*Asian Journal of Water, Environment and Pollution,* Vol. 14, No. 3 (2017), pp. 27–37.
DOI 10.3233/AJW-170023

# An Optimization Model Using the Standard Deviation Method and Multiple Decision Making Statistics in Water Treatment Plants in Northeastern India

**Sudipa Choudhury*, Mrinmoy Majumder[1] and Apu Kumar Saha**

Department of Mathematics, National Institute of Technology, Agartala, Tripura, India
[1]School of Hydro-Informatics Engineering, National Institute of Technology, Agartala, Tripura, India
✉ Sudipachoudhury032@gmail.com

*Received September 27, 2016; revised and accepted April 19, 2017*

**Abstract:** Water treatment plants provide an integral service to both households and industries by supplying an essential component for day to day living as well as for commercial processes. In order to maintain an efficient and sustainable water supply, the various components implicit in the processes in WTPs need to be aligned in an optimal configuration of settings that balances various input parameters. In order to identify these optimal allocations, this study aims to propose an indicator that represents the suitability of the instruments in surface water treatment plants. It utilizes a new adaptation of multi-criteria decision making techniques, the Standard Deviation Method alongside the well adapted Analytical Hierarchy Process for this purpose. In total six criteria, four sub-criteria and twelve alternatives were considered for the study with the global priorities being computed with the help of the AHP and STD methods.

The GMDH modelling framework was also used to evaluate the relation between various input parameters and the indicator. These methods in effect work to identify priority quality parameters of inputs with respect to the overall performance of the instruments. To refine and improve the MCDM methods used, this study developed twelve different models by adapting the number of inputs as well as the types of training algorithms to increase representative accuracy. Results suggest that daily changes in turbidity were the most significant parameter followed by pH affecting the efficiency of the WTP's key processes.

**Key words:** MCDM, AHP, standard deviation method.

## Introduction

In water treatment plants, that collects and process surface water sources, there are four to five stages of operation before the pure water is produced for supply. The performance of the entire system relies heavily on the working of the four individual components namely, the aerator, clari-flocculator, filter bed and chlorination units which work to process the water. The efficiency of the systems also depends on rated lifetime, time in use, quality of the water, climatic impacts, energy requirements etc. (Kumar et al., 2010). Each of the instruments either removes or reduces the concentration of pollutants. Table 1 in the appendix depicts the equipment and the quality parameters it affects.

**Table 1: The machines utilized in a surface water treatment plant and the quality parameters it can affect**

| *Sl No.* | *Name of the instrument* | *Quality parameter it effects* |
|---|---|---|
| 1 | Aerator | DO |
| 2 | Clariflocculator | TDS, Turbidity |
| 3 | Filtration | Turbidity |
| 4 | Chlorination | pH |

*Corresponding Author

## Methodology

The methodology of the present investigation includes the application of a newly developed MCDM method, known as the Standard Deviation Method alongside the more traditional Analytical Hierarchy Process. The application of these methods aims to identify the most significant priority parameters in attaining systems efficiency. The importance value derived from the MCDM methods will be used to calculate the weight of the input parameters (Velasquez and Hester, 2013).

In addition to the AHP and the Standard Deviation Method, a neural network based algorithm in the form of the Group Method of Data Handling, was also used to estimate the value of the indicator (Anastasakis and Mort, 2001).

The study utilized these methods to analyze the various quality parameters of the water intake at one, two and three day intervals. Specifically the concentration of pH, Dissolved Oxygen, Turbidity and Total Solids parameters were addressed. The priority value of all these parameters were calculated with respect to Lifetime, Time in Use, Efficiency, the Cost of Procurement, Quality of Water, Climatic Impact and Energy Requirement of or on the instruments. These considerations were used as criteria to evaluate the importance of the parameters in terms of their impact on the performance efficiency of the Aerator, Clari-flocculator, Filtration and Chlorination units within the WTP.

The goal of decision making is to identify and represent the impact of the input parameter on the decision making. The influence of all the parameters is not equal in any decision making problem. The method which can substantially display the difference of importance for the parameter with respect to the decision objective is preferred compared to another process which provides nearly differentiable values to represent importance of the parameters. The existing method of AHP, the geometric mean of the ratio of importance between the parameter being compared with the parameter with which it is being compared is calculated to depict the overall significance of the parameter being compared with respect to all the parameters with which it is being compared. But the difference of geometric means between the parameters are not significant and may not be differentiable if actuated after two or lesser decimal spaces. That is why there is an urgent need of calculation of significance which will be sufficiently distinct and differentiable from the same of the other parameters. The deviation of two unique set of numbers is completely distinct from each other.

Thus the determination of standard deviation of the two sets of significance ratios, as derived from comparing the parameters with each other, will yield a distinct magnitude compared to that of geometric mean and hence the deviation instead of geometric mean was used to estimate row priority of each parameter.

The reason for not using variance of the significance ratios is the set of the importance ratios will always be univariate and squaring the standard deviation will estimate variance of the set. But to avoid one extra step for calculation of variance, deviation was used.

### Analytical Hierarchy Process

Developed by Saaty (1980, 1996) in the year of 1978, the AHP method was developed to represent the priority of various competing parameters in order to provide the optimal allocation recommendations for decision makers. It functions by categorizing various relevant parameters into a hierarchy based on their importance to obtaining a specified set of criteria. Pairwise comparisons both within and between hierarchies are then carried out in order to represent the interrelationships between criteria and identify priority more closely (Saaty, 2005). The strength of the AHP method includes its ease of use, flexibility and consideration of both qualitative and quantitative parameters in the decision making processes. In the past it has been used in a range of scenarios. For instance recent uses include the assessment of suppliers in order to meet environmental goals in commercial purchasing decisions (Robert, 2002), as well as the criteria evaluated for the allocation of public sector contracts in Hong Kong. It has also been used to study the best response strategies to natural disasters, for instance the susceptability of landslides in perialpine Slovenia in 2006 helped to provide recommendations for road building and population distribution to minimize repercussions of landslides.

However, the weakness of the method includes some overlapping errors, whilst the scale of importance often mis-represents the priority of those comparison of parameters where difference of importance is at a minimum, owing to the scale of the parameters.

### Standard Deviation Method (STD)

One of the major challenges to methods like AHP and Analytical Network Process is that the pairwise comparison rating is often hazy, indeterminate and non-specific especially for those comparisons where importance is nearly the same. Many studies have applied Fuzzy Logic Decision Making to solve this problem but due to the non-uniformity in the fuzzy scale the representation of the importance between the parameters become erroneous.

The present investigation attempted to utilize the standard deviation between the parameters to depict the comparison of importance. This standard deviation is also multiplied with the importance rank of the row parameter. Thus the parameter with highest importance deviation remains unchanged whereas for other parameters deviation is multiplied by the importance rank of the row parameter. Equation (1), as shown below, represents the governing equation to find the pair-wise comparison of importance between the row and column parameter with the help of STD method.

$$Pr_{\mathrm{ij}} = R_{\mathrm{i}} \times \mathrm{STDEV}(R_{\mathrm{i}}, R_{\mathrm{j}}) \quad (1)$$

where $Pr_{\mathrm{ij}}$ is the output of the comparison between $i^{\mathrm{th}}$ row and $j^{\mathrm{th}}$ column parameter, $R_{\mathrm{i}}$ is the rank of importance of the $i^{\mathrm{th}}$ parameter, STDEV is the standard deviation function of $R_{\mathrm{i}}$ and $R_{\mathrm{j}}$ and $R_{\mathrm{i}}$ and $R_{\mathrm{j}}$ are the rank of importance of the between $i^{\mathrm{th}}$ row and $j^{\mathrm{th}}$ column parameter respectively. $P\mathrm{r}_{\mathrm{ij}}$ is a member of set of real positive integer number and real positive numbers respectively.

Another difference with the AHP method seems to be the way in which the ratings of the row are aggregated. In the STD method, the average of the pairwise comparisons was taken as the overall importance or Priority Value (PV) of the row parameters as opposed to using the geometric mean which is used in the AHP. As the pair-wise rating is already multiplied, geometric mean is avoided. Another difference is that the Saaty scale of importance is replaced with the rank of importance of the parameter which is calculated from the citation frequency of the parameter in various experts' literature, reports and books. All the other steps of AHP were followed to find the final preference degree for each of the parameter.

## Methodology

The objective of the present investigation was achieved by applying MCDM and GMDH methods. In total, two different MCDM methods were used namely AHP and STD. The pre-processing procedures of the method included the selection of criteria and alternatives. Both of which were adopted following a comprehensive literature survey. Figures 1 and 2 (in the Appendix) respectively depict the schematics of the methodology adopted to estimate S-value and the hierarchy structure of the selected criteria and alternatives for the decision making model utilized in this investigation.

The main advantage of the new method was it can estimate the difference of importance for the decision variables in a more distinct manner compared to that derived from AHP or MACBETH method. Another benefit of using this method is less time of convergence as less number of steps has to be followed. The benefit also lies in the fact that due to the deviation method the uncertainty of the normalization output also gets reduced due to the prominence of the generated row priority value for the row parameter. The automated decision making as imbibed by the application of PNN method have also reduced the time of decision making.

### Multi Criteria Decision Making

The ranking of the alternatives were performed with the help of the information collected from various reports, papers, monographs etc. related to the study objective. These were then used to estimate the degree of preference of each of the parameter using the help of AHP and STD processes.

The four criteria, eight sub-criteria and twelve alternatives in the hierarchy are shown in Figure 1.

Using these data inputs the Normalized Priority Value (NPV) (Equation 2) was estimated by the AHP and STD method respectively. This is a measure that is directly proportional to the importance of the parameters with respect to the study objective.

$$\mathrm{NPV} = PV_i \times \left( \sum_{i=1}^{12} PV_i \right)^{-1} \quad (2)$$

### Development of Group Method of Data Handling Model

In total 12 different models were developed by changing the MCDM methods within the STD and AHP processes, with the number of inputs and training algorithm between GMDH and Quick Combinatorial (QC) being kept the same. Table 2 in the Appendix depicts the configuration of all the developed models where output of the frameworks is the weight function of the alternatives (Equation 3).

$$s\text{-value} = \frac{\sum_{l=1}^{3}\left(\sum_{m=1}^{3}(W \times DO)_{lm}\right)}{\sum_{l=1}^{3}\left(\sum_{m=1}^{3}(V \times pH)_{lm} + \sum_{m=1}^{3}(V \times TDS)_{lm} + \sum_{m=1}^{3}(V \times Turbidity)_{lm}\right)} \quad (3)$$

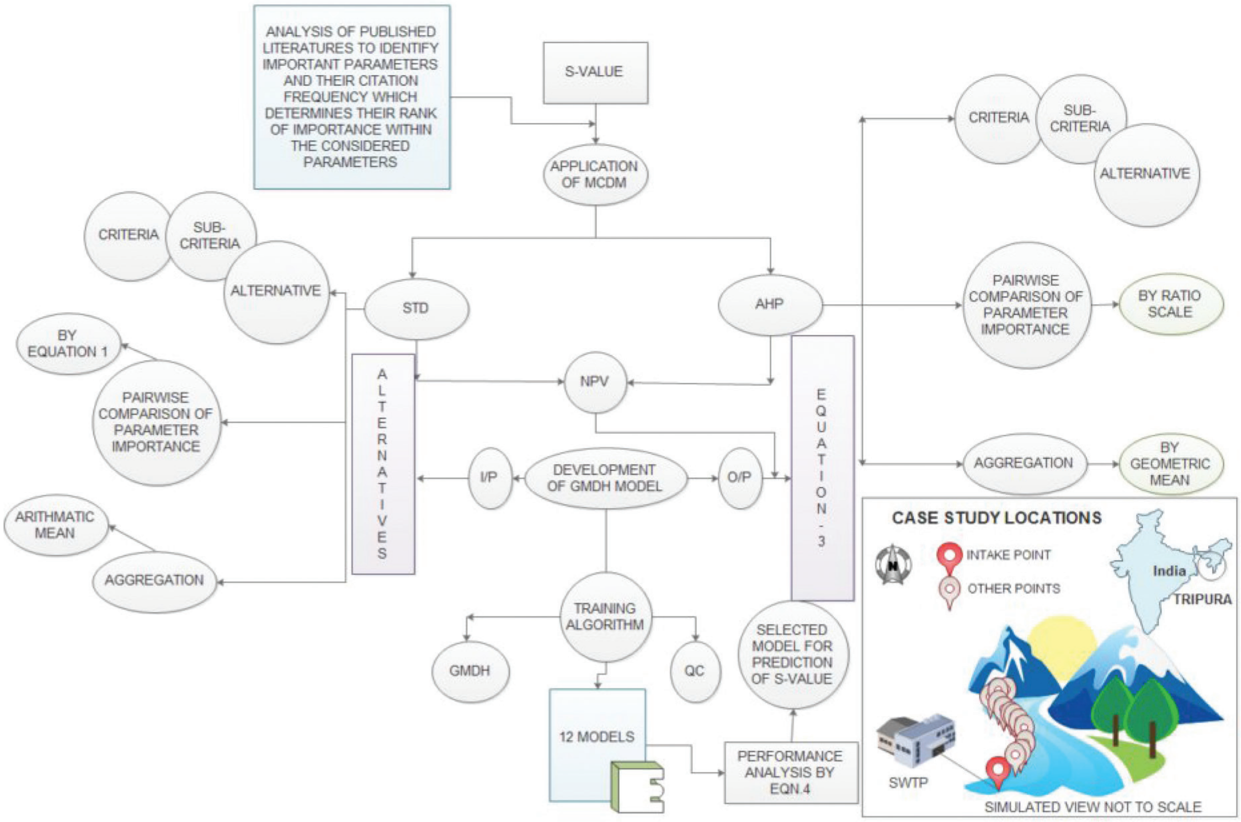


**Figure 1: Schematics of the methodology adopted to achieve the study objective.**

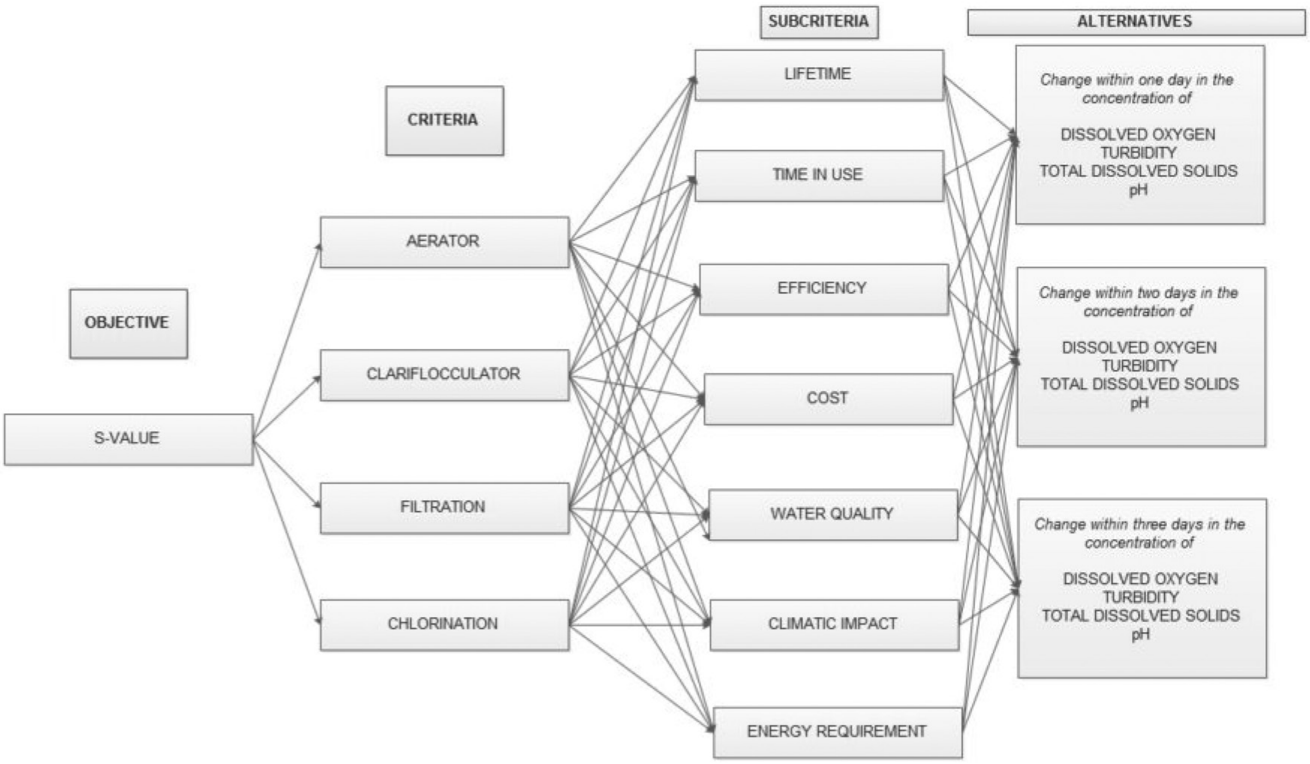


**Figure 2: Decision hierarchy of the MCDM utilized in the present study.**

**Table 2: The characteristics of the models developed to predict S-value**

| *Sl No.* | *Model No.* | *No. of I/P* | *No. of O/P* | *MCDM* | *Training Algorithm* |
|---|---|---|---|---|---|
| 1 | 121STDGMDH | 12 | 1 | STD | GMDH |
| 2 | 81STDGMDH | 8 | 1 | STD | GMDH |
| 3 | 41STDGMDH | 4 | 1 | STD | GMDH |
| 4 | 121AHPGMDH | 12 | 1 | AHP | GMDH |
| 5 | 81AHPGMDH | 8 | 1 | AHP | GMDH |
| 6 | 41AHPGMDH | 4 | 1 | AHP | GMDH |
| 7 | 121STDQC | 12 | 1 | STD | QC |
| 8 | 81STDQC | 8 | 1 | STD | QC |
| 9 | 41STDQC | 4 | 1 | STD | QC |
| 10 | 121AHPQC | 12 | 1 | AHP | QC |
| 11 | 81AHPQC | 8 | 1 | AHP | QC |
| 12 | 41AHPQC | 4 | 1 | AHP | QC |

Here, *s*-value is the suitability of water to be treated by the machines, $l$ is the number of days, $m$ is the number of parameters and $W$ and $V$ are the priority values of the beneficiary and non-beneficiary parameters respectively.

This weight function was developed with the help of the twelve alternatives. According to this model the parameters which increase the suitability of the water to be treated by the machines are placed in the numerator and the rest of the parameters which are found to be non-beneficiary with respect to the study objective are kept in the denominator.

In this investigation the change in concentration of Dissolved Oxygenate one, two and three days intervals was found to be beneficiary whereas the changes in the concentration of all the other considered parameters such as Total Dissolved Solids (TDS), Turbidity and pH within one, two and three days were taken as non-beneficiary parameters. As the priority of all the parameters were not same, the NPV as determined by the MCDM methods were used as the weightage of the parameters in the weight function.

The ANN is commonly used to estimate the inter relationship between highly non-linear and nearly un-mappable variables from a given set of data. The trial and error method utilized for development of the network topology and magnitude of the weight of the connections between the input, hidden and output layers imbibes uncertainty in the accuracy of the predictions. Sometimes various nature based search algorithms or conventional gradient or propagation algorithms were used to estimate the topology as well as the weight magnitude. But as many algorithms were required to be utilized, the requirement of computational infrastructure also gets increased aggravating the cost involved in the development of the model.

PNN on the other hand have the capability to self-estimate the topology and weight magnitude for optimal result. That is why the space and time required for learning a problem for a PNN model is less compared to that of the ANN model. That is why the PNN model instead of ANN was utilized to develop the modelling framework.

The model was trained with 600 randomly generated situations where the division of training and testing data was 60 and 40% respectively. Key to note, all these inputs featured non-linear reference functions, with the model output being compared with the actual output to find the performance efficiency of the frameworks. The performance metrics used to identify the better model among the various selected models were estimated by Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Covariance (Cover) and differences in peak (DP) of the actual and predicted maximum. The models were selected based on the 60% of testing metrics and 40% of training metrics and as per PI (Equation 4) which is directly proportional to model suitability.

$$PI = \{0.6 \times (MAE_{kT} + RMSE_{kT} + Covar_{kT} + DP_{kT}) + 0.4 \times (MAE_{kT} + RMSE_{kT} + Covar_{kT} + DP_{kT})\}^{-1} \quad (4)$$

where *PI* is the Performance Index and *MAE*, *RMSE*, *Cover* and *DP* are the Mean Absolute Error, Root Mean Square Error, Covariance and Difference of Peak between the actual and predicted training (T) and testing (t) data of the $k^{th}$ model.

### Case Study

The model was used for the Bardowali WTP situated in semi-urban city of Agartala, Tripura located in North-Eastern part of India.

The indicator was calculated for the water at the intake of the Surface Water Treatment Plant (SWTP) and nineteen numbers of points previous to this point in the river channel was estimated to represent the suitability of the water to be treated by the available machines.

The indicator was developed in such a way that more the value of the indicator more will be suitability of the water to be treated by the machines available in the SWTP.

The segmented function was used to include the impact and abstraction of all the input variables on the output indicator variable because the indicator is used to depict the performance efficiency of the WTP in terms of all the correlated variables that control the performance of WTP.

The urban surface runoff is fed to the SWTP. The catchment is mostly pervious and has high density of population. Although in the higher altitude runoff from agriculture basins have sufficient contribution in deciding the quality of water in the downstream. As a result the BOD is high in the upstream compared to downstream whereas the COD is higher in case of latter as compared to the former location. The pH lies in the acidic region in the upstream and alkaline in the downstream due to the presence of fertilizers used for cultivation. The faecal and total coliform of the intake water is high in the city area compared to that in the rural areas. The presence of heavy metals is rare but fluoride hazards are commonly observed in the region.

## Results and Discussion

The results from the STD and AHP methods regarding the Priority Value (PV) of the sub-criteria and alternatives are shown in Tables 3, 4, 5 and 6 respectively in the appendix, whereas results of the performance metrics from the 12 models developed to predict S-value is depicted in Table 7. The value of the indicator for the intake and the eighteen different locations before the intake point are shown in Table 8. The sensitivity analysis of the selected model has been depicted in Table 9 which shows the result of the case study.

The results depicted suggest that the temporal variation over a single day is the most important factors among all the parameters and with respect to both STD and AHP methods followed by pH and DO.

The results from the comparison of the sub-criteria suggest that the cost of operation and maintenance of the instruments followed by their efficiency are the two most important parameters with respect to the results from both the STD and AHP methods. The NPV from the STD and AHP was also compared, and it was found that for alternatives the NPV from AHP is more pronounced than STD whereas in case of the NPV of sub-criteria, the STD is a more specialized measure compared to AHP.

However in case of the pairwise comparison ratings of the parameters, the values of the STD appear to be greater than the same from AHP method. This suggests that the ability of the former to clearly and specifically represent comparison ratings of two parameters may make it better adapted to create clearer and specific decision recommendations. The better model among all the frameworks in the testing phase was found to have a STD GMDH value with an MAE and RMSE equal to 0.000259 and 0.011000 respectively along with a covariance of 0.015. These values are 0.16, 0.84 and 0.74 times less than the AHP GMDH model. The PI metrics of the former model was found to be better than 1.37 times compared to the latter model. For this reason the STD GMDH model was used to predict the S-value of the intake point as well as the other eighteen points before the intake.

The results from the sensitivity analysis showed that the sensitivity of all the parameters are not same as the PV of the alternatives but the relationship between the parameters and the output was maintained in each

**Table 3: Priority values of the sub-criteria as estimated by STD method**

| *Wt of crit* | *0.200* | *0.400* | *0.240* | *0.160* | | |
|---|---|---|---|---|---|---|
| *SC* | *Aerator* | *Clariflocculator* | *Filtration* | *Chlorination* | *PV* | *NPV* |
| Lifetime | 0.096 | 0.083 | 0.180 | 0.076 | 0.027 | 0.108 |
| Time in use | 0.077 | 0.092 | 0.180 | 0.099 | 0.028 | 0.111 |
| Efficiency | 0.240 | 0.210 | 0.097 | 0.218 | 0.048 | 0.190 |
| Cost | 0.240 | 0.210 | 0.243 | 0.218 | 0.056 | 0.225 |
| Water quality | 0.135 | 0.210 | 0.097 | 0.218 | 0.042 | 0.169 |
| Climatic | 0.135 | 0.105 | 0.102 | 0.074 | 0.026 | 0.105 |
| Energy reqnt | 0.077 | 0.092 | 0.102 | 0.097 | 0.023 | 0.092 |

*Note:* Wt of crit = Weight or Priority value of the criterion, SC = Name of the sub-criterion, PV = Priority value and NPV = Normalized priority value.

**Table 4: Priority values of the alternatives as estimated by STD method**

| *Wt of crit* | *0.108* | *0.111* | *0.190* | *0.225* | *0.169* | *0.105* | *0.092* | | |
|---|---|---|---|---|---|---|---|---|---|
| *ALT* | *Lifetime* | *Time in Use* | *Efficiency* | *Cost* | *Water Quality* | *Climatic* | *Energy reqnt* | *PV* | *NPV* |
| DO1 | 0.087 | 0.100 | 0.154 | 0.052 | 0.144 | 0.160 | 0.087 | 0.016 | 0.111 |
| pH1 | 0.144 | 0.100 | 0.133 | 0.147 | 0.144 | 0.136 | 0.144 | 0.020 | 0.137 |
| Turbidity1 | 0.144 | 0.138 | 0.114 | 0.147 | 0.144 | 0.136 | 0.144 | 0.020 | 0.138 |
| TDS1 | 0.144 | 0.138 | 0.096 | 0.078 | 0.087 | 0.056 | 0.144 | 0.014 | 0.101 |
| DO2 | 0.048 | 0.054 | 0.081 | 0.060 | 0.070 | 0.095 | 0.048 | 0.009 | 0.066 |
| pH2 | 0.070 | 0.054 | 0.068 | 0.109 | 0.070 | 0.077 | 0.070 | 0.011 | 0.078 |
| Turbidity2 | 0.070 | 0.100 | 0.058 | 0.109 | 0.070 | 0.077 | 0.070 | 0.012 | 0.081 |
| TDS2 | 0.070 | 0.100 | 0.052 | 0.065 | 0.048 | 0.056 | 0.070 | 0.009 | 0.064 |
| DO3 | 0.045 | 0.061 | 0.051 | 0.074 | 0.045 | 0.055 | 0.086 | 0.008 | 0.059 |
| pH3 | 0.045 | 0.061 | 0.054 | 0.055 | 0.045 | 0.048 | 0.045 | 0.007 | 0.051 |
| Turbidity3 | 0.045 | 0.047 | 0.062 | 0.055 | 0.045 | 0.048 | 0.045 | 0.007 | 0.051 |
| TDS3 | 0.086 | 0.047 | 0.077 | 0.050 | 0.086 | 0.056 | 0.045 | 0.009 | 0.065 |

*Note:* Wt of crit = Weight or Priority value of the Criterion, ALT = Name of the alternatives, PV = Priority value and NPV = Normalized priority value.

**Table 5: Priority values of the sub-criteria as estimated by AHP method**

| *Wt of crit* | *0.120* | *0.480* | *0.240* | *0.160* | | |
|---|---|---|---|---|---|---|
| *SC* | *Aerator* | *Clariflocculator* | *Filtration* | *Chlorination* | *PV* | *NPV* |
| Lifetime | 0.080 | 0.044 | 0.176 | 0.053 | 0.020 | 0.081 |
| Time in use | 0.064 | 0.066 | 0.176 | 0.066 | 0.023 | 0.092 |
| Efficiency | 0.320 | 0.263 | 0.088 | 0.266 | 0.057 | 0.228 |
| Cost | 0.320 | 0.263 | 0.353 | 0.266 | 0.073 | 0.292 |
| Water quality | 0.107 | 0.263 | 0.088 | 0.266 | 0.051 | 0.203 |
| Climatic | 0.046 | 0.038 | 0.059 | 0.044 | 0.011 | 0.045 |
| Energy reqnt | 0.064 | 0.066 | 0.059 | 0.038 | 0.015 | 0.059 |

*Note:* Wt of crit = Weight or Priority value of the criterion, SC = Name of the sub-criterion, PV = Priority value and NPV = Normalized priority value.

aspect except the change in concentration of pH within two days.

The sensitivity analysis of the input parameters with respect to the output parameter was carried out with the help of One at a Time or OT sensitivity analysis method.

In addition, the NPV of Turbidity was shown to be at a maximum followed by the pH. However, in the case of sensitivity, the DO is followed by the TDS, Turbidity and pH were found to be the most sensitive in the model with respect to the changes in concentration within a day. But this can be attributed to the fact that DO is taken as the only beneficiary parameter of the weight function. This may also be the reason why DO becomes the most sensitive parameter not only in terms of one day temporal changes but be for two and three days temporal measures also. On the other hand, the sensitivity of the non-beneficiary parameters depends on the pH, Turbidity and TDS. The results suggest that the TDS was found to be most sensitive compared to the other two factors whereas NPV of Turbidity is shown to be the highest followed by pH.

The reason for this result can be that the minor difference that exists between the three parameters arises due to daily variations. It was found that the NPV of Turbidity is 1.003 and 1.370 times greater than pH and TDS respectively which may be the reason why the model fails to understand the difference of importance between the turbidity, pH and TDS. The case study results also depicted the need for adjustment in the instruments installed in the WTP based on the indicator

**Table 6: Priority values of the alternatives as estimated by AHP method**

| *Wt of crit* | *0.081* | *0.092* | *0.228* | *0.292* | *0.203* | *0.045* | *0.059* | | |
|---|---|---|---|---|---|---|---|---|---|
| *ALT* | *Lifetime* | *Time in use* | *Efficiency* | *Cost* | *Water Quality* | *Climatic* | *Energy reqnt* | *PV* | *NPV* |
| DO1 | 0.057 | 0.083 | 0.322 | 0.027 | 0.228 | 0.299 | 0.057 | 0.022 | 0.157 |
| pH1 | 0.228 | 0.083 | 0.161 | 0.270 | 0.228 | 0.150 | 0.228 | 0.030 | 0.208 |
| Turbidity1 | 0.228 | 0.249 | 0.107 | 0.270 | 0.228 | 0.150 | 0.228 | 0.030 | 0.211 |
| TDS1 | 0.228 | 0.249 | 0.081 | 0.054 | 0.057 | 0.030 | 0.228 | 0.015 | 0.102 |
| DO2 | 0.028 | 0.036 | 0.064 | 0.025 | 0.046 | 0.075 | 0.028 | 0.006 | 0.042 |
| pH2 | 0.046 | 0.036 | 0.054 | 0.090 | 0.046 | 0.060 | 0.046 | 0.009 | 0.060 |
| Turbidity2 | 0.046 | 0.083 | 0.046 | 0.090 | 0.046 | 0.060 | 0.046 | 0.009 | 0.063 |
| TDS2 | 0.046 | 0.083 | 0.040 | 0.045 | 0.028 | 0.030 | 0.046 | 0.006 | 0.043 |
| DO3 | 0.025 | 0.023 | 0.036 | 0.022 | 0.025 | 0.043 | 0.019 | 0.004 | 0.027 |
| pH3 | 0.025 | 0.023 | 0.032 | 0.039 | 0.025 | 0.037 | 0.025 | 0.004 | 0.031 |
| Turbidity3 | 0.025 | 0.028 | 0.029 | 0.039 | 0.025 | 0.037 | 0.025 | 0.004 | 0.031 |
| TDS3 | 0.019 | 0.028 | 0.027 | 0.030 | 0.019 | 0.030 | 0.025 | 0.004 | 0.026 |

*Note:* Wt of crit = Weight or Priority value of the criterion, ALT = Name of the alternatives, PV = Priority value and NPV = Normalized priority value.

value of all the points considered. This is because as the normalized suitability value of the water at intake point was found to be only 5.58%, it appears to be the eighth most suitable point compared to the 19 points in total that are considered in the study. Among these it was found that the water at the fourth point was most suitable and at the seventh point before the intake was least suitable and required to be treated more by the existing instruments available at the plant.

**Scientific Benefit**

The indicator was developed with respect to the impact of water quality parameters on the operational procedure of the four units installed in most of the WTP. The system was made adaptive as well as non-preferential as described in the methodology. For this reason the output from the indicator can be treated as reliable and as such appears to be a true representation of the situation. It suggests that so long as uncertainty can be identified, expenditure can be reduced by making the systems proactively responsive to the input parameters thereby making them more efficient.

**Limitation**

The inclusion of six top level criteria followed by the sub-criteria and alternatives contributed to the indicator value increasing it by 72 units. The procedure also required multiple data entries in order to get the complete ranking from the MCDM and in order to give a verification of its accuracy. The situation can be more optimized if the intake point of the internal treatment cycle was used but it was not generally possible due to financial constraints of the plant.

## Conclusion

The present investigation has attempted to produce an indicator which can alert the user about the possible impact on the equipments installed in the WTPs. In total six criteria, four sub-criteria and twelve alternatives were considered for the study with the global priorities being computed with the help of the AHP and STD methods. The GMDH modelling framework was also utilized with training algorithms being generated using the PV of the STD method as weights for the output to establish the interrelationship between the input parameters and the indicator under observation. The methodology involved monitoring the performance of input variables over three days with six input factors being observed which included pH, Dissolved Oxygen levels, Turbidity and Total Solids; the priority values being calculated were generated keeping in mind the Lifetime, Time in Use, Efficiency and Cost of Procurement in establishing and maintain the standards of the Quality of Water, Climatic Impact and Energy Requirements. In order to improve accuracy, twelve different models were developed for this study by changing the MCDM methods applied as well as the number of inputs and the types of training algorithms used. Performance metrics like MAE, RMSE, Cover and DP were also used for this end.

**Table 7: Performance metrics of the models developed to predict S-value**

| *Sl No.* | *Model name* | *No of I/P* | *No of O/P* | *MCDM* | *Training algorithm* | *Training metrics* | | | | *Testing Metrics* | | | | *PM* | *RANK* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *RMSE* | *MAE* | *Covar* | *DP* | *RMSE* | *MAE* | *Covar* | *DP* | | |
| 1 | 121STDGMDH | 12 | 1 | STD | GMDH | 0.010045 | 2.19E-16 | 0.019060 | 0.027483 | 0.011176 | 0.000259 | 0.015421 | -0.024204 | 41.277298 | 1 |
| 2 | 81STDGMDH | 8 | 1 | STD | GMDH | 0.054169 | 3.63E-16 | 0.016227 | 0.075501 | 0.065391 | 0.003101 | 0.012447 | -0.048833 | 12.882860 | 4 |
| 3 | 41STDGMDH | 4 | 1 | STD | GMDH | 0.090995 | 5.14E-16 | 0.010881 | 0.490351 | 0.077359 | 0.003937 | 0.009669 | 0.141960 | 2.655017 | 9 |
| 4 | 121AHPGMDH | 12 | 1 | AHP | GMDH | 0.009592 | 3.12E-18 | 0.026884 | 0.002819 | 0.013172 | 0.001654 | 0.020609 | -0.006417 | 30.184961 | 2 |
| 5 | 81AHPGMDH | 8 | 1 | AHP | GMDH | 0.025203 | 1.25E-16 | 0.026341 | -0.009990 | 0.034895 | 0.001158 | 0.019461 | 0.004077 | 19.092710 | 3 |
| 6 | 41AHPGMDH | 4 | 1 | AHP | GMDH | 0.049199 | 5.98E-17 | 0.024555 | -0.000279 | 0.079204 | 0.003756 | 0.019960 | -0.884888 | 2.273812 | 11 |
| 7 | 121STDQC | 12 | 1 | STD | QC | 0.043520 | 3.95E-15 | 0.017267 | 0.482257 | 0.029863 | 0.001636 | 0.015442 | 0.058823 | 3.562831 | 5 |
| 8 | 81STDQC | 8 | 1 | STD | QC | 0.067957 | 3.95E-15 | 0.014543 | 0.541372 | 0.063744 | 0.005013 | 0.012946 | 0.084126 | 2.864947 | 8 |
| 9 | 41STDQC | 4 | 1 | STD | QC | 0.094478 | 3.6E-15 | 0.010235 | 0.579643 | 0.078286 | 0.004981 | 0.009432 | 0.214575 | 2.182897 | 12 |
| 10 | 121AHPQC | 12 | 1 | AHP | QC | 0.060641 | 3.79E-15 | 0.023299 | 0.573726 | 0.038744 | 0.004445 | 0.020814 | 0.062133 | 2.952049 | 6 |
| 11 | 81AHPQC | 8 | 1 | AHP | QC | 0.065692 | 3.66E-15 | 0.022661 | 0.592246 | 0.045880 | 0.005899 | 0.020477 | 0.053796 | 2.874629 | 7 |
| 12 | 41AHPQC | 4 | 1 | AHP | QC | 0.079748 | 3.3E-15 | 0.020616 | 0.593511 | 0.052651 | 0.006618 | 0.018672 | 0.113900 | 2.546766 | 10 |

**Table 8: S-value of the intake and other 18 points before the intake**

| *Sl No.* | *Distance from intake (km)* | $DO_1$ | $pH_1$ | $Turbidity_1$ | $TDS_1$ | $DO_2$ | $pH_2$ | $Turbidity_2$ | $TDS_2$ | $DO_3$ | $pH_3$ | $Turbidity_3$ | *TDS3* | *SV* | *NSV* | *Relative Rank* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intake | 0 | 0.827 | 0.395 | 0.927 | 0.273 | 0.343 | 0.839 | 0.141 | 0.303 | 0.686 | 0.764 | 0.630 | 0.438 | 0.361 | 0.05575 | 8 |
| 2 | 1 | 0.310 | 0.404 | 0.296 | 0.494 | 0.393 | 0.289 | 0.547 | 0.532 | 0.205 | 0.002 | 0.644 | 0.636 | 0.234 | 0.036074 | 13 |
| 3 | 2 | 0.481 | 0.887 | 0.573 | 0.242 | 0.663 | 0.062 | 0.103 | 0.628 | 0.162 | 0.326 | 0.851 | 0.175 | 0.248 | 0.038343 | 12 |
| 4 | 3 | 0.692 | 0.213 | 0.631 | 0.137 | 0.530 | 0.376 | 0.652 | 0.260 | 0.431 | 0.726 | 0.590 | 0.840 | 0.435 | 0.067059 | 6 |
| 5 | 4 | 0.520 | 0.532 | 0.189 | 0.142 | 0.698 | 0.115 | 0.339 | 0.377 | 0.687 | 0.255 | 0.915 | 0.456 | 0.582 | 0.089846 | 1 |
| 6 | 5 | 0.195 | 0.231 | 0.141 | 0.027 | 0.413 | 0.945 | 0.067 | 0.746 | 0.799 | 0.554 | 0.366 | 0.200 | 0.305 | 0.047092 | 10 |
| 7 | 6 | 0.474 | 0.481 | 0.151 | 0.371 | 0.346 | 0.482 | 0.367 | 0.602 | 0.951 | 0.637 | 0.365 | 0.699 | 0.405 | 0.062438 | 7 |
| 8 | 7 | 0.320 | 0.501 | 0.935 | 0.685 | 0.399 | 0.933 | 0.487 | 0.738 | 0.859 | 0.886 | 0.492 | 0.858 | 0.179 | 0.027685 | 19 |
| 9 | 8 | 0.710 | 0.338 | 0.389 | 0.117 | 0.803 | 0.214 | 0.551 | 0.658 | 0.468 | 0.990 | 0.540 | 0.410 | 0.533 | 0.082177 | 3 |
| 10 | 9 | 0.829 | 0.270 | 0.243 | 0.768 | 0.946 | 0.605 | 0.903 | 0.546 | 0.343 | 0.471 | 0.046 | 0.709 | 0.543 | 0.083791 | 2 |
| 11 | 10 | 0.589 | 0.147 | 0.547 | 0.174 | 0.586 | 0.806 | 0.756 | 0.264 | 0.832 | 0.151 | 0.219 | 0.113 | 0.464 | 0.07153 | 5 |
| 12 | 11 | 0.320 | 0.265 | 0.051 | 0.814 | 0.030 | 0.017 | 0.960 | 0.241 | 0.246 | 0.622 | 0.289 | 0.685 | 0.211 | 0.032566 | 15 |
| 13 | 12 | 0.568 | 0.581 | 0.516 | 0.075 | 0.856 | 0.465 | 0.272 | 0.862 | 0.087 | 0.124 | 0.234 | 0.072 | 0.359 | 0.055336 | 9 |
| 14 | 13 | 0.507 | 0.671 | 0.842 | 0.753 | 0.116 | 0.217 | 0.540 | 0.697 | 0.880 | 0.501 | 0.078 | 0.596 | 0.223 | 0.034374 | 14 |
| 15 | 14 | 0.397 | 0.865 | 0.176 | 0.937 | 0.497 | 0.971 | 0.723 | 0.752 | 0.498 | 0.772 | 0.739 | 0.158 | 0.192 | 0.029638 | 17 |
| 16 | 15 | 0.770 | 0.729 | 0.342 | 0.611 | 0.034 | 0.725 | 0.724 | 0.616 | 0.200 | 0.900 | 0.620 | 0.730 | 0.287 | 0.044221 | 11 |
| 17 | 16 | 0.795 | 0.057 | 0.756 | 0.298 | 0.809 | 0.529 | 0.533 | 0.207 | 0.528 | 0.219 | 0.628 | 0.863 | 0.525 | 0.081055 | 4 |
| 18 | 17 | 0.187 | 0.651 | 0.814 | 0.999 | 0.999 | 0.616 | 0.690 | 0.700 | 0.916 | 0.833 | 0.153 | 0.351 | 0.186 | 0.028654 | 18 |
| 19 | 18 | 0.335 | 0.784 | 0.568 | 0.736 | 0.862 | 0.976 | 0.651 | 0.297 | 0.389 | 0.010 | 0.916 | 0.439 | 0.210 | 0.032371 | 16 |

*Note:* SV is the S-value and NSV is the normalized S-Value. Relative rank is the rank according to the S-value of the points. The first rank is for the point with maximum S-value.

**Table 9: Sensitivity analysis of the selected model**

| *Name of I/P* | *Sensitivity* | *Beneficiary(B)/Non-Beneficiary(NB)* |
|---|---|---|
| $DO_1$ | 0.881591 | B |
| $pH_1$ | -0.015901 | NB |
| $Turbidity_1$ | -0.018564 | NB |
| $TDS_1$ | -0.020549 | NB |
| $DO_2$ | 0.129491 | B |
| $pH_2$ | 0.003803 | NB |
| $Turbidity_2$ | -0.002935 | NB |
| $TDS_2$ | -0.005691 | NB |
| $DO_3$ | 0.067815 | B |
| $pH_3$ | -0.000001 | NB |
| $Turbidity_3$ | -0.004427 | NB |
| $TDS_3$ | -0.014633 | NB |

The number in the subscript indicates the number of days within which the change in concentration of the parameter has occurred.

According to the results of the model developed which featured 12 inputs, the GMDH training algorithms was found to be the better model. In addition, among the input parameters change in turbidity within a day was considered to be the most important factor followed by pH. A similar result was also shown when the AHP was applied.

The framework developed here can also be implemented in other treatment plants. The strength of the tool lies in the fact that WTPs frequently require automation and so if data is fed into the indicators by sensors then the optimal functioning of the WTP can be possibly based on feedback from the indicator. In addition, inexpensive sensors are now available to facilitate the establishment of feedback mechanisms.

In the present version, the method can only be applied to SWTP but in the future more modification and development will be made to provide an efficient and cheap framework of decision making for monitoring SWTP as well as WWTP.

The parameters selected for finding the decision is identified in such a manner that the condition of any urban or rural SWTP can be represented.

The study proposed a new method for estimation of performance status of a SWTP. In this aspect AHP was used after modification of the priority of each parameter by the adaptation of the way such values are estimated. The complete automation of the process will reduce time as well as space required to store the priority values.

The standard deviation method utilizes the following assumptions:

1. The rating of the parameter importance will be given by the complement of rank of the alternative when all the parameters are arranged in a descending manner with respect to respective citation frequency. It is assumed that the rank achieved by the parameter with respect to its citation frequency is the representative of parameter significance.
2. The standard deviation of upto two digits after the decimal was considered while comparing the parameters with respect to the standard deviation of the ratio of importance for a parameter.

The PNN phase of the model assumed that:

1. The normalized value of the parameters will be entered to the model as the input. The normalization with respect to the values of the same parameter for the other options will only be considered.

## References


Anastasakis, L. and N. Mort (2001). The development of Self-organization techniques in modelling: A review of the Group Method of Data Handling (GMDH). https://www.gmdhshell.com/old/sites/default/files/Research%20Report%20about%20GMDH%20-%20Anastasakis&Mort.pdf.

Kumar, K. Sundara et al. (2010). Performance evaluation of waste water treatment plant. *International Journal of Engineering Science and Technology*, **2(12):** 7785-7796.

Marko, K. (2006). A landslide susceptibility model using the Analytical Hierarchy Process method and multivariate statistics in Slovenia. *Geomorphology*, **74(1-4):** 17-28.

Robert, H. et al. (2002). Applying environmental criteria to supplier assessment: A study in the application of the Analytical Hierarchy Process. *European Journal of Operational Research*, **141(1):** 70-87.

Saaty, T. (1980). The Analytic hierarchy process. McGraw-Hill, New York.

Saaty, T. (1996). Decision making with dependence and feedback: The analytic network process. RWS Publications, Pittsburgh.

Saaty, T. (2005). Theory and Applications of the Analytic Network Process. RWS Publications, Pittsburgh, PA.

Tahriri, F. et al. (2008). AHP approach for supplier evaluation and selection in a steel manufacturing company. *Journal of Industrial Engineering and Management*, **1(02):** 54-76.

Velasquez, M. and P.T. Hester (2013). An Analysis of Multi-Criteria Decision Making Methods. *International Journal of Operations Research*, **10(2):** 56-66.

**Asian Journal of Water, Environment and Pollution**

**Volume 13 Number 4** **October – December, 2016**

# Contents