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Evaluation of odour intensity from activated sludge based sewage treatment works

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ABSTRACT

The objective of this work was to develop a relationship between odour intensity and sewage concentration by using data collected from various sensitive areas of an activated sludge based sewage treatment plant at Titagarh, near Kolkata, India. A number of well-known psychophysical models (e.g., Weber–Fechner law, Steven's power law, Beidler's and Laffort's models) that can successfully relate the perceived intensity with the sewage concentration have been discussed. Respective parameters for each of the models were estimated by the nonlinear Levenburg–Marquardt parameter estimation method. The overall performance of the model was tested statistically against sets of data from the panel method analysis. The model based on the Weber–Fechner law was ranked 1 in the case of three out of eight samples and it was found more representative of the more intense odour samples. The model based on power law equation represented the intensity–concentration relationship better with extremely low uncertainties on both parameters k_1 and k_2 for comparatively less intense odour samples. Only 1 sample out of the 8 samples based on Beidler's model was found more representative for the high intense sewage samples.

Keywords: Odour intensity; Sewage; Activated sludge; Non-linear least square; Uncertainties

1. Introduction

The treatment of waste is always combined with odour emissions which can be annoying to people living near the waste treatment plants. To identify and evaluate these odour emissions, different methods are used. Odours from sewage treatment plants (STPs) comprise complex mixtures of a large number of volatile compounds. Compounds produced by sewage-processing and waste management operations, including volatile organosulphides and various oxygenated compounds, may occasionally exceed olfactory detection thresholds and represent a source of potential odour complaints in the local urban environment [1].

Odour concentration is a measure of the detectability of the odour as assessed by a panel of people [2]. Odour intensity is defined as the perceived magnitude of a stimulus [3]. Odour intensity and offensiveness are subjective measures of the strength and unpleasantness of an odour as assessed by a panel of people. Odours of equal concentration will not necessarily be of equal perceived intensity or offensiveness. The idea could also be utilized by legislators to establish minimum separation distances between the sewage treatment plant and zones of potential complaints based on objective criteria.

In this paper, the main focus will be given to the

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selection of various psychophysical models for the correlation of odour intensity to sewage concentration and estimation of their parameters with suitable techniques. Afterwards, the models will be evaluated by means of statistical analysis.

The results will be discussed with respect to the semi-solid sewage samples taken from various locations within a STP site. There will be an attempt to rank the models according to their performance and to select the best ones as the basis for community nuisance analysis. One of these psychophysical models, discriminated on the basis of its performance, will be used to convert the intensity scales reported by the panel/community sniffers to the sewage concentration (g/l), which may be used to validate the results from dispersion analysis/receptor models respectively.

2. Description of the study site: the Titagarh sewage treatment plant

Titagarh is a small town located on the east bank of the River Ganga at a distance of about 22 km from the north of the city of Kolkata, India. The combined sewerage and drainage system within the Titagarh Municipality was constructed by the British Government between 1925 and 1930. It was an activated sludge based sewerage treatment plant for a capacity of 4.54 MLD (million l/d). But the plant was kept idle till 1977–78 when KMDA carried out some augmentation works and constructed an oxidation pond having a capacity of 4.54–9.58 MLD. Titagarh was brought under the Ganga Action Plan (Phase I) in order to stop the pollution of the River Ganga due to the number of existing drains directly discharging into the river. It was decided then that these drains should be intercepted and diverted to the existing STP for treatment.

In the treatment plant (Fig. 1), a splitter box has been provided just before the inlet to the primary settling tank for sending 4.54 MLD of sewage directly into the oxidation pond. This would ensure that the existing sewage treatment plant would be able to cater to 9.08 MLD of sewage. A side overflow weir has also been provided just before the splitter box to take care of any additional sewage flow by sending it to the storm water tank. After passing through the splitter box the sewage first enters into the primary sedimentation tank from where the effluent is sent into three aeration tanks (each of equal capacity) for mechanical aeration. The flow into the tanks is controlled by "V" notches fixed in the channels leading to the tanks and these help dividing the effluent into three equal parts. After mechanical aeration the effluent from the aeration tank is sent into the three secondary settling tank. The arrangement for sludge return from the secondary settling tank to the aeration tank has been made in such a way that the sludge volume equivalent to 50% of sewage flow into the aeration tank is returned from the secondary settling tank by re-circulation pumps.

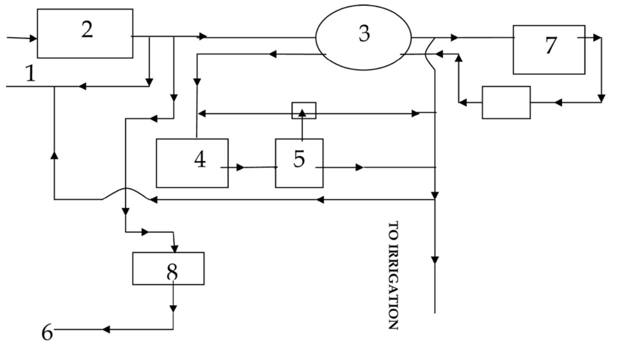

Fig. 1. Schematic block diagram of sewage treatment plant, Titagarh (courtesy of Kolkata Municipal Development Corporation, KMDA). $STPT_1$ – raw sewage; $STPT_2$ – grit chamber; $STPT_3$ – primary clarifier; $STPT_4$ – aeration tank; $STPT_5$ – secondary clarifier; $STPT_6$ – final effluent; $STPT_7$ – sewage sludge; $STPT_8$ – oxidation pond.

From the secondary settling tanks the final effluent is led into the storm water tank through the concrete channel from where it goes into the Ganga through anti malaria Khal and Khardah Khal. There is also an arrangement for sending the final effluent into the agricultural fields around, through 600 mm diameter concrete pipe.

The settled sludge in the primary and secondary settling tanks is sent to the sludge lagoons by slurry pumps.

3. Psychophysical functions

In order to describe the mathematical relationship between perceived odour intensity and concentration, various questions need to be addressed. It is doubtful whether one type of mathematical function could describe the growth of intensity for all types of odours or odour mixtures. Even if there would have been just one type of function, the next question would have been on the variation of the parameters of the equation from one odorant to the other. Since there is no linear relationship between scales produced by direct interval scaling and those produced by direct ratio scaling, it is to be expected that the two techniques give rise to different mathematical descriptions for the same psychophysical function. This is true for olfaction like all other sense modalities. Various psychophysical functions have been discussed in details in [4–6].

4. Methods

The steps to develop a relationship between odour intensity and sewage sample concentration is as follows:

- Determination of odour intensity from specific concentrations of samples taken from the sewage treatment plant site

- Selection of the models and estimation of parameters using the specific parameter estimation techniques
- Evaluation of the models using statistical techniques

Odour intensity [7] values were obtained for each of the sewage samples against the sewage concentrations by panel method.

5. Determination of odour intensity

5.1. Sampling from the STP site

The first essential step for monitoring the odours emitted by any sewage treatment plant is an in depth study and analysis of the process, which is necessary in order to identify all possible odour emission sources. Gostelow et al. [8] discussed the methods applied to odour measurement for sewage treatment works. Sensory and analytical measurements were reviewed along with a recent development, the electronic nose.

In the case of Titagarh sewage treatment plant, odour emissions are associated both with the waste water and the sludge processing units. In this specific case, the principal odour sources identified at the Titagarh sewage treatment plant are marked as $STPT_1$–$STPT_8$ (Fig. 1).

Odorous samples of sewage were collected from the domestic waste water treatment plant on the site. Samples for analysis were collected in odour-free Teflon containers of 125 ml size, which were sterilized by radiation and covered immediately. Containers were sealed with laboratory film Parafilm "M" of 4"×4" size to prevent leaks and transported to the odour laboratory for analysis. Temperatures ranged from 25°C to 27°C during the outdoor sampling period. Equipment used in the sampling process is designed to minimise the likelihood of adsorption, chemical transformation or diffusion both in the sample train and in the container. Sufficient quantities of samples were taken to ensure that the odour intensity was adequately quantified by 6 trained sniffers. The sniffers used a portable hood tightly fitted on the Teflon containers to avoid any dilution with the ambient air. The sniffing port (nose shaped) of the hood was placed on the sniffer's nose. Replicate samples were then taken to enable computation of basic measurement statistics.

5.2. Sniffing technique by panel method

We prepared 8 different concentrations of each sewage sample by diluting them with ultra pure water and then presented these samples to the sniffers (chosen as panel members through the n-Butanol test) [7] in random order for psychophysical odour assessment in blind fashion. Panelists made their decision by scaling the intensity of each sample from 1 to 8, as described in the following section.

For each sniffer, all different dilutions of each sewage sample were presented in 8 wide mouthed, sealed Tarsons, PP 60 ml bottle. The bottles were correctly labeled by code and presented in a randomized manner to the panelists. Where on occasion sniffers made their judgements without confidence, the presentation was repeated twice to get improved reliability of the results.

Average odour intensity (geometric mean) was then calculated for each of the samples based on the sniffers' judgement. The procedure ensures that a minimum interval of 15 min between each of the consecutive headspace samples was allocated for each judge to allow a recovery time for each panelist. Mean values of the intensity data for each determination at every concentration series were then plotted against the sewage concentrations.

5.3. Odour intensity

The assessment of odour intensity indicates the effect of differing odour dilutions on the likely smell sensation for an individual. Odour intensity measurement involves measuring people's perception of the strength of an odour at a range of suprathreshold concentrations. Intensity measurements are carried out relying on a "sniffing" panel using a subjective scale (usually 0–7) from *no odour* to *obnoxious.* Depending upon odour type and selection of the panel, high confidence levels can be achieved from these qualitative decisions. From these measurements, relationships can be derived between sewage concentration and perceived intensity.

Odour intensity was measured using a category estimation technique [9]. Following the determination of odour concentration, ranges of suprathreshold dilutions were presented in random order. The panelists were required to indicate their perception of intensity at each dilution according to the scales given in Table 1.

Mean intensity scores were obtained at each dilution presented to the panel. The sewage concentration at each dilution was calculated as the sample initial concentration divided by the dilution factor.

6. Model selection and estimation of model parameters

Depending on the suitability, various psychophysical

Table 1
Odour intensity scales and their description as per category estimation technique

Intensity scale	Description
0	No odour
1	Very faint
2	Faint
3	Mild
4	Odorous
5	Strong
6	Very strong
7	Obnoxious

functions were chosen to demonstrate the relationship between perceived intensity and sewage concentration for the samples drawn from the STP site.

6.1. Model 1

This is based on the Weber–Fechner law [9] which states that equal ratio changes in olfactory sensation differences correspond to equal changes in the stimulus magnitude.

$$I = k_1 \log C + k_2 \quad (1)$$

where *I* stands for a perceived intensity, *C* stands for the corresponding odour concentration, and k_1 and k_2 are constants in Eq. (1).

6.2. Model 2

This is based on Steven's psychophysical power law and implies that equal ratio changes in sensation magnitude correspond to equal changes in the stimulus magnitude.

$$I = k_1 (C)^{k_2} \quad (2)$$

where k_1 is a constant of proportionality and k_2 depends on the type of odorant [10].

6.3. Model 3

Beidler's model [11] relates the response magnitude with concentration as follows:

$$I = \frac{k_1 k_2 C}{1 + k_2 C} \quad (3)$$

6.4. Model 4

This model, based on Laffort's expression [12] can be described as in Eq. (4):

$$I = \left(\frac{C}{1 + k_2 C} \right)^{k_1} \quad (4)$$

7. Parameter estimation method

The nonlinear Levenburg–Marquardt [13] parameter estimation method was used to obtain the parameters in each of the four models. According to this method, a merit function* chi-squared (χ^2) is defined, and the best-fit parameters is determined by its minimisation. The parameters are iteratively adjusted, due to nonlinear dependences, to minimise chi-squared in order to achieve a global minimum. We start with a set of trial values for the parameters to be estimated, which are gradually improved and the procedure is then repeated until χ^2 effectively stops decreasing. A sensitivity matrix [14] was derived for the four models for the odour intensity function with respect to the parameters k_1 and k_2.

The sensitivity matrix can be written as:

For Model 1:

$$\frac{\partial I}{\partial k_1} = \log C, \qquad \frac{\partial I}{\partial k_2} = 1.0 \quad (5)$$

For Model 2:

$$\frac{\partial I}{\partial k_1} = C^{k_2}, \qquad \frac{\partial I}{\partial k_2} = k_1 C^{k_2} \cdot \log C \quad (6)$$

For Model 3:

$$\frac{\partial I}{\partial k_1} = \frac{k_2 C}{(1 + k_2 C)}, \qquad \frac{\partial I}{\partial k_2} = \frac{k_1 C}{(1 + k_2 C)^2} \quad (7)$$

For Model 4:

$$\frac{\partial I}{\partial k_1} = \left(\frac{C}{1 + k_2 C} \right)^{k_1} \cdot \log\left(\frac{C}{1 + k_2 C} \right), \qquad \frac{\partial I}{\partial k_2} = -k_1 \cdot \left(\frac{C}{1 + k_2 C} \right)^{(k_1 + 1)} \quad (8)$$

8. Evaluation of the four models [15]

Inference about the nonlinear regression parameters require the evaluation of the following statistical parameters:

1. The minimized chi-squared function**, χ^2, which is the least-squares measure of fit (the smallest χ^2 gives the best model). The χ^2 minimization is a useful means

* A merit function, also known as a figure-of-merit function, is a function that measures the agreement between data and the fitting model for a particular choice of the parameters. By convention, the merit function is small when the agreement is good. In non-linear regression analysis, parameters are adjusted based on the value of the merit function until a smallest value is obtained, thus producing a best-fit with the corresponding parameters giving the smallest value of the merit function known as the best-fit parameters [14, p. 498].

** If X_i are *k* independent, normally distributed random variables with mean 0 and variance 1, then the random variable $Q = \sum_{i=1}^{k} X_i^2$ is distributed according to the chi-square distribution with k degrees of freedom. This is usually written $Q \approx X_k^2$. The chi-square distribution has one parameter: *k – a* positive integer that specifies the number of degrees of freedom (i.e. the number of X_is).

for estimating parameters even if the measurement errors are not normally distributed.

2. The uncertainties associated with the estimate of each parameter, formally termed as the standard error* σ. These are the square-root of the error term covariance matrix C_{ij} of the fit. The closer this value is to zero, the better the fit.

When the method used to estimate the parameters is χ^2 minimization, there is a natural choice for the shape of the confidence intervals. If the confidence level and the degrees of freedom are known the confidence interval ∂a for each of the fitted parameters can be computed as:

$$\partial a_1 \cong \pm\sqrt{\Delta\chi^2_\upsilon}\sqrt{C_{11}} \quad (9)$$

where $\Delta\chi_\nu^{\ 2}$ are given in tables as functions of confidence levels and degrees of freedom (ν). This relation is approximate and holds good when

- The fit is good.
- The error terms (noise) in the nonlinear regression model are normally distributed and
- The sample size is large.

9. Results and discussion

Table 2 gives the details of the analyses carried out by the stated panel method to find out the perceived odour intensities relevant to the various dilutions of the sewage samples when presented to the trained panelists. Parameter estimation results are given in Table 3 where the uncertainties and confidence intervals of each parameter are presented for each of the four models (described in section 6) for various samples. Models are ranked according to their performance in the nonlinear least squares fit and rated with their respective values of χ^2 (Table 3). Table 4 gives the ranges of residual intensities (defined as residual intensity = predicted intensity-measured intensity) with respect to the four models tested.

Fig. 2 shows how the measured odour intensity varies with the sewage concentration for the raw sewage sampled ($STPT_1$) from Titagarh STP with respect to each of the four models. The performance of Model 1 was best with a rank of 1 out of 4 based on the estimate of minimum χ^2 (χ^2 = 22.807) and quite low values of uncertainties on k_1 = 0.019 and k_2 = 0.008. The corresponding 95% confidence intervals were worked out with a χ^2 estimate for each of the parameters. The widths of the interval with regard to both model parameters look quite narrow (Table 3). In Fig. 3 residual intensities are plotted against measured sewage concentration. It did not show serious departures from the model assumptions, for Model 1, with the residuals ranging from –1.22 to +1.68. Models 3 and 4 had a regression trend with the residuals ranging from –3.61 to +0.22 (Model 3) and from –3.14 to +0.65 (Model 4). Both of them have higher values of χ^2 than Model 1. Model 2 has

Table 2
Odour intensities (*I*) and corresponding concentrations of the sewage samples (*C*)

Samples	Step	1	2	3	4	5	6	7	8
$STPT_1$	*C*	0	12.5	25	50	100	250	700	1000
	I	1	1.56	2.340	3.482	3.482	4.605	5.704	6.101
$STPT_2$	*C*	0	12.5	25	50	100	250	700	1000
	I	1	1.56	2.616	3.618	3.741	4.743	5.970	6.361
$STPT_3$	*C*	0	12.5	25	50	100	250	700	1000
	I	1	2.47	3.223	3.350	3.741	4	4.743	5
$STPT_4$	*C*	0	12.5	25	50	100	250	700	1000
	I	1	1.45	2	2.340	2.590	2.866	3.868	4.743
$STPT_5$	*C*	0	12.5	25	50	100	250	700	1000
	I	1	1.31	1.565	1.565	1.861	2.590	3.868	4.870
$STPT_6$	*C*	0	12.5	25	50	100	250	700	1000
	I	1	1.31	1.456	1.565	2	2.449	3.741	3.743
$STPT_7$	*C*	0	12.5	25	50	100	250	700	1000
	I	1	3.35	3.600	4	4.605	6.611	6.871	7
$STPT_8$	*C*	0	12.5	25	50	100	250	700	1000
	I	1	2	3.741	4	5	5.488	6	6.611

* The standard error of the mean, SEM [16] is the standard deviation of the sample mean estimate of a population mean. (It can also be viewed as the standard deviation of the error in the sample mean relative to the true mean, since the sample mean is an unbiased estimator.) SEM is usually estimated by the sample estimate of the population standard deviation (sample standard deviation) divided by the square root of the sample size (assuming statistical independence of the values in the sample): $SE_{\bar{x}} = {s}/{\sqrt{n}}$.

Table 3
Results of parameter estimation

Sample	Model	k_1	k_2	d.f.	χ^2	$\rho(\chi^2)$	Uncertainties on		Model rank	95% confidence limits (k_1)		95% confidence limits (k_2)	
							k_1	k_2		Lower	Upper	Lower	Upper
$STPT_1$	1	–0.859	2.306	6	22.807	0.999	0.019	0.008	1	–0.920	–0.798	2.279	2.333
	2	1.109	0.252	6	53.211	1	0.002	0.001	3	1.090	1.107	0.251	0.233
	4	3.235	0.647	6	41.912	1	0.000	0.000	2	0.284	0.284	0.001	0.001
$STPT_2$	1	–0.833	2.386	6	23.720	0.999	0.019	0.009	1	–0.894	–0.772	2.359	2.418
	2	1.176	0.248	6	60.138	1	0.004	0.000	2	1.168	1.185	0.247	0.249
	3	6.156	0.024	6	89.678	1	0.007	0.000	3	6.136	6.176	0.024	0.024
	4	3.361	0.641	6	821.476	1	0.273	0.023	4	2.509	4.212	0.571	0.711
$STPT_3$	1	1.300	1.208	6	10.383	0.935	0.020	0.009	1	1.239	1.361	1.180	1.235
	2	1.929	0.138	6	12.047	0.966	0.006	0.001	2	1.909	1.948	0.135	0.139
	3	4.598	0.078	6	57.933	1	0.004	0.000	3	4.585	4.611	0.077	0.079
	4	3.277	0.065	6	129.025	1	0.031	0.254	4	2.324	4.234	0.569	0.727
$STPT_4$	1	–0.268	1.506	6	46.483	1	0.020	0.00872	2	–0.329	–0.207	1.479	1.533
	2	0.848	0.240	6	25.734	0.999	0.003	0.001	1	0.839	0.856	0.238	0.242
	3	2.500	0.200	6	620.557	1	0.004	0.002	4	2.488	2.512	0.193	0.208
	4	3.835	0.754	6	404.242	1	0.531	0.278	3	2.182	5.468	0.668	0.641
$STPT_5$	1	–1.102	1.756	6	122.680	1	0.020	0.009	2	–1.240	–0.964	1.694	1.818
	2	0.428	0.343	6	33.713	0.999	0.001	0.001	1	0.424	0.432	0.342	0.345
	3	2.500	0.200	6	749.217	1	0.004	0.002	4	2.473	2.527	0.183	0.217
	4	4.013	0.789	6	710.043	1	0.670	0.029	3	1.925	6.102	0.698	0.876
$STPT_6$	1	–1.020	1.691	6	108.023	1	0.019	0.009	2	–1.081	–0.955	1.669	1.718
	2	0.439	0.335	6	31.043	0.999	0.001	0.000	1	0.435	0.443	0.333	0.336
	3	2.500	0.200	6	669.612	1	0.000	0.002	4	2.488	2.512	0.192	0.207
	4	3.960	0.785	6	631.395	1	0.658	0.029	3	1.920	6.016	0.693	0.877
$STPT_7$	1	0.650	2.181	6	81.783	1	0.020	0.009	2	0.589	0.711	2.154	2.208
	2	2.086	0.182	6	91.121	1	0.004	0.000	1	2.073	2.100	0.181	0.188
	3	6.875	0.042	6	214.767	1	0.001	0.000	3	6.859	6.891	0.041	0.042
	4	3.035	0.560	6	624.647	1	0.206	0.215	4	2.394	3.676	0.494	0.628
$STPT_8$	1	0.351	2.105	6	81.093	1	0.020	0.009	2	0.290	0.118	2.078	2.132
	2	0.955	0.283	6	528.981	1	0.002	0.000	4	0.940	0.961	0.281	0.283
	3	6.324	0.042	6	55.675	1	0.006	0.000	1	6.308	6.34	0.042	0.042
	4	3.195	0.596	6	489.283	1	0.224	0.021	3	2.497	3.892	0.530	0.661

Table 4
Range of residual intensities for various models

Samples	Range of residuals			
	Model 1	Model 2	Model 3	Model 4
$STPT_1$	–1.22–1.68	–0.54–0.51	–3.61–0.22	–3.14–0.65
$STPT_2$	–1.55–1.65	–0.52–0.63	–0.45–0.60	–1.92–1.44
$STPT_3$	–0.20–0.32	–0.22–0.25	–0.41–1.69	–0.88–0.39
$STPT_4$	–2.43–0.34	–0.29–0.32	–2.25–0.33	–1.81–0.54
$STPT_5$	0.19–2.09	–0.30–0.25	–2.38–0.71	–2.29–0.77
$STPT_6$	0.01–1.85	–0.31–0.33	–2.26–0.71	–2.14–0.80
$STPT_7$	–2.87–(–0.45)	–0.91–0.34	–0.99–0.94	–1.24–1.20
$STPT_8$	–3.45–0.48	–1.49–0.11	–0.52–0.28	–1.41–1.49

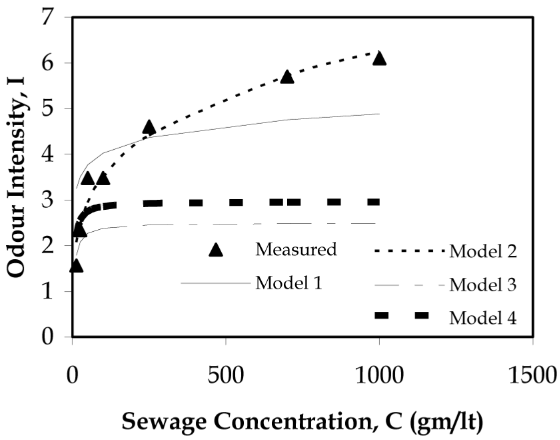

Fig. 2. Comparisons of the measured data with models for the $STPT_1$.

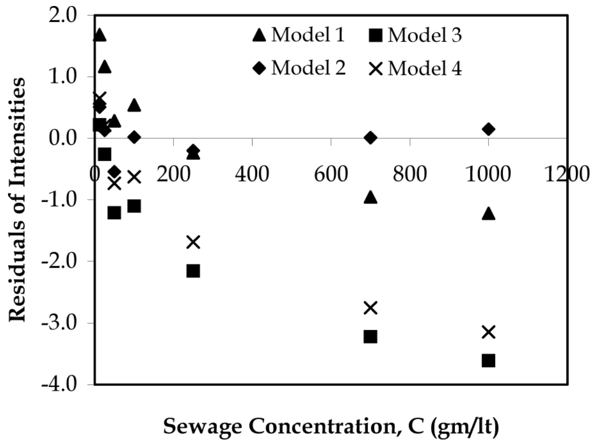

Fig. 3. Plot of residual intensities for the four models for the $STPT_1$.

largest value of χ^2 (χ^2 = 53.211) and can be discarded .Thus it was found that Model 1 (based on the Weber–Fechner law) and the corresponding regression function could be accepted for the intensity analysis of the sewage sample from $STPT_1$. Similarly, for samples $STPT_2$ and $STPT_3$ again Model 1 did the best (Table 3).

For the next set of samples from $STPT_4$ Model 2 performed best. In these cases, lowest value of χ^2 (χ^2 = 25.734) and corresponding low uncertainties on the estimated parameters were found on Model 2, (Fig. 4) and for $STPT_5$ (Fig. 6) value of χ^2 (χ^2 = 33.713). In Fig. 5, the residuals ranged from –0.29 to +0.32 for Model 2, while in Fig. 7 the range was from –0.30 to +0.25 for Model 2. The trend was similar for $STPT_6$ and $STPT_7$ (Fig. 8 and Fig. 9, respectively). The levels of sewage concentrations and corresponding odour intensities for the samples from $STPT_4$, $STPT_5$, $STPT_6$ and $STPT_7$ could be best related with Model 2. But we see that Model 4 gives the largest value of χ^2 (χ^2 = 821.476, uncertainties estimated on k_1 = 0.273 and k_2 = 0.023) for the sewage sample from $STPT_2$ and Model3 gives the largest value of χ^2 (χ^2 = 749.217, uncertainties estimated on k_1 = 0.004 and k_2 = 0.002) for the sewage sample from $STPT_5$. In both of these cases we

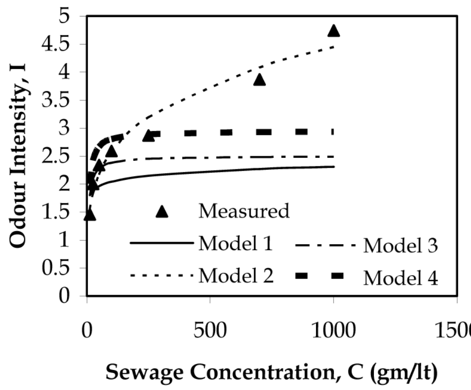

Fig. 4. Comparisons of the measured data with models for the $STPT_4$.

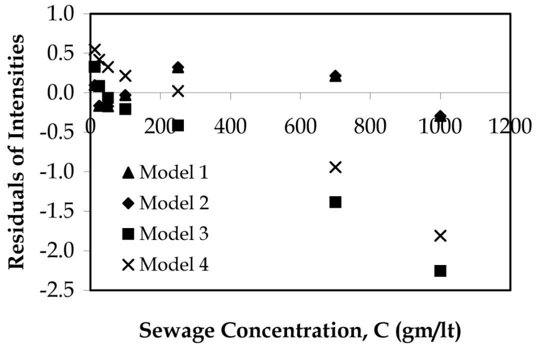

Fig. 5. Plot of residual intensities for the four models for the $STPT_4$.

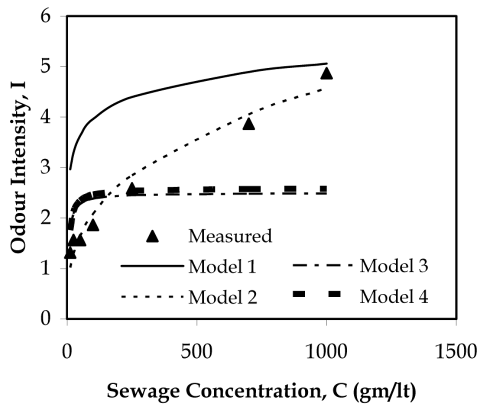

Fig. 6. Comparisons of the measured data with models for the $STPT_5$.

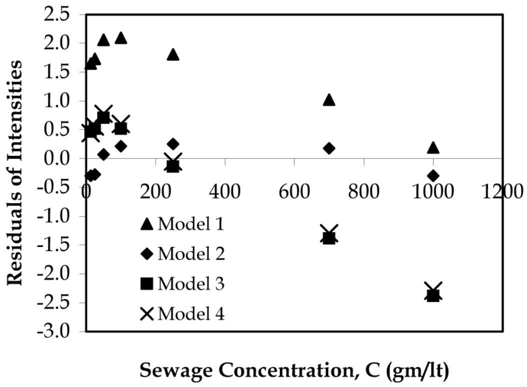

Fig. 7. Plot of residual intensities for the four models for the $STPT_5$.

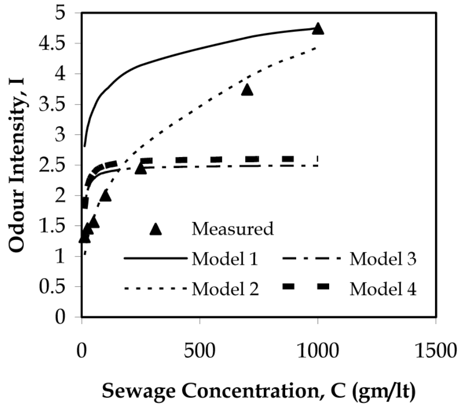

Fig. 8. Comparisons of the measured data with models for the $STPT_6$.

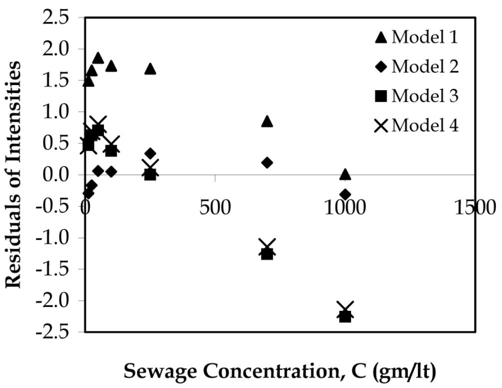

Fig. 9. Plot of residual intensities for the four models for the $STPT_6$.

Table 5
Overall model performance

Rank	Model 1	Model 2	Model 3	Model 4
1	3	4	1	0
2	3	3	1	1
3	0	1	3	4
4	0	1	3	3

find that, Models 3 (Rank 4) and Model 4 (Rank 4) did not perform well due to their very high values of χ^2 even though the uncertainties on k_1 and k_2 were both quite low.

Only for $STPT_8$ we can see from Table 3 that Model 3 (Beidler's model) did the best. Table 5 gives a picture of overall performance of all the models based on the goodness of fit. It could be inferred that Model 1 and Model 2 both performed well and they correlate the intensity with sewage concentration capably for most of the sewage samples from Titagarh.

10. Conclusions

Odour intensity of sewage samples from the STP site was evaluated using established psychophysical models.

Respective parameters for each of the models were estimated and the overall performance of each model was tested against sets of data from the panel method analysis. The following inferences were drawn:

- Each of the models, based on one of the well-known psychophysical laws could describe the relationship between odour intensity and sewage concentration and based on it a theoretical model could be developed with estimated regression parameters.
- The power law performed little better than Weber–Fechner law since the scaling technique used was category estimation and not ratio scaling. However, these two laws, which were expected to be the most widely used laws perform the best for all types of sewage samples from various sources of the STP site. In the above analysis, Model 1 (based on Weber–Fechner law) was ranked 1 in the case of 3 samples out of 8 and it has been found that Model 1 fitted best to the more-intense sewage samples ($STPT_1$, $STPT_2$ and $STPT_3$).
- Model 2 was ranked 1 in the case of 4 samples out of 8. Model 2 (based on power law) could correlate the intensity with sewage concentration very well for samples from $STPT_4$, $STPT_5$, $STPT_6$ and $STPT_7$. Power law equation has specifically represented the intensity–concentration relationship better for comparatively less intense sewage samples.
- Model 3 has performed well for sample from $STPT_8$. So for only this sample Beidler's model represented the intensity-concentration relationship better for high intense odour samples.

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References

[1] J. Leach, A. Blanch and A.C. Bianchi, Volatile organic compounds in an urban airborne environment adjacent to a municipal incinerator, waste collection centre and sewage treatment plant. Atmosph. Environ., 33 (1999) 4309–4325.
[2] CEN, EN 13725, Air Quality. Determination of Odour Concentration by Dynamic Olfactometry, Brussels, 2003.
[3] ASTM. Standard Terminology Relating to Sensory Evaluation of Materials and Products. Annual Book ASTM Stand., 1991.
[4] W.S. Cain, Differences in the exponent of the psychophysical function. Perception Psychophys., 6 (1969) 349–354.
[5] W.S. Cain, Odour intensity after self-adaptation and cross-adaptation. Perception Psychophy., 7 (1970) 271–275.
[6] B. Berglund, U. Berglund, G. Ekman and T. Engen, Individual psychophysical functions for 28 odorants. Perception Psychophys., 9 (1971) 379–384.
[7] VDI Guideline 3882, Part 1. Olfactory – Determination of Odour Intensity, VDI Handbook on Air Pollution Prevention, Vol. 1, 1992.
[8] P. Gostelow, S.A. Parsons and R.M. Stuetz, Odour measurements for sewage treatment works. Water Res., 35(3) (2001) 579–597.
[9] P.N. Cheremisinoff and R.A. Young, Industrial Odor Technology Assessment. Ann Arbor Science Publishers, Michigan, 1975.
[10] S.S. Stevens, The psychophysics of sensory function. Amer. Sci., 48 (1960) 226–253.
[11] H. Stone and S.M. Oliver, Beidler's theory and human taste stimulation. Perception Psychophys., 1(10) (1966) 358–360.
[12] W.S. Cain and H.R. Moskowitz, Psychophysical scaling of odors. In: A. Turk and J.W. Johnston, eds., Human Responses to Environmental Odors. Academic Press, New York, 1974, pp. 1–32.
[13] J.V. Beck and K.J. Arnold, Parameter Estimation in Engineering and Science. Wiley, NewYork, 1977.
[14] W.H. Press, S.A. Teukolsky, W.T. Vetterling and B.P. Flannery, Numerical Recipes in Fortran, Cambridge University Press, Cambridge, UK, 1992.
[15] J. Neter, W. Wasserman and M.H. Kutner, Applied Linear Regression Models, Richard D. Irwin, Homewood, 1983.
[16] B.S. Everitt, The Cambridge Dictionary of Statistics, CUP, 2003.