A simple field essay for detecting departures from expected performance in small-scale, remote or rural wastewater treatment plants

Marcos von Sperling, Emmanuelle Machado Maia Nogueira Lima and Mirene Augusta de Andrade Moraes

ABSTRACT

A scientific basis is given to the traditional method of inferring effluent quality based on visualization of samples in transparent flasks. A scale of 1–6, with different printed grey intensities, is placed behind transparent PET bottles containing the sample, and gives an indication of the range of turbidity in the sample (1 is the most transparent and can only be visualized if the effluent is well clarified; in the other spectrum, 6 is the darkest and indicates highly turbid effluents). Turbidity has been correlated with total suspended solids (TSS), particulate biochemical oxygen demand (BOD) and particulate chemical oxygen demand (COD) based on thousands of monitored data collected in the effluent from seven different treatment processes in Brazil: upflow anaerobic sludge blanket (UASB) reactor, trickling filters, activated sludge, horizontal wetland, vertical wetland, polishing ponds and coarse filter after pond. The method is simple and instantaneous, can be used in virtually all places and in every visit of the operator to the remote treatment plant, allows recording of the image in smartphones, does not use any equipment, chemicals or energy, and has been showed to represent well the effluent quality of existing treatment plants. This essay is complementary and does not substitute specific traditional sampling and analysis, but allows easy inference of deterioration of effluent quality.

Key words | effluent quality, Grey Scale monitoring, PET bottles

HIGHLIGHTS

- A scientific basis is given to the traditional method of inferring effluent quality based on visualization of effluent samples in transparent flasks.
- A scale of 1–6, with stripes with different printed grey intensities, is placed behind transparent PET bottles containing the sample, and gives an indirect indication of the range of turbidity in the sample.
- Turbidity was correlated with TSS, particulate BOD and particulate COD based on thousands of monitored data collected in seven different treatment processes.
- The method is simple and instantaneous, can be used in virtually all places and on every visit of the operator, allows recording of the image in smartphones, does not use any equipment, chemicals or external energy, and has been showed to represent well the effluent quality of existing treatment plants.

This is an Open Access article distributed under the terms of the Creative Commons Attribution Licence (CC BY 4.0), which permits copying, adaptation and redistribution, provided the original work is properly cited (http://creativecommons.org/licenses/by/4.0/).

doi: 10.2166/wst.2020.421
INTRODUCTION

In small wastewater treatment plants (WWTP) and in localities in rural or remote areas, effluent quality monitoring is usually performed at very low frequencies and it is not uncommon to have plants with no samples collected and analysed over a long period. Frequently, staff is reduced, adequate training is scarce, and the cost of monitoring, difficulties of logistics in sample transportation and preservation and lack of laboratories at a reasonable distance are obstacles that are often not overcome, which may cause monitoring to be non-existent or insufficient. Moreover, one should question the reliability of the interpretation of very small datasets that do not have the potential to sustain statistical evaluations (Oliveira 2006; von Sperling et al. 2020). These limitations are identified in Brazil (von Sperling 2016), the country of residence of the authors, but are also characteristic in Latin America, due to the prevalence of small-sized treatment plants (Noyola et al. 2012), and, to a larger extent, to developing countries in general, when facing the challenge of complying with regulatory standards (Johnstone & Norton 2000).

It should be borne in mind that process monitoring and control is important, not only to comply with local regulations associated with conformity assessment of discharge standards, but also to ensure the effectiveness of the system. Many WWTPs have problems such as the frequent occurrence of untreated sewage by-pass, hydraulic and organic overload in the units, energy and equipment failure and problems in the capacity to waste surplus sludge. Furthermore, physicochemical analyses, which are generally not performed at the treatment plant itself, may require an excessive time to be useful for the detection of operational failures. However, it should be understood that, when necessary, microbiological and physical-chemical analysis, together with other specific experimental methods, can be used in order to enhance the understanding of the behaviour of the treatment plant (Van Loosdrecht et al. 2016; Lourenço & Nunes 2020).

A simple, unmechanized and very low-cost alternative for a quick visual assessment of effluent quality is the on-site settleability test, using the Imhoff cone. This is a test described in Standard Methods – method 2540 F (APHA/AWWA/WEF 2017), has been widely cited in water quality and wastewater treatment literature (e.g. Qasim 1999; Sawyer et al. 2003; Metcalf & Eddy 2014) and is included in discharge standards in some countries. The Imhoff cone test does not require chemicals, needs only a standardized transparent flask (cone), and is performed within one hour. One limitation relates to the non-detection of suspended solids that are not settleable within this one-hour period. For example, effluents from stabilization ponds, a process widely used in rural areas, contain algae in high concentrations and thus, despite having a highly turbid effluent, the value obtained in the Imhoff cone test may be low due to the low settleability of algae.

A simple approach that is sometimes informally used is the visual examination of the effluent appearance (clean or turbid) in samples placed in transparent flasks. This method is simple, does not require waiting time, equipment, chemicals or energy, and is essentially inexpensive. If the bottle is a transparent PET bottle, as is often found everywhere, then no costs are involved. However, as is done, this approach allows only informal visual communication with the public, since it does not incorporate any quantitative relationship with the quality of the effluent.
The purpose of the present work is to take advantage of the ease of this intuitive test with transparent bottles, and to provide conceptual bases so that it can be an auxiliary instrument in the evaluation of the performance of small WWTPs. This was achieved by the inclusion of a ‘solids evaluation scale’, here simply called Grey Scale. Given its simplicity, the test can be done each time the operator goes to the WWTP, immediately generating a semi-quantitative result. The effluent sample and the Grey Scale can be recorded photographically with a mobile phone and sent to the plant manager (with location and date/hour record). This practice can produce a time series of results, enabling the statistical treatment of data by the plant manager, whose consolidated results can be sent to environmental or regulatory agencies. Furthermore, due to the prompt response of the test, any deviations from the expected quality of the effluent may be immediately investigated by the operator while he/she is still on site. The procedure was developed having in mind treatment of domestic wastewater (sewage), but could, with pertinent adaptations, also be used for other types of effluents.

Considering that most small and remote WWTPs aim at removing primarily suspended solids and organic matter, it is natural to associate a well-clarified effluent to a low turbidity and to low concentrations of suspended solids and particulate organic matter (particulate fractions of biochemical oxygen demand (BOD) and chemical oxygen demand (COD)). Conversely, less transparent effluents are associated with high turbidity values and high concentrations of suspended solids and particulate BOD and COD. Therefore, turbidity can be considered a surrogate for evaluating wastewater treatment performance (Mullins et al. 2018). On the other hand, the interpretation of total BOD and COD in the effluent is more complex, as it depends on the performance of the biological reactor (which causes a greater influence on the soluble fraction of BOD and COD, not addressed in this article) and of the solids-liquid separation stage, if existent in the treatment line (which impacts the particulate fractions of BOD and COD, and is addressed in this work). If the plant is working well and without excessive applied loads, the concentrations of soluble and suspended organic matter would be expected to be low, according to the treatment process employed. However, it is known that the largest episodes of effluent quality deterioration in biological sewage treatment are related to solids loss in the final effluent, either because of insufficient sludge wastage or inadequate solids-liquid separation (in upflow anaerobic sludge blanket (UASB) reactors, trickling filters and activated sludge), clogging (wetlands) or excessive algae (ponds), causing high turbidity, suspended solids and particulate organic matter (von Sperling & Chernicharo 2003). Thus, it is relevant to be able to identify deviations in the quality of the effluent, which are likely to be symptoms of operational problems in the plant. This is another justification for the proposal of this article, related to an easy method of inferring and attributing quantitative values to the departures in terms of turbidity, suspended solids and particulate organic matter.

Depending on the size or degree of importance of the wastewater treatment plant, it should be understood that the proposed method should be integrated with the monitoring practices that are – or should be – carried out. There is no explicit proposal here to eliminate the recommended procedures, especially physicochemical analyses, which should be done according to an adequate and realistic sampling plan for each WWTP. However, it is admitted that, in small, remote and rural WWTPs, which have never been monitored, this method may allow the initiation of a closer follow-up by managers, allowing the identification of the need for possible improvements. This is even especially the case in developing countries, where resources for laboratory analysis or acquisition and maintenance of sensors are usually scarce. In the context of this publication, there are no specific indicators to formally characterize the concepts of ‘developing countries’, ‘small scale’, ‘remote or rural plants’; this is left open in order to encompass all possible situations in which it is felt that the utilization of such a simplified procedure could be beneficial for the sanitation service providers and environmental institutions.

Expeditious performance evaluations also have the potential of being indicators of the WWTPs that should be prioritized in actions to improve operation and maintenance by sanitation companies, because they present routine results below what is expected in accordance with current legislation or the treatment process. With this information, quick evaluations also become a tool for the analysis of the service provider’s overall performance on a local or regional scale (Sweeney et al. 2012).

METHODS

Concept of the Grey Scale

The principle of the proposed Grey Scale is simple: fill a transparent flask (e.g. 500- or 600-mL PET bottle) with a sample of the treated effluent and place the scale behind it. The scale consists of six stripes and ranges of grey.
Scale 1 is the most transparent and can only be visualized if the effluent is well clarified. In the other spectrum, Scale 6 is the darkest, and could be visualized even with very turbid effluents. The intermediate ranges are associated with different levels of effluent clarification (see Figure 1).

In order for the method to be used without restrictions in most WWTPs, it was considered important to develop a single scale that could be correlated to turbidity and, indirectly, to the concentration of suspended solids and particulate organic matter in the effluent, in such a way that it could represent the main technologies used in wastewater treatment plants. In summary, the conceptual flow of information to be obtained was postulated in this sequence:

Grey Scale → Turbidity → Suspended solids → Particulate BOD and particulate COD

Formulation of the Grey Scale based on measured turbidity values

The association between the Grey Scale ranges and the turbidity, suspended solids, particulate BOD and particulate COD values was made from effluent sampling of different sewage treatment systems, covering important intensive and extensive treatment processes used on a worldwide basis. The treatment processes investigated were: UASB reactor, trickling filter, activated sludge, horizontal wetland, vertical wetland, stabilization ponds and coarse filter. The systems were installed at the Centre for Research and Training in Sanitation (CePTS UFMG/Copasa) in Belo Horizonte, Brazil. The treatment units received actual municipal wastewater and represented real systems designed to operate in small communities, with population equivalents between 50 and 700 PE – population equivalents (with the exception of the activated sludge system, which was a large system). Some units have been in operation since 2000, while others have been implemented in later years. Table 1 provides the characteristics of the units used here.

Specific sampling campaigns were carried out collecting grab samples from raw sewage and effluents from the treatment systems. Besides the original samples collected, others were produced from the original samples, some of which have been made more concentrated (with separation of solids by sedimentation) and others have been diluted, in order to increase the spectrum of turbidity values, but without altering the intrinsic characteristics of the solids.

Samples have been collected and dilutions/concentrations have been tested on a trial and error basis until turbidity values that could be considered representative for each Grey Scale range had been obtained. Turbidity was measured with a portable 2100P Hach® Turbidimeter. The resulting turbidity values for each Grey Scale and treatment process are presented in Supplementary Material 2.

Relationship between TSS and turbidity, particulate BOD and TSS, particulate COD and TSS

Once the correspondence between the Grey Scale ranges and the turbidity values was established, the next step was to allow estimates of the values of total suspended solids (TSS), particulate BOD and particulate COD for each range of the scale. The ratios of TSS/Turbidity \( n = 1,032 \), particulate BOD/TSS \( n = 497 \) and particulate COD/TSS \( n = 503 \) were calculated using historical monitoring data of the same treatment systems described in Table 1, covering periods of several years, with typical weekly or fortnightly monitoring frequency. Each system had a different quantity of data, depending on the monitoring period in which the data used in this work were obtained (see Supplementary Material 1).

Composition of the Grey Scale

After several trials, an adequate composition of the solids evaluation scale was obtained, and is presented in Figure 1. The number of each range varies from 1 to 6, and is presented next to the stripes in an ascending order of
turbidity. Range 1 (stripe 1) represents the lowest turbidity and 6, the highest. Each stripe should be referred to by its number, thus allowing a semi-quantitative standardized indirect expression of the degree of turbidity.

For the preparation of the Grey Scale in a standardized way, the following procedures were followed. The Grey Scale was made in Microsoft Office® software, version 365, by inserting six identical rectangular shapes, which can be produced in either Excel, Word or PowerPoint. All were filled with solid fill, with the theme colour ‘Black 1’. After that, different transparency levels were implemented in each fill through the colour customization tool, ranging from 0 up to 99%. The proposed version of the Grey Scale is presented in Figure 1, showing the number of each category, its transparency percentage, and the resulting grey level.

### Indications for the correct use of the Grey Scale

The correct use of the Grey Scale, the standardization of results and the possibility of comparison between treatment systems in other places require the observation of several practical aspects, which are detailed below.

- **Recommended conditions for the visualization of the effluent sample and the Grey Scale.** The appropriate environmental conditions for the photographic record were analysed in the study, assuming that they could be influential in the outcome. Regular models of smartphones were used to take the photo, considering that they constitute a widespread device, even in poor and/or remote regions. However, a significant difference in photographic results was verified depending on the position in which the bottle with effluent and the scale were placed in relation to sunlight. The most appropriate results of the photographic record were those made indoors, with the most natural lighting possible, without the light being directly frontal or posterior. This helped to reduce the variations of the results due to weather. It is recommended to select a constant place to perform the photographs.

  - **Use of flashlight and photographic enhancements.** The use of indoor camera flash with natural lighting was tested. The flash was observed to distort the apparent colouring of the effluent and could lead to different results depending on the device used or their settings. Ideally, the use of flash and the camera configuration should be standardized by the sanitation company. If this is not possible, it is recommended not to use the flash.

  - **Type of transparent flask for containing the effluent and allowing visualization of the Grey Scale.** Given the possibility of distortions to the visualization of the scale associated with bottles with corrugations, undulations or irregularities, it is recommended to use a smooth transparent plastic bottle. PET bottles for soft drinks or mineral water can be used. Considering that the standardization of the procedure is important to reduce the uncertainty of the results, it is also recommended to use

### Table 1 | Characteristics of the intensive (compact) and extensive (natural) treatment systems used in the study

| Treatment system         | Type     | Abbreviation in the paper | Comments                                                                 |
|--------------------------|----------|---------------------------|--------------------------------------------------------------------------|
| UASB reactor             | Intensive| Anaerobic                 | Conventional upflow anaerobic sludge blanket (UASB) reactor. Receives raw sewage after preliminary treatment. Approximately 600 PE. |
| Trickling filter         | Intensive| Trick filter              | Three different units of trickling filter have been used. All are high-rate units and receive effluent from UASB reactors. Two have stones as filter medium and one has plastic medium. The effluent data from the three units were treated together in this study. Between 250 and 600 PE. |
| Activated sludge         | Intensive| Activ slu                 | Conventional activated sludge, with primary settler, aeration tank and secondary settler, aiming mainly at carbon removal. Large system. |
| Horizontal wetland       | Extensive| H wet                     | Receives the effluent from a UASB reactor. It is planted with *Typha latifolia*. Approximately 50 PE. |
| Vertical wetland         | Extensive| V wet                     | First stage of French system of vertical wetlands. Receives raw sewage after preliminary treatment. Planted with Tifton 85. Approximately 100 PE. |
| Stabilization ponds      | Extensive| Ponds                     | Polishing (maturation) ponds. Samples from two units in series have been used. The first unit in the series follows a UASB reactor, and the second unit follows the first pond. Approximately 250 PE. |
| Coarse filter            | Extensive| Coar F                    | This unit aims at removing suspended solids (mainly algae) from the last polishing pond. Approximately 250 PE. |
bottles with volumes of 500 or 600 mL, which will allow the use of a standard size of the Grey Scale.

- **Printed scale or scale displayed in smartphones and computer screens.** Possible differences were evaluated between the visualization obtained with the use of printed grey scales or those displayed on smartphone screens or computer screens. Printed scales can vary with the printer characteristics, quality, and settings, which can affect the visualization of the scale. In this study, the scale was printed by a laser printer on an A4 sheet, but cut to a smaller size that was more comfortable to hold with one’s hands. It was also laminated, so that it would ensure better conservation and hygiene, besides remaining rigid when being held. Although the laser printing of the scale led to good results, the evaluation made with mobile phones was the one that demonstrated the best results. For this purpose, a pdf file with the Grey Scale was saved on the mobile phone, and the mobile was positioned behind the bottle with the effluent to be evaluated. The brightness of the mobile screen was adjusted according to the ambient conditions at the time, but this was not influential in the visual identification of the results. If a mobile phone is used, a second one will be necessary for taking the picture. Placing the bottle in front of a computer screen displaying the scale also led to good results. Figure 2 illustrates two of these procedures for using the Grey Scale, either holding a printed version or using a smartphone display.

- **Record keeping.** The scale was conceived to complement the physicochemical analyses and, therefore, should follow the same indications of record keeping and processing of results, so that the information can be passed on by the plant manager and used by those involved with the treatment plant – sanitation company, environmental agencies or regulatory entities.

### RESULTS AND DISCUSSION

#### Examples of visualization of different samples representing the six grey scales

Figure 3 presents photographs of different samples inside PET bottles and the Grey Scale behind them, covering scales from 1 to 6. Some samples were direct effluents from treatment process, while others have been concentrated or diluted in order to produce liquids with higher or lower turbidity. The first stripe (lowest number) to be seen dictates the corresponding value of the Grey Scale. The visualization may be difficult in Figure 3, because of the reduction of the photographs to fit the size of the page, but was clear on site. The operator may be in doubt in the selection between one stripe or the adjacent one, but this uncertainty is believed not to alter the key message that needs to be passed: is the plant working as expected or is the performance departure mild or severe? Assuming that a photographic recording will be made at every visit of the operator to the treatment plant, robustness is achieved by having a large number of samples per month or year, and not based on a single evaluation.

#### Association between turbidity and Grey Scale

The table in Supplementary Material 2 shows the turbidity values and associated grey scales for the effluent samples collected and those prepared by dilution or concentration. The relationship between the grey scales and the turbidity values (as presented in the table), without distinction of the treatment process, is shown in Figure 4. As expected, the results are coherent, in that larger values of the Grey Scale are associated with higher turbidity values in an increasing pattern. For practical reasons in the utilization of the Grey Scale, the two curves have been manually adjusted to produce rounded minimum and maximum values of turbidity in each range.

#### Relationship between turbidity and TSS, TSS and particulate BOD and TSS and particulate COD

After being able to estimate the expected values of turbidity based on the grey scale values, it was necessary to convert...
turbidity into TSS and, after that, TSS into particulate BOD and particulate COD. This was performed by using the historical dataset from each treatment process, based on monitoring over the years, starting in 2000, as described in the Methods section. The descriptive statistics of these relationships is presented in Supplementary Material 1. For the sake of simplicity, both wetlands types (horizontal and vertical) have been grouped into one category (wetlands), assuming similarity of the characteristics of the effluent solids. Polishing ponds and coarse filters have also been grouped into one category (ponds) under the assumption that the characteristics of the solids are similar (mainly algae). Regression analyses between the variables were tried, but the wide scatter of the data led to the approach of calculating a simple ratio between medians. The visualization of the ratios (TSS/Turbidity, particulate

![Figure 3](http://iwaponline.com/wst/article-pdf/82/7/1380/772744/wst082071380.pdf)

Figure 3 | Visualization of examples of different samples classified in Grey Scales 1–6.
BOD/TSS and particulate COD/TSS) can be seen in Figure 5 (summary statistics are presented in Supplementary Material 3). It can be seen that there is a wide dispersion of the ratios obtained within each treatment system and also between them, highlighting the variability that is inherent to sewage treatment processes, since the quality of the treated effluent suffers disturbances influenced by inflow, environmental conditions, characteristics of the influent wastewater and type of processes used (Niku & Schroeder 1994).

Even though there were differences within treatment processes, it was decided to use the overall medians of the ratios (all systems grouped together), in order to simplify and widen up the applicability of the Grey Scale. If it is desired to develop the relationship for one particular process, or other processes not investigated here, specific ratios may be obtained and further adopted. The median values of the ratios obtained for all the systems were: (a) TSS/Turbidity = 1.36; (b) particulate BOD/TSS: 0.60; particulate COD/TSS = 1.28.

Summary of the proposed Grey Scale

The turbidity values defining the boundaries of each range (Figure 4) allowed the establishment of the boundaries for TSS, simply by multiplying turbidity by 1.36. In the sequence, the boundaries of particulate BOD and particulate COD have been defined based on the boundaries for TSS (by multiplying by 0.60 and 1.28, respectively). After a small rounding of values to lead to more practical ranges, the final values proposed for the Grey Scale have been obtained. Figure 6 presents a synthesis of these values, showing the overall structure of the Grey Scale, the estimated values of turbidity, particulate BOD and particulate COD for each scale value, and how each range complements each other.

For instance, based on Figure 6, if for a particular sample the reading of the Grey Scale was 2, the manager would expect an effluent turbidity between 50 and 110 NTU, TSS between 70 and 150 mg/L, particulate BOD between 40 and 90 mg/L and particulate COD between 90 and 190 mg/L. The manager should understand that these ranges are wide and do not substitute specific traditional sampling and analysis, but he/she would easily infer that the effluent quality is not particularly good (depending on the treatment process and local effluent requirements). Moreover, due to the immediate response of the test, a prompt investigation of the potential causes for the effluent deterioration could be carried out.

Assessment of the representativeness of the Grey Scale using historical monitoring data from the various treatment systems studied

Using again the routine monitoring data from the historical records, represented by the thousands of samples analysed (see summary statistics in Supplementary Material 1), it was verified whether the Grey Scale could be representative of the treatment systems investigated, and also of raw sewage. Figure 7 presents the percentage of samples falling inside each range of the Grey Scale. For instance, in the case of TSS, the construction of the figure was based on the determination of the percentage of TSS values from each treatment process that fell inside the boundaries for each Grey Scale. In this case, as an example, for the effluent from the UASB reactors, it was observed that 80% of the TSS values were between 0 and 70 mg/L (boundaries of...
It can be observed that the composition and distribution of the ranges of the Grey Scale seem adequate. The indications related to the four variables (turbidity, 

Scale 1) and 17% of the values were between 70 and 150 mg/L (boundaries for Scale 2) (see boundary values in Figure 6).
TSS, particulate BOD and particulate COD) are compatible among themselves. The first column in each chart from Figure 7 covers raw sewage (or it could also represent a very poorly treated sewage), which would be mainly inserted in scales 2, 3 and 4. Regarding treated sewage, it is noted that the effluent from the treatment systems are, in general, predominantly within Scale 1, as expected, indicating a good performance. It should be mentioned that the Grey Scale is not sensitive to discriminate between ‘good’ and ‘very good’ performances, since both of them fall into Scale 1. This is because, in the development of the scale, preference was given to the detection of departures from ‘good’ or ‘very good’ performances.

The systems with the highest number of samples within Scale 2 are UASB reactors (known to have an inherent low treatment efficiency) and stabilization ponds (because of the high algae content in the effluent). However, in the other systems there were indications of deterioration in the quality of the effluent, with varying percentages of occurrences within Scale 2 and, in a smaller amount, also within Scale 3. It is understood that, in these cases, the Grey Scale is
Figure 7 | Percentage of samples from historical monitoring associated with each Grey Scale: (a) turbidity; (b) total suspended solids; (c) particulate BOD; (d) particulate COD. Note: Raw: raw sewage; UASB: effluent from anaerobic sludge blanket reactors; Trick F: effluent from trickling filters; Act Slu: effluent from activated sludge; H Wet: effluent from horizontal wetland; V Wet: effluent from vertical wetland; Ponds: effluent from maturation ponds; Coar F: effluent from coarse filters for polishing ponds effluent; All syst: all systems grouped together.
fulfilling its role, being indicative of the drop in the treated effluent quality.

It should be realized that this method does not account for the deterioration in the effluent quality related to the dissolved fractions of organic matter (soluble BOD and soluble COD). Usually, these fractions are related to the performance of the biological reactor, and their deterioration is frequently not so drastic as those associated with episodes of loss of suspended solids in the effluent (von Sperling & Chernicharo 2005). The assessment of the dissolved fractions require physical-chemical analyses, but indirect inferences of possible drops in performance may be possible via surveys of the treatment plant (searching for equipment malfunctioning, visual indications of structural problems in the units, pipes blockages, pump failures etc.), plus an evaluation of possible hydraulic or organic overloading conditions. This is outside the scope of this paper.

**CONCLUDING REMARKS**

The objective of this work was to improve and give a conceptual basis to support the utilization of the simple widely-used visual method of assessing the appearance of the final effluent from a treatment plant using a transparent bottle. The Grey Scale consists of six stripes in ascending order of transparency of grey, which are linked to the clarification level of the effluent. The scientific basis for the proposal was derived from specific tests associating the visualization of the scales and the measured turbidity in the effluent from different biological treatment processes. Furthermore, the analysis of thousands of existing monitoring data allowed the establishment of a relationship between turbidity and TSS, TSS and particulate BOD and TSS and particulate COD (total BOD and total COD are not inferable from this simple essay). The main purpose is the detection of departures from the expected treatment performance in small-scale, remote or rural wastewater treatment plants, in which a consistent implementation of traditional monitoring procedures would be difficult.

As a summary of the overall procedure, the operator simply needs to collect the sample from the final effluent, put it in a transparent bottle, mix it, place the scale behind the bottle, read the first visible grey stripe/scale, photograph the whole set for recording purposes, and send the value (or the photo) of the Grey Scale to the plant manager. With the sequence of such measurements, the manager could construct a database comprising dates and times of sampling and grey scale values, and could prepare appropriate summary statistics and adequate graphs (e.g. time series, box plot or percentile charts) after a sufficient number of grey scale values have been obtained (what would be difficult to achieve with traditional sampling and analysis, because most likely the number of samples would be minimal, or even non-existent in such small treatment plants).

Finally, a validation of the proposal was made by applying the Grey Scale retrospectively to the thousands of values of the historical monitoring of the same treatment systems over several years. The conclusion of this procedure is that the results were coherent with the systems’ performances. Nevertheless, possible forthcoming applications of the proposed Grey Scale and a consolidation with new monitoring results made by other users may indicate that some adaptations should be made in the future.

As with any experimental method, there are also inherent limitations associated with this one. The Grey Scale has been developed to identify large departures from a desired effluent quality, and has a reduced sensitivity to detect small deteriorations in an effluent with prevailing good quality. Well-operating treatment systems are likely to produce effluents that will fall in the Scale 1 range, and even with small losses of efficiency they would still remain in the same Scale 1. Also, no strict numerical associations between the scales and precise values of total suspended solids and particulate organic matter should be expected, but only a possible range of values. This is due to the wide variability that is found as a result of the diversity of treatment process, influent quality, applied loading rates, operational practices, and environmental conditions.

Finally, no inferences related to dissolved solids or dissolved organic matter in the final effluent can be done from this essay.

Of course the method proposed here can be further adapted by any potential user to embrace local specificities, regional regulations and other treatment processes. The key point here is that it has been shown in this study that there is a scientific basis for the utilization of such a simplified and accessible essay, improving the widely used informal procedure of visual inspection of treated effluents.

**ACKNOWLEDGEMENTS**

The authors would like to thank the Brazilian agencies CAPES, CNPq, FAPEMIG and FUNASA, the Water and Sanitation Company COPASA, and Bill & Melinda Gates Foundation (SaniUP project, under the coordination of IHE Delft, The Netherlands).
DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

APHA, AWWA, WEF 2017 Standard Methods for the Examination of Water and Wastewater, 23rd edn. American Public Health Association, Washington, DC, p. 1546.

Johnstone, D. W. M. & Norton, M. R. 2000 Development of standards and their economic achievement and regulation in the 21st century. In: Paper Presented at C.I.W.E.M/Aqua Enviro Joint Millennium Conference, April 2000. University of Leeds, Leeds, UK, pp. 13.

Lourenço, N. & Nunes, L. M. 2020 Review of dry and wet decentralized sanitation technologies for rural areas: applicability, challenges and opportunities. Environmental Management 65, 642–664.

Metcalf & Eddy 2014 Wastewater Engineering: Treatment and Resource Recovery, 5th edn. Metcalf & Eddy/AECOM, New York, NY, p. 2018.

Mullins, D., Coburn, D., Hannon, L., Jones, E., Clifford, E. & Glavin, M. 2018 A novel image processing-based system for turbidity measurement in domestic and industrial wastewater. Water Science and Technology 77 (5), 1469–1482. doi:10.2166/wst.2018.030.

Niku, S. & Schroeder, E. D. 1987 Factors affecting effluent variability from activated sludge processes. Journal Water Pollution Control Association 53 (5), 546–559.

Noyola, A., Padilla-Rivera, A., Morgan-Sagastume, J. M., Guereca, L. P. & Hernández-Padilla, F. 2012 Typology of municipal wastewater treatment technologies in Latin America. Clean – Soil, Air, Water 40 (9), 926–932.

Oliveira, S. M. A. C. 2006 Análise de desempenho e confiabilidade de Estações de Tratamento de Esgotos (Performance Assessment and Reliability of Wastewater Treatment Plants). PhD Thesis (Doutorado em Saneamento, Meio Ambiente e Recursos Hídricos), Departamento de Engenharia Sanitária e Ambiental, Universidade Federal de Minas Gerais, Belo Horizonte (in Portuguese).

Qasim, S. R. 1999 Wastewater Treatment Plants: Planning, Design and Operation, 2nd edn. CRC Press, Boca Raton, FL, p. 1107.

Sawyer, C. N., McCarty, P. L. & Parkin, G. F. 2005 Chemistry for Environmental and Engineering Science, 5th edn. McGraw Hill Inc., New York, NY.

Sweeney, D. G., Louey-Gung, J. & Dysart, A. 2012 A risk-based approach to improve monitoring and performance of remote waste stabilisation ponds. Water Science and Technology 66 (8), 1735–1742.

Van Loosdrecht, M. C. M., Nielsen, P. H., Lopez-Vazquez, C. M. & Brdjanovic, D. 2016 Experimental Methods in Wastewater Treatment. IWA Publishing, London, UK, p. 360.

Von Sperling, M. 2016 Urban Wastewater Treatment in Brazil. Inter-American Development Bank. Water and Sanitation Division. Technical Note N° IDB-TN-970. http://dx.doi.org/10.18235/0000397.

Von Sperling, M. & Chernicharo, C. A. L. 2005 Biological Wastewater Treatment in Warm Climate Regions, Vol. 2. IWA Publishing, London, UK, p. 1496.

Von Sperling, M., Verbyla, M. E. & Oliveira, S. M. A. C. 2020 Assessment of Treatment Plant Performance and Water Quality Data: A Guide for Students, Researchers and Practitioners. IWA Publishing, London, UK, p. 644.

First received 10 June 2020; accepted in revised form 20 August 2020. Available online 2 September 2020

Downloaded from http://iwaponline.com/wst/article-pdf/82/7/1392/772744/wst082071392.pdf by guest