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ABSTRACT

Monitoring wastewater treatment plants in Jordan has mostly focused on a few effluent parameters to meet the regulations of Water Authority of Jordan (WAJ) and other ministries. Image-based monitoring of wastewater quality parameters provides an easy tool to improve plant efficiency and accurate process control. This study used the digital image analysis (DIA) and artificial neural networks (ANN) techniques to develop an economical method for monitoring wastewater quality in terms of BOD5, SS and Turbidity. The study used two types of wastewater samples including real wastewater samples, which were collected from Jordan University of Science and Technology's wastewater treatment plant (WWTP) and Wadi Arab WWTP, in addition to synthetic wastewater samples which were prepared by dilution of real wastewater with de-ionized distilled water. Two ANN models were developed to classify wastewater digital images and to predict wastewater quality parameters. The first ANN model was developed for predicting BOD_5 concentration in wastewater while the second model was developed for predicting SS concentration and Turbidity content in wastewater. The color indices associated with each wastewater image pixels were used as the only inputs for each ANN model. The results showed good correlations between observed and predicted values of $BOD_{5,}$ SS and turbidity. ANN models were able to classify wastewater digital images and to predict $BOD_{5,}$ SS and turbidity in wastewater from digital images colors indices.

Keywords: monitoring, wastewater, digital images, neural networks, model.

Introduction

Monitoring wastewater quality parameters in the treatment process provides useful data that improves plant's efficiency and enables process control. In Jordan, such monitoring has mostly focused on a few effluent parameters to meet regulations of water authority and other ministries in Jordan. Traditional collection of wastewater quality data is both costly and time consuming. Therefore; it is impossible to get quick data acquisition or on-line monitoring by these traditional methods.

Control and monitoring of wastewater treatment using image analysis and artificial neural networks have been used in many applications in wastewater treatment. For example, digital image analysis and artificial neural networks were used for on-line monitoring of wastewater true color by Fange et al. [1].

Several authors have reported successful application of image analysis in wastewater treatment to characterize the morphology data of filamentous bacteria (the size, shape and projected area) data of bacterial flocs [2-7].

In this study, the use of DIA and ANN techniques for monitoring wastewater quality was tested. The main objective of this study was to develop an economical method for monitoring wastewater quality in terms of BOD_5, SS and Turbidity. Two ANN models were developed to provide predictions of BOD_5, SS and Turbidity from the color indices of wastewater digital images.

Materials and Methods

Wastewater Samples

The wastewater samples for this study were obtained from Jordan University of Science and Technology's wastewater treatment plant and Wadi Arab wastewater treatment plant. The parameters BOD_5, SS, and turbidity were determined according to the "Standard Methods for the Examination of Water and Wastewater 98".

<u>Experiments with Synthetic Wastewater Sample</u>

A synthetic wastewater sample was used to be the training sample of neural network models to save time in getting wastewater samples with different characteristics for the ANN training purpose. Such synthetic wastewater was needed to enable the neural models to learn the diurnal pattern of wastewater characteristics that entering the wastewater treatment plant on different days of the week during dry weather or wet weather.

The synthetic wastewater was prepared by dilution of real wastewater samples, which was collected from the influent of JUST's (Jordan University of Science and technology) wastewater treatment plant with de-ionized distilled water with seven-dilution factor (0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9). Two methods were applied to prepare synthetic wastewater; the first method was applied by filtration of wastewater before it was diluted for BOD_5 neural network model since BOD_5 measurement is usually done after filtration in Jordan. The second method was applied by dilution of real wastewater without filtration for the suspended solids and turbidity models. In Table 1, training wastewater sample parameters are shown.

Table 1. *Training Wastewater Sample Parameters*

Training Sample	Synthetic wastewater samples parameters		
	BOD_5 (mg/l)*	SS (mg/l)	Turbidity (NTU)
1	50	65	58
2	100	130	95
3	140	165	134
4	260	210	150
5	320	225	165
6	340	230	185
7	370	276	210

*Filtered wastewater

Experiments with Real Wastewater Sample

Real wastewater sample was used to be the verifying sample of ANN models. Wastewater samples were collected from JUST wastewater treatment plant between March 2006 and April 2006. BOD_5, SS, turbidity were tested; also wastewater sample was collected from Wadi Arab wastewater treatment plant. In Table 2 verifying wastewater sample parameters are shown.

Table 2. *Verifying Wastewater Sample Parameters*

Verifying Sample	Real wastewater samples parameters		
	BOD_5 (mg/l)*	SS (mg/l)	Turbidity (NTU)
1	470	330	218
2	350	296	230
3	420	310	208
4	380	293	195
5	520	289	215
6	380	340	220
7	750	580	300

* Filtered wastewater

Experimental Setup of the Digital Imaging

Image Capture

A SONY Cyber-shot DSC-S6000, optical zoom 3x digital camera was used to acquire digital images of wastewater on (JUST) campus. Images were taken on March, April 2006 for training samples and for the verifying sample. The pictures were taken at several randomly chosen sunny locations. The digital camera was always at the same height about (1.5 m) to capture the wastewater image. It was found that wastewater sample should be in sunny location since the image varied significantly from one location to another and to avoid reflection. In Figure 1 a wastewater sample prior to image capture is shown.

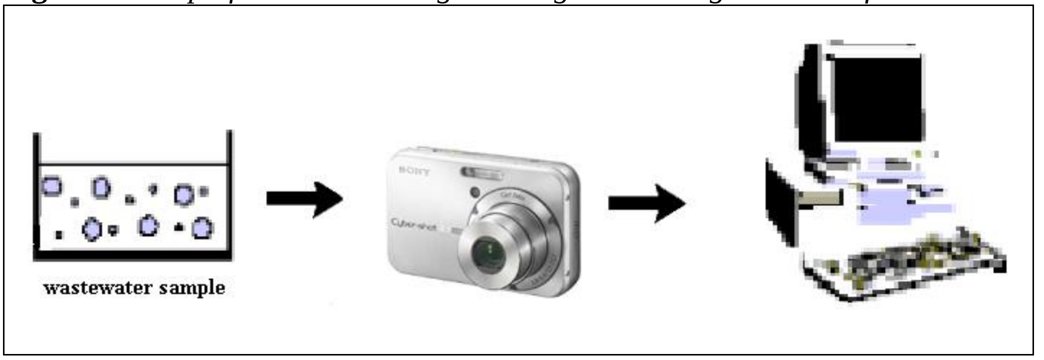
Figure 1. *Wastewater Sample Ready for Image Capture*

Image Analysis

The digital images were downloaded to a personal computer and were converted from the native digital Sony camera format (Dsc) to the 8-bit colour bitmap format (BMP). The part of image which includes wastewater only was selected as the image. The size of the images was 1632*1224 (2 Mega) pixels. These images were resized to a size of 100x100 pixels, because if we use the 1632*1224 pixel images, we will get two millions pixels and this would be very difficult for ANN model and would take much time and effort.

Image Processing Toolbox for MATLAB v 6.5 was used to analyse the obtained BMP images. The BMP images were converted to indexed images based on a red-green-blue (RGB) color system. Each pixel of an image was classified into one of 256 categories, represented by an integer in the range from 0 (black) to 255 (white). Each color index was used as an artificial neural network input, so 10000 (100x100) inputs for each wastewater image. The color indices were the only inputs used in this study. In Figure 2, experimental setup for digital image recording and transfer is shown.

Figure 2. *Setup of Wastewater Digital Image Recording and Transfer*



Development of Artificial Neural Networks Models

The Neural Network Toolbox for MATLAB v6.5 was used to build the neural network models. Two neural network model were presented with output data. The first model output was for BOD_5 concentration; the second model output was for SS and turbidity. Each neural network was consisting of three layers, the first layer is an input layer, the second is a hidden layer(s), and the last layer is an output layer.

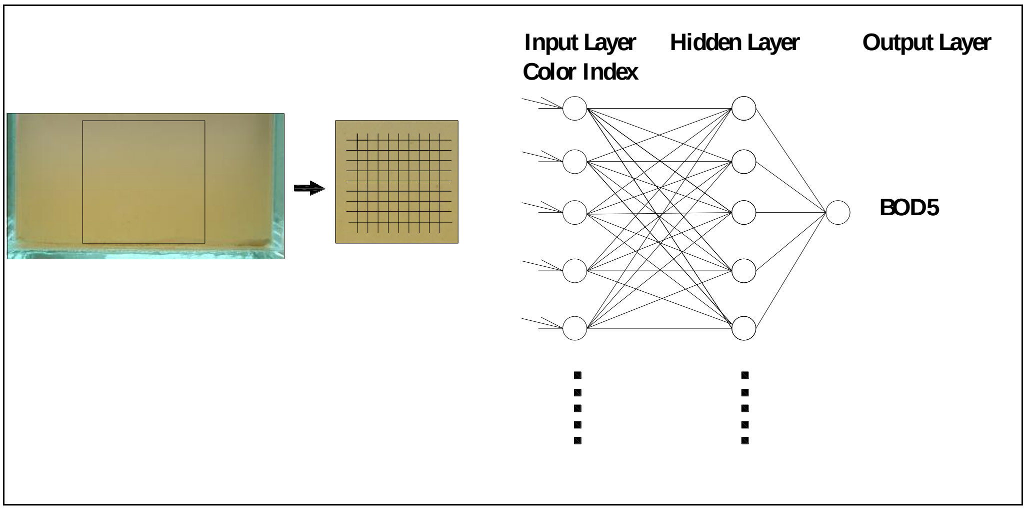
After investigate a different of structures of neural networks model, it was find that the neural networks model with one hidden layer presents the lowest mean square error, and high ability for prediction in two developed models. For an input layer, 10000 nodes were used to represent color indices in each pixels of wastewater image. Each node in the input layer received the colour index value of each pixel in the input wastewater images. One node was used in an output layer in the first model to represent BOD_5 and two nodes were used in an output layer for second model to present suspended solid and turbidity in wastewater. Seven images of synthetic wastewater were used to train each neural networks model. Testing was done with seven images of real wastewater.

Normalization of input/output variable to range from zero to one were done, because a log sigmoid transfer function was used in each model .The input data was normalized to range from zero to one (instead of from zero to 255) by divided each input by 255. The output variables in each model were normalized by dividing each parameter by the maximum expected values (BOD_5, SS, turbidity) were divided by (3000,3000,1000) respectively. The training was done to 10000 epochs, Variable learning rate training algorithm was chosen as training function.

BOD_5 Neural Network Model

The BOD_5 ANN model was trained and verified for prediction of BOD_5 concentration in wastewater. In Figure 3 the structure of BOD_5 neural networks was shown. This structure consists of input layer with 10000 nodes to represent color indices in each pixel of wastewater images, one hidden layer with 10 nodes and output layer with one node, which represent BOD_5 in wastewater.

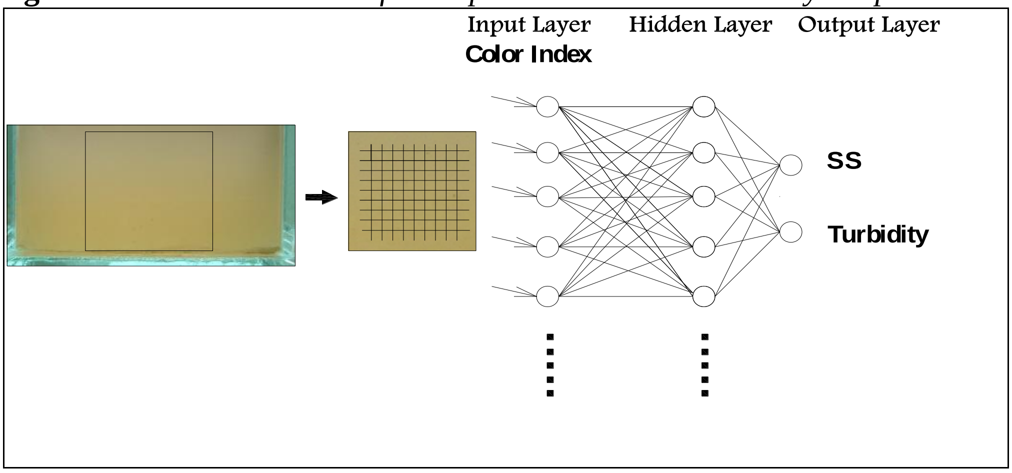
Figure 3. *The ANN Structure for BOD_5 Output*



SS/Turbidity Neural Network Model

The SS/Turbidity ANN model was trained and verified for prediction of SS concentration and turbidity in wastewater. In Figure 4, the structure of SS/Turbidity neural network model was shown. In this which consist of input layer with 10000 nodes to represent color indices in each pixel of wastewater images, one hidden with 10 nodes in each layer and output layer with two nodes which represent SS concentration and turbidity in wastewater.

Figure 4. *The ANN Structure for Suspended Solid and Turbidity Output*



Artificial Neural Network Models Training and Verifying

As mentioned in previous section, synthetic wastewater sample images, which were prepared by two method of wastewater dilution with deionized water, were used for training neural networks and real municipal wastewater image were used for verifying neural networks. Variable Learning Rate was used as training function.

BOD_5 Neural Network Model

BOD_5 ANN model was run for training and verification data. In Figure 5 and Table 3 comparisons between the observed and predicted BOD_5 concentrations in wastewater sample is shown. In Figure 6 the relationship between the observed and predicted value of BOD_5 was shown. In Table 4 correlation coefficient and average absolute errors percent between observed and predicted for BOD_5 are shown.

Table 3. *Observed and Predicted Data of the BOD_5 Artificial Neural Network Model*

Sample No.		Observed BOD_5	Predicted BOD_5
Training Samples	1	50	66.608
	2	100	106.31
	3	140	202.33
	4	260	293.05
	5	320	328.18
	6	340	342.17
	7	370	391.76
Verifying Sample	8	470	430.47
	9	350	439.3
	10	420	305.77
	11	380	431.38
	12	520	366.18
	13	380	444.88
	14	750	723.03

Table 4. *Correlation Coefficient (R^2) and Average Absolute Error for BOD_5 Neural Model*

Statistical Parameters	Training & Verifying Sample	Training Sample	Verifying Sample
R^2	0.829	0.958	0.527
Average absolute error	16.48%	15%	17.84%

Figure 5. *Simulation of BOD_5 using Digital Image and Neural Network*

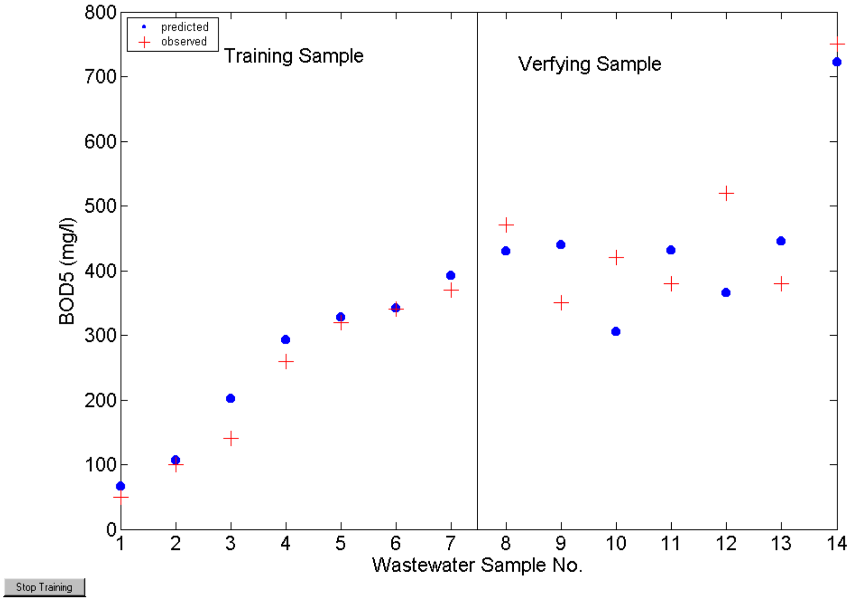
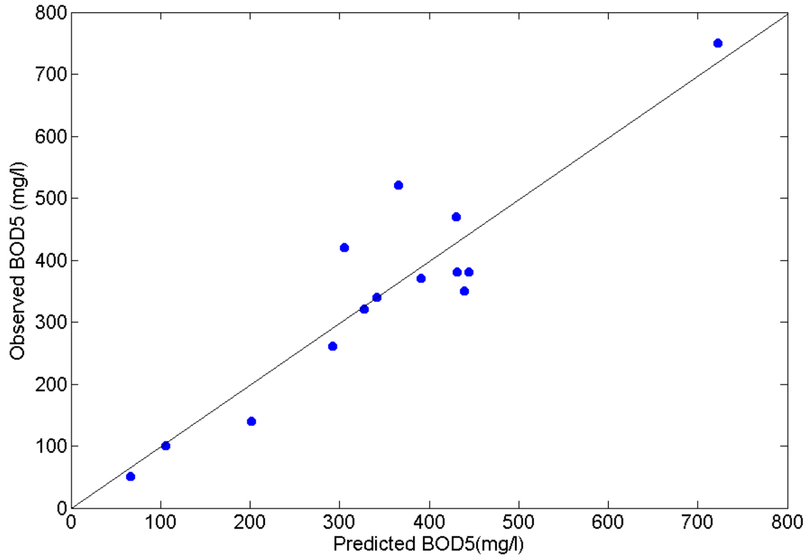


Figure 6. *Observed versus Predicted BOD_5*



SS/Turbidity Neural Network Model

SS/Turbidity ANN model was run for training and verification data. In Figures 7 and 8 comparisons between the observed and predicted data for suspended solid and turbidity were shown. In Figures 9 and 10 the relationship between the observed and predicted values of suspended solid and turbidity were shown. In Table 5 compared the observed and predicted solid and turbidity in wastewater sample. In table 6 correlation coefficient and average absolute errors percent between observed and predicted for suspended solid and turbidity were shown.

Figure 7. *Prediction of SS using Digital Image and Neural Network*

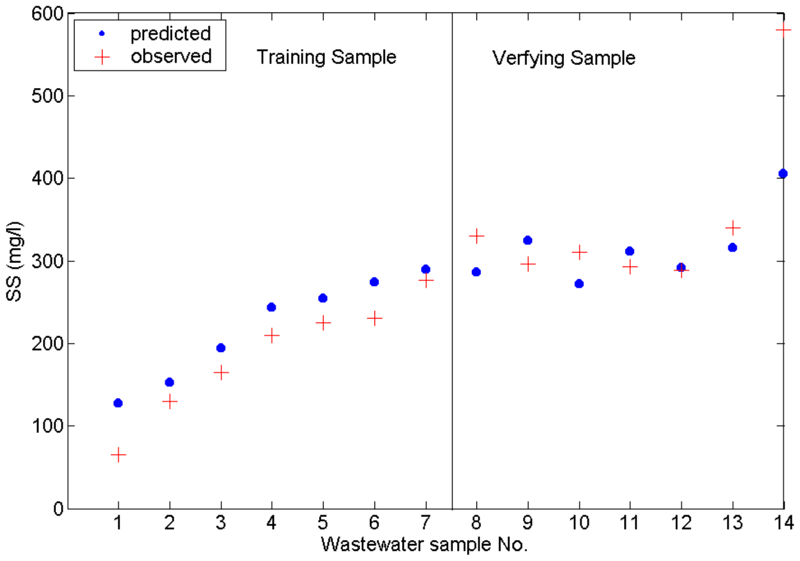


Figure 8. *Prediction of Turbidity using Digital Image and Neural Network*

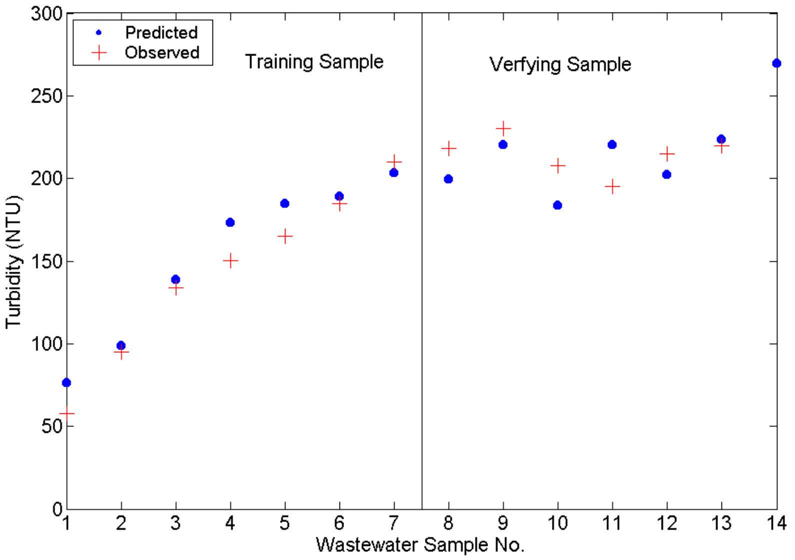


Figure 9. *Observed versus Predicted Suspended Solid*

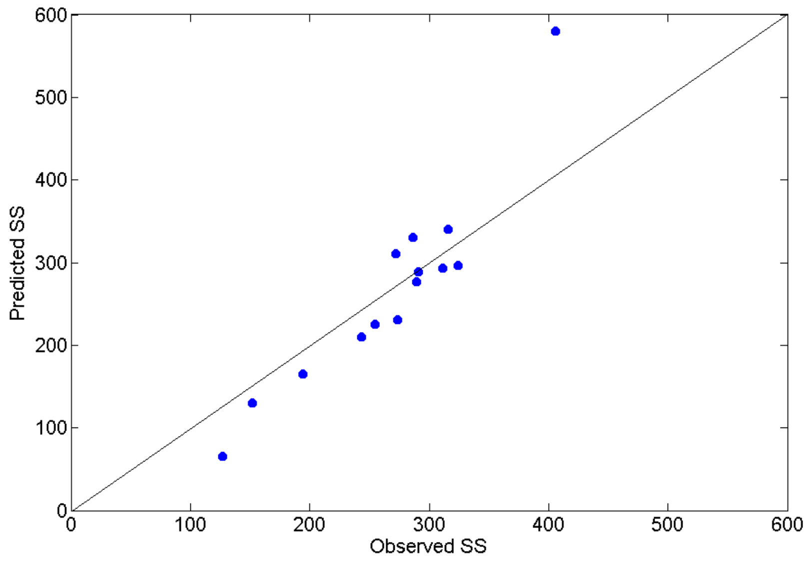
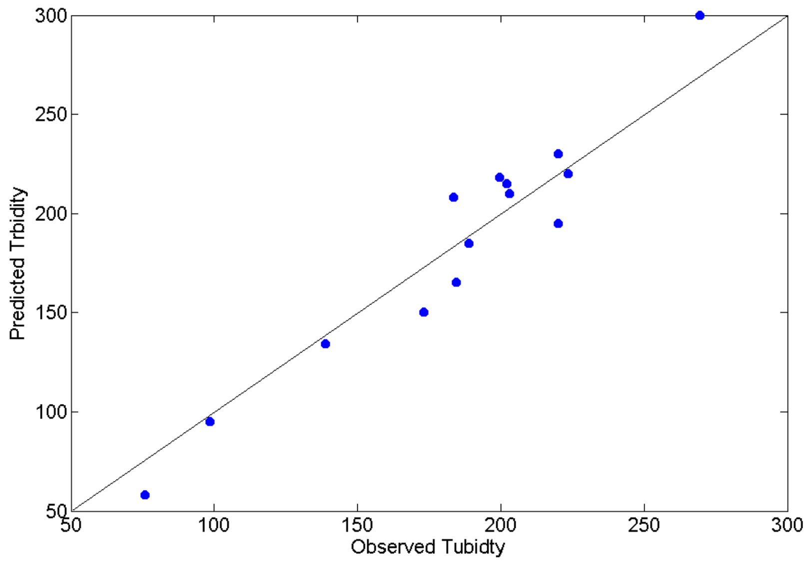


Figure 10. *Observed versus Predicted Turbidity*



Results and Discussion

Wastewater parameters (BOD_5, SS and turbidity) monitoring system, based on digital image analysis and artificial neural networks, has been developed for the purpose of on-site, on-line and real-time monitoring of practical wastewater. Color index of image was used as the input of the monitoring system.

Results indicated that the artificial neural network was well able to classify digital images and predict the three wastewater quality parameters from digital images of wastewater as follows:

(1) Predicting of wastewater parameter using digital image analysis and neural models was good (Tables 4 and 6). Errors were less than 26%.
(2) The neural models were able to simulate complicated relations strongly. Results indicated that the neural model had good simulating effects (Figures 6, 7 and 8).
(3) The wastewater quality parameters could be predicted from digital image using trained ANN models.

Conclusions

The wastewater quality parameters: BOD_5, SS and Turbidity could be successfully predicted from digital images using artificial neural networks. It was found that neural networks are able to classify wastewater digital images. Synthetic wastewater samples could solve problems related to applications of recognition techniques in image processing and neural networks learning. Fast image recognition and classification can be useful and economic in the monitoring of real wastewater.

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