A FUZZY-TOPSIS DECISION-MAKING MODEL FOR
SELECTIONS OF WETLAND TECHNOLOGY
FOR GREYWATER TREATMENT

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Abstract: The use of constructed wetlands for improving greywater treatment by improving nutrient removal at a lower cost than conventional methods has recently attracted renewed interest. The majority of these studies have predominantly pre-defined a wetland configuration for wastewater treatment, which introduces a lot of empiricism in decision-making. To address this problem, this study aims to develop a Decision Support System (DSS) for the selection, design, and optimization of constructed wetlands technologies (CWT) during greywater treatment. To evaluate WT for greywater treatment and determine which physic-chemical and microbial properties need to be treated. A multi-criteria decision-making (MCDM) tool is used simultaneously with a conformity assessment. The DSS was developed after a thorough review of the literature on the design and implementation of various WT (HFWSF, HSSF, VSSF, and VFSF) and greywater characteristics using Microsoft Visual Studio 2010. This study is interesting in that, it integrates contextual data (wastewater characteristics) with WT removal efficiency characteristics to assist you in selecting the best WT.

Typha domingensis and Hyacinth (Eichhornia crassipes) were effective at removing contaminants when combined with HFWSF WT. After four-month of study, The HFWSF CWT treatment with hyacinth was found to be effective, for the HFWSF- CWT treatment with hyacinth, the removal efficiency of Faecal coliform, Total coliform, Oil and Grease, Ammonia, Total Phosphate, and COD, 78.46%, 74.33%, 73.08%, 69.23%, 25.29%, and 80% respectively. DSS decision on HFWSF-CWT DSS has demonstrated that it is a competently designed novel dashboard for choosing CWT for the treatment of greywater.

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**INTRODUCTION**

The past two decades have seen increasingly rapid advances in wastewater treatment. Of particular concern is the use of constructed wetland technologies as an alternative wastewater treatment system. The technology is increasingly recognized and widely accepted because of its environmental friendliness, frequency of maintenance, and its cost-effectiveness compared to alternative treatment technologies [1]. Artificially constructed wetland plays a significant role in reducing nutrient concentrations, degrading organic compounds, and retaining heavy metals from wastewater, which include sewage waters, mining wastewater, landfills, farmyard runoff, residual dye bath, and municipal wastewater [2].

Several researchers have reported on the results of a constructed wetland that combines saturated vertical flow constructed wetland (VFCW), free drain VFCW and horizontal flow constructed wetland (HFCW. Aside from this, other studies have also focused on other factors that promote plant removal performance, such as the type of constructed wetland and its configuration (vertical, horizontal, surface, or subsurface flow), with or without recirculation. Furthermore, most of these studies have predominantly predefined a wetland configuration for treating wastewater, which introduces a lot of empiricism in decision-making. The authors explore the aspects of the plant’s role in wastewater treatment using constructed wetland technologies and greywater from households as a case study.

**MATERIAL AND METHODS**

**Study Area:** The experimental evaluation of the wetland technology was conducted at the National Water Resources Institutes (NWRI) premises behind the block of flats opposite the NWRI Demonstration Shonghai Integrated farm (Figure 1). The NWRI is in Kaduna between the latitude 1170473.024 meters and longitude 327176.533 meters, while the wetland construction is at the latitude 1170107.89 meters and longitude 327053.237 meters.

**Sample collection:** Before subjecting the greywater to this location for treatment, samples of greywater were collected and evaluated. Samples from wetland technology cells consisting of the treatment of Hyacinth (*Eichhornia crassipes*) and *Typha domingensis* were collected for four months, thus between June 8th to 16th September and August 6th to 28th November 2022, respectively. The greywater samples from both the influent and effluent were collected for physicochemical and biological analysis on two weeks intervals.

**Physico-chemical and microbial analysis:** The physical, chemical, and microbiological analyses of the greywater sample were conducted. The sample was analyzed immediately, after sample collection, and the rest sample was carried to the laboratory with an icebox for analysis instantly.
The selected physical parameters measured onsite include pH, temperature, turbidity (NTU), electric conductivity (EC), and total dissolved solids (TDS) using the palintest pH meters although the other chemical and microbial parameters determined in the laboratory are suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrate (TN), total phosphate (TP), Ammonia (NH₃), oil/grease, total coliform (TC), and faecal coliform (FC). The above-mentioned parameters were analyzed following the standard method of examination of water and wastewater according to the 22nd edition [8] protocols. Table 1 presents the summary of the experiment analysis of fifteen different parameters.

### Table 1. Biological and physicochemical properties of greywater/Statistical Analysis

<table>
<thead>
<tr>
<th>S/N</th>
<th>Parameters</th>
<th>Units</th>
<th>Value</th>
<th>Discharge limits</th>
<th>A significant difference (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>pH</td>
<td></td>
<td>6.5</td>
<td>6 – 9</td>
<td>Yes (0.0071)</td>
</tr>
<tr>
<td>2</td>
<td>Temperature</td>
<td>°C</td>
<td>23.7</td>
<td>&lt;3°C above ambient</td>
<td>Yes (0.0091)</td>
</tr>
<tr>
<td>3</td>
<td>Electrical Conductivity</td>
<td>µS/cm</td>
<td>238</td>
<td>&lt;1500</td>
<td>No (0.0684)</td>
</tr>
<tr>
<td>4</td>
<td>Total Dissolve Solid</td>
<td>ppm</td>
<td>119</td>
<td>&lt;1000</td>
<td>No (0.0787)</td>
</tr>
<tr>
<td>5</td>
<td>Turbidity</td>
<td>NTU</td>
<td>73.0</td>
<td>&lt;75</td>
<td>Yes (0.0215)</td>
</tr>
<tr>
<td>6</td>
<td>TSS</td>
<td>mg/l</td>
<td>20</td>
<td>50</td>
<td>Yes (0.0112)</td>
</tr>
<tr>
<td>7</td>
<td>BOD</td>
<td>mg/l</td>
<td>20</td>
<td>50</td>
<td>Yes (0.0112)</td>
</tr>
<tr>
<td>8</td>
<td>COD</td>
<td>mg/l</td>
<td>600</td>
<td>250</td>
<td>No (0.3333)</td>
</tr>
<tr>
<td>9</td>
<td>Total Phosphate</td>
<td>mg/l</td>
<td>2.70</td>
<td>2.0</td>
<td>Yes (0.0495)</td>
</tr>
<tr>
<td>10</td>
<td>Total Nitrate</td>
<td>mg/l</td>
<td>3.41</td>
<td>50</td>
<td>Yes (0.0495)</td>
</tr>
<tr>
<td>11</td>
<td>Ammonia</td>
<td>mg/l</td>
<td>1.9</td>
<td>1.0</td>
<td>Yes (0.0449)</td>
</tr>
<tr>
<td>12</td>
<td>Sulphate</td>
<td>mg/l</td>
<td>42</td>
<td>200</td>
<td>Yes (0.0492)</td>
</tr>
<tr>
<td>13</td>
<td>Oil/grease</td>
<td>mg/l</td>
<td>780</td>
<td>5</td>
<td>Yes (0.0333)</td>
</tr>
<tr>
<td>14</td>
<td>Total coliform</td>
<td>CFU/100 mL</td>
<td>600</td>
<td>400</td>
<td>No (0.5058)</td>
</tr>
<tr>
<td>15</td>
<td>Faecal coliform</td>
<td>CFU/100 mL</td>
<td>130</td>
<td>10</td>
<td>Yes (0.0999)</td>
</tr>
</tbody>
</table>

In the parenthesis is the p-value, with a significance level set at p < 0.05. The p-value for the wastewater characteristics was estimated using MATLAB.

**Design Considerations:** The following were the steps taken during the development of the DSS for the selection, design, and optimization of constructed wetlands technologies (CWT) during greywater treatment:

1. The premise for coupling Fuzzy-TOPSIS
2. Decision model formulation
3. Defining a list of technological alternatives
4. Identification and screening of assessment attributes (criteria) for selecting the best-constructed wetland technology
Performance modeling of the Fuzzy-TOPSIS framework

Having looked at objectives, a list of alternative wetland technology, and criteria, we now move to describe the algorithm to be deployed for the decision-making process. The paragraph below represents the steps involved in the framework.

**Step 1:** Select constructed wetland technology alternatives from the literature.

**Step 2:** Select evaluation criteria

**Step 3:** Select fuzzy linguistic variables and their respective fuzzy triangular numbers (or member functions). The linguistic variables and their corresponding TFN used in this study include low (1, 3, 5), moderate (3, 5, 7), and good (5, 7, 9).

**Step 4:** Aggregate the alternative and criteria weight-age decision matrix.

\[
\text{TFN} = (1, 3, 5), \quad \tilde{a}_{ij} = (x_{ij}, y_{ij}, z_{ij}) \quad \ldots \ldots \ldots \ldots \ldots \ldots . \quad (1)
\]

**Step 5:** Calculate the fuzzy Euclidian distance to the \( A^+ \) and \( A^- \)

\[
M_i^+ = \sqrt{\frac{1}{3} \sum_{j=1}^{n} (m_{ij} - m_j^+)^2} \quad i = 1, 2, \ldots, m \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \quad (2)
\]

\[
M_i^- = \sqrt{\frac{1}{3} \sum_{j=1}^{n} (m_{ij} - m_j^-)^2} \quad i = 1, 2, \ldots, m \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \quad (2a)
\]

**Step 6:** Rank the alternatives according to relative closeness to the ideal solution

RESULTS AND DISCUSSION

Decision-making dashboard

Figure 1 presents the interface of the application software for determining the optimal constructed wetland technology for treating wastewater. The application software was built based on the models defined in Eq. 1 and 2.

The software was built on two main levels, the first focuses on the characteristics of the greywater, whilst the latter is the characteristics of the wetland technology. This approach introduces robustness in the decision-modeling layer of the software.

The software performs three primary functions (1) estimates which component or pollutant requires treatment; (2) predicts the best CWT by simultaneously considering the pollutants to be treated as well as the characteristics of the technology; (3) presents a visual representation of the proposed technology. The most interesting aspect of this application is its flexibility in allowing the user to enter pollutant parameters readily available. In other words, the user does not need to estimate all the 15 physiochemical and biological characteristics of the wastewater.
Also, the application can estimate any wastewater of interest to the user if the characteristics concentrations are known. Again, because the application was constructed using Microsoft Excel, we can host it on any computer. We can also use it as a standalone software; however, this is beyond this study.

![Dashboard Image]

**Figure 1.** The user interface of the novel dashboard for wastewater evaluation and selection of the best wetland technology

**Principles for implementing the decision support system**

The development of the novel dashboard presented in Figure 1 is based on integrating two methods. Figure 1 displays an overview of the method used in developing the decision support system.

![Flowchart Image]

**Figure 2.** Fundamental layers for building the decision support architecture

The flowchart assumes that the user has conducted experiments to determine the characteristics of the greywater. From Figure 2, we observe the framework has two distinct layers. The first defines a set of characteristics that need to be treated by comparing it to the discharge limits.
The output of the layer focuses on conformity or non-conformity of the pollutant to discharge limits. This serves as an input to the second layer, where the selected pollutants are matched to the predetermined characteristics of wetland technology. 15 parameters were used; however, the application is flexible in that if the user does not have the required parameter, an analysis can still be conducted.

**Evaluation of treatment to the proposed technology**

Moving on, the recommended Horizontal Free Water Surface Flow constructed wetland was constructed and tested over four months. However, because vegetation is one of the major components for removing pollutants, we selected *Typha domingensis* and water Hyacinth (*Eichhornia crassipes*) for treatment. The vegetation was lowered steadily to increase the plant cover and ensure steady contact with the wastewater throughout the observation period. We measured the concentration change of the pollutants after the 4 months study period against the discharge limits (Figures 3 and 4 for the two vegetation). The percentage removal of biological contaminants was obtained from the relation.

\[
\text{Contaminant removal (\%) } = \frac{C_{in} - C_{out}}{C_{in}} \times 100\% \tag{3}
\]

Where: \( C_{in} \) is the influent concentration

\( C_{out} \) is the effluent concentration in mg/L or CFU/100.

![Figure 1](image)

**Figure 1. Change in the concentration of contaminants using *Typha domingensis* vegetation**

Figure 3, four interesting observations can be made: (1) the selected plant *Typha domingensis* and the engineered technology were relatively effective at removing the contaminants (2) there was no significant change in the concentration of faecal coliform after the four months study period. This implies that *Typha domingensis* was ineffective at the removal of fecal Coliform.
On the contrary, we observe that the total coliform concentration reduces by over 36.33%. Despite this low removal efficiency, it met the municipal requirements. What is surprising is that the concentration of faecal coliform rather increased from 130 CFU/100mL to 135 CFU/100mL. (3) Again, it was relatively effective at removing oil/grease as we observe close to 65.38% removal, although this does not meet the municipal requirements. Although Total Phosphate was somehow removed from the greywater, it was not below the minimum requirements, with a final concentration of 2.33 mg/L (2 mg/L). Howbeit the removal and retention of COD surpassed the municipal requirements with a removal efficiency of 66.17%. This implies that the proposed wetland configuration, as well as the vegetative plant, proved relatively effective in removing two contaminants out of the seven. This result also corroborates strongly with the work of [9], who treated municipal sewage water by deploying a mesocosm scale to remove effectively Total phosphate and COD. Again, the observed results may be attributed to the inherent contaminant transformation potential peculiar to the designed technology. Also, the period used for the study may be contributing factor to the incomplete removal of contaminants in the wastewater.

Figure 2. Comparison of greywater characteristics using the water Hyacinth (Eichhornia crassipes) vegetation.

Figure 4 compares the relative removal rates of contaminants against the Discharge limits. As can be seen, the removal efficiency of faecal coliform, total coliform, and oil/grease was 78.46%, 74.33%, and 73.08% respectively. Despite this effective removal rate, Total coliform was the only contaminant among the above three that met the municipal removal requirements. The incomplete removal of these contaminants is consistent with the current literature presented by [10], which achieved 72% and 76% removal of total coliform and faecal coliform, respectively. On the contrary, the other two contaminants were out of the range of the limit of reuse according to [11]. This may be attributed to the shorter period used for the study. What stands out in this Figure 4 is that Ammonia, Total Phosphate, and COD were simultaneously removed effectively with a removal rate of 69.23%, 25.29%, and 80% respectively.
This result is somewhat counterintuitive as the results correlate with the work of [12], [13] who tested raw domestic wastewater using HFWSF in an in-situ application to effectively remove COD, BOD, Ammonia, and Total Phosphate in China and Italy, respectively.

Experimental model validation (Treatment for conform and non-conform)

So far, the study has shown the effectiveness of the proposed model-based framework in selecting a constructed wetland technology, and in treating greywater. In this section, we demonstrate the dynamic behavior of the Horizontal Water Free Surface Flow constructed wetland over four months.

Three interesting observations can be made. First, we observe that Water hyacinth (Eichhornia crassipes) has a greater contaminant removal potency than Typha domingensis. This is evidenced by its profiles lying below that of Typha domingensis. Again, with COD, we observe that water Hyacinth (Eichhornia crassipes) removal efficiency reached a maximum peak of about 500% removal efficiency between weeks 8 and 9. Similar observations can be made for the other contaminants.

Second, with water Hyacinth (Eichhornia crassipes), a consistent decrease in the concentration of contaminants is observed except for the total Sulphate and Ammonia. Again, we see that after week 4 and week 8, the pollutant removal remains consistent. These results may be due to the maximum biomass growth achieved by the plant, hence the steady nutrient absorption rate. Also, such a level shows a need to change vegetation plants as perhaps a maximum biomass limit had been achieved. On the contrary considering, the Typha domingensis, an inconsistent removal rate was observed. One unexpected finding was the removal of faecal coliform by Typha domingensis. We observe a steady decrease in concentration, howbeit, the final concentration did not differ significantly from the initial concentration. The results imply that water Hyacinth (Eichhornia crassipes) is efficient in municipal WWT and corroborates strongly with the work of [14], [15] who tested the performance of wetlands using water Hyacinth (Eichhornia crassipes).

Turning now to dynamics of change in contaminants that met the discharge limit. These include pH, temperature, total coliform, fecal coliform, turbidity, and total dissolved solids. What is surprising is the consistent fluctuations in the concentration, especially for turbidity and total dissolved solids. This inconsistency may be due to the environmental conditions since we experimented in an open place.

Contrary to expectations, a significant difference between the initial and final concentration for all parameter cases.

CONCLUSIONS

The experiment conducted confirmed that the novel Constructed Wetland Dashboard was useful in determining the components of greywater to be treated and effective in predicting CWT to treat the greywater based on its characteristics. An implication of this is the possibility that the dashboard will be adopted by key stakeholders and engineers during the user-specific design of constructed wetland technologies.
Also, one of the more significant findings to emerge from this study is how the engineered wetland using water Hyacinth (*Eichhornia crassipes*), proved effective in removing four of the seven contaminants. Howbeit, because of the shorter time in which the experiment was not all contaminants were completely removed.

The results of the study indicate that it is worth investing in constructed wetland technologies for greywater treatment, however, the dashboard presented can go a long way in improving wastewater-specific wetland technology design. Whilst this study did not confirm the absolute removal of contaminants such as oil/grease, faecal coliform, and total coliform, it did partially substantiate the need for additional technology. In addition, stakeholders can use the novel methodological framework and decision support dashboard developed with Microsoft Excel when planning the design and implementation of the technology in other communities.

**ACKNOWLEDGMENTS**

Our team expresses gratitude to the following institutions: Kwame Nkrumah University of Science and Technology (KNUST) under Regional Water and Environmental Sanitation Centre, Kumasi, (RWESCK). African Centre’s of excellence (ACE), Kumasi Ghana, and Department of Civil Engineering, and National Water Resource Institute (NWRI), Kaduna Nigeria for the financial their immense technical support provided for the conduct of the study.

My appreciation also goes to the Director (NWRI) Prof. E. A Adanu and my husband Abiodun Ameso their encouragement and financial support.

**REFERENCES**


FUZZI-TOPSIS MODEL ODLUČIVANJA ZA IZBOR TEHNOLOGIJE TRETMANA OTPADNIH VODA IZ MOČVARA

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Apstrakt: Korišćenje formiranih močvara za popravku tretmana otpadnih voda poboljšanjem uklanjanja otpadnih materija po nižoj ceni od konvencionalnih metoda, nedavno je privuklo novo interesovanje. Većina ovih studija je pretežno unapred definisala konfiguraciju močvargornog područja za tretman otpadnih voda, što unosi mnogo empirije i donošenje odluka. Da bi se rešio ovaj problem, ova studija ima za cilj da razvije sistem za podršku odlučivanju (DSS) za odabir, projektovanje i optimizaciju izgrađenih tehnologija močvara (CWT) u toku tretmana otpadnih (sivih) voda. Da se proceni WT za tretman otpadnih voda i odredi koje fizičko-hemijske i mikrobiološke osobine trebu tretirati, alat za donošenje više kriterijuma (MCDM) se koristi istovremeno sa ocenjivanjem usaglašenosti.
Sistem DSS je razvijen nakon detaljnog pregleda literature o dizajnu i implementaciji različitih tretmana WT (HFVSF, HSSF, VSSF i VFSF) i karakteristika otpadnih voda koristeći programski paket Microsoft Visual Studio 2010. Ova studija je zanimljiva po tome što integriše najvažnije podatke (karakteristike otpadnih voda) sa karakteristikama efikasnosti uklanjanja WT kako bi pomogli u odabiru najboljeg tretmana voda (WT).

Rogoz (Tipha domingensis) i zumbul (Eichhornia crassipes) bili su efikasni u uklanjanju zagađivača u kombinaciji sa HFVSF WT. Posle četiri meseca istraživanja, ova studija HFVSF je utvrdila da je CWT tretman zumbulom efikasan. Za HFVSF-CWT tretman zumbulom, efikasnost uklanjanja fkalne koliformne, ukupne koliformne, ulja i masti, amonijaka, ukupnog fosfata i COD 78,46%, 74,33%, 73,08%, 69,23%, 25,29% i 80% respektivno. Odluka DSS o HFVSF-CVT DSS je pokazala da je kompetentno dizajnirana nova kontrolna metoda za odabir CWT tretman otpadnih voda.

**Ključne reči:** Sistem za podršku odlučivanju, izgrađena kontrolna tabla za močvare, tretman otpadnih voda, tehnologija za močvare.

**Prijavljen:** Submitted: 07.02.2023.

**Ispravljen:** Revised: 10.05.2023.

**Prihvaćen:** Accepted: 15.05.2023.