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Analyzing the Key Barriers in Implementing Eco-Toilet Systems (ETS) under Uncertainty via Neutrosophic Decision-Making Trial and Evaluation Laboratory (DEMATEL) Method

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Over two billion (10^9) people have no or limited access to sanitation and more than two-thirds of these unserved people are also found in the rural communities. As still many areas in the Philippines use septic tank systems, most effluent is likely to be discharged without proper treatment and contributes to “nutrient pollution” to water bodies. Those poorly designed or maintained septic tanks may also result in an increased incidence of waterborne diseases in rural areas. Eco-toilet system (ETS) offers an innovative solution for nutrient recovery on a household or community level. Large-scale implementation of eco-toilet systems can contribute towards water footprint reduction and increased availability of nutrients for the cultivation of food crops. Such implementation is challenging as this requires high social acceptance due to the transition from a water-dependent facility to waterless technology. To address this challenge, key social, behavioral, and political barriers are needed to be identified. Influential barriers are needed to be determined and prioritized to increase implementation scale; however, uncertainties are present, and evaluating these barriers will be a problem. In this study, a neutrosophic Decision-Making Trial and Evaluation Laboratory (DEMATEL) approach is used to identify and analyze the barriers to implementing ETS. Neutrosophic sets have been used to represent uncertainties by accounting for incomplete, vague, inconsistent, inaccurate, and subjective data or expert judgment. The uncertainty is addressed by treating responses in terms of their membership, non-membership, and indeterminacy towards the intended meaning of the response. A case study is presented to illustrate the approach.

1. Introduction

Sanitation for all is one of the objectives of the 6th Sustainable Development Goals but to meet the target seems ambitious due to many barriers such as lack of financial resources, socio-cultural conditions, among others. For example, over 2 billion people still lacked basic sanitation services while there are still disparities in sanitation coverage (United Nation, 2021). Urban areas in developed countries typically have centralized sanitation system but many households from urban and rural areas in developing countries still rely on on-site sanitation facilities such as pit latrine for septage management. The impacts of poor sanitation systems in these areas range from negatively impacting the water quality and causing health risks to the populations.

In the Philippines, the on-site septic tanks could contribute to nutrient pollution as the effluent is discharged to the water bodies without any effective treatment. Moreover, the poorly designed or maintained septic tanks may result to an increased incidence of water-borne disease such as diarrhea. One approach to solve these problems is to rethink the sanitation system as a resource-oriented system to reduce cost burden and losses of nutrients relative to existing systems. Eco-toilet system (ETS) can be part of such resource-oriented system. ETS is designed for feces and urine to be collected separately using a urine diverter and kept undiluted during the entire sanitation process. Various options of treatment methods for pathogen destruction and nutrient recovery can then be applied to the collected feces and urine. The products from the resource recovery may include soil conditioner and fertilizer which can be applied in agriculture for food production. Figure 1 describes an example of a resource-oriented sanitation system which involve eco-toilets such as that of urine-diverting dry toilet (UDDT) (Lohman et al., 2020). For example, recent studies done by Lohman et al. (2020) indicate the potential

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of nutrient recovery from such system (see Figs.1b and1c) ranging from 80 - 98 % recovery and calculated the acceptable rate of return of investment at selling price of $1.5 to 2 per kg of total recovered nutrients in Africa. In addition, water footprint of such resource-oriented sanitation system is expected to be reduced to 3 m^3/household/day as compared to that of a conventional system with a water footprint of 16 m^3/household/day based on a US case study (Romeiko, 2019). However, there is still limited progress on implementation of such resource-oriented sanitation system in the Philippines due to inhibiting factors or barriers which are context specific and may vary from one region to another (Ignacio et al., 2018). For example, in urban or metropolitan areas, the ETS faces some challenges in the implementation as there is little or no agriculture is being practiced (Lapid, 2012). Logistics become inhibiting as there is a need to transport the urine or biosolids from urban to rural areas. Moreover, the level of awareness and social acceptability from the point of view of end-user such as farmers and consumers are another issue. It has been suggested that ETS will be more appropriate in rural areas and water-scarce communities. However, another inhibiting factors would be the lack of financing scheme, operational experience and technical expertise to ensure safe storage, treatment and field application. Sustained promotion and adoption of ETS among institutional stakeholders as part of the sanitation plan is also an issue. These are just one of the many barriers that may result to complex problematic situation in implementing ETS in the Philippines.

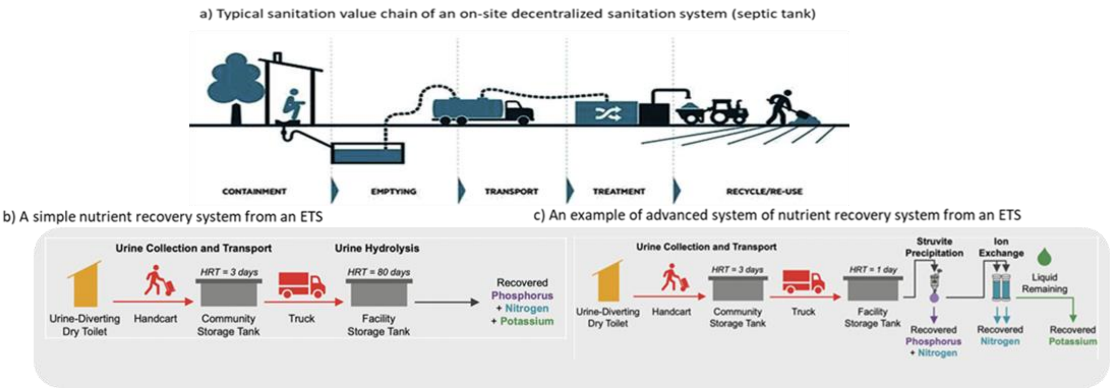

Figure 1: Examples of eco-toilet system (ETS) in a resource-oriented sanitation system to recover nutrients.

Thus, this study explores neutrosophic DEMATEL as tool to resolve the complexity of such problematic situation and understand the interrelationship among these inhibiting factors or barriers for implementation of ETS. DEMATEL stands for Decision Making Trial and Evaluation Laboratory (DEMATEL) technique, which was originally developed by the Geneva Research Centre of the Battelle Memorial Institute to elucidate complex problems by visualizing the structure of causal relationships through matrixes or digraphs (Fontela and Gabus, 1972). It has been applied for structural analysis of problems such as the implementation of eco-industrial parks (Promentilla et al., 2016), circular economy (Gue et al., 2019), chemical engineering education (Aviso et al., 2018) among others. Neutrosophic DEMATEL extends the classical DEMATEL to deal with uncertainty in general, considering ambiguity, inconsistency, vagueness, imprecision, and indeterminacy (Abdel-Basset et al., 2018). The extension applies the concept of neutrosophic sets that defines uncertainty by three characteristic functions, namely, truth, falsity, and indeterminacy functions (Smarandache, 2006). Neutrosophic sets has been also applied to consider uncertainty in tools such as data envelopment analysis (Tapia, 2021) and analytic hierarchy process (Kahraman et al., 2020). Through a systematic problem analysis via neutrosophic DEMATEL, interventions or policy recommendation can be informed from insights that can be derived from such structural analysis under uncertainty.

2. Neutrosophic DEMATEL

DEMATEL has been used for analysis of factors that influences a given decision-making process. This entails uncertainty resulting from human judgment, thus, the neutrosophic set is applied to address the uncertainty. The steps in performing the neutrosophic DEMATEL, based on Kilic et al. (2021), is explained as follows:
Step 1: The responses of the experts are obtained using a survey instrument that asks for degree of influence between factors. Table 1 shows the triangular values used for the survey instrument. In this case, the most possible value for the qualitative judgement is given by the modal value while the lower and upper bounds are the least possible value. The modal value also represents the approximate quantitative equivalent of the expert's judgement when the decision-making is done deterministically.

Table 1: Qualitative response of the expert on the use of ETS

	Lower Bound	Modal Value	Upper Bound
No Influence (NI)	0	0	0
Very Little Influence (VLI)	0	1	2
Low Influence (LI)	1	2	3
High Influence (HI)	2	3	4
Very High Influence (VHI)	4	4	4

In a decision-making under neutrosophic sets, the truth (T), falsity (F), and indeterminacy (I) components are represented as measurements of uncertainty. Here, the degree of truth is represented by the measurement of how certain the given judgment is, while the falsity represents the degree of imprecision that the expert has about the given judgement. Note that in neutrosophic set, these two components are not necessarily complementary with each other, thus, they are rated independently. The indeterminacy component is represented by the vagueness due to lack of information, i.e., the expert estimates how much he/she does not about the influence between two factors. All three components are independent with each other and thus, they are given separate ratings.

Step 2: The qualitative degrees of influences are converted into triangular neutrosophic numbers as illustrated in Figure 1. Then, the ratings of the experts about the neutrosophic components of uncertainty, the scores are converted from triangular neutrosophic number to a single crisp value. The conversion can be done by the score function given by Eq(1):

$$S_{ij} = \frac{1}{8}(A_{ij} + B_{ij} + C_{ij})(2 + a_{ij} - b_{ij} - c_{ij}) \quad (1)$$

Where A_{ij}, B_{ij}, and C_{ij} are the lower, modal, upper values of the triangular neutrosophic number and a_{ij}, b_{ij} and c_{ij} are the truth, falsity and indeterminacy levels set by the expert about the influence of factor *i* to factor *j*. Eqn(1) generates the crisp score S_{ij}. The range of value can be from 0 where no influence is given as judgement to a value of 4.5 when very high influence judgment is given with the highest certainty. The direct relation matrix can be generated from here.

Step 3: The direct relation matrix, *D*, is normalized by dividing it by the maximum between the maximum row sum or the maximum column sum. The elements in the direct relation matrix contains values between 0 to 1.

Step 4: The total relation matrix, *T* is calculated by the following equation:

$$T = D(I - D)^{-1} \quad (2)$$

where *I* is the identity matrix with the same size as *D*. The total relation matrix captures the direct and indirect influences between factors by considering the higher-order interactions.

Step 4: The prominence-causal relationship is determined from *T*. The row sums are computed and denoted as R_i and the column sums are computed and denoted as C_i. The sum given by $R_i + C_i$ provides the total effects given and received by factor *i* and the difference by $R_i - C_i$ gives the net effect of factor *i.* If the net effect is positive, it is considered as a causal factor while if it is negative, it is considered as an effect factor. These are plot consists of points where the x and y coordinates are $R_i + C_i$ and $R_i - C_i$, respectively.

Step 5: The threshold value is determined by taking the average of all entries in the total relation matrix. This threshold value will be used to generate a digraph where the direction of the edges is from point *i* to *j* in the total relation matrix where the threshold value is attained or exceeded.

3. Illustrative case study

A case study analyzing the barriers for implementing ETS is used to illustrate the approach. Table 2 shows the qualitative responses between factors while Table 3 shows the neutrosophic truth, falsity and indeterminacy values given by the expert. Five barriers are identified for the study: financial barrier for the installation of ETS (B1), psychological and socio-cultural barrier towards the use of ETS (B2), lack of code and regulation to support and incentivize the installation of ETS (B3), lack of organizational infrastructure and support services (B4), and lack of awareness and knowledge on the use and maintenance of eco-toilet (B5). In this case, there are 20 pairs to be evaluated by the expert. The neutrosophic components given in Table 3 shows the characteristics of the uncertainty in each value given by the expert. For instance, the influence of factor B1 to B3 represented in Table 3 as <0.7,0.3,0.6> for low influence (LI in Table 2) can be described as 70 % certain based on known information, 30% imprecise as perceived by the expert and 60 % indeterminate based on the lack of knowledge on the actual phenomenon relating the two factors.

Table 2: Qualitative response of the expert on the use of ETS

	B1	B2	B3	B4	B5
B1	NI	HI	LI	HI	HI
B2	NI	NI	VLI	VLI	LI
B3	NI	NI	NI	VLI	LI
B4	NI	LI	NI	NI	LI
B5	NI	LI	VLI	VLI	NI

Table 3: An example of neutrosophic components of each judgement given as triplet <T, F, I>

	B1	B2	B3	B4	B5
B1	<1.0, 0.0, 0.0>	<0.5, 0.5, 0.1>	<0.7, 0.3, 0.6>	<0.3, 0.5, 0.4>	<0.5, 0.5, 0.2>
B2	<0.6, 0.1, 0.2>	<1.0, 0.0, 0.0>	<0.4, 0.1, 0.8>	<0.1, 0.8, 0.1>	<0.1, 0.3, 0.7>
B3	<0.5, 0.6, 0.3>	<0.5, 0.6, 0.3>	<1.0, 0.0, 0.0>	<0.8, 0.2, 0.6>	<0.8, 0.2, 0.6>
B4	<0.2, 0.8, 0.1>	<0.3, 0.8, 0.1>	<0.7, 0.6, 0.5>	<1.0, 0.0, 0.0>	<0.6, 0.2, 0.2>
B5	<0.1, 0.1, 0.9>	<0.1, 0.2, 0.9>	<0.9, 0.3, 0.1>	<0.3, 0.7, 0.0>	<1.0, 0.0, 0.0>

The crisp values are obtained and summarized in Table 4 for the direct relation matrix. Note that this matrix describes the intensity of influence of one barrier over the other by transforming the linguistic rating into numerical value. In classic DEMATEL, this matrix is populated by ratings (0,1,2,3,4) analogous to a 5-point Likert scale where 0 means no influence while 4 is the highest intensity of influence. In the case of neutrosophic DEMATEL, we can estimate the degree at which each factor influences one another by incorporating the degree of uncertainty given by the neutrosophic set. The values are generally lower considering the uncertainties under neutrosophic environment. For instance, the influence of factor B1 to B3 has a crisp value of 1.350 compared to the deterministic value of 2.000 at the same qualitative judgement (little influence). Thus, the uncertainties allow a more conservative approach towards judging the influence between factors. This is true especially in the implementation of ETS, where the influence of socio-economic factors is highly uncertain due to the mostly qualitative evaluation made.

Table 4: Crisp value of the expert judgement given for the case study

	B1	B2	B3	B4	B5
B1	0.000	2.138	1.350	1.575	2.025
B2	0.000	0.000	0.563	0.450	0.825
B3	0.000	0.000	0.000	0.750	1.500
B4	0.000	1.050	0.000	0.000	1.650
B5	0.000	0.750	0.938	0.600	0.000

The values of the direct influence in Table 4 are normalized (see Table 5) prior to the calculation of total relation matrix described in Table 6. Normalization ensures that Eq.2 will approximate the total influences which captures both direct and indirect relation between barriers. The threshold can then be used to filter out the significant influences. For example, a threshold of 0.134 is used, i.e., the average of the values in the total relation matrix. The total influence of B2 on other barriers (e.g., 0.079 to B2) are considered weak as the values are less than 0.134. In contrast, the total influence of B1 on the other barriers (e.g., 0.286 to B5) is strong. The values in Table 6 are also used to calculate the degree of prominence and net relation (cause/effect) as summarized in Figure 2. Here, it is shown that the most prominent barrier is the lack of awareness and knowledge with the use of ETS (B5), while the least prominent barrier is the lack of code and regulation to support and incentivize the ETS to the community (B3). This shows that community acceptance is mainly caused by the availability of information on how the ETS can be used and what are its benefits to the community. Then, the lack of incentive to support the ETS would just be easier to address once solution to other barriers are already implemented. The network relation map is illustrated in Figure 2. Here it is evident that the main key barrier that drives or influences other barriers is the financial barrier for the installation of ETS (B1) while the most dependent but prominent in the network is lack of awareness and knowledge on the use and maintenance of eco-toilet (B5).

With such elucidation of the problem via neutrosophic DEMATEL, it will aid in developing interventions from a policy standpoint. For example, government and other institutions may consider advocating sanitation-derived fertilizer enterprises by incorporating recovered nutrients into formal fertilizer subsidy program. It will be important to introduce training and knowledge exchange to increase the awareness about ETS and the potential products that can be derived from such sanitation system. It is also important to understand farmer attitudes and other consumers toward the potential use of human excreta-derived fertilizers and the crops grown from such fertilizers as this could drive the success of any business strategies focusing on this fertilizer market.

Table 5: Normalized direction matrix calculated for the case study

	B1	B2	B3	B4	B5
B1	0.000	0.302	0.190	0.222	0.286
B2	0.000	0.000	0.079	0.063	0.116
B3	0.000	0.000	0.000	0.106	0.212
B4	0.000	0.148	0.000	0.000	0.233
B5	0.000	0.106	0.132	0.085	0.000

Table 6: Total relation matrix calculated for the case study

	B1	B2	B3	B4	B5
B1	0.000	0.398	0.284	0.317	0.466
B2	0.000	0.031	0.103	0.090	0.163
B3	0.000	0.047	0.038	0.134	0.256
B4	0.000	0.183	0.051	0.040	0.274
B5	0.000	0.131	0.152	0.115	0.074

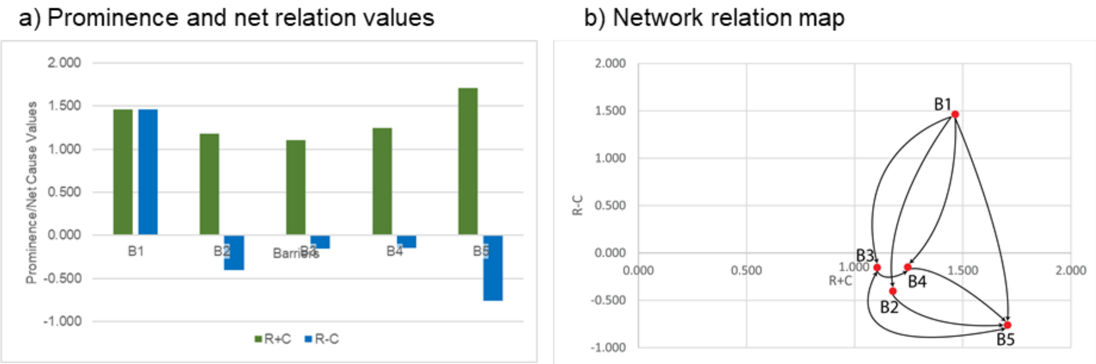

Figure 2: Interrelationship among barriers for this case study

Table 7: Comparison between deterministic and neutrosophic approaches to DEMATEL

	R+C (Neutrosophic)	R-C (Neutrosophic)	R+C (Deterministic)	R-C (Deterministic)
B1	1.464	1.464	1.534	1.534
B2	1.176	-0.403	1.564	-0.455
B3	1.104	-0.152	0.994	-0.144
B4	1.246	-0.149	1.368	-0.237
B5	1.707	-0.761	1.806	-0.697

The results from neutrosophic DEMATEL could provide insights on the interventions or policy recommendation based on such structural analysis under uncertainty. A comparison between deterministic and neutrosophic approaches is also done and summarized in Table 7. The deterministic approach involves a crisp value of the qualitative judgement equivalent to the modal value in Table 1. Considering the neutrosophic set as a representation of the uncertainty, the ranking between prominence also changes. The change in ranking happens between B2 and B4 when evaluated using the approach in a deterministic vs neutrosophic manners. This shows that the presence of neutrosophic sets as representation of uncertainty in the human judgment affects how the influence between factors are perceived. It means that considering the expert's assessment on his knowledge about the barriers, the degree of influence of the factors that affect the ETS implementation may be affected.

4. Conclusions

A neutrosophic DEMATEL approach was utilized to identify the barriers affecting the implementation of ETS. The approach involves uncertainties represented by neutrosophic sets with components of truth, falsity, and indeterminacy function. In this approach, the experts can evaluate the uncertainty in terms of how certain a given judgment is (level of truth), how imprecise they perceived about the given judgement is (level of falsity), and how vague the given judgement due to the lack of information (level of indeterminacy). Five barriers were identified for the case study in which the most prominent barrier is the lack of awareness and knowledge of the use and maintenance of ETS. From structural analysis, key barrier that drives the other barriers is the financial aspect of implementing ETS. Future work includes extending the approach to incorporate interactions between neutrosophic components and integrating the technique in multi-criteria decision-making framework.

Nomenclature

A_{ij} – lower bound of the qualitative judgement on the influence of factor i to j.
a_{ij} – truth value of the qualitative judgement on the influence of factor i to j.
b_{ij} – falsity value of the qualitative judgement on the influence of factor i to j.
B_{ij} – modal value of the qualitative judgement on the influence of factor i to j.
C_i – column sum in total relation matrix for factor i.
c_{ij} – indeterminacy value of the qualitative judgement on the influence of factor i to j.
C_{ij} – upper bound of the qualitative judgement on the influence of factor i to j.
D – direct relation matrix.
F – falsity value of a neutrosophic set.
I – indeterminacy value of a neutrosophic set.
i, j – Indices for factors.
R_i – row sum in total relation matrix for factor i.
S_{ij} – crisp score of the qualitative judgement on the influence of factor i to j.
T – total relation matrix.
T – truth value of a neutrosophic set.

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