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Development of a cost-benefit analysis approach for water reuse in irrigation

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Abstract: Water reuse is one of the alternatives to counteract the already experienced water shortages. However water reuse as any other investment is associated with costs. This article looks at water reuse for irrigation as one of the areas that has recently gained attention. However, water reuse requires a prior installation of wastewater treatment and the irrigation systems of which all requires financial resources. Analysis of the costs and benefits of water reuse remains one of the key tools for decision making. Unfortunately there has been no universal way for doing cost benefit analysis that can fit all reuse applications and the local settings. The objective of this study was to customize the existing water reuse cost benefit analysis methods and develop cost benefit analysis for water reuse in irrigation. The net benefit value approach was studied, examined and modified to incorporate all the relevant cost items and benefits associated with water reuse in irrigation. Based on the approach developed a discussion have been made whereby it was evident that the main cost elements for water reuse in irrigation are those associated with land for installations, the treatment plant and the irrigation systems involving their installations, operation and maintenance. On the other hand it has been shown that the main elements for benefits are related to natural resources recovered, improved agricultural production and the environmental benefits.

Keywords: Cost Benefit Analysis, Wastewater Treatment, Water Reuse, Irrigation Cost

1. Introduction

Water as one of the basic human needs need to be properly managed. The competition among different water demands under the experienced water scarcity, calls for alternative water supplies including reuse of treated wastewater and the effective management of the water resources [1]. Water reuse is considered as the only solution to close the loop between water supply and wastewater disposal whereby wastewater that was termed as waste can now be considered as a resource after the appropriate treatment is done [2]. Water reuse for irrigations purposes has advantages of provision of water and the associated essential nutrients for crop growth and may substitute fertilizers use which is rather expensive [3,4]. [3; 4].It follows that, wastewater irrigation can mitigate water scarcity, save disposal costs, reduce pumping energy cost and thus minimize carbon emissions to the environment [5].

Cost benefit analysis (CBA) for reuse of treated wastewater effluent has gained interest among researchers. This is because the need to reuse water for various purposes including irrigation has become more apparent with experienced drought conditions[6]. Scientists need to understand whether investing on water reuse can be viable or not by looking not only on the technological aspects but also the environmental aspects [2; 7].The major cost element in water reuse is attributed by the investment costs incurred in the construction of the wastewater treatment plant [8]. Because of this, cost minimization remains one of the overriding objective in wastewater treatment if other constraints such as compliance to the environmental standards are taken care of [9]. The cost t effectiveness of reuse projects is directly related to the volume of reclaimed water used such that the more water utilized, the more cost-effective the project becomes. Hence, in this sense, irrigation provides the highest potential for water reuse [2]. Similarly it has been observed that large treatment plants are more cost effective than the smaller ones. Therefore, whenever there is a large volume of reclaimed water used in irrigation, the project is expected to be viable as the environmental benefits are significant [10].

Researchers have attempted to develop and use several techniques for CBA. Molino-Senante et al [2011] developed a theoretical methodology for assessing the internal and external economic impacts of water reuse with an evaluation of some wastewater treatment plants in Spain and concluded that, the major environmental benefit is the prevention of nitrogen and phosphorus from causing eutrophication in the water receiving bodies. Godfrey et al [2009] considered internal and external cost and benefit in the cost benefit analysis of the grey water treatment and reuse system for small systems in India and arrived at a conclusion that the benefits of grey water reuse system exceeded the costs and that the major contributor to the profits was the health benefits. Cheng and Wang [2009] used the net benefit model to evaluate the cost and benefit of the wastewater treatment and reuse in China and made a recommendation that the proposed net benefit model and its calculation methods need further study and modification. Hernandez *et al* [2006] presented a methodology for feasibility assessment of water reuse projects taking into account the internal and external impacts as well as the opportunity costs. Through this study it was revealed that, it is possible to have monetary values for calculation of the impacts but there exist a series of extenalies for which no explicit market exists and the evaluation in such cases uses hypothetical scenarios [11]. Despite the availability of some attempts to do cost benefit analysis, none of the approach or analysis has been comprehensive and accurate. For water reuse in irrigation, some new economic components that are usually not accounted by many approaches are introduced and need to be well accounted [12]. Thus, there is no universal way that can fit all cases due to difference in local circumstances [7].The main challenge is on the accurate calculation of the project benefits with the difficulty being on comprehensive evaluation and valuing of the environmental benefits [13]. Therefore in this case, development of new techniques for cost benefit analysis or customization of the existing approaches to fit into the local situations becomes important.

This article highlights the basic considerations for development of the CBA for water reuse in irrigation. The objective of the study was to define, describe and modify important elements involved in the cost benefit analysis and come out with a unique approach for water reuse in irrigation.

2. Establishment of the Methodology for Cost Benefit Analysis

Before arriving at the actual development of the model for cost-benefit analysis for water reuse in irrigation, the following models or approaches were studies carefully and analysed whether can fit into use. The below description provides useful information on the available models their strength and weakness in analysis of the cost-benefit for water reuse in irrigation. This information forms a justification for adopting the proposed approach or model.

The cost-benefit analysis for water reuse approach:

This is the approach was developed by Molinos-Senante *et al* [2011] for general water reuse projects that considers the internal benefit, external benefit and opportunity cost. It provides the equations by which each of the parameters can be computed. It also gives some considerations for water reuse in irrigation by providing an input parameter as internal benefit [8]. The approach uses complicated equations especially in the computation of the external benefit and becomes not user friendly for normal practitioners. Again the approach does not comprehensively cover water reuse in irrigation as it does not incorporate all the cost and benefit elements. Only some inputs from the model have been borrowed and used in the development of the approach for cost-benefit analysis for water reuse in irrigation.

The technical feasibility of grey water reuse:

This approach was used by Godfrey *et al* [2009] in India for cost-benefit analysis of grey water reuse system. Like the above described approach, this approach looked into the internal, external and opportunity cost but for a decentralized grey water system [13]. Within this approach considerations for nutrient recovery using the ecological sanitation technologies were considered. Within the ecosan water supply is not an integral part of it as it is with wastewater reuse in irrigation. This approach does not adequately account for the water reuse in irrigation and it mainly geared towards decentralized wastewater treatment system. This approach was not adopted for use.

The water reuse feasibility analysis approach:

The approach was presented by Henandez *et al* [2006] for conducting economical feasibility studies for water reuse projects. The approach proposed the analysis of both the internal and external costs and benefits for each project [11]. The approach however failed to account for many externalies that are involved in the analysis and again some of the important elements for water reuse in irrigation were not well addressed.

The net benefit value approach:

This approach was used by Cheng and Wang [2009] for cost-benefit analysis for general water reuse targeting decentralized system and aiming at environmental protection. The net benefit value approach identifies the cost items as mainly from the installation and operation and maintenance cost and itemized different benefit elements including the environmental protection and public health protection [7]. However the approach lacks a comprehensive coverage of all the important cost and benefit elements pertaining to water reuse in irrigation. But it was promising to customize it to fit into analysis for water reuse in irrigation.

Based on the analysis above, the cost benefit analysis of the water reuse in irrigation under establishment tries to customize the methodology used by Chen and Wang in China for general water reuse and modify it to focus on the water reuse for irrigation taking into consideration the benefits that can be realized when the reuse type is for agricultural production.

The adapted procedure is as described below:-
The net benefit value (NBV) is the proposed model for evaluation where by the computation can be done according to the equation:-

$$NBV = \sum B_i - \sum C_i \tag{1}$$

Whereby B_i is the net value of benefit and C_i is the value of cost item. Description of the relevant cost elements and benefit elements is as discussed below.

2.1. Evaluation of the Costs Involved

The cost calculation for water reuse in irrigation was undertaken by considering the cost for land, treatment works, pipe work, and conveyance system to the from the treatment plant to the irrigation farms. Considering these cost elements then Chen and Wang approach [2009] could be modified to account for the land and the irrigation conveyance system from treatment plant to the irrigation farms as separate entities. Therefore the total cost for water reuse in irrigation can be expressed as:-

$$\sum C_i = \sum C_L + \sum C_e \tag{2}$$

Where CL is the total cost for land to harbor the treatment works and C_e is the cost related to the treatment works, pipe works and their operation and maintenance costs.

The cost element C_e can be expressed as:-

$$\sum C_e = \alpha\delta Q^\beta + 365\gamma Q + \varepsilon\alpha Q^\beta \tag{3}$$

Whereby Q is the average daily flow rate, α is the coefficient related to treatment works or pipe work or conveyance farms or farms; β=exponential coefficient related to cost scale effect; δ=rate of depreciation; γ=unit cost of operation; ε=coefficient of annual maintenance.

Because the treatment works, pipe works and the conveyance system can have different coefficients, further modification can be done and it follows that equation 3 can be rewritten as:-:

$$\sum C_{ei} = \alpha_i\delta_i Q_i^\beta + 365\gamma_i Q_i + \varepsilon_i\alpha_i Q_i^\beta \tag{4}$$

If the term Ct is used to represent the cost for the treatment works, term C_p represents the cost for the pipe work and C_c represents the cost for the conveyance system to the irrigation farms and C_f represents the cost for the irrigation farms, and if Q_1 is to represent the pipe and treatment plant average flow rate Q_2 as the flow rate after treatment (discharge in the conveyance system to irrigation farms), then:-

$$\sum C_{ei} = C_t + C_p + C_c + C_f \tag{5}$$

$$C_t = \propto_t \delta_t Q_1^\beta + 365\gamma_t Q_1 + \varepsilon_t \propto_t Q_1^\beta \tag{6}$$

$$C_p = \propto_p \delta_p Q_1^\beta + 365\gamma_p Q_1 + \varepsilon_p \propto_p Q_1^\beta \tag{7}$$

$$C_c = \propto_c \delta_c Q_2^\beta + 365\gamma_c Q_2 + \varepsilon_c \propto_c Q_2^\beta \tag{8}$$

$$C_f = \propto_f \delta_f Q_2^\beta + 365\gamma_f Q_2 + \varepsilon_f \propto_f Q_2^\beta \tag{9}$$

Whereby t, p, c and f represent the coefficients for the treatment works, pipe network, conveyance system and irrigation farms respectively. Q_1 represent the flow rate in the sewerage network (pipe network) and within the treatment plant and Q_2 the treated flow rate in the conveyance after treatment and in the irrigation farms.

2.2. Evaluation of the Benefits Gained

The benefit for water reuse in irrigation was evaluated considering the following benefit elements:-

- Benefit from the resources gained from water reuse which is the treated water with the contained nutrients. The water obtained becomes available for irrigation purposes hence supplying additional water for crop production. The nutrients from the wastewater are also used to supply the basic plant nutrients (nitrate, phosphorus and Potassium) for crop growth subsidizing the cost of fertilizers.
- The agricultural benefit arising from improved crop production.
- Benefit through employment where by the presence of the treatment works and the irrigation system engages some people into paid labor.
- The benefits related to the environment which includes the reduced pollutant loading, better downstream water quality, improved public health, local environmental protection and the reduced impact of the downstream aquatic ecosystems.

2.2.1. Benefit from Gained Resources

The value of useful water gained from wastewater can be directly computed from the amount of reclaimed water which is available for irrigation purposes. The assignment of monetary value for this water would depend on the local situation and as governed by the fresh water availability, the consumers' willingness to pay and the income status of local communities. Alternatively the benefit from the resources (water and nutrients) can be evaluated based on the fresh water tariff by the equation adapted from Chen and Wang [2009] which is hereby modified as:

$$B_1 = B_{11} + B_{12} \tag{10}$$

$$B_{11} = 365 \sum_{i=1}^{n} a_i Q_i \tag{11}$$

Whereby B_{11} is the benefit from water gained, B_{12} is the benefit gained from use of nutrients, Q_i is the average water flow rate used for irrigation (note that Q_i can be equal to Q_2 assuming that the treated water is all used for irrigation), a_i is the water tariff for irrigation purposes.

The value of benefit gained from fertilizer (B_{12}) can be computed directly from costing the amount of fertilizer that would have been used if fresh water is used for irrigation. The amount of fertilizer that can be supplied can be estimated from the fact that the conventional wastewater treatment plant can avail treated effluent with 50mg/L of Nitrogen, 10mg/L of Phosphorus and 30mg/L of Potassium [14].

2.2.2. Benefit from Improved Agricultural Production

The agricultural benefits (B_2) can be evaluated from valuing the extra amount of produce obtained from use of treated effluent for irrigation in comparison with the produce obtained when rain or fresh water is used for the same agricultural production. Through use of treated effluent for irrigation, fertilizer is applied to the crops without some additional labor. The cost that would be incurred in labor for fertilizer application could also be accounted under the agricultural benefits.

2.2.3. Benefit from Employment

The benefit from employment (B3) can be achieved through hiring community members as laborers in the irrigation farms. Wastewater irrigation may provide a continuous employment opportunity as crop production can be done throughout the year. For example, experiences in Tanzania has shown that people who use treated effluent for irrigating paddy in lower Moshi, are able to cultivate the crop twice in a year which is one extra season compared to the rain fed paddy farming [15]. Evaluation of the employment opportunity into monetary value can be one of the most difficult tasks. However one approach would be to value the money gained by those employed in the farm. In this case the opportunity would be evaluated as:-

$$B_3 = N \sum b_i \, C_i \qquad (12)$$

Whereby N=the paid number of days in a year, b_i is the number of laborers employed in irrigation activities, C_i the average unit cost paid to one laborers in a day.

2.2.4. Benefits from the Environment Wellbeing

The environmental benefits (B_4) can be calculated by considering the benefit relating to treated wastewater discharge reduction (B_{41}) which accounts for reduced nutrients which otherwise would lead to eutrophication and/or other associated impacts on the downstream ecosystems; the benefits related to local environment improvement through reduced pollutant loading (B_{42}) and the benefits related to the protected human health (B_{43}). It must be noted however that water reuse in irrigation can also have some negative human health impact and in such cases the impact arising from it turns to cost rather than benefit [9]. In adapting the Chen and Wang approach, the environmental benefits can be calculated as follows:-

$$B_4 = B_{41} + B_{42} + B_{43} \qquad (13)$$

$$B_{41} = 365 \sum_{i=1}^{x} \emptyset_i \frac{e_i}{1000 n_i} Q_p \qquad (14)$$

Where $\emptyset$ is the unit discharge fee per pollution equivalent of pollutant i, ei is the concentration of pollutant i, ni is the standard concentration of pollutant i and Q_p is the discharge flow rate (not that Q_p can be equal to Q_2).

$$B_{42} = 365 \sum_{i=1}^{y} h_i \, (m_i - n_i) Q_p \qquad (15)$$

Whereby hi is the cost for reduction weight of pollutant i, mi is the discharge concentration of pollutant i, ni is the permissible concentration of pollutant in the environment.

$$B_{43} = \mu \sum_{i=1}^{z} d_i S \, (p_i + w_i) \qquad (16)$$

Whereby μ is the average income, d_i is the rate of disease i, S is the population in the serviced area, pi is the labor loss per person due to disease i and w_i is the therapy cost per person due o disease i.

The total benefit for water reuse in irrigation can therefore be obtained by summing up the benefits as

$$\sum B_i = B_1 + B_2 + B_3 + B_4 \qquad (17)$$

$$\sum B_i = 365 \sum_{i=1}^{n} a_i \, Q_i + B12 + B_2 + N \sum b_i \, C_i + 365 \sum_{i=1}^{x} \emptyset_i \frac{e_i}{1000 n_i} Q_p + 365 \sum_{i=1}^{y} h_i \, (m_i - n_i) Q_p + \mu \sum_{i=1}^{z} d_i S \, (p_i + q_i) \qquad (18)$$

2.3. Discussion

More than the net benefit value model, the developed approach considers extra items both for cost and benefit evaluation. In terms of the costs, the approach considers land and irrigation channels as major cost items. The land in these aspects covers the land to be used for the treatment plant and that to be used for irrigation farms. The wastewater treatment plants in most of the developing countries use the waste stabilization ponds and/or constructed wetland all of which requires a relatively big piece of land. However, in most of countries land for treatment works is usually set and allocated in the city plans also in countries such Tanzania, where land is owned by public and managed by the government [16] land acquisition becomes easy and therefore land becomes not an important cost element such that can even be ignored in computation of the costs. On the other hand if land is to be acquired at any means on commercial rates especially already developed urban centers, the cost becomes higher and might even tend to make the water reuse in irrigation projects not cost effective.

Another cost element that is specific to water reuse in irrigation is the cost for constructing the irrigation channels. This cost becomes higher with the distance from the treatment plant to the farm intended for irrigation. It is desirably that the channels are constructed in such a way to allow gravity movement of the water otherwise additional cost for pumping would be incurred that would rise the costs even higher. Also it has been reported in other studies [17] that coating of the irrigation channels make the cost higher thus, reducing the cost effectiveness of the system. Therefore areas with impermeable soils can provide a low cost irrigation channel as lining will not be required and the opposite applies for permeable soils areas.

In Chen and Wang approach, human resources was considered negative as the labor wages is an additional cost [7]. While this is true in one sense but can be looked into a different perspective when it comes to water reuse in irrigation. With a constant availability of water for irrigation the labor requirements gives a constant and reliable employment opportunity to people. Therefore this has been considered as a benefit in this approach as explained before. The cost related to payment of wages in this case, has been considered as part of operation and maintenance costs.

Some of the cost elements that have not been adequately accounted in this approach is the fact that effluent irrigation can lead to soil salinity and affect the ground water quality [18; 5]. The cost can be added by employing soil remediation techniques such as compositing [19; 20]. Therefore irrigation management strategies to ensure that salinity problem is minimized need to be developed and implemented right in the design stage of the irrigation system. The public health impacts associated with the use of treated effluent is another cost element that needs to be investigated. Although the assumption is that the water used for irrigation has been thoroughly treated, but in some situation the treatment system can perform under its capacity. Water reuse in this case can pose some health risks to the workers who handle it but also to the consumers of the products. Therefore to ensure that public health is avoided the treatment plant should be closely monitored to perform to its capacity and ensure that the health precautions and measures are taken care. The public health risks can also be minimized by ensuring the suitable irrigation methods as per design are used and implemented in a proper way [18]. However, for water reuse in irrigation to be with a significant net benefit, irrigation management procedures as well as the public health measures should be well adapted and implemented.

The evaluation of the benefits remains to be one of the challenging aspects of cost benefit analysis. This is because most of the benefits are difficult to be valued into monetary value. Therefore it is expected that the equivalent fees would vary from one area/situation to another. It can also depend on the applicable local standards and guidelines for the environmental benefits whereby the benefit for countries with strict regulations can be relatively higher than those countries where the same is less strict. One of the environmental benefits pointed out is the local environmental improvement. Though the expression to account for this is shown, it must be noted that it is difficult to demarcate and account the contribution of wastewater treatment and reuse to the overall local environment improvement simply because some other factors including the natural processes may contribute to the same.

2.4. Conclusion

The analysis of the previous models or approaches for cost-benefit analysis indicates that most of them do not comprehensively account for all the cost and benefit elements for water reuse in irrigation. Hence customization of the most appropriate model was necessary. The NBV approach can be well customized to fit into the cost benefit analysis of the water reuse in irrigation. The major cost elements are the investment cost, the operation and maintenance costs while the major benefits are in terms of the employment opportunities, the agricultural production and environmental protection. Proper implementation and well management of the water reuse in irrigation projects can avail some benefits which otherwise would be cost items. Elements such as the public health and environmental improvement cannot be easily predicted as some of these elements may be benefits in one situation but a cost in another.

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