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Effect of Pelleting Parameters on Remediation of Oil Polluted Water Bodies using Kenaf Pellets: A Comparative Analysis using Artificial Neural Network (ANN), Support Vector Machines (SVM) and Response Surface Methodology (RSM)

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Abstract
Environmental degradation from oil spilled has adversely affected ecological life. The study researches the utilisation of locally produced durable biodegradable kenaf pellets in remediating oil spills as well as the use of machine learning and response surface methodology in analysing experimental data. Recent advances in data modelling have necessitated the use of machine learning for predicting experimental outcomes. ANN, SVM and RSM were used in the analysis to analyse the effect of parameters on remediated crude oil polluted water samples. Statistical indices such as MSE, RMSE, MAE, MAD, MAPE, RCoV, rMBE, R^2 were obtained and compared. Graphical plots were also generated and finally, computational codes and mathematical equations were established. Comparisons were made between the three data modelling methods and it was established that based on the optimal choice would be based on the desired output.

Keywords: Pelleting Parameters, Remediation, Water Pollution, ANN, SVM, RSM, Data Analysis

1. Introduction

Crude oil pollution of water bodies is one of the major forms of environmental degradation experienced worldwide, it is a biological hazard that hampers the ecological life therefore distorting ecological equilibrium as well as posing risk of fire outbreaks. Remediating oil polluted water bodies has always been expensive and requires a variety of methods such as mechanical skimming, chemical dispersion, bacteria degradation, combustion etc. [1-4].

Recovering oil spilled has led to the utilisation of agricultural and synthetic absorbent materials such as wool, jute, kenaf, polypropylene, sol-gels for pilot scale experimentation [4-8]. Durable Kenaf starch bonded pellets were produced using a screw type pelletizer with interchangeable auger and were evaluated using a durability testing drum [9,10].

The utilisation of kenaf starch bonded pellets bore down to its oleophilic properties, its environmentally friendly composition as well as to improve handling during dispersion and retraction from water bodies [4,11,12]. There is the need to evaluate its efficacy in remediating oil polluted water, associate pelleting parameters with its efficiency using machine learning tools as well as optimise and predict improvisions.

This would involve the use of Regression learning tool in MATLAB for Artificial Neural Network (ANN) and Support Vector Machine (SVM), as well as Response Surface Methodology (RSM) in Design Expert. These would generate models, plots and codes that can be used to predict future experiments with regards to the utilisation of kenaf in remediating oil polluted water bodies. Ratio of oil in water removed and changes in pH were the properties of oil polluted water evaluated.

2. Materials and Methods

Experimental trials were designed using Central Composite Design on Design Expert software. Simulated oil spill samples were created using 200 ml of water and 50 ml of crude oil obtained from Con oil Nig. Ltd in Port Harcourt, Rivers State, Nigeria. The samples were allowed to sit for 30 minutes. 34g of Kenaf pellets produced in accordance with the experimental design were added to the samples and allowed to sit for 15 minutes before being retrieved. This procedure was repeated for all trials. The parameters of evaluating remediation were proportion of oil removed and changes in pH of the water.

2.1. Proportion of Oil Removed

The proportion of oil removed during the remediation was determined by dividing the oil content before and after remediation as portrayed in equation (1). The oil content in the water before and after remediation was determined in accordance with ASTM standard ASTM D7575 using a HACH DR/2000 spectrophotometer.

$$Ratio\ of\ Oil\ Removed = \frac{Initial\ Amount\ of\ Oil\ in\ Water\ (ppm)}{Final\ Amount\ of\ Oil\ in\ Water\ (ppm)}$$

2.2. Changes in pH.

The changes in the pH of the water samples before and after remediation were also recorded. The pH of the samples was determined using a RoHS ATC pen type pH meter. The pH meter was first calibrated using a standard buffer solution of 7.0 before use. The probe was then inserted to determine the pH of the polluted water and then recorded.

2.3. Data Analysis

The data for each trial was collated, tabulated and analysed using ANN, SVM and RSM. ANN and SVM are regression learning tools in MATLAB program while RSM is an optimisation tool in Design Expert that shows the effects of two or more independent variables on a dependent variable. ANN is a machine learning language that imitates the human nervous system processing data through interconnected artificial nodes called neurons [13].

Collated data were validated (trained) and tested using machine learning and data correlation indices were recorded and tabulated using a 70:30 ratio respectively. Predictive models (ANN and SVM) were generated using the tabulated results. The best model was selected based on the statistical indices especially the coefficient of determination (R^2). These indices were compared. Plots were also obtained from the models and compared.

The collated data was also optimised using RSM, mathematical models were generated, R Squared (Coefficient of determination) values as well as mathematical equations with respect to the analysed data were obtained.

Data plots were obtained and presented for the three analytical methods.

3. Results

The results from the remediation experiment are presented in Table 1, variable factors were screw pitch, die size (aperture), pelleting speed and starch/kenaf ratio. Comparative analysis of oil removed from the polluted water with regards to data training and testing were presented in Tables (2) and (3).

A: Screw Pitch mm	**B: Die Size mm**	**C: Pelleting Speed rpm**	**D: Starch/Kenaf Ratio**	**Oil in Water (ppm)**	**pH**
Factor 1	Factor 2	Factor 3	Factor 4	Response 13	Response 14
70	35	70	1.75	6060.61	0.09
40	32.5	60	1.5	20000	0.06
80	32.5	60	1.5	16666.7	0.08
50	35	70	1.75	14285.7	0.22
70	30	50	1.75	33333.3	0.02
50	30	50	1.25	4761.91	0.07
70	35	70	1.25	20000	0.18
60	32.5	60	1.5	25000	0.12

70	35	50	1.75	28571.4	0.01
60	32.5	60	1.5	25000	0.12
70	30	50	1.25	16666.7	0.06
50	30	70	1.75	4347.83	0.08
50	35	70	1.25	5263.16	0.2
60	32.5	60	1	11111.1	0.06
70	30	70	1.75	12500	0.07
60	32.5	40	1.5	13333.3	0.05
50	30	70	1.25	5555.55	0.01
60	32.5	60	1.5	25000	0.12
50	35	50	1.25	33333.3	0.01
60	32.5	60	2	22222.2	0.03
50	30	50	1.75	4444.44	0.09
70	30	70	1.25	5000	0.04
60	32.5	60	1.5	25000	0.12
60	37.5	60	1.5	50000	0.02
60	32.5	60	1.5	25000	0.12
70	35	50	1.25	33333.3	0.02
50	35	50	1.75	4255.32	0.09
60	27.5	60	1.5	4166.67	0.02
60	32.5	60	1.5	25000	0.12
60	32.5	80	1.5	22222.2	0.07

Table 1: Results from the Remediation Trials

Analysis Method	**Statistical Indices**							
	MSE	RMSE	MAD	MAE	MAPE	RCoV	rMBE	R^2	Prediction Output
ANN	8.373e7	9.150e3	4.948e3	NA	27.02	0.2969	-5.8588	NA	Code
SVM	1.784e8	1.338e4	NA	1.012e3	NA	NA	NA	0.05	Code
RSM	NA	NA	NA	NA	NA	NA	NA	0.6607	Equation

Table 2: Comparative Analysis of Trained Data on Oil Removed in Water Bodies using ANN. SVM and RSM

Analysis Method	**Statistical Indices**								
	MSE	RMSE	MAD	MAE	MAPE	RCoV	rMBE	R^2	Prediction Output
ANN	1.255e8	1.120e4	7.384e3	NA	65.292	0.1979	25.8221	NA	Code
SVM	3.965e7	6.297e3	NA	4.59e3	NA	NA	NA	0.17	Code
RSM	NA	NA	NA	NA	NA	NA	NA	0.6607	Equation

Table 3: Comparative Analysis of Tested Data on Oil Removed in Water Bodies using ANN. SVM and RSM

ANN response plots for both trained and tested data with respect to Oil removed from water during the remediation process are presented in figures 1 and 2 respectively.

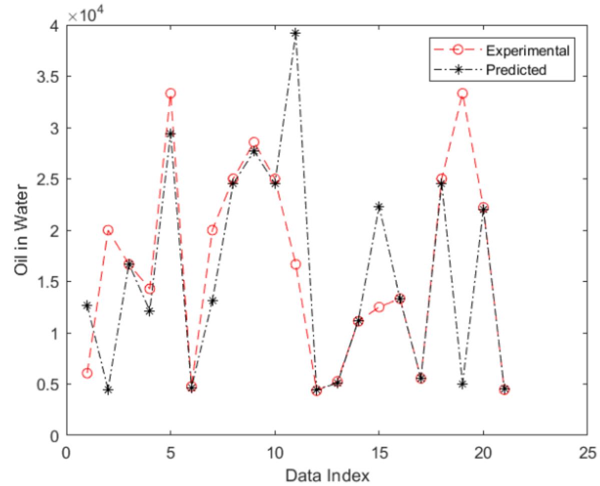

Figure 1: ANN Response Plot for Trained Data on Oil Removed from Water

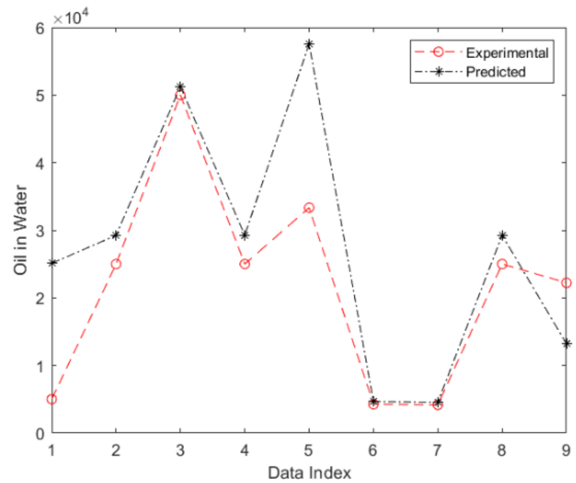

Figure 2: ANN Response Plot for Tested Data on Oil Removed from Water

SVM predicted model using the Fine Gaussian method also generated a plot against the experimental trials as shown in Figure 3.

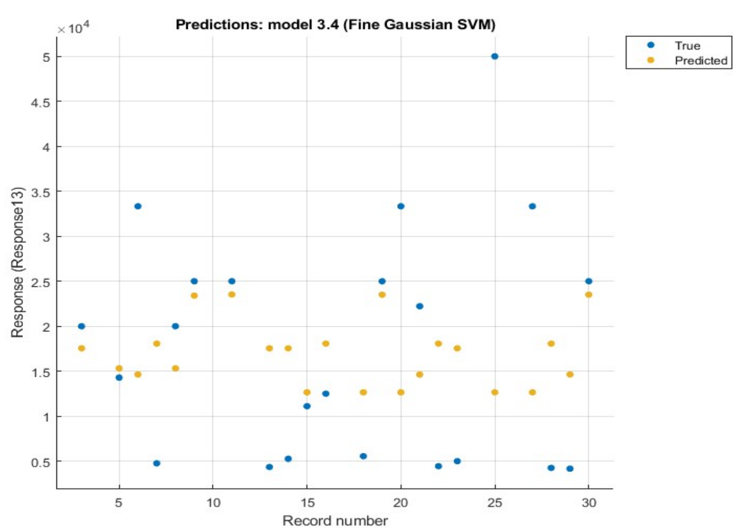

Figure 3: SVM Response Plot on Oil Removed from Water

Similarly, the 3D surface graphs representing analysis using RSM were also generated as displayed in Figures 4 and 5. The equation describing the correlation between the parameters and oil removed from water is presented in Equation 1.

$$Oil\ in\ Water = \sqrt[1.2]{\begin{array}{c} -3.32032E+05\ +2894.02594\ DD\ -0.986244\ SP^2 \times SR \\ +8.82228\ SP \times DD^2 + 4.71509\ DD \times SR^2 - 0.137156\ DD^2 \times SR^2 \end{array}}$$

Where DD = Die Diameter/ Size (mm)
SP = Screw Pitch (mm)
SR = Speed of Rotation (RPM

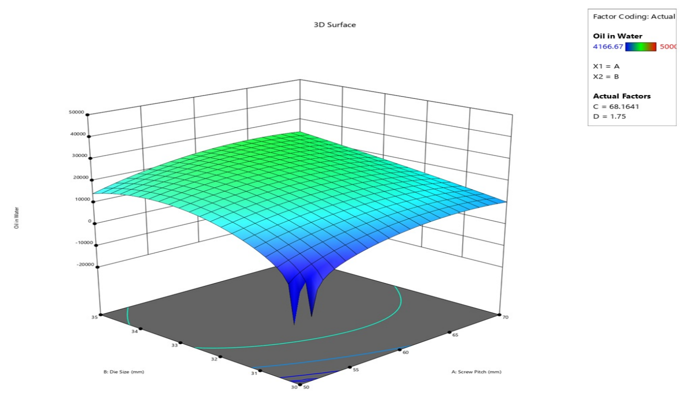

Figure 4: 3D Optimisation Graph of Oil in Water Removed

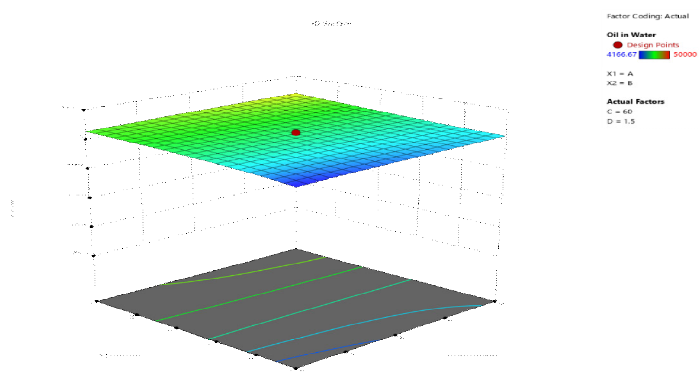

Figure 5: 3D Surface Graphs of Oil in Water

Data relating to changes in pH of the water samples were also analysed using the three methods and tabulated in tables 4 and 5.

Analysis Method	Statistical Indices							
	MSE	RMSE	MAD	MAE	MAPE	RCoV	rMBE	R^2	Prediction Output
ANN	0.0005	0.0232	0.0112	NA	40.5258	0.1607	-0.3707	NA	Code
SVM	2.85e-3	5.34e-2	NA	3.79e-2	NA	NA	NA	0.29	Code
RSM	NA	NA	NA	NA	NA	NA	NA	0.5743	Equation

Table 4: Comparative Analysis of Trained Data on Changes in pH using ANN. SVM and RSM

Analysis Method	Statistical Indices								
	MSE	RMSE	MAD	MAE	MAPE	RCoV	rMBE	R^2	Prediction Output
ANN	0.0025	0.0499	0.0442	NA	94.7241	0.1607	11.0226	NA	Code
SVM	1.28e-3	3.57e-2	NA	2.995e-2	NA	NA	NA	0.30	Code
RSM	NA	NA	NA	NA	NA	NA	NA	0.5743	Equation

Table 5: Comparative Analysis of Tested Data on Changes in pH using ANN. SVM and RSM

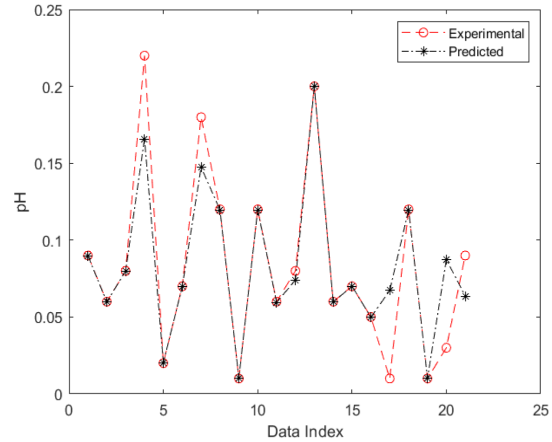

Figure 6: ANN Response Plot for Tested Data on Changes in pH of the Remediated Water Samples

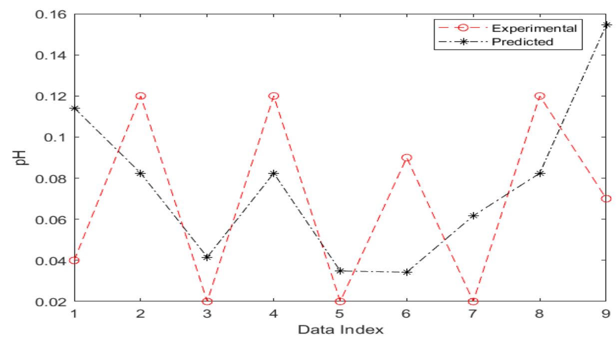

Figure 7: ANN Response Plot for Tested Data on Changes in pH of the Remediated Water Samples

The effect of variations in the parameters on changes in pH value of the remediated water samples as analysed using medium gaussian SVM was also displayed in Figure 8.

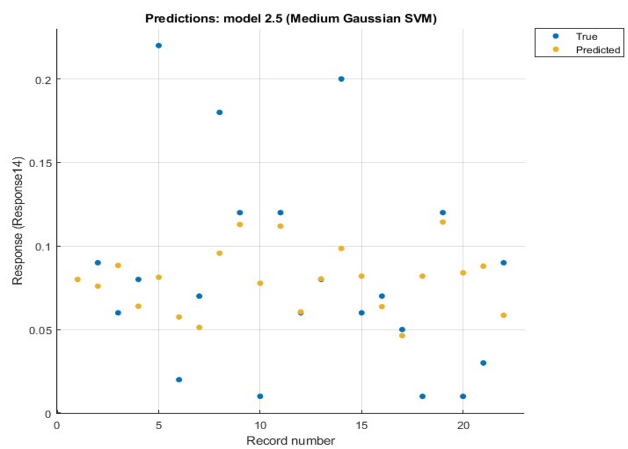

Figure 8: SVM Response Plot on Changes in pH of Remediated Water Samples

The relationship between the parameters and changes in pH as revealed during the data analysis using RSM was established using the equation 2. The graphical representation of the correlative impact of the parameters on the alteration in pH values of the remediated water samples are presented in Figures 9 and 10.

$$pH = \sqrt[1.5]{\begin{matrix} 1.22473 - 0.000421\ SP - 0.037983\ DD - 0.021404\ SR \\ -0.000060\ SP \times BR + 0.000693\ DD \times SR \end{matrix}}$$

Where DD = Die Diameter/ Size (mm)
SP = Screw Pitch (mm)
SR = Speed of Rotation (RPM)
BR = Binder Ratio (Starch/Kenaf Ratio)

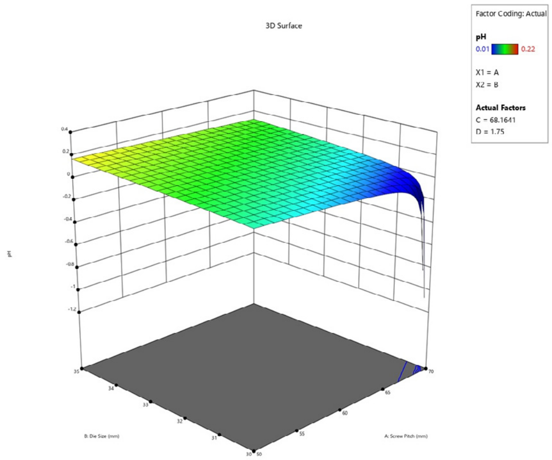

Figure 9: 3D Optimisation Graphs of Numerical of Changes in pH During Remediation

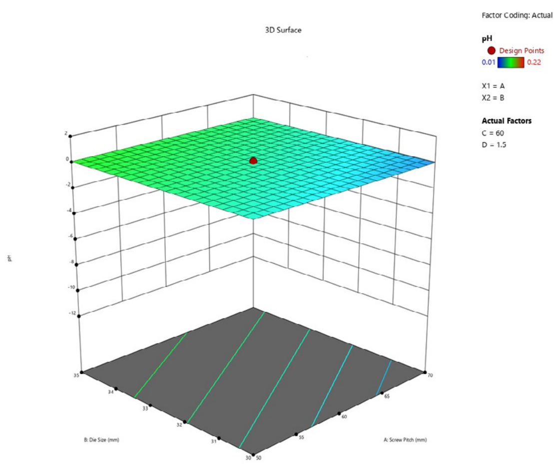

Figure 10: 3D Surface Graphs of pH for Changes in pH During Remediation

4. Discussion

A comparative assessment of the ANN and SVM analysis reported a reduced error indication indices in the SVM model for both oil removed and changes in pH during remediation. Error/ deviation indicating indices such as MSE, RMSE, MAD/MAE were compared for both methods of data analysis. This signifies a better precision recorded in the use of the SVM model. There was a distinctive presentation of data for both ANN and SVM despite have similar percentages for trained and tested data as ANN separated both classification on different plots whereas SVM combined both trained and tested data on a single plot. R^2 value was obtained for SVM analysed models whereas ANN analysis was devoid of R^2 value even though both were analysed through computational codes on MATLAB.

The comparison of ANN and RSM revealed a significant amount of difference, the presence of statistical indices measuring deviation in ANN were devoid in RSM. The output of analysis in ANN was a computational code while that of RSM was a mathematical equation coupled with the coefficient of determination (R^2). Graphical representation of data also differ as ANN analysis are reported using markers with broken lines where as RSM were reported using 3D surface plots.

Finally, the contrastive evaluation of SVM and RSM analytic methods revealed substantial differences as vital error indicative statistical indices precent in SVM were devoid in RSM. The method of graphical presentation also differs as SVM are reported in scattered plots while RSM were in 3D surface plots. Although, both had R^2, the value of R^2 in RSM were significantly higher than that of SVM. The output of both also differed, SVM generated computational codes while RSM generated mathematical equation.

5. Conclusion

The presence of error/ deviation measuring indices in the computational analysis methods (ANN and SVM) is an added advantage for forecasting even though the RSM generated easily comprehensible mathematical equations. RSM also showed the direct relationship between the parameters and the remediation process. RSM 3D graphs were also easy to interpret compared to the graphs of ANN and RSM. The reduced error indicators in SVM when compared to ANN indicated the model used in SVM was more accurate than that used in ANN even though ANN presented more indicators than SVM.

In summary, the choice of analytic models is dependent on the nature of information and purpose of analysis as each method has its advantages.

Credit Authorship Contribution Statement

Oluwaseun Kadiri- Writing, Design, material and technical sourcing, SVM analysis, investigation.
Ademola Aremu- Supervision, technical assessment and review.
Raji A. O.- Conceptualisation, Supervision and Review
Akinoso Rahman- Supervision, Coordination, RSM analysis

Declaration of Competing Interest

The authors hereby declare that there exists no conflict of interest that may have appeared to influence the research reported in this publication.

Data Availability

Data used for the research described in the article were obtained from Kadiri (2023).

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