by year 2037 from its current 20% status. The collection and treatment of sewage result in the generation of sludge that requires an accepted and environmentally stable management before its final disposal [1]. Moreover, the projected increase in population will also contribute in the increase in sewage sludge generated. In Metro Manila, with a population boom from 11.5 million in 2010 to a 13.8 million in 2040 per Philippine Statistics Authority (2016). This correlates to the increase in the sludge formation that can reach up to 690 metrics ton dry matter per day by 2040 [2]. With this scenario, the current means of sludge management (i.e. mainly composting) in Metro Manila, Philippines, may not be able to accommodate the ultimate sludge to be generated once all the STPs are up and running. Therefore it is necessary to explore alternative options of managing sewage sludge. A range of sludge treatment and management options have been explored in western countries (European countries, the USA, etc) which can be used as benchmark for local application. In European countries, the most popular technologies are anaerobic and aerobic digestion that is applied in 24 and 20 countries, respectively [1]. Japan considered dewatered sludge melting as the most environmentally optimal and economically affordable [3]. Many aspects will be considered in evaluating a possible option for a new sludge management and treatment. Some of the possible sludge treatment

methods that can be considered in Metro Manila are composting, anaerobic digestion, thermal treatment, and alkaline stabilization.

In evaluating potential options, this study presents a concrete assessment in the usage of the calibrated fuzzy Analytic Network Process (ANP) as a decision-making tool for determining the most appropriate alternative for sludge management in the Philippines. Calibrated Fuzzy ANP, which is basically the Analytical Network Processincorporated with Fuzzy Logic which addresses the vagueness of judgement. While the calibrated fuzzy scale is used to describe the ambiguity by providing the lower limit, modal value, and upper limit of the five verbal judgments typically used in AHP [4-6].

**Methodology**

*Defining Alternatives*

Four treatment alternatives are being evaluated in this study namely, (a) composting, (b) anaerobic digestion, (c) thermal treatment, and (d) alkaline stabilization. Composting is the aerobic decomposition of the organic matter in the sludge to a relatively humus-like material similar to fertilizer [7]. Compost from sludge contains organic substances and nutrients (nitrogen and phosphorus) that make this a valuable soil improver to farmers for agricultural applications. This is the main treatment process being employed in Metro Manila wherein the sludge is being transported outside of the metro to be processed using aerobic composting or vermicomposting. The unsustainable nature of this option for future scenario can be attributed to the high cost of transporting a wet sludge outside the metro since the whole process requires big land area which is not available at the STP site. Moreover, the application of the final product is also found in the suburb. With these limitations, other processes are considered. Anaerobic digestion is the biological degradation of complex substances in the absence of free oxygen and the process mainly produces methane, carbon dioxide, and water [8]. The anaerobic digestion process can produce a solid residue which has applications in the agriculture sector as a conditioner. The solid residue product contains valuable organic substances and nutrients which can improve soil quality. Thermal treatment refers to the complete thermal destruction of materials to their inert constituents typically in the presence of oxygen. Thermal treatment facilities can recover the heat being generated and convert it into energy. Ash that is obtained from sludge incinerators have various applications in construction and concrete mixing. Lastly, alkaline stabilization uses hydrate lime, quicklime, and fly-ash among others to stabilize dewatered sludge. The alkaline stabilized product is optimal for multiple applications such as agriculture, landscaping, and daily landfill cover. One application in agriculture was the alkaline stabilized product is capable of improving different soil properties to maximize and increase the efficiency of crop yields.

*Criteria and Sub-Criteria*

The four technology alternatives presented above are assessed based on three main criteria: (a) economic viability, (b) socio-environmental concerns, and (c) implementability. The sub-criteria were chosen based on the past studies done by Promentilla et al. [9] which include the following: for economic viability it includes investment cost, operating cost and energy cost; socio-environmental criterion on the other hand considered sub-criteria like carbon footprint, pathogens and bacteria reduction and environmental risk; implementability criterion has process safety, system complexity and market viability.

The criteria and sub-criteria were either classified as either qualitative or quantitative by nature. A survey was conducted to obtain expert judgement on some criteria and sub-criteria that are qualitative by nature. Questionnaires were given to experts from private enterprise, government sector, and from the academe. Quantitative information were obtained for the following: investment cost, maintenance cost, energy cost, carbon footprint, and pathogens and bacteria reduction.

*Analytical Network Process Structure*

Using a calibrated fuzzy ANP address the ambiguity involved in giving judgments which provides a decision framework that allows interdependencies among criteria or between criteria and alternatives, the factors that affects the decision making will be considered with a proper evaluation. Factors were weighted through value judgment elicitation. In order to address the vagueness in the judgment elicitation, the proposed five-point verbal judgement scale was used in this study. Figure 1 shows the problem structure used in this study showing the alternatives, criteria and sub-criteria, and the interdependencies among them.

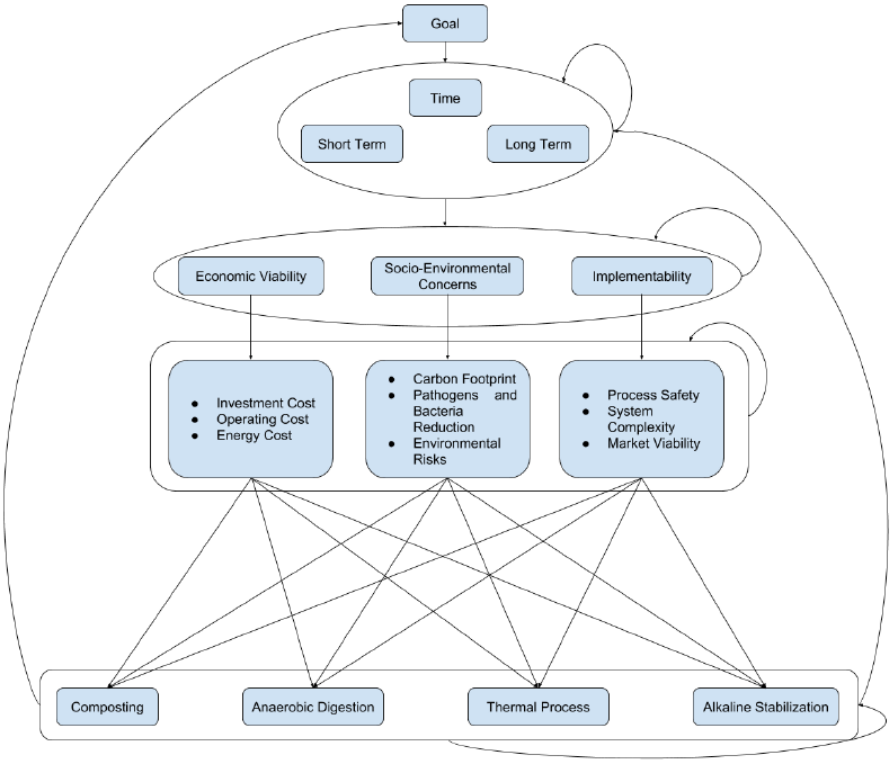


Figure 1 Problem framework for sludge management using ANP structure

The arrows in the structure represent the relationship of the elements or cluster to other components in the structure. Arrows that points inward to the cluster describes the interrelationship of the elements inside the cluster. This kind of structure is based from Promentilla et al., [10] which uses a planning time horizon and has five levels. The formation and the pairwise comparison will be based from this decision structure.

**Results and Discussion**

The priority weights for the criteria from all the expert clusters are summarized and presented in Table 1. The overall weights of the criteria were aggregated by geometric mean. It was observed that among the different criteria the most preferred is Socio-Environmental with a value of 0.407, followed by Economic Viability with a value of 0.367, and lastly, Implementability with a value of 0.226. It has been observed that there is a wide variability across groups. Government representatives gave more weight to socio-environmental aspect while both private enterprise and academe representatives rated economic viability as the highest.

Table 1. Priority weights for the criteria

| Experts | Economic Viability | Socio-Environmental Concerns | Implementability |
|---|---|---|---|
| Private enterprise | 0.424 | 0.326 | 0.251 |
| Government | 0.104 | 0.728 | 0.167 |
| Academe | 0.576 | 0.267 | 0.157 |
| **Overall** | **0.367** | **0.407** | **0.226** |

The priority weights for the sub-criteria are presented in Table 2. From the judgement of the private enterprise decision makers, the qualitative sub-criteria with the highest priority was found to be Process Safety with a value of 0.185, meanwhile the sub-criteria with the lowest priority weight was found to be Market Viability with a value of 0.027. All of the private enterprise decision makers shared their preference that Process Safety was the most important sub-criteria as they are concerned with the health and safety of their fellow employees first and foremost. From the government decision makers' judgement, the sub-criteria with the highest priority weight was found to be Environmental Risks with a value of 0.292, followed by Process Safety with a value of 0.118, then Market Viability

with a value of 0.037, and lastly System Complexity with a value of 0.012. From the academic decision makers' judgment, the sub-criteria with the highest priority weight was found to be Process Safety with a value of 0.082, followed by Environmental Risks 0.069, then Market Viability with a value of 0.049, and lastly System Complexity with a value of 0.026.

Table 2. Priority weights for the qualitative sub-criteria

| Experts | Environmental Concerns | Process Safety | System Complexity | Market Viability |
|---|---|---|---|---|
| Private enterprise | 0.068 | 0.185 | 0.040 | 0.027 |
| Government | 0.292 | 0.118 | 0.012 | 0.037 |
| Academe | 0.069 | 0.082 | 0.026 | 0.049 |
| **Overall** | **0.105** | **0.157** | **0.032** | **0.037** |

Table 3 shows the final priority weights and sludge treatment alternative rankings. Composting was observed to be the most preferred method for treating sludge. Although it was observed that Composting had a low score for Carbon Footprint emissions, which meant that composting has very large amounts of greenhouse gas emissions, it was also observed that composting had very high scores in terms of Process Safety and Environmental Risks and System Complexity and Market Viability which meant that Composting is a relatively safe and simple process which produces a valuable product which can be used in other applications.

Anaerobic Digestion was found to be the 2nd most preferred alternative. Anaerobic digestion was the most preferred in terms of Carbon Footprint sub-criteria, this is due to the collection of the biogases that are being produced and not being released into the atmosphere. Although Anaerobic digestion was found to have low amounts of carbon emissions, it could not reduce the amount of pathogens and bacteria as adequately as the other alternatives. It was observed that Anaerobic digestion also had a high score in Market Viability, which could be attributed to biogas being produced to be converted into energy.

The third most preferred alternative was observed to be Alkaline Stabilization. Alkaline Stabilization has a very low Investment Cost score, but a very high Operating Cost score, this meant that the cost to construct the facility is quite low, but the cost to operate is quite high. Alkaline Stabilization also has a low score in market viability, but also a relatively high score in terms of Process Safety.

The least preferred alternative was found to be Thermal Process. The Thermal Process was found to be the least preferred in terms of Investment Cost, Energy Cost, Environmental Risks, Process Safety, System Complexity and Market Viability. Although, Thermal Process has a relatively high score in terms of Pathogens and Bacteria Reduction.

The results that were obtained were similar to a study done by Bottero et al. [2], which focused on the application of the Analytic Hierarchy Process and the Analytic Network Process for the assessment of different wastewater treatment systems. In their study, out of all the different wastewater treatment methods that were considered for their AHP and ANP models, it was shown that Composting was found to be the most preferred method of treatment, because of its overall simplicity and low economic and environmental impacts. And knowing that composting is one of the earliest process used for solid waste and not just sludge [11] having composting as the most preferred treatment will be a common result. In the study that was conducted, anaerobic digestion ranked second. In the USA, the most common main sludge treatment done is anaerobic digestion [11] since anaerobic digestion is considered the most common treatment for sludge this could be one reason as to why anaerobic digestion ranked second in the study, due to the fact that it is so widely accepted and utilized. Alkaline stabilization is the easiest process for treating sludge but have various disadvantages that may have caused it to become the third priority in the final rankings. Thermal treatment was shown to be the least preferred alternative. In a study done by Hong et al. [3], which focused on the environmental and economic life cycle assessment for sewage sludge treatment in Japan, results showed that incineration was found to have the highest economic impact as compared to the other sludge treatment methods, i.e. when compared to different sludge treatment methods such as composting or anaerobic digestion,

Table 3. Final Priority Weights and Sludge Treatment Alternative Rankings

| **Criteria** | **Sub- Criteria** | **Alternatives** | | | |
|---|---|---|---|---|---|
| | | **Composting** | **Anaerobic Digestion** | **Alkaline Stabilization** | **Thermal Process** |
| Economic Viability | Investment Cost | 0.134 | 0.178 | 0.583 | 0.105 |
| | Operating Cost | 0.325 | 0.389 | 0.167 | 0.119 |
| | Energy Cost | 0.321 | 0.268 | 0.277 | 0.134 |
| Socio-Environmental Concerns | Carbon Footprint | 0.066 | 0.800 | 0.073 | 0.061 |
| | PBR* | 0.340 | 0.151 | 0.255 | 0.255 |
| | Environmental Risks | 0.415 | 0.229 | 0.202 | 0.153 |
| Implementability | Process Safety | 0.438 | 0.211 | 0.235 | 0.116 |
| | System Complexity | 0.398 | 0.229 | 0.226 | 0.147 |
| | Market Viability | 0.429 | 0.258 | 0.157 | 0.155 |
| Final Weights | | 0.323 | 0.266 | 0.258 | 0.153 |
| Ranking | | **1st** | **2nd** | **3rd** | **4th** |

*PBR - Pathogens and Bacteria Reduction

**Conclusions**

This study focused on applying a decision model known as calibrated Fuzzy Analytical Network Process to prioritize sludge management alternatives in the Philippines. The problem structure that was proposed consisted of a 5-level structure with a goal, a planning time horizon, criteria, sub-criteria, and alternatives. Appropriate selection of criteria, sub-criteria, and alternatives were done through literature review. The alternatives considered included composting, anaerobic digestion, thermal process and alkaline stabilization. The criteria used are economic viability, socio-environmental concerns and implementability. Composting was the most preferred criteria to it having the highest priority weights with a value of 0.323, and the most preferred criteria was Socio-Environment with 0.407 priority weight, and the most important sub-criteria was Process Safety with 0.157. Anaerobic Digestion ranks second whereas Alkaline stabilization ranks third. Thermal treatment is the least preferred. Future work will investigate the robustness of model results through sensitivity analysis.

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