Selection of Municipal Wastewater Reuse Technology for Agricultural Water by Using Multi Criteria Analysis (MCA): The Case of Walcheren Wastewater Treatment Plant, The Netherlands

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ABSTRACT

The water demands for agricultural purposes are increasing along with the population growth. Unfortunately, the water source is not sufficiently available nowadays. Furthermore, the quality of available water is more deteriorated due to the contamination from many sources such as households, industrial areas and other activities. Water board Scheldestromen handles 16 wastewater treatment plants located in Province of Zeeland in The Netherlands. The total production of treated effluent water from 16 wastewater treatment plants is 50 million annually. Quality of the effluent is relatively good, however, some potential risks related to the number of pathogenic microorganism and some trace metals are still there. The treated effluent is mostly discharged to river near to the treatment plant. The high amount of effluent discharge would potentially to be re-used for fulfill the demand for agricultural water. Therefore, this study aimed to evaluate the feasibility of treated effluent from one of Walcheren wastewater treatment plants located in Ritthem, Province of Zeeland. This study used the method of Multi Criteria Analysis (MCA) for looking the best way to re-use the effluent for agricultural purposes. The MCA questionnaire was developed based on the thorough literature review of effluent reuse. There were six criteria that need to be weighted and six scenario alternatives that need to be scored for the MCA questionnaire. The result show that the effluent water contained pathogenic bacteria (*E. coli*) and some trace metals (Ni and Cu) more than suggested by FAO standard. Hence the most preferred technology was combination between closed conduits and UV system, with weighted score 0.78 while others had less weighted score compared to the selected one.

Key words: *Agricultural, MCA, Wastewater*

INTRODUCTION

The water demands for agricultural purposes are increasing along with the population growth. Future human population by 2050 will reach 3.7 billion and the highest water use is agricultural sector (Wallace,

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2000). Unfortunately, the water source is not sufficiently available nowadays. Global climate change and over withdrawal of surface water and ground water had triggered water crisis worldwide. Global climate change have contributed to the long drought events and increased the extreme precipitation events (Tao, Yokozawa, Hayashi, & Lin, 2003).

These are the reason of the increasing number of natural disaster. Population growth is a key factor of every water crisis occurred in this world. Furthermore, the quality of available fresh water is more deteriorated due to the contamination from many sources such as households, industrial areas and other activities (Chang, 2008). Therefore, the alternative water source for agriculture is required to overcome the potential problem of water in the future. Agricultural water comprises of water for irrigation, washing and processing.

In Netherlands, the total production of treated effluent water from 16 wastewater treatment plants is 50 million annually. The quality of the effluent is relatively good, however, some potential risks related to the number of pathogenic microorganism and some trace metals are still there (Nieuwlands, 2017). The treated effluent is mostly discharged to river near to the treatment plant. Due to this practice, there is possibility of people health threatening particularly those who live near the riverbank and treatment plants. The high amount of effluent discharge would potentially to be re-used to fulfill the demand for agricultural water. However, a study to look at its feasibility as water source for agriculture have to be conducted to get thorough analysis particularly its impact on human, crops, and infrastructure. Therefore, this study aimed to evaluate the feasibility of treated effluent from one of Walcheren

wastewater treatment plants located in Rithem, Province of Zeeland.

Decision making is a crucial process that determines the sustainability of a project and the satisfactory of the stakeholders. The dilemmas in making a decision often encounter conflict of sociopolitical, economic and environmental interests which eventually constitute a complex problem. Therefore, the solution needs a multidimensional approach such as Multi Criteria Analysis (MCA). Multi criteria analysis (MCA) is an approach that assigns several criteria to address different aspects that affecting a project. MCA analysis has been proven to be systematic process to find the best alternative among different offered alternatives which is preferred by the involved stakeholders and most effective tool for solving such multifactor opposing goal problems. These techniques have been classified into a group of methods, which have been improved very much during last 30 years (Carriço, Gonçalves, Covas, Almeida, & Alegre, 2014).

Multi criteria analysis involves participation of many people, organization and groups of private and state sector which is called as stakeholders. The procedure of MCA is structurally defined below (Hadipour, Rajaei, Hadipour, & Seidirad, 2016):

- a. Determination of the alternative scenarios
- b. Determination of evaluation criteria.
- c. Assigning the weight and its definition.
- d. Distribution of the questionnaire contains MCA scenarios and evaluation criteria.
- e. Ranking the alternative scenarios
- f. Analysis of the results
- g. Selection of the best scenario.

Schematization of the selected scenario

The advantages of using MCA to make a decision compared to informal judgment are (Kalavrouziotis, Filintas, Koukoulakis, & Hatzopoulos, 2011):

a. The method of MCA is identified to be an open and explicit method. The objectives and criteria selection made by decision making group can be openly analyzed and it is possible to be changed and developed if those criteria are considered to be not sufficient. The scores and weighs determined in this method are explicit and developed based on the established techniques. If necessary, those scores and techniques could be amended and cross-referenced to other sources on their relative values.

b. Easy for the decision maker since the performance measurement can be sub-contracted to experts.

c. As an important means of communication between the decision-making group and the affected and wider community through the developed score and weight.

Despite of the advantage offered by MCA, there is also a limitation of MCA in relation with the welfare of the people impacted by a project. The application of MCA does not guarantee that a project adds more to welfare compared to detract (Department for Communities and Local Government, 2009).

METHODS

Case Study Site

The Walcheren wastewater treatment plant is in Ritthem, Province of Zeeland, the

Figure 1. Case study site: (a) Potential Agricultural Area that can be supplied by treated wastewater, (b) Location of Treated Water Storage, and (c) Location of WWTP

Netherlands. Walcheren WWTP built in 1988 and it was expanded in 2003 and 2017. It serves 200,000 p.e. The flowrate in dry weather average is $25,000 \text{ m}^3 \text{ day}^{-1}$ and in wet weather average is $140,000 \text{ m}^3 \text{ day}^{-1}$. The maximum flowrate that has been recorded is $7,800 \text{ m}^3 \text{ hour}^{-1}$. There are two separated processes in the WWTP, they are water line

with the intention of water purification and the sludge line which aiming to process the excess sludge. The waterline consist of several treatment unit, they are bar screen, pre-settling tanks, anaerobic tanks, aeration tanks for denitrification, nitrification, and phosphate removal and final settling tanks (Scheldestromen, 2017).

Procedure

The procedure initiated by analyzing wastewater quality for physical, chemical, microbiological parameter and then compared to the standard of water for agriculture. The historical data of wastewater quality from 1990 to 1997 was also analyzed. From the analysis, the technology setup was created to address the problem identified in the analysis. The evaluation criteria were developed based on the literature study for wastewater reuse.

To assign weights, questionnaires were distributed. For this purpose, experts from Water Board Scheldestromen involved in the process and asked to evaluate the importance of each criteria and their preference on the scenario alternatives.

In the questionnaire distributed to respondent, there were two tables that need to be filled in. The first table was to determine the weight of every criterion for the project of Walcheren WWTP effluent re-uses for agricultural purpose. The second table was evaluation matrix to determine the preference score for every proposed alternative which considers each criterion. In total, there were

six criteria to be assigned weights and there were six alternatives that need to be scored.

Determination of Alternative Scenario

According to the wastewater quality analysis, it is known that the problematic parameters are the existence of fecal coliform and the high concentration of metal concentration. After conduction test on effluent water aggressivity, the results showed that pH of effluent tend to be corrosive. Therefore, it was needed to create a set of treatment facility and carrying pipes that were able to handle the problems. Table 1 presents six sets of scenario alternatives to overcome the problem exist in the water.

Determination of Evaluation Criteria

The evaluation criteria were developed based on the literature review. From literature of wastewater reuse and comparing with the data of effluent quality, there were listed six criteria which include the safety risk, costs, operation and maintenance simplicity, perception issues, required area and treatment efficiency. The justification of selected criteria is described in Table 2.

Table 1. Alternative Scenarios

No.	Alternatives	Description	
		Transmission Line	Fecal Coliform and Metal Treatment
1.	Coated Closed Conduit – Natural Process (maturation pond)		1. Maturation pond is a shallow pond which allows the UV from the sun penetrated into the bottom of the pond (Stott & Tanner, 2005) (Fu & Wang, 2011). 2. Constructed wetland is treatment systems that use wetland vegetation, soils and their associated microbial assemblages.
2.	Coated Closed Conduit – Natural Process (constructed wetland)	The closed conduit is the conduit buried in the ground and usually uses pipes. The coated conduit is necessary to prevent the early deterioration due to internal corrosion caused by transported water	Reduction of metals and fecal coliforms can be removed in the system (Department Natural Resources Management and Environment, 1992) (Stott & Tanner, 2005).
3.	UV radiation system (in WWTP) – Coated Closed Conduit		3. UV radiation system is physical treatment that has high efficiency in removing the pathogenic bacteria. The UV system is planned to be installed in the Ritthem WWTP. So the effluent from secondary clarifier is radiated by UV before it is sent to agriculture land (Parker & Darby, 1995) (Müller-Steinhagen & Branch, 1988).
4.	Coated Open channel – Natural Process (maturation pond)	Coated open channel to prevent the internal corrosion caused by the transported water.	Similar to number 1
5.	Coated Open channel – Natural Process (constructed wetland)	There is a chance of metal treatment in the channel because some metals such as Pb and Ni flocculate more in the situation of high DO concentration.	Similar to number 2
6.	UV system (in WWTP) – Coated Open channel		Similar to number 3

Table 2. Evaluation Criteria

No.	Criterion	Description
1.	Safety Risks	Evaluation of both human and environmental risk, that is, to assess the safety for workers in operating and maintaining the system as well as the agricultural worker that use the effluent of the treated wastewater. The security in case of bad operations and maintenance or accidents is also considered in this criterion (Kalavrouziotis, Filintas, Koukoulakis, & Hatzopoulos, 2011).
2.	Costs	This criterion contains investment cost to develop a system as well as operating, maintaining, personnel, energy and chemical products cost for every alternative (Carriço, Gonçalves, Covas, Almeida, & Alegre, 2014).
3.	Operation & Maintenance Simplicity	The selection should take into account the special needs of system operation and maintenance. If the operation needs many people to be involved, it can be a reason for a policy maker to refuse it. The simplicity of the system could determine the long-term O & M success of the system (Hadipour, Rajaei, Hadipour, & Seidirad, 2016).
4.	Perception Issues	This criterion is about the view of local population affected by the system. The perception could be caused by the aesthetic impact caused by the presence of the facilities on the landscape, bad smell which can be produced by the open channel to irrigate the water as well as the treatment facilities. As well as the perception of the population about their health risk due to the facilities installation (Hadipour, Rajaei, Hadipour, & Seidirad, 2016).
5.	Area	The impacted area due to the installation of the system. The proposed alternatives require a certain land area to install the system and the barrier area which might need very wide area.
6.	Treatment Efficiency	Efficiency in reducing pathogenic microorganism and metal concentration. This criterion considers the variability of treatment effectiveness under normal and emergency operation. Evaluation on this criterion is not only limited to the ability to

No.	Criterion	Description
		eliminate pathogens, but also the ability to remove other undesirable contaminants such as metal.

In the questionnaire, the criteria were arranged as Table 3 and the respondent was asked to weight the criteria based on their importance. The assigned weight could be in between 0% - 100%, however, the total percentage from all criteria should be 100%.

Table 3. Weighting Percentage

No.	Criteria	Weight (%)
1.	Safety Risks	
2.	Costs	
3.	Operation & Maintenance Simplicity	
4.	Perception Issues	
5.	Area	
6.	Treatment Efficiency	
TOTAL		100%

Table 4. Score and the level of preference

Score	Definition	Explanation
5	Extremely preferred	A criterion or technique is extremely preferred to another
4	Strongly preferred	A criterion or technique is strongly preferred to another
3	Preferred	A criterion or technique is preferred to another
2	Strongly non-preferred	A criterion or technique is strongly non-preferred to another
1	Extremely non-preferred	A criterion or technique is extremely non-preferred to another

MCA Evaluation Matrix

The evaluation matrix is intended to score the scenario based on six criteria. There were five score which represents the preference of the technology based on the certain criteria. The score ranged from one to five with the explanation lists in Table 4.

In the questionnaire, the MCA evaluation matrix was arranged as Table 5. Every alternative was judged by each criterion with score 1 to 5. The assigned score was weighted based on the weight in Table 3. The total score was the summation of every technology

Table 5. MCA Evaluation Matrix

No	Alternatives	Criteria					
		Safety Risks	Costs	Operation & Maintenance Simplicity	Perception Issues	Area	Treatment Efficiency
1	Coated Closed Conduit – Natural Process (maturation pond)						
2	Coated Closed Conduit – Natural Process (constructed wetland)						
3	UV radiation system (in WWTP) – Coated Closed Conduit						
4	Coated Open channel – Natural Process (maturation pond)						
5	Coated Open channel – Natural Process (constructed wetland)						

RESULTS AND DISCUSSION

Collected data from the effluent of Rittiem WWTP is shown in Table 1. The historical data of metal parameter from 1990 to 1997 are

presented in Figure 2 to Figure 5. Some effluent quality data was measured on site (DO; pH_{actual}; ORP; conductivity; TDS; salinity and temperature). Other parameters such as metal; P, total-N, and fecal coliform were measured in laboratory.

Table 6. Measurement Quality Data from the Effluent of Rittiem WWTP

Parameters*	Concentration	Standard**	Interpretation	Effect to Pipe/Human/Crops
DO	5.01 mg/L			
pH _{actual}	7.02	6.5 – 8.4		pH _a < pH _s , water tends to be corrosive to pipe/infrastructure
pH _{saturated}	7.39			
ORP	250.4 mV			
Conductivity	2,191 µS cm ⁻¹	0 – 3,000 µS cm ⁻¹		There is a possibility to increase in summer
TDS	1,092 mg L ⁻¹	0 – 2,000 mg/L		

Parameters*	Concentration	Standard**	Interpretation	Effect to Pipe/Human/Crops
Salinity	1.11 PSU			
Temperature	14.98 °C			
Ni	0.227 mg/L	Max. 0.2 mg/L		Toxic number 0.5 – 1, reduced toxicity at neutral or alkaline pH
Zn	<0.2 mg/L	Max. 2 mg/L		Many variations wide range plant, reduced toxicity at pH > 6
Cu	0.126 mg/L	0.1 – 1 mg/L		Toxic at 0.1 – 1
Pb	< 0.1 mg/L	5 mg/L		Inhibits plants cell growth
PO ₄ ³⁻	0.236 mg/L	0 – 2 mg/L		
Total N	5.53 mg/L	20 mg/L		
Fecal Coliform	5,896 CFU/100 ml	< 1000 CFU 100 mL ⁻¹		Endanger human health (diarrhea, skin infection)

Note: *parameters are sampled in winter, **Source: (Ayers & Westcot, 1994)

	: Exceed the standard/dangerous level
	: Warning
	: Permitted

Comparison with FAO standard shows some of the parameter such as nickel, copper and fecal coliform exceeded allowed concentration for agriculture water according to FAO which is shown in red color. pH for the effluent was in range FAO standard however after testing the saturated pH then the comparison between actual pH and saturated pH shows that the effluent water tended to be corrosive to pipes or any other metal infrastructure. The conductivity and the total

dissolved solids are in the range of FAO standard; however, the concentration is in upper range. Therefore, there would be possibility of increasing concentration in summertime since those results presented on the table was taken during winter.

The results of the historical data analysis are presented in Figure 2 to Figure 5. In those figures, the red and green line was added to show the standard of FAO (red line) and the recent field measurements (green line).

Figure 2. Historical data of Ni

Figure 3. Historical data of Pb

Figure 4. Historical data of Cu

Figure 5. Historical data of Zn

The analysis results show that metal concentration of Nickel (Ni) was far below the current measurement and the standard. It means that the Nickel concentration increases for 10 years duration. The other current metal concentration of Pb, Cu and Zn are quite close to the concentration that was measured 10 years ago, however all those parameters concentration in current measurement is higher than the historical data. The standard of FAO

was higher up far from the measurement concentration.

The criteria weights assigned by the stakeholders are presented in Table 7. The scoring of scenario alternatives is presented in Table 8 while the calculated weights of criteria considering all the scenario alternatives is presented in Table 9.

Table 7. Criteria Weighting

No.	Criteria	Weight (%)
1.	Safety Risks	10
2.	Costs	30
3.	Operation & Maintenance Simplicity	10
4.	Perception Issues	10
5.	Area	10
6.	Treatment Efficiency	30
TOTAL		100%

Table 8. Scenario Alternative Scoring

Alternatives	Criteria					
	Safety Risks	Costs	Operation & Maintenance Simplicity	Perception Issues	Area	Treatment Efficiency
	(1)	(2)	(3)	(4)	(5)	(6)
Coated Closed Conduit – Natural Process (maturation pond)	3	2	3	3	1	3
Coated Closed Conduit – Natural Process (constructed wetland)	3	2	3	3	1	3
UV radiation system (in WWTP) – Coated Closed Conduit	4	3	4	4	3	5
Coated Open channel – Natural Process (maturation pond)	3	2	3	2	2	3
Coated Open channel – Natural Process (constructed wetland)	3	2	3	2	2	3
UV system (in WWTP) – Coated Open channel	2	3	4	3	3	5

The results showed that the most important criterion is costs and treatment efficiency and the least important is safety risks, O & M simplicity, perception and required area. It must be noted that the one of the most important one is costs which consist of cost of investment; operation and maintenance. Cost component determine the sustainability of the solution because the expensive technology and spare parts could cause problem in long term operation and maintenance. The other most important is treatment efficiency because it is related to the quality of effluent which eventually directly related to human health.

From the questionnaire, the stakeholders have assigned score based on their preference on each criterion. The results are presented in Table 8. The highest score was given to the scenario of using Ultra Violet treatment. From the treatment efficiency, it was considered to be the best option to handle the main problem on the effluent water since Water Board Scheldestromen is very much concern with the issues of pathogenic microbes' presence in the effluent. Closed conduit is also a scenario that receives high scoring in term of safety risk and perception issues since the closed conduit lay

underground and will not be exposed to the public.

CONCLUSION

In this study, an MCA has been applied to find the best alternative for wastewater reuse application in the Walcheren WWTP, The Netherlands. The MCA matrix built in this study was distributed to the stakeholders and all aspect related to wastewater reuse from WWTP's effluent was judged for every scenario offered in this study. The matrix built based on the wastewater analysis results and literature study of wastewater reuse. It was found from the study that the best alternative for wastewater reuse is UV radiation system combined with closed conduit for transporting the treated water to agricultural land. Total score for this alternative is 0.78 which is the highest compared to other scenarios. Results from this study can be useful for policy makers and decision-makers in water resource management in Water Board Scheldestromen to make better decisions to reuse the treated wastewater.

Final weights and ranking of alternatives are shown in Table 9. Results of MCA matrix was obtained by weight calculation with the formula below :

$$\frac{\text{Weighted Score}}{\text{Max Score}} \times \frac{\text{Weight (\%)}}{100 (\%)} = \dots\dots\dots(1)$$

$$\text{Total Score} = \sum_{i=1}^n WS_i = WS_1 + WS_2 + WS_3 \dots + WS_n \dots\dots\dots(2)$$

From the calculation and listed in Table 9, the UV radiation method combined with closed conduit has the highest total score that is 0.78. The UV radiation system and closed conduit was the best alternative to overcome

the problem of pathogenic bacteria and minimizing the risk of safety, and health issues according to Water Board Scheldestromen. Therefore, the treatment and transportation scheme will be based on the selected technology as can be seen in Figure 6.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to the Ministry of Research, Technology, and Higher Education of Indonesia Republic which have provided funding for this research through the Program of Retooling of Vocational Higher Education Lecture.

Table 9. Final Weight and Rankings of Alternative

Alternatives	Criteria						Weighted Score						Total Score
	Safety Risks	Costs	O & M Simpli city	Perception Issues	Area	Treatment Efficiency	Safety Risks	Costs	O & M Simpli city	Perception Issues	Area	Treatment Efficiency	
Coated Closed Conduit – Natural Process (maturation pond)	3	2	3	3	1	3	0.06	0.12	0.06	0.06	0.02	0.18	0.5
Coated Closed Conduit – Natural Process (constructed wetland)	3	2	3	3	1	3	0.06	0.12	0.06	0.06	0.02	0.18	0.5
UV radiation system (in WWTP) – Coated Closed Conduit	4	3	4	4	3	5	0.08	0.18	0.08	0.08	0.06	0.3	0.78
Coated Open channel – Natural Process (maturation pond)	3	2	3	2	2	3	0.06	0.12	0.06	0.04	0.04	0.18	0.5
Coated Open channel – Natural Process (constructed wetland)	3	2	3	2	2	3	0.06	0.12	0.06	0.04	0.04	0.18	0.5
UV system (in WWTP) – Coated Open channel	2	3	4	3	3	5	0.04	0.18	0.08	0.06	0.06	0.3	0.72
Weight	10	30	10	10	10	30

Figure 6. Treatment and Transportation Scheme

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