Integrating Analytic Network Process (ANP) Decision Modeling Technique in Selecting Urine Diversion Eco-Toilet System for Rural Sanitation and Nutrient Recycling in the Philippines

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Abstract: Environmental friendly sanitation technologies such as urine diverting eco-toilets are suggested to be established in the rural communities to help mitigate environmental pollution to the groundwater and soil by the excreta and, at the same time, to supply additional fertilizer sources. Researchers needed to have stronger reference in selecting the urine diverting technology to the community. Analytic network process (ANP) is a useful technique to answer the decision making problems throughout the process. In this study, ANP method is applied to analyze how other factors affects other variables and to select the urine diversion technology for rural sanitation and nutrient recycling with considerations to the following criteria: Nutrient Reuse (RE), Social Acceptability (SA), Water Saving Capability (WS), and Affordability (AF). The alternatives that are considered in the selection are namely 1) basic urine diversion toilet (UDT), 2) urine diversion twin pit pour flush (wet)-TPT, 3) urine diversion dehydration (dry)-(UDDT), and 4) the composting toilet (CT). The outcome using the ANP method shows that CT is the most preferred urine diversion eco-toilet system (UD ETS) to be installed in the rural area and that Social Acceptance is a great factor in selecting the UD ETS. The ANP method was accompanied by a sensitivity analysis to assess how variations in the weights of the criteria affects the overall ranking of the alternatives.

Keywords: urine diversion toilet; ecotoilet; waterless toilet; rural sanitation; analytic network process

1. INTRODUCTION

Designing an eco-toilet is very crucial for project managers and environmental researchers who are focusing on improved rural sanitation system. Many factors are important to consider to come up with a feasible design of the eco-toilet. This involves understanding its role to rural water and sanitation, analyzing its benefits and costs, and considering the acceptance of the society (Colley & Smith, 2012).

The main reason for having an eco-toilet is because of sanitation issues. Sanitation refers to the safe management of human excreta. This is highly important especially in the rural communities since there are only limited access to clean water and to improved sanitation thereof. Rural areas in the Philippines are at risk of groundwater pollution because of poor sanitation (Ishii & Boyer, 2016).

The nutrients existing in human waste have value to the society when recycled to the agriculture. Urine, feces, and other biodegradable solids contain nitrogen (N), phosphorus (P), and potassium (K) which, in significant amount of concentration, are good nutrients (Vinneras, 2001).

A type of eco-toilet that can help improve rural sanitation is called urine separation technology. It is becoming more popular and is more likely to enhance management of water and treatment of wastewater (Rieck, von Müench, & Hoffman, 2013). In Europe, urine separation technology has been receiving good level of acceptance to majority of urine-source-separation toilet users. The urine separation technology has not only opened the use of more environmental friendly toilets, but also a growing positive attitude in accepting urine as fertilizer (Lienert & Larsen, 2010).

Some researchers explore the feasibility of urine diversion toilet system for rural sanitation. Based on a case study by Holmer, Factura III, Miso, Sol, Santos Jr, Elorde, and Montes (2009), the urine diversion toilet system in the Philippines needs more improvement and needs to address some constraints such as maintenance, hygiene, wash or wipe system, and infestation management.

In this study, the researchers aim to assess and to identify the optimum urine diversion toilet system, that are suitable for rural sanitation and nutrient recycling in the Philippines, by using Analytic Network Process.

2. Analytic network process (ANP) Methodology

Analytic Network Process (ANP) is a multi-criteria decision-making analysis (MCDA) method that has been popularly applied as a problem solving tool in different industries. Some decision-making problems cannot be organized in a hierarchical manner such as in Analytic Hierarchy Process (AHP) because they implicate interaction, inner or outer dependence with another variable or element. Unlike AHP, alternatives and criteria in ANP does not assume independency from each other. Through ANP, we can evaluate not only the importance or preference of the alternatives, but also the significance of the alternatives to the criteria (Sadeghi, 2012). However, there is no related literature that utilized ANP or other methods as a decision tool in selecting a urine diversion technology.

Figure 1 shows the summary of the methodology for the optimum selection of the urine diversion eco-toilet system.

The first step in using the ANP decision structure is to identify the goal. For this study, the goal of the researchers is to select the optimum system of a urine diversion eco-toilet.

Next is to identify the possible alternatives of Urine Diversion Eco-Toilet System. There are four alternatives that will be evaluated in this study. These are the (1) basic urine diversion toilet-UDT, (2) urine diversion twin pit pour flush (wet)-TPT, (3) urine diversion dehydration (dry)-UDDT, and (4) the composting toilet-CT (WaterAid, 2011).

The third step is to identify the criteria for the selection of the Urine Diversion Eco-Toilet System. According to WaterAid, there are four important variables that need to be considered in designing a urine-diversion toilet system. These are nutrient reuse (RU), social acceptance (SA), water saving capability (WS), and affordability of the system (AF).

Nutrient reuse refers to the efficient amount that can be possibly recovered and reused from the source-separated urine and feces. Since human excreta contains N, P, and K, which are good nutrients for the agriculture, fractions of these can be recovered and recycled by using fecal/urine separation. However, the nutrients recovered from the excreta could diminish when any or both of feces or urine will be mixed with flush water (Vinneras, 2001). Social acceptance simply means the perception of the people to adapt the urine diversion toilet culture. Other criteria such as water saving and affordability are respectively defined as the capability to conserve water and the capacity to be low cost in terms of installation and maintenance.

After the criteria and alternatives are known, the interdependence of the criteria and/or alternatives must be identified. In this step, the connections between the elements to another including their influences to each other will be determined.

The fifth step is construct the ANP model structure using a decision making software called SuperDecision version 2.0. This program will generate all the tools that are needed for analysis. In our structure, the network structure is constructed with a hierarchical structure from the goal to the alternative, a feedback from the alternatives to the criteria, an inner dependency of the criteria, feedback from alternatives to goal, and feedback from criteria to goal. The feedback loop and the inner dependence arrows only show that the source element is influenced by where the arrow is pointing to.

Before proceeding with the software, a researcher conducting a study about eco-toilet system has been asked to answer a set pairwise questions. This is to assess the professional's perceptions in designing a urine-diversion eco-toilet system. Unfortunately, in the Philippines, the resource of eco-toilet professionals is very limited. These pairwise question includes the relationships between the: (1) criteria with respect to goal, (2) alternatives with respect to the criteria, (3) criteria with respect to alternatives, and (4) criteria that influences other criteria.

Subsequently, the supermatrices are obtained after all the data from the interview has been inputted to the SuperDecisions software. The weights represent the result of the evaluation of the respondent.

Unweighted and Weighted supermatrices are generated and the result is based on the pairwise comparison data. The result of the supermatrix will be raised to the large powers to establish a Limit matrix. SuperDecisions also shows the consistency index to check for the reliability of the judgments. Finally, a Sensitivity Analysis will be conducted to check how the rankings are affected by the changes in the priority weights of the criteria.

The overall ranking will be based on the ANP result obtained from the Supermatrices.

3. RESULTS AND DISCUSSIONS

In order to get data, a pairwise comparison survey has been administered. The target respondents are researchers who are designing eco-toilet system for rural areas. This is substantial in learning the perspectives of the researchers in terms of commercial and environmental basis of their design. The number of pairwise questions depends on how the network has been structured.

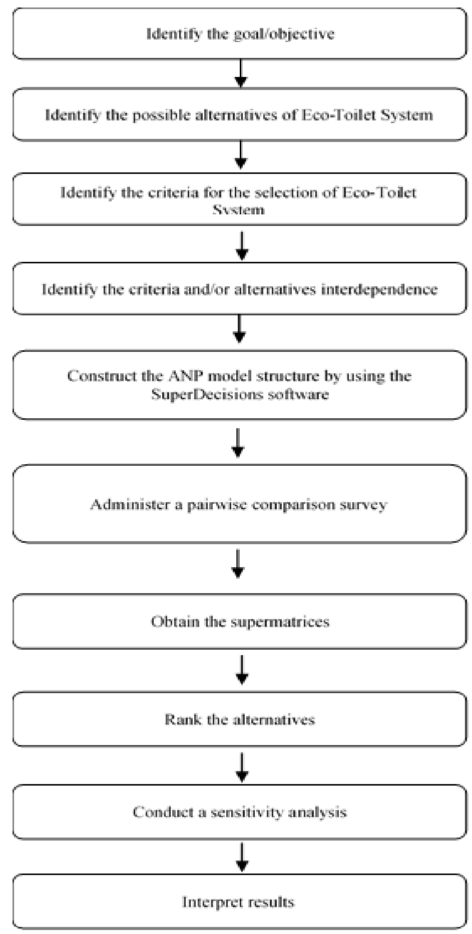

Fig. 1. Summary of methods

The network structure that is being examined in this study is shown in Figure 2. After the pairwise comparison result has been encoded in the Super Decisions program, the Supermatrices will be generated by the tool. The result is as shown in Table 1-2. The Unweighted Supermatrix, in Table 1, shows the eigenvectors values as the result of the pairwise comparison, while Weighted Supermatrix, in Table 2, are the normalized values. Table 3 shows the Limit matrix which is simply the Weighted Supermatrix raised in to larger powers.

Finally, the result for the optimum selection of the urine diversion eco-toilet system is shown in Table 4-5. In Table 4, it shows that the criterion that is considered the

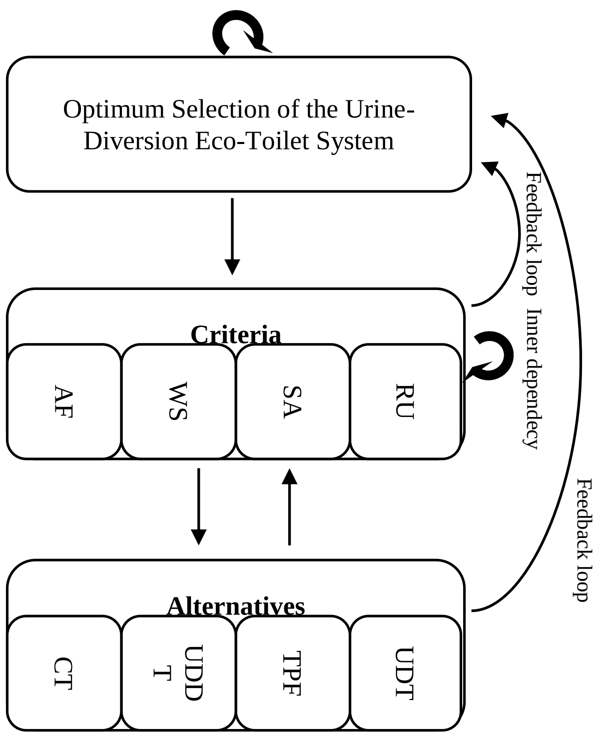

Fig. 2. The decision-making network for making an optimum selection of urine diversion eco-toilet system

most important in optimum selection of urine diversion system is the Social Acceptance with a priority weight of 0.41365, followed by Water Saving. The least favored criterion is the potential reuse of the excreta as fertilizer. The pairwise comparison between the four criteria has low and acceptable inconsistency rate of 0.05787.

Table 1. Unweighted Supermatrix

	Reuse	Social Acceptance	Water Saving	Affordability	UDT	TPF	UDDT	CT	Goal
Reuse	0.20849	0.11815	0.09557	0.125	0.20849	0.15118	0.15849	0.20849	0.12965
Social Acceptance	0.48745	0.48745	0.28671	0.375	0.48745	0.50829	0.47548	0.48745	0.38895
Water Saving	0.20849	0.11815	0.39428	0.375	0.20849	0.26533	0.27452	0.20849	0.30312
Affordability	0.09557	0.27624	0.22344	0.125	0.09557	0.0752	0.09151	0.09557	0.17829
UDT	0.06085	0.3679	0.06654	0.48268	0	0	0	0	0
TPF	0.06503	0.3679	0.08439	0.24725	0	0	0	0	0
UDDT	0.30177	0.09557	0.38328	0.17614	0	0	0	0	0
CT	0.57236	0.16864	0.46579	0.09393	0	0	0	0	0
Goal	1	1	1	1	1	1	1	1	1

Table 2. Weighted Supermatrix

	Reuse	Social Acceptance	Water Saving	Affordability	UDT	TPF	UDDT	CT	Goal
Reuse	0.0695	0.03939	0.03186	0.04167	0.10425	0.07559	0.07925	0.10425	0.06482
Social Acceptance	0.16248	0.16248	0.09557	0.125	0.24372	0.25414	0.23774	0.24372	0.19447
Water Saving	0.0695	0.03939	0.13143	0.125	0.10425	0.13267	0.13726	0.10425	0.15156
Affordability	0.03186	0.09208	0.07448	0.04167	0.04779	0.0376	0.04575	0.04779	0.08915
UDT	0.02028	0.12263	0.02218	0.16089	0	0	0	0	0
TPF	0.02168	0.12263	0.02813	0.08242	0	0	0	0	0
UDDT	0.10059	0.03186	0.12776	0.05871	0	0	0	0	0
CT	0.19079	0.05621	0.15526	0.03131	0	0	0	0	0
Goal	0.33333	0.33333	0.33333	0.33333	0.5	0.5	0.5	0.5	0.5

Table 3. Limit Matrix

	Reuse	Social Acceptance	Water Saving	Affordability	UDT	TPF	UDDT	CT	Goal
Reuse	0.05891	0.05891	0.05891	0.05891	0.05891	0.05891	0.05891	0.05891	0.05891
Social Acceptance	0.17728	0.17728	0.17728	0.17728	0.17728	0.17728	0.17728	0.17728	0.17728
Water Saving	0.11767	0.11767	0.11767	0.11767	0.11767	0.11767	0.11767	0.11767	0.11767
Affordability	0.07472	0.07472	0.07472	0.07472	0.07472	0.07472	0.07472	0.07472	0.07472
UDT	0.03757	0.03757	0.03757	0.03757	0.03757	0.03757	0.03757	0.03757	0.03757
TPF	0.03248	0.03248	0.03248	0.03248	0.03248	0.03248	0.03248	0.03248	0.03248
UDDT	0.03099	0.03099	0.03099	0.03099	0.03099	0.03099	0.03099	0.03099	0.03099
CT	0.04181	0.04181	0.04181	0.04181	0.04181	0.04181	0.04181	0.04181	0.04181
Goal	0.42857	0.42857	0.42857	0.42857	0.42857	0.42857	0.42857	0.42857	0.42857

Table 4. Relative importance of criteria

Criteria	Weight
Reuse	0.13745
Social Acceptance	0.41365
Water Saving	0.27457
Affordability	0.17434

Table 5. Overall priorities of ETS alternatives

Alternatives	Weight
UDT	0.26296
TPF	0.22739
UDDT	0.21695
CT	0.2927

As shown in Table 5, after evaluating the data, the alternative that received the highest ranking is the Composting Toilet (0.29270) followed by the basic Urine Diversion Toilet (0.26296), while the least recommended is the Urine Diversion Dehydration Toilet (0.21695). Note that Composting Toilet ranks highest in terms of Reuse and Water Saving criteria, but lowest on the Affordability.

A sensitivity analysis for each criterion has been conducted to examine how the overall priority ranking of the alternatives is affected by the varying weights of each criterion.

The sensitivity analysis for the four criteria are shown in Figure 2-5. It is found out that the Composting Toilet is highly prioritized up to at least 50% of the weight of each of the varying criterion except for the Affordability. When the relative weight for Affordability increases to 0.3316, the ranking for Composting Toilet lowers down and gradually keep on depleting as the weight increases.

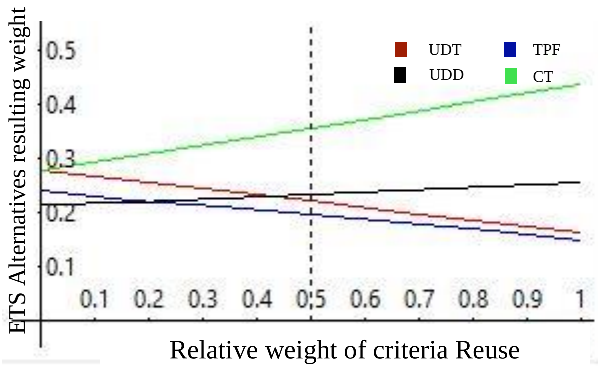

Fig. 2. Sensitivity Analysis Graphical Representation: Reuse

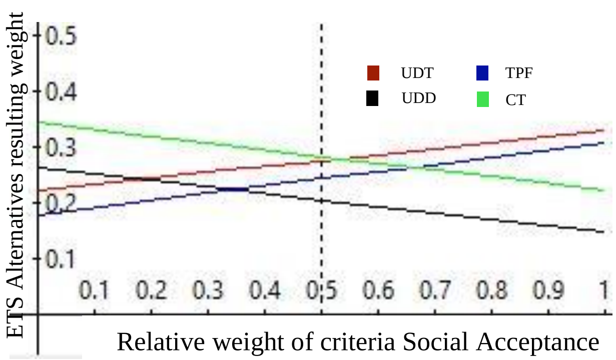

Fig. 3. Sensitivity Analysis Graphical Representation: Social Acceptance

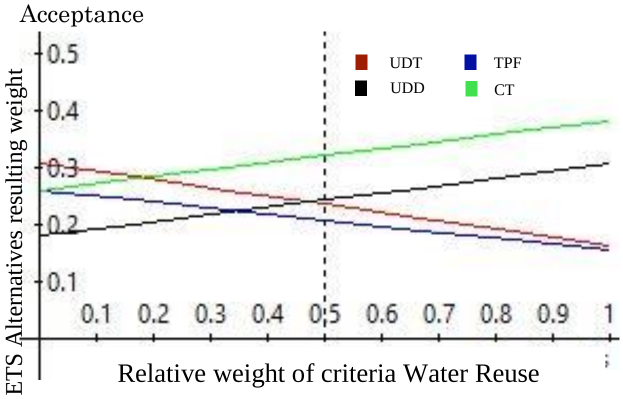

Fig. 4. Sensitivity Analysis Graphical Representation: Water Saving

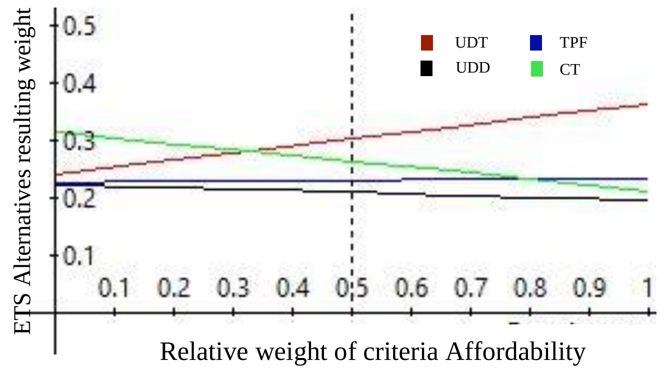

Fig. 5. Sensitivity Analysis Graphical Representation: Affordability

4. CONCLUSION

In deciding for selection of the optimum urine diversion technology for rural sanitation, there are four important criteria that are considered: 1) reuse, 2) social acceptance, 3) water saving, and 4) affordability. Analytic Network Process (ANP) is a helpful decision making tool to evaluate the criteria and alternatives and to examine the interaction and influence of the variables to all the other components of the network.

The result of the ANP analysis suggests that the urine diversion technology that will be designed must have a strong appeal to the users. Social Acceptance has been recognized the most important factor by eco-toilet researchers. It greatly influences all other criteria in decision making and, thus, making it a stronger criterion.

The urine diversion technologies that are strongly socially accepted are the basic Urine Diversion Toilet and the Urine Diversion Twin Pit Pour Flush Toilet. However, these two are not the most preferred alternatives since Composting Toilet surpasses their ranking in other criteria. Composting Toilet, however, is the least affordable, but possesses very outstanding value to the environment (reuse and water saving).

However, the judgment of a respondent in the Philippines may be affected by the limited knowledge and existence of any eco-toilet system in the country.

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