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PREDICTION OF SOLID WASTE GENERATION WITH ANFIS AND ITS COMPARISON WITH SYSTEM DYNAMIC MODELING: A CASE STUDY OF KHULNA CITY

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ABSTRACT

The prediction of Municipal solid waste (MSW) generation plays an important role in solid waste management. The MSW is mainly generated by human activities. Accurate forecasting of MSW generation is difficult for sustainable management system and planning. In addition, to the population growth and migration, underlying economic development, household size, employment changes, and the impact of waste recycling would influence the solid waste generation interactively. This study was conducted to estimate the MSW generated in Khulna city from 2019 to 2040. The objectives of this study are to find out the influential variable that affect the generation of MSW generation and to predict the future MSW generation in Khulna city. In this study adaptive neuro fuzzy inference system (ANFIS) through MATLAB and system dynamic modeling (SDM) were implemented. In this analysis, population, educated people, uneducated people, MSW generation rate, effect of urban population growth, fuel consumption and number of trips of trucks was considered as input and forecasted value of MSW as output. There are two steps for analysis one was testing and another one was training. To check the performance of this selected models, the prediction parameters like R^2, RMSE, MSE and ARE were considered. The comparison of the results from these models will be performed to select a best model for the prediction of MSW generation rate in Khulna city. All the results in this study can be utilized as part of solid plans for renewable energy development and eco-environmental recycle industry which require MSW as raw material. In this study, results show that three input variables such as educated people, fuel consumption and number of trips of trucks were good enough to predict MSW generation in Khulna. It is estimated that the amount of generated MSW in Khulna will increase at a per capita rate of approximately 2.08% annually. On the other hand, SDM were improved to predict the MSW through Stella software. In this model, the same input variables were used for comparison. The estimation of waste quantum during the period of 2019-2040 shows that, the MSW in the study area can be expected by ANFIS model using MATLAB as around 330774 ton and using system dynamic modeling through Stella is around 307681 ton by the year 2040. It has been found out from previous data that the generation rate of people is approximately 2.6% annually. The central idea in this work is to utilize radial basis function approach of ANFIS model and SDM so as to minimize the discrepancy between the predicted values and observed values of MSW. In addition, result reveals that SDM showed comparatively better results than that of ANFIS. Therefore, the SDM might be used for the prediction of MSW generation rate in Khulna, Bangladesh. This study offers a new perspective on both forecasting and modeling for the prediction of MSW in Khulna city, Bangladesh.

Keywords: *Khulna city, MSW, ANFIS, SDM and Prediction, Waste generation rate.*

1. INTRODUCTION

Civilization and industrialization are related with various waste products. Disposal of waste product is a challenge now-a-day. Sometimes some non-biodegradable materials often lead to waste disposal crisis (Bos M. et al., 1993). Human health and environment can be protected by proper solid waste (Koroneos C. J. & Nanaki E. A., 2012). Both quality and quantity of municipal solid waste (MSW) are changing with time due to influences of variable life style and consumption behaviors (Unnikrishnan S. & Singh A., 2010). Prediction of MSW is crucial for sustainable waste management, it is key element for planning and selecting the handling, treatment and disposal options (Beigl P. et al., 2008). However, due to influence of multiple factors that change with time, solid waste forecasting is complex task (Younes S M. K. et al., 2013). As a result of rapid development, urbanization, increase per capita income, and consumption behaviors, the solid waste generation increases dramatically in Khulna. Khulna is Bangladesh's third-largest city, after Dhaka and Chittagong. In the south-western part of the country, on the Rupsha and Bhairab Rivers, it covers an area of 59.57 square kilometers (23.00 sq. mi). The district covers 4,394.46 square kilometers (1,696.71 sq. mi) and had a population of 1188000 (2011 census). Khulna is south of Jessore and Narial, east of Satkhira, west of Bagerhat and north of the Bay of Bengal. It is part of the Ganges Delta, the world's largest river delta. The Sundarbans, the world's largest mangrove forest, is in the southern part of the delta. Khulna is in the northern part of the district, and the Mayur River is the western boundary of the metropolitan area. A literature survey was done to evaluate the recent applications of artificial intelligence (AI) based modeling studies in the environmental engineering field. The results of the literature survey showed that most AI based prediction models were implemented for the solution of water/waste water (56%) and air pollution (31%) related environmental problems compared to solid waste (14%) management studies. ANFIS is a dynamic data driven model, uses feed forward network to search for a fuzzy membership function between an inputs and outputs (Shafie A. E. et al., 2011). It combines the powers of fuzzy logic and the neural networks (Noori R. et al., 2009). Moreover, it can be used for short, medium- and long-term forecasting (Mordjaoui & Boudjema, 2011). The fuzzy inference system contains five functional blocks (i) rule base that contains the if-then rules (ii) data base (iii) decision making (iv) fuzzification block that gives the degree of matching (v) defuzzification that transforms the fuzzy results into crisps (Subasi A., 2007). The fuzzy inference system usually employs the input historical data in order to tune and develop the final shape of membership function using either an only backpropagation algorithm or in association with least square method (Ghandoor A. A. & Samhouri M., 2012). However, there are some limitations while employing ANFIS model. If the number of generated rules N for a system with n inputs and p premises is ($N=P^n$) therefore, it might become unaffordable to use ANFIS for problems with several variables. A small increment in the input variables can increase the number of rules and consequent parameters. To remove this error the best input combinations that minimize the model error can be used. RMSE (Lin et al., 2013) and the coefficient of determination (R^2) were used to evaluate the appropriate input selection and model performance and ability to produce precise forecast (Shafie A. E. et al., 2011). However, ANFIS has become more popular due to its accuracy, efficiency and capability of large amount of nonlinear and noisy data. For instance, it is used to predict the MSW in Khulna city using population, educated and uneducated people's, fuel consumption and number of trips of trucks. Again, another analysis was done using system dynamic modeling (SDM) through Stella. This study represents a new approach-system dynamic modeling-for the prediction of MSW in Khulna with limited samples and data available. Where the system environment is not fully defined and understood, system dynamic modeling can be used there for forecasting practice. It can also be used when the database is not sufficient to support the traditional statistical forecasting analysis. To address the impact on sustainable development city wide, the practical implementation was done by a case study in Khulna city. It represents various trends of MSW generation associated with a model using a system dynamic simulation tool-Stella. Finally, the forecast result will be helpful the decision makers properly establishment of sustainable waste management plans. As having seasonal pattern of generating waste, ANFIS and SDM through Stella is used to predict the MSW generation rate in Khulna city.

2. METHODOLOGY ADOPTED

2.1 Case study and data collection

Khulna is located in the south-western part of Bangladesh shown in Figure 1. It covers an area of 59.57 square kilometers with a population of 1344000 in 2015. According to the report of Khulna City Corporation, in latest years the growth rate of population in Khulna city is 2.6% which city has been caused in expanding the MSW generation and as a result making a problem for the MSW management system. According to the CD report, the current actual collected MSW per day is 35% only, whereas, MSW generation rate is 0.40 Kg per capita per day. In the other hand, the rapid population growth rate and urbanization cause the significant fluctuations of MSW generation in this city which consequently results many problems for MSW management system. According to existed reports the amount of generated MSW in Khulna is 450-500 tons per day (Rafizul I. M. & Mahanta P. K.), thus offering an appropriate model for estimating the quantity of generated waste and its fluctuation can be useful for true programming and deciding which is made by related organizations.

Figure 1: Khulna city as case study area (South-Western region of Bangladesh)

2.2 Input Parameters

The MSW generation in a city depends on population, income, living standard, employment and unemployment, educated and uneducated peoples, GDP, fuel consumption, number of trips of truck etc. In the ANFIS model analysis, five inputs and one output were used. In this study, for the prediction of yearly MSW generation, the five input parameters such as populations, educated peoples, uneducated peoples, fuel consumptions and number of trips of truck and hence discussed in the following articles. However, only reasonable variables that are available and affect MSW were used for the analysis. The input variables were population, uneducated people, educated people, fuel consumption (Liter) and number of trips of trucks. The output variable is annual MSW(Tons/Year) generation. There are other variables like family incomes, numbers of family member, family education level, individual income rate etc. However, these variables can't be used to justify the MSW generation rate because some or most of these data are not available in country level. For the estimation of future quantity of populations, fuel consumptions, number of trips of truck, educated and uneducated peoples, the following Equations 1 and 2 were used.

$$\sum y = na + b\sum x \quad (1)$$

$$\sum xy = a\sum x + b\sum x^2 \quad (2)$$

Where, y=prediction input parameter, x=time deviation, n=number of samples, a and b are unknown variables.

2.2.1 Estimated population in study area

In this study, for the prediction of yearly MSW generation, the future population of Khulna city were estimated through least square method by using the following Equation 1. In addition, the population of 1344000 for the year of 2015 was considered. According to KCC report, the yearly increasing rate of population 2.6% was considered. The estimated amount of population for the year of 2019 to 2040 is shown in Figure 2.

$$Y = 1334350 + 46800X \quad (3)$$

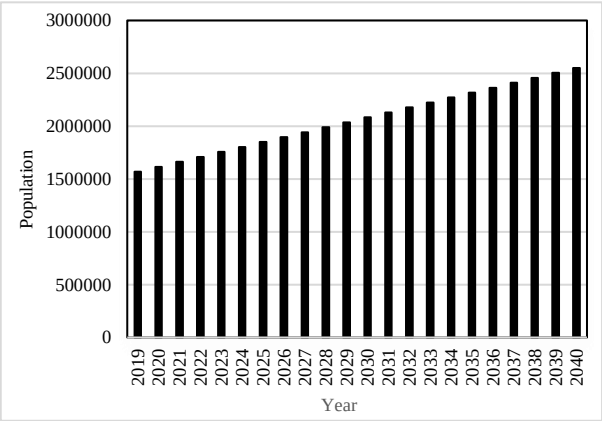

Figure 2: Estimated population of the study area

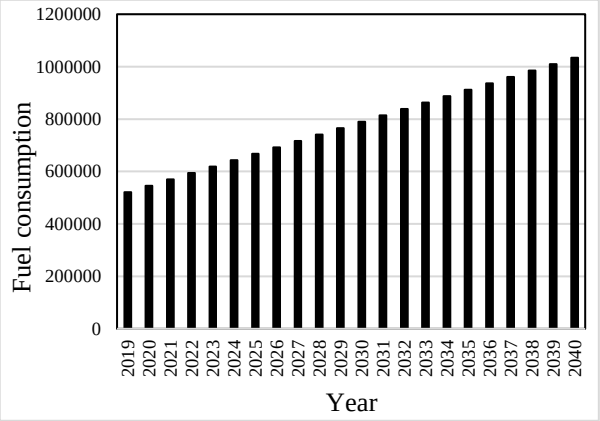

Figure 3: Estimated fuel consumption of the study area

2.2.2 Fuel Consumption

In the study for the prediction of fuel consumption, Equation 4 was used. In addition, the fuel consumption of 436542 liter for the year 2016 was considered. According to KCC report, the yearly rate of fuel consumption 6.5% was considered. The estimated values of fuel consumption for the year 2019 to 2040 is shown in the Figure 3.

$$Y = 423888.23 + 24403.05X \quad (4)$$

2.2.3 Number of trips of truck

Number of trips of trucks is directly related to MSW generation. In the study number of trips of trucks were predicted by using the Equation 5. By counting the trips of trucks, it can be easily found that how much waste is collected in a day. The number of trips of trucks of 53482 was considered for the year 2017. The estimated values of number of trips of trucks for the year 2019 to 2040 is shown in the Figure 4.

$$Y = 10914 + 42568X \quad (5)$$

2.2.4 Educated people's

The number of educated people is also another important factor for maintaining MSW generation rate. The educated people generate less MSW than the uneducated people. In the study number of educated people is estimated by the equation 6. According to KCC report, the yearly rate of educated people 2.9% was considered. The estimated values of number of educated people of 771783 was considered for the year 2012. The estimated values of educated people are shown in the Figure 5.

$$Y = 728436.75 + 9632.5X \quad (6)$$

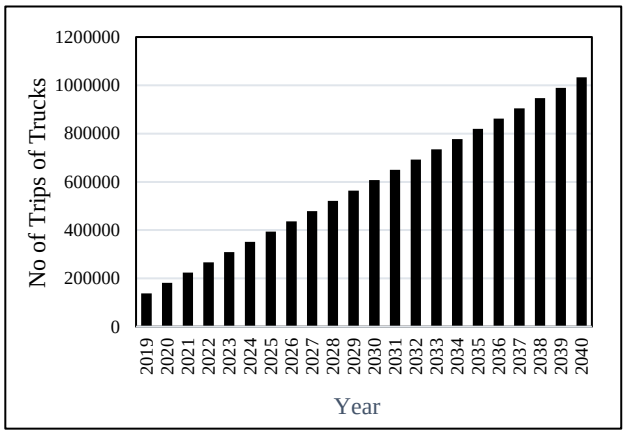

Figure 4: Estimated number of trips of the study area

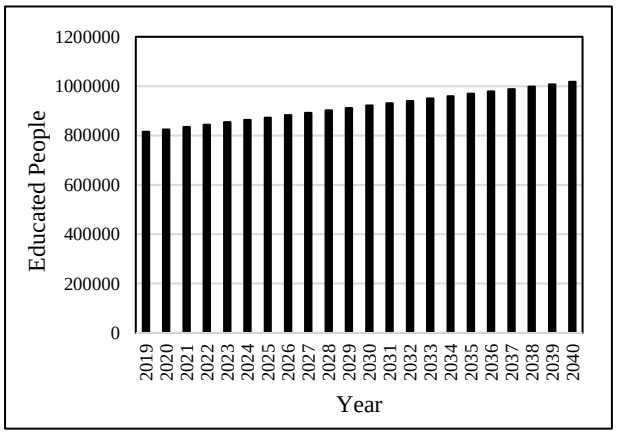

Figure 5: Estimated educated people of the study area

2.2.5 Waste Generation in Khulna

In Khulna city, the yearly MSW generation was found 188000, 195820, 200190, 204190, 208320, 214007, 218908, and 223809 tons for 2011, 2012, 2013, 2014, 2015, 2016, 2017 and 2018 respectively. This yearly MSW generation rate was considered for forecasting of MSW generation rate for the year of 2019 to 2040. By using these previous data, future prediction was done in this study through ANFIS and system dynamic modeling.

2.3 Soft Computing Systems

In this study, for forecasting of MSW in Khulna city, ANFIS and SDM (System dynamic modeling) were implemented. In these two systems, past input variables are needed to predict the future. In the study MSW was predicted from the year 2019 to 2040 by using these two-computing systems. By applying the fuzzy logic and system dynamic modeling both systems can predict the future outcome. Details of working procedure of these two models are given in the following articles.

2.3.1 Adaptive Neuro-Fuzzy Inference System (ANFIS)

Various models for different input parameters were analyzed using Neuro-Fuzzy Designer. For the prediction of MSW through ANFIS, the values of prediction parameters like root mean square error (RMSE) and regression coefficient (R^2) were considered to check the validity of the model. Details of ANFIS is given in the following articles:

2.3.1.1 Data processing

To train ANFIS, a Training data set has been loaded that contained desired input/target data of the system to be modelled. In this study, population, fuel consumption, number of trips of trucks, educated and un educated people were used as input and observed MSW was used as target which placed at last column for modelling a Training data set.

2.3.1.2 Workspace and load data

The input and output parameters were set in the workspace and at the time of training the data were loaded from workspace.

2.3.1.3 Generate FIS

For initializing and generating FIS, two partition methods Grid Partitioning of ANFIS and Subtractive Clustering Method of ANFIS can be used. In our study Grid Partitioning method was used. There are several choices for input membership function like trainmf, trapmf, gbellmf, gaussmf, gauss2mf, pimf, dsigmf and psigmf also only two choices for the output membership function: constant and linear. In the study gaussmf and constant membership function was used to predict the output.

2.3.1.4 FIS output and training

After generating the FIS training was done and RMSE was shown in the toolbox. Then the result was export to workspace for the final output.

2.3.1.5 Output of training from ANFIS

As the file was already exported to workspace, the only input and output was saved in the workspace in two different folders in work space. Then by typing the following code the final output was gained.

Output = evalfis (input, fismat)

The regression graph was found out for the value of R by typing the following code:

Plotregression (target, output)

Then by pressing the enter value regression graph and the value of R was shown in the screen.

2.3.2 System Dynamic Modeling

In most computer simulation applications in system dynamic model Stella software is used as it is very much user friendly. The procedure of these model development is designed based on a visualization process. They offer a flexible way for building variety of simulation models through stock, flow and converter shown in Figure 6. Simulations runs are entirely dependent on prescribed timeline. The following figure shows the diagram of flow, stock and converter. In the stock tons per service center should be inserted first and in the flow the tons rate should be in given as an input. By system dynamic process the final output can be found out by the converter through graph or table chart. The system will calculate dynamically the future MSW generation rate. In the study, it has been seen that the dynamic models presented characterize solid waste generation as exhibiting the behavior of linear growth. There are several simulations models which are used to estimate the solid waste generation. But in this study only one model is used and the driving factor in generation is population. Only considering the population, the final outcome is found out.

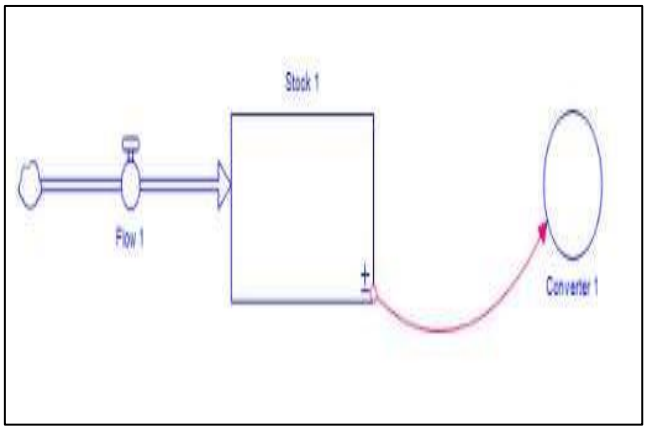

Figure 6: Stella diagram showing stocks, flow and converter

3. RESULTS AND DISCUSSIONS

3.1 Validation of Input Variables

The results of RMSE and R for the combination of input parameters is shown in Figure 7 and Figure 8, respectively. For the input combinations of educated people, fuel consumption and number of trips, the values of RMSE was minimum (435.37) and R was maximum (0.999). On the other hand, for the input combinations of uneducated people, fuel consumption and number of trips, RMSE was maximum and R was minimum and it's values were 4212.12 and 0.990, respectively. For this reason, the input combinations of educated people, number of trips and fuel consumption were selected for prediction of MSW. In these five inputs, the best three input combinations that has the minimum RMSE was used to predict the MSW. The best three combinations were educated people, fuel consumptions and no of trips of trucks.

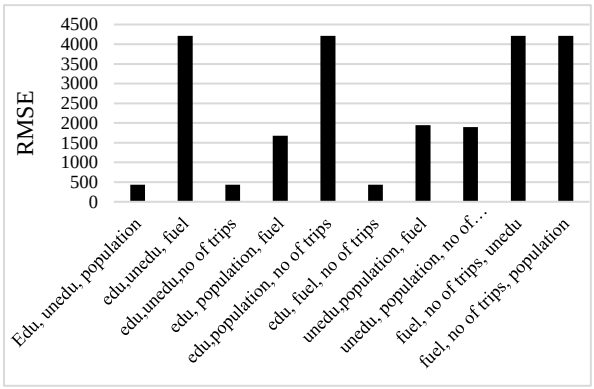

Figure 7: Input combinations against RMSE

In the Figure 9, it is seen that for 100 epochs the RMSE was minimum. For this in the ANFIS, 100 epochs is considered for getting the more accurate result.

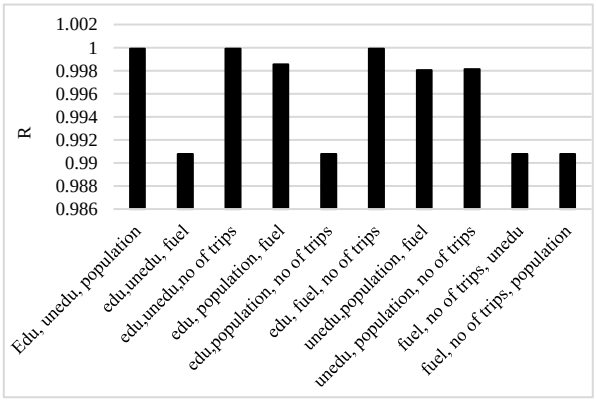

Figure 8: Input combinations against R

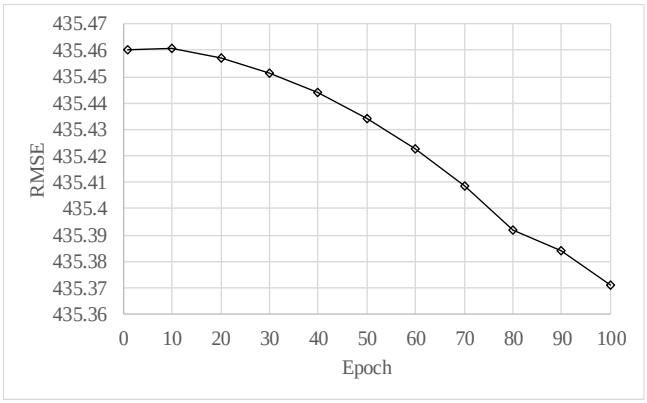

Figure 9: Model performance over 100 epochs.

3.2 Model Outcomes

The best three combintions is shown in Figure 10. In the graph, it is clear that the observed value of MSW and the predicted value of MSW is quite on the similar line. That's because the errors in our predicted data is too small. On the other hand, in Figure 11, the graph is plotted for the worst combinations. In the graph, it is clear that the observed line and the predicted line is quite different from each other as the RMSE is quite large for this input combinations.

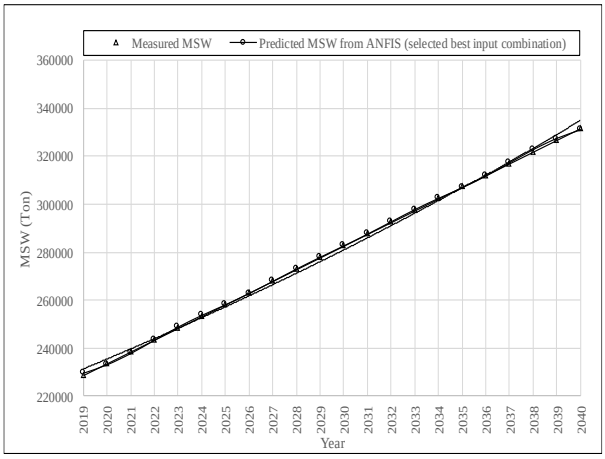

Figure 10: Measured MSW vs Predicted MSW (For best combination)

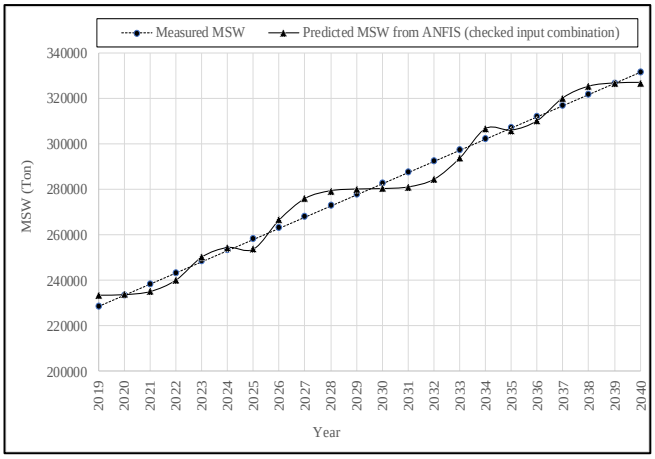

Figure 11: Measured MSW vs Predicted MSW (For worst combination)

At the same time, a simulation model was run through Stella showed in Figure 12. In the following model regression analysis was done in terms of educated people, fuel consumption and no of trips of trucks. The comparison performance of ANFIS and SDM through Stella is shown in the Figure 13.

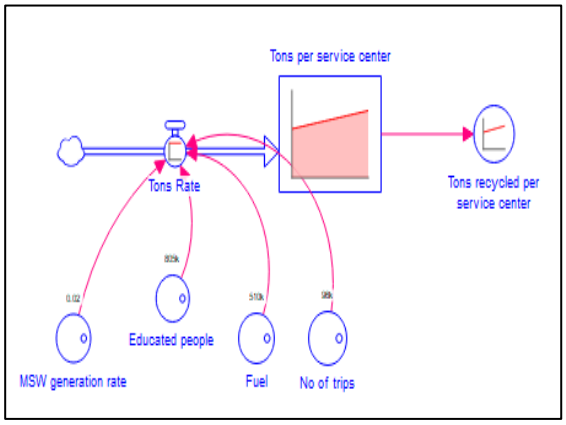

Figure 12: Generalized form of model used to simulate tons generated by historical amount generated.

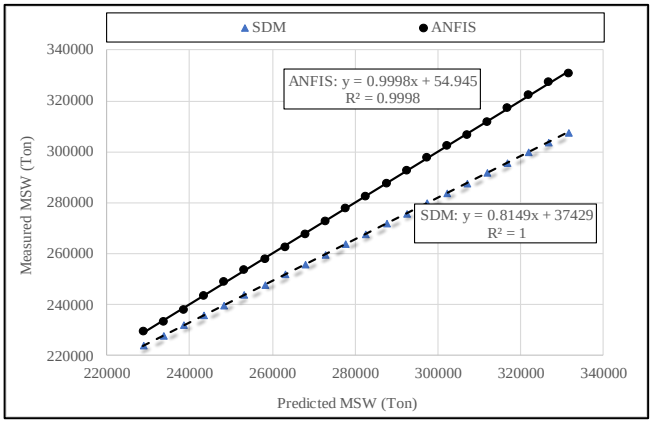

Figure 13: Comparison performance of ANFIS and SDM

4. CONCLUSIONS

Selecting proper input variables is essential to simulate relatively good models. Without proper input variables simulated models will not run properly and give comparatively low quality of result. So, it is important to select qualitative input variables to facilitate modelling in these countries. Thus, the model complexity can be minimized and the model usability can be maximized. In this study, results show that three input variables such as educated people, fuel consumption and number of trips of trucks were good enough to predict MSW generation in Khulna. It is estimated that the amount of generated MSW in Khulna will increase at a per capita rate of approximately 2.08% annually. On the other hand, SDM were improved to predict the MSW through Stella software. In this model, the same input variables were used for comparison. It has been found out from previous data that the generation rate of people is approximately 2.6% annually. The central idea in this work is to utilize radial basis function approach of ANFIS model and SDM so as to minimize the discrepancy between the predicted values and observed values of MSW. In addition, result reveals that SDM showed comparatively better results than that of ANFIS. Therefore, the SDM might be used for the prediction of MSW generation rate in Khulna, Bangladesh. This study offers a new perspective on both forecasting and modeling for the prediction of MSW in Khulna city, Bangladesh.

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