Monitoring and assessment of *Dracaena*-based constructed vertical flow wetlands treating textile dye wastewater

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Abstract The monitoring and assessment of multiple constructed vertical flow wetlands (CVFWs) treating textile dye wastewater (metanil yellow as dye) are studied covering three seasons. Three CVFWs (CVFW-1, dye—5 mg/l; CVFW-2, dye—50 mg/l; and CVFW-3, dye—100 mg/l) and a control (dye—5 mg/l) were used. The CVFWs with *Dracaena* (an ornamental plant) efficiently removed contaminants like dye, COD, NH$_4^+$-N, and PO$_4^{3-}$-P from the wastewater under varying inlet dye concentrations, indicating its dependence on meteorological conditions. Substantial dye removal was observed to be maximum in summer (control, 44.3%; CVFW-1, 75.1%; CVFW-2, 76.1%; CVFW-3, 46%), but lesser in winter (control, 45%; CVFW-1, 73.1%; CVFW-2, 76.8%; CVFW-3, 42.6%) and minimum in monsoon (control, 40.8%; CVFW-1, 63.5%; CVFW-2, 51.6%; CVFW-3, 37.1%), respectively. Efficiency was less in CVFW-3 as it observed plant stress due to higher inlet dye concentration. COD removal was higher in winter, followed by summer and monsoon. A first-order kinetic model was used to investigate the efficiency of the CVFW system w.r.t. contaminant removal. Various functional groups were characterized using Fourier transform infrared spectroscopy (FTIR) from the inlet and outlet water samples of different CVFWs. The *Dracaena* accumulated various elements and oxides during the treatment with no stress on its health. No effects on plant health highlight the suitability of *Dracaena* for textile wastewater treatment. The results were validated using statistical tools like the Mann–Whitney *U* test and principal component analysis (PCA).

Keywords Metanil yellow removal · Chemical oxygen demand · Kinetics · Principal component analysis · Fourier transform infrared · X-ray fluorescence

Introduction

Annually approximately 70 million tonnes of synthetic dyes is generated each year globally, primarily utilized in the manufacturing of textiles, cosmetics, and leather. About 30 to 150 thousand tonnes of dye-containing wastewater is released into the water bodies (Zou & Wang, 2017). Nowadays, the world is fascinated by using various synthetic dyes, and azo dye is famous for its applications. Nearly 70% of dyes were used as
a coloring material in multiple industries, categorized under the azo group (Benkhaya et al., 2020). Azo dyes are substances that contain one or more azo linkages and are made up of a diazotized amine coupled to an amine or a phenol. Aromatic amines are the primary precursors of azo colors (Chung, 2016). In the past, at least 3000azo dyes were used in the paper and pharmaceutical sectors, printing inks, paints, varnish, lacquer, and wood stains. Azo dyes are also used as colorants in synthetic and natural textile fibers, hair dyes, waxes, petroleum, plastics, and leather (Chung, 2016). The azo compounds have antibacterial, antiviral, antifungal, and cytotoxic properties in addition to their typical coloring activity (Ali et al., 2018). The azo double-bound groups are harmful and difficult to degrade in nature, potentially leading to significant environmental concerns and harming public health. Therefore, azo dye effluent must be treated before being released into aquatic bodies (Li et al., 2016).

Metanil yellow as an azo dye is used in various sectors, viz., food, pharmaceutical, leather, paper, textile, and chemical laboratories. Metanil yellow (a non-permitted food color) has been used as a food additive in making sweets, spices, pulses, beverages, and soft drinks to enhance their appearance (Kourani et al., 2020). Consumption of metanil yellow for a more extended period stimulates oxidative stress, prevents the indigenous antioxidant system, and produces free radicals. Moreover, it has a toxic impact on the digestive, excretory, reproductive, cardiovascular, and nervous systems, respectively (Ghosh et al., 2017). The presence of the azo group in metanil yellow blocks the sunlight in the aquatic environment, which affects the photosynthetic organisms and their activity (Ramadhani et al., 2020). The byproduct of the azo group, i.e., aromatic amine, causes various disorders like allergic, mastitis, skin irritation, gene alteration, etc. (Yaseen & Scholz, 2017). Although many researchers have developed methods like coagulation, chemical precipitation, electro-Fenton, electrochemical oxidation, and other advanced oxidation processes (Matyszczak et al., 2020) for the effective treatment of synthetic dye wastewater, all corresponding concern high operational and maintenance cost, vast applications of chemicals and electrical energy are the shortcomings of these methods.

Constructed wetlands (CWs) are considered sustainable and cost-effective approaches that undergo both phytoremediation and microbial remediation while treating various wastewaters (Muduli et al., 2022). The use of CWs for dye removal and textile wastewater is under investigation. Multiple researchers have reviewed the effectiveness of CWs in treating textile wastewater and dye removal (Dogdu & Yalcuk, 2016; Haddaji et al., 2019; Oon et al., 2020); however, very scanty literature is available covering all seasons. Under anaerobic conditions, the azo bond (present in the azo dye) can be broken easily to undergo the decolorization process; further, primary amine as a product can be degraded under aerobic conditions (Tee et al., 2015). Therefore, combining aerobic and anaerobic processes is advisable for complete dye degradation. Treatment of the metanil yellow dye using water hyacinth and specific bacterial strains like Bacillus sp. AK1 and Lysinibacillus sp. AK2 has been studied (Anjaneya et al., 2011; Guerrero-Coronilla et al., 2019).

Literature related to metanil yellow (acid yellow 36) removal using CWs is inadequate; furthermore, the use of ornamental species in the constructed vertical flow wetlands (CVFWs) is the uniqueness of this study. Dracaena reflexa is an ornamental species that has been used in the present study instead of wetland species. The main aim for choosing Dracaena reflexa is to undergo phytoremediation of textile wastewater, as it can withstand various environmental conditions and is simple to propagate by stem cuttings. Moreover, the root system of Dracaena has a propensity to develop micro-aerobic regions, contributing to the continuous degradation of organic matter (Dadrasnia & Pariatatamy, 2016). In addition, the availability of native wetland species, especially in the arid and semi-arid areas, is challenging, where ornamental plants can play a vital role in wastewater management.

The present study uses CVFWs, which provide proper aeration (Hussein & Scholz, 2018) for the dye removal. This work aims to monitor and assess the Dracaena-based CVFWs’ potentiality for treating synthetic wastewater contaminated with metanil yellow, chemical oxygen demand (COD), and nutrients like NH4+−N and PO4 3−P, respectively. The related objective was to (i) monitor the treatment efficiency (dye and other physicochemical contaminants) of the CVFWs operated in different seasons, (ii) kinetics of dye and nutrients removal, (iii) statistical analysis to validate pollutant removal, (iv) characterize the compounds present in the inlet and outlet water samples using Fourier transform infrared (FTIR), (v) elemental and oxide accumulation
study of *Dracaena* by using X-ray fluorescence (XRF), (vi) compare the efficiency of the systems concerning the different concentration of dye mixture, and (vii) study the impact of synthetic dye mixture on the plant development.

**Material and methods**

Lab-scale CVFW setup, design, and operation

The experimental setups were made from opaque PVC pipes (to prevent algae growth) with a 4-inch diameter and 24-inch height (for providing space for grow of the plant root), providing an empty volume of 4.94 l. Each system was filled with two different natural media in layers with a particle size of 25–35 mm (gravels) and 8–12 mm (pea gravels) from bottom to up to support the plant species. CVFWs like CVFW-1, CVFW-2, and CVFW-3 were planted with the ornamental plant species named *Dracaena reflexa* except control system to study the influence of plant species on the treatment efficiency. The whole experimental setup was shown (Fig. 1). After plantation (single plant in each CVFW), the CVFWs were kept for 2 months to stabilize. The daily inlet dye mixture (synthetic wastewater) was 24 h for different CVFWs. This batch-scale experimental setup was located (21.7590° N, 72.1443° E) within the Council of Scientific and Industrial Research-Central Salt And Marine Chemicals Research Institute (CSIR-CSMCRI) Bhavnagar district of Gujarat. The system is exposed to ambient meteorological conditions. The CVFWs undergo vertical down-flow movement of wastewater. The outlet samples were collected every day (10 AM, with 24-h interval) from the outlet valve present at the bottom of each CVFW and were analyzed based on three seasons (summer, 02.03.2020 to 14.07.2020; monsoon, 17.07.2020 to 30.09.2020; and winter, 27.10.2020 to 24.11.2020), and the sample collection was stopped from 25 March to 7 June 2020 due to nationwide lockdown imposed by the Government of India for COVID-19 pandemic.

Characteristics of wastewater

Metanil yellow (acid yellow 36) is a commercial azo dye used in this study. The stock solution (1000 ppm) of the dye was prepared. The required concentrations for our investigation, i.e., 5 ppm, 50 ppm, and 100 ppm of volume 2 l, were prepared from the stock solution. In each dye concentration

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**Fig. 1** Schematic diagram of the experimental setup treating the textile dye wastewater
(i.e., 5, 50, 100 ppm), an equal amount of nutrients, i.e., diammonium hydrogen phosphate and potassium nitrate, were added. The dye mixtures were prepared inside the laboratory at a temperature of about 25 ºC by mixing all compounds properly (Table 1). During this study, all the used chemicals were analytical grade.

Water quality analysis

Inlet and outlet samples were sampled and analyzed correctly. Parameters like pH and TDS were measured on the spot immediately after sampling, and the remaining parameters (COD, color removal, chlorophyll estimation, nitrate, phosphate, and ammonium) were analyzed as per the procedure prescribed (APHA, 2017; Mohanty et al., 2015; Ray et al., 2014a). BOD analysis for water samples was not conducted as COD typically oxidizes more organic compounds chemically rather than biologically (Lee et al., 2016).

Chemical contaminants from water

The inlet and outlet water samples were analyzed using FTIR (Perkin Elmer, Model: Spectrum GX) (Ladwani, 2016) to see the presence of functional groups.

Biochemical characterization of Dracaena

Roots and stem from each CVFW were collected and analyzed during summer and winter for different biochemical characteristics. For ash content, the oven-dried roots and stem samples were kept in the muffle furnace at 500 ºC for 30 min. Further, the ash was dissolved in distilled water, and the filtrate was analyzed to determine the nutrient uptake (nitrogen, phosphorous). The chlorophyll concentrations (chlorophyll-a, chlorophyll-b, and total chlorophyll) were undertaken for leaf samples, where the leaf was collected under dark conditions and was analyzed.

Elemental analysis

The dried pulverized forms of plants (roots and stem) and media (composite sample: both gravels and pea gravel) samples were pressed to form homogeneous pellets using boric powder as a binder and further analyzed using “wavelength dispersive X-ray fluorescence spectrometer” (WDXRF, Model: Bruker S8 TIGER II) delivers with its high sense technology for all elements from “Be to Am.” Elemental compositions of the samples were analyzed by “complete analysis vac 34 mm” methods (Muduli et al., 2022).

Kinetic study

First-order kinetics model (Gajewska et al., 2020) was used to study the removal rate of the pollutants (COD, \( \text{NH}_4^+ \)-N, and \( \text{PO}_4^{3-} \)-P) and dye through the systems. Microsoft Excel-2010 was used for the evaluation of decomposition rate.

Statistical analysis

The statistical analysis was undertaken using Statistical Package for Social Sciences (SPSS) (Ver 22) (Ray et al., 2014b, 2019). Mann–Whitney \( U \) test was used to elucidate whether any significant difference exists between seasons concerning parameters. The principal component analysis (PCA) was undertaken to explain the inter-relationship between different parameters. The mean and standard deviation was calculated using Microsoft Office Excel 2010. The experimental data were collected in triplicates, and the mean was considered for interpretation with an experimental error within ±5%.

### Table 1: Wastewater composition

| Wetland type | Metanil yellow (mg/l) | \((\text{NH}_4)_2\text{HPO}_4\) (mg/l) | \(\text{KNO}_3\) (mg/l) | Wastewater volume (l) |
|--------------|------------------------|-------------------------------------|------------------------|-----------------------|
| Control      | 5                      | 14                                  | 12.48                  | 2                     |
| CFW-1        | 5                      | 14                                  | 12.48                  | 2                     |
| CFW-2        | 50                     | 14                                  | 12.48                  | 2                     |
| CFW-3        | 100                    | 14                                  | 12.48                  | 2                     |

*Metanil yellow: color index name—acid yellow 36, molecular composition—\( \text{C}_18\text{H}_{14}\text{N}_3\text{NaO}_3\text{S} \), molecular weight (g/mol)—375.38, \( \lambda_{\text{max}} \) (nm)—439, chemical class—mono azo (anionic), solubility—water; daily average inflow volume—2 l; daily average outflow volume—1.9 l
Results and discussion

Meteorological observations

Meteorological data like ambient air temperature, rainfall, and humidity were recorded (India Meteorological Department, 2020) and analyzed during the study, as they significantly influence the efficiency of the CWs during wastewater treatment (Yin et al., 2017). The ambient air temperature varied from 22.95 to 32.7 °C during the study, representing the local steppe climate. The average (± SD) ambient air temperatures for summer, winter, and monsoon were 28.7 ± 2.6, 29.7 ± 0.7, and 25.6 ± 1.9 °C, respectively. The rainfall was observed only in monsoon and varied from 0 to 1.4 mm, whereas the average (± SD) humidity for summer, monsoon, and winter were 69.9 ± 12.9, 78.7 ± 6.8, and 36 ± 5.4%, respectively.

Performance of the CVFWs for pollutant removal

During wastewater treatment, removing pollutants like dye, COD, PO$_4^{3-}$-P, and NH$_4^+$-N is a primary concern (Hussein & Scholz, 2018). During the study, the concentrations of the above pollutants were measured for both inlet and outlet water samples (Table 2). Over the study period, the inlet water quality showed not much variation for all the CVFWs (control, CVFW-1, CVFW-2, and CVFW-3) as they were prepared in the laboratory. In contrast, outlet water showed variation, especially for all the CVFWs planted with Dracaena, highlighting its role and dependence on meteorological factors.

Substantial dye removal was observed during the study period, maximum in summer, slightly lesser in winter, and the least in monsoon, respectively (Table 2). The dye removal in CVFW-3 is less than in CVFW-2, which may be due to the stress of a more significant inlet concentration of dye on Dracaena. Dye removal was achieved due to phytoremediation activities and media adsorption. Here the CVFWs with Dracaena can efficiently remove dye (37.1–76.8%) as compared with the previous study reported (Hussein & Scholz, 2018), i.e., 37–82%, treating other dyes using common reed. The relationship between ambient air temperature, air humidity, and dye removal during the study period is shown in Fig. 2. During summer, COD removal coincides with temperature, which may be due to the increased metabolism of plants and microbes in the wetland system; however, high air humidity hampers COD removal efficiency in monsoon. An increase in temperature would lead to a rise in carbon and nitrogen removal and vice versa. In winter, decreasing humidity accelerated the dye removal.

In this study, CVFWs could efficiently remove nutrients like PO$_4^{3-}$-P (19.5–58.2%) and NH$_4^+$-N (93.1–96.7%) (Table 2). In summer, the PO$_4^{3-}$-P removal efficiency was more than the other two seasons; the reason may be the higher rate of evapotranspiration and nutrient uptake (Nandakumar et al., 2019). Media adsorption and chemical precipitation may be the other reason for PO$_4$-P reduction. Here gravels (low in cost and collected locally) worked as reactive media as it contains Al, Ca, and Fe having a better affinity for phosphorus (Yin et al., 2017). The composite sample was collected at the end of the experiment and the elemental composition for gravels (control—Al: 48,900 ppm, Ca: 127,000 ppm, Fe: 78,400 ppm; CVFW-1—Al: 49,700 ppm, Ca: 142,000 ppm, Fe: 75,300 ppm; CVFW-2—Al: 43,800 ppm, Ca: 124,000 ppm, Fe: 74,900 ppm; CVFW-3—Al: 40,700 ppm, Ca: 115,000 ppm, Fe: 74,700 ppm) was analyzed using WDXRF. Better
Table 2 Performance of the *Dracaena*-based constructed vertical flow wetland (CVFW) system during different seasons

| Seasons | Wetland types | Parameters   | Observations | Inlet | Outlet | Removal (%) |
|---------|---------------|--------------|--------------|-------|--------|-------------|
|         |               |              |              | Min   | Max    | Mean±SD     | Min   | Max    | Mean±SD     |
|         |               |              |              | Mean±SD| Mean±SD|             | Mean±SD| Mean±SD|             |
|         |               |              |              |       |        |             |       |        |             |
| Summer  | Control       | Dye (mg/l)   | 34           | 5     | 5.95   | 5.5±0.2    | 0.55  | 5.3    | 3±0.9       | 44.3  |
|         |               | COD (mg/l)   | 34           | 28    | 36     | 32±2.2     | 28    | 36     | 32±2.1      | 0.9   |
|         |               | TDS (mg/l)   | 9            | 483   | 517    | 505.6±1    | 483   | 552    | 532±56      | n/a   |
|         |               | PO₄³⁻-P (mg/l)| 7          | 2.92  | 3.26   | 3.1±0.1    | 1.69  | 1.89   | 1.7±0.1     | 43    |
|         |               | NH₄⁺-N (mg/l)| 7           | 2.99  | 3.45   | 3.2±0.1    | 0.06  | 0.16   | 0.1±0        | 96.5  |
|         |               | DO (mg/l)    | 7            | 8.18  | 8.64   | 8.3±0.1    | 2.72  | 3.77   | 3±0.4        | n/a   |
|         |               | pH           | 9            | 7.92  | 8.23   | 8±0.1      | 7.61  | 8.2    | 7.8±0.1     | n/a   |
|         | CVFW-1        | Dye (mg/l)   | 34           | 5     | 5.95   | 5.5±0.2    | 0.1   | 2.2    | 1.3±0.4     | 75.1  |
|         |               | COD (mg/l)   | 34           | 28    | 36     | 32±2.2     | 8     | 16     | 12.3±2.1    | 61.8  |
|         |               | TDS (mg/l)   | 9            | 483   | 517    | 505.6±1    | 544   | 664    | 581±36.3    | n/a   |
|         |               | PO₄³⁻-P (mg/l)| 7          | 2.92  | 3.26   | 3.1±0.1    | 1.18  | 1.48   | 1.3±0.1     | 58.2  |
|         |               | NH₄⁺-N (mg/l)| 7           | 2.99  | 3.45   | 3.2±0.1    | 0.05  | 0.19   | 0.1±0        | 96.5  |
|         |               | DO (mg/l)    | 7            | 8.18  | 8.64   | 8.3±0.1    | 2.77  | 3.77   | 3.3±0.4     | n/a   |
|         |               | pH           | 9            | 7.92  | 8.23   | 8±0.1      | 7.26  | 7.73   | 7.5±0.1     | n/a   |
|         | CVFW-2        | Dye (mg/l)   | 34           | 50    | 59.25  | 52.2±2.4   | 8     | 18.55  | 12.4±2.8    | 76.1  |
|         |               | COD (mg/l)   | 34           | 62    | 72     | 68.2±3.2   | 12    | 26     | 20.1±4.1    | 70.5  |
|         |               | TDS (mg/l)   | 9            | 507   | 550    | 535.6±21.5 | 621   | 728    | 666.6±34.7  | n/a   |
|         |               | PO₄³⁻-P (mg/l)| 7          | 2.92  | 3.26   | 3.1±0.1    | 1.22  | 1.49   | 1.3±0.1     | 57.2  |
|         |               | NH₄⁺-N (mg/l)| 7           | 2.99  | 3.45   | 3.2±0.1    | 0.03  | 0.14   | 0.1±0        | 96.7  |
|         |               | DO (mg/l)    | 7            | 8.15  | 8.64   | 8.3±0.1    | 2.58  | 3.5    | 3.1±0.3     | n/a   |
|         |               | pH           | 9            | 8.08  | 8.21   | 8.1±0      | 7.29  | 7.7    | 7.5±0.1     | n/a   |
|         | CVFW-3        | Dye (mg/l)   | 34           | 100   | 115.15 | 107±4.3   | 37.45 | 69.8   | 57.6±6.7    | 46    |
|         |               | COD (mg/l)   | 34           | 96    | 130    | 113.1±9.9  | 30    | 66     | 45.9±11.5   | 59.4  |
|         |               | TDS (mg/l)   | 9            | 550   | 584    | 572.6±17   | 637   | 782    | 712.4±44.5  | n/a   |
|         |               | PO₄³⁻-P (mg/l)| 7          | 2.92  | 3.26   | 3.1±0.1    | 1.26  | 1.5    | 1.3±0.1     | 56.3  |
|         |               | NH₄⁺-N (mg/l)| 7           | 2.99  | 3.45   | 3.2±0.1    | 0.1   | 0.32   | 0.1±0.1     | 94.4  |
|         |               | DO (mg/l)    | 7            | 8.15  | 8.64   | 8.4±0.1    | 2.58  | 3.5    | 3.1±0.3     | n/a   |
|         |               | pH           | 9            | 8.06  | 8.29   | 8.1±0      | 7.29  | 7.72   | 7.5±0.1     | n/a   |
| Monsoon | Control       | Dye (mg/l)   | 19           | 5.22  | 5.61   | 5.4±0.1    | 2.66  | 3.7    | 3.2±0.2     | 40.8  |
|         |               | COD (mg/l)   | 19           | 28    | 34     | 32±1.6     | 28    | 34     | 32±1.6      | Nil   |
|         |               | TDS (mg/l)   | 9            | 483   | 517    | 505.6±17   | 483   | 552    | 532.5±22.8  | n/a   |
|         |               | PO₄³⁻-P (mg/l)| 19          | 2.92  | 3.26   | 3.1±0.1    | 2.25  | 2.65   | 2.5±0.1     | 19.5  |
|         |               | DO (mg/l)    | 19           | 8.15  | 8.64   | 8.3±0.1    | 2.42  | 3.52   | 3±0.4       | n/a   |
|         |               | pH           | 34           | 7.8   | 8.23   | 8±0.1      | 7.61  | 8.2    | 7.8±0.2     | n/a   |
|         | CVFW-1        | Dye (mg/l)   | 19           | 5.22  | 5.61   | 5.4±0.1    | 1.05  | 3.13   | 2±0.7       | 63.5  |
|         |               | COD (mg/l)   | 19           | 28    | 34     | 32±1.6     | 12    | 18     | 15.7±1.6    | 50.5  |
|         |               | TDS (mg/l)   | 9            | 483   | 517    | 505.6±17   | 544   | 664    | 581±36.3    | n/a   |
| Seasons | Wetland types | Parameters | Observations | Inlet | Min | Max | Mean ± SD | Outlet | Min | Max | Mean ± SD | Removal (%) |
|---------|--------------|------------|--------------|-------|-----|-----|----------|-------|-----|-----|----------|-------------|
| Winter | Control      | Dye (mg/l) | 9            | 5.23  | 5.94| 5.5 ± 0.2 | 2.23  | 3.85| 3.6 ± 0.6 | 45           |
|         | COD (mg/l)   | 9          | 32           | 39    | 33.2 ± 2.3 | 32    | 38  | 32.8 ± 2  | 0.9          |
|         | TDS (mg/l)   | 9          | 432          | 475   | 451.4 ± 16.1 | 418   | 549  | 469.4 ± 36.6 | n/a          |
|         | PO₄³⁻-P (mg/l) | 9     | 2.92         | 3.26  | 3.1 ± 0.1 | 1.76  | 1.96 | 1.8 ± 0.1 | 40.6         |
|         | NH₄⁺-N (mg/l) | 9     | 2.98         | 3.67  | 3.2 ± 0.2 | 0.02  | 0.74 | 0.2 ± 0.2 | 93.1         |
|         | NO₃⁻-N (mg/l) | 9     | 1.7          | 1.9   | 1.7 ± 0.1 | 2.4   | 2.9  | 2.6 ± 0.1 | n/a          |
|         | DO (mg/l)    | 9          | 8.15         | 8.6   | 8.4 ± 0.1 | 2.76  | 2.96 | 2.8 ± 0.1 | n/a          |
|         | pH           | 9          | 7.9          | 8.23  | 8 ± 0.1  | 7.61  | 8.2  | 7.8 ± 0.2 | n/a          |
| CVFW-1  | Dye (mg/l)   | 9          | 5.23         | 5.94  | 5.5 ± 0.2 | 1.19  | 2    | 1.4 ± 0.2 | 73.1         |
|         | COD (mg/l)   | 9          | 32           | 39    | 33.2 ± 2.3 | 8     | 16   | 11.8 ± 2.5 | 64.4         |
|         | TDS (mg/l)   | 9          | 432          | 475   | 451.4 ± 16.1 | 430   | 495  | 467.3 ± 20.3 | n/a          |
|         | PO₄³⁻-P (mg/l) | 9     | 2.92         | 3.26  | 3.1 ± 0.1 | 1.64  | 1.85 | 1.7 ± 0.1 | 43.7         |
|         | NH₄⁺-N (mg/l) | 9     | 2.98         | 3.67  | 3.2 ± 0.2 | 0.07  | 0.19 | 0.1 ± 0   | 96.2         |
|         | NO₃⁻-N (mg/l) | 9     | 1.7          | 1.9   | 1.7 ± 0.1 | 3     | 3.3  | 3.1 ± 0.1 | n/a          |
|         | DO (mg/l)    | 9          | 8.15         | 8.6   | 8.4 ± 0.1 | 2.73  | 3.46 | 2.9 ± 0.2 | n/a          |
|         | pH           | 9          | 7.9          | 8.23  | 8 ± 0.1   | 7.39  | 7.94 | 7.6 ± 0.2 | n/a          |
| CVFW-2  | Dye (mg/l)   | 9          | 53.99        | 57.14 | 55.2 ± 0.9 | 8.8   | 14.23| 12.8 ± 1.7 | 76.8         |
|         | COD (mg/l)   | 9          | 62           | 72    | 68.2 ± 3.5 | 12    | 24   | 18.8 ± 5.2 | 72.3         |
|         | TDS (mg/l)   | 9          | 313          | 488   | 447.8 ± 53.5 | 443   | 506  | 479.2 ± 19.9 | n/a          |
|         | PO₄³⁻-P (mg/l) | 9     | 2.92         | 3.26  | 3.1 ± 0.1 | 1.36  | 1.62 | 1.4 ± 0.1 | 53.7         |
NH₄⁺-N removal was achieved, which may be due to proper aeration enhancing the nitrification activities. The vertical hydraulic flow pattern and the rhizosphere zone of *Dracaena* enhanced the oxygen level. However, NO₃⁻-N concentration increased, which may be resulted from ammonia oxidation. The average TDS outlet concentration slightly exceeds the inlet (Table 2), observed in an earlier study (Hussein & Scholz, 2018). The average pH and DO values were given for both inlet and outlet water samples (Table 2). Overall the treatment performance of the wetland system was higher in both summer and winter, followed by the monsoon, where temperature and humidity play a vital role.

**First-order kinetics model**

The first-order kinetics model was used as a reliable tool to investigate the efficiency of a working system related to contaminant removal. Gajewska et al. (2020) have mentioned the first-order kinetics model for a vertical flow constructed wetland in their study.

\[
\frac{C_{Out}}{C_{In}} = e^{-\frac{K_A}{q}}
\]  

By solving Eq. (1), we can get

\[
K_A = -q \ln \frac{C_{Out}}{C_{In}}
\]  

where \(K_A\): decomposition rate constant in m/d; \(C_{out}\): outlet concentration in mg/l; \(C_{in}\): inlet concentration in mg/l; and \(q\): hydraulic loading rate in m d⁻¹.

Using Eq. (2), we calculated the decomposition rate constants for various parameters like COD, dye, PO₄³⁻-P, and NH₄⁺-N for different seasons. From Table 3, we found a remarkable removal rate, i.e., 0.33, was achieved by CVFW-1, especially in the summer season compared to the control system. However, both systems have been treated with the same concentration of dye mixture. This result indicated that plant species planted in CVFW-1 significantly contributed to the removal rate. From the decomposition rate constant value calculated for the other two systems named CVFW-2 and CVFW-3 treated with 50 and 100 ppm dye, respectively, we realized that CVFW-2 had greater \(K_A\) value, i.e., 0.34, during summer as compared to the other three systems. This result indicated that using *Dracaena*, we can treat dye mixture up to 50 ppm. Concentration more than 50 ppm may create a stressful condition for that plant species.

**Table 2 (continued)**

| Seasons  | Wetland types | Parameters          | Observations | Inlet         | Outlet         | Removal (%) |
|----------|---------------|---------------------|--------------|---------------|----------------|-------------|
|          |               | NH₄⁺-N (mg/l)       | 9            | 2.98          | 3.67           | 3.2 ± 0.2    | 0.06        | 0.24        | 0.1 ± 0.4    | 95.6         |
|          |               | NO₃⁻-N (mg/l)       | 9            | 1.7           | 1.9            | 1.7 ± 0.1    | 2           | 2.2         | 2.1 ± 0.1    | n/a          |
|          |               | DO (mg/l)           | 9            | 8.15          | 8.57           | 8.2 ± 0.1    | 2.58        | 3.47        | 3 ± 0.3      | n/a          |
|          |               | pH                  | 9            | 8.07          | 8.33           | 8.1 ± 0.1    | 7.11        | 8.15        | 7.5 ± 0.3    | n/a          |
|          | CVFW-3        | Dye (mg/l)          | 9            | 102.42        | 110.04         | 106.5 ± 2.9  | 52.38       | 67.19       | 60.9 ± 4.7   | 42.6         |
|          |               | COD (mg/l)          | 9            | 100           | 130            | 113 ± 9.4    | 30          | 60          | 42.5 ± 9.9   | 62.5         |
|          |               | TDS (mg/l)          | 9            | 451           | 492            | 472.5 ± 15   | 450         | 510         | 488.1 ± 22.5 | n/a          |
|          |               | PO₄³⁻-P (mg/l)      | 9            | 2.92          | 3.26           | 3.1 ± 0.1    | 1.56        | 1.75        | 1.6 ± 0.1    | 47.2         |
|          |               | NH₄⁺-N (mg/l)       | 9            | 2.98          | 3.67           | 3.2 ± 0.2    | 0.01        | 0.25        | 0.1 ± 0.1    | 96.2         |
|          |               | NO₃⁻-N (mg/l)       | 9            | 1.7           | 1.9            | 1.7 ± 0.1    | 1.75        | 1.95        | 1.8 ± 0.1    | n/a          |
|          |               | DO (mg/l)           | 9            | 8.15          | 8.64           | 8.4 ± 0.1    | 2.79        | 3.54        | 3.1 ± 0.3    | n/a          |
|          |               | pH                  | 9            | 8.06          | 8.39           | 8.2 ± 0.1    | 7.2         | 8.05        | 7.5 ± 0.3    | n/a          |

*Dye* azo dye metanil yellow, acid yellow 36, *COD* chemical oxygen demand, *TDS* total dissolved solids, *PO₄³⁻-P* phosphate phosphorous, *NH₄⁺-N* ammonium nitrogen, *NO₃⁻-N* nitrate nitrogen, *DO* dissolved oxygen, *SD* standard deviation, average air temperature, °C (summer: 28.7 ± 2.6SD, monsoon: 29.7 ± 0.7SD, winter: 25.6 ± 1.9SD), average air humidity, % (summer: 69.9 ± 12.9SD, monsoon: 78.7 ± 6.8SD, winter: 36 ± 5.4SD), average rainfall, mm (monsoon: 0.1 ± 0.3)
Moreover, during summer, high ambient temperature provides a favorable condition to the plant species to treat the dye mixture.

By analyzing the $K_A$ value of COD for four CVFWs, i.e., control, CVFW-1, CVFW-2, and CVFW-3, we observed a greater $K_A$, i.e., 0.308, by CVFW-2. From this result, we may conclude that the winter season may be providing favorable conditions to that plant species for the removal of COD. During the experiment, excellent performance was observed for removing $\text{NH}_4^{+}$-N by all systems. $K_A$ value of $\text{NH}_3$-N varies between 0.6 and 0.9 for all CVFWs. Between two seasons, i.e., summer and monsoon, the out-standing $K_A$ value of $\text{NH}_3$-N, i.e., 0.81, was achieved during summer. The design and configuration of all the systems and rhizospheric bacteria present around the root zones of plant species is the key contributor to the oxidation of $\text{NH}_4^{+}$-N.

Decomposition rate constants for $\text{PO}_4^{3-}$-P of all seasons by all the four reactors were studied, and we got to know that $K_A$ was found to be between 0.1 and 0.2. CVFW-3 achieved higher removal during summer. Both phyto-accumulation and adsorption by gravels used inside the CVFWs contributed towards $\text{PO}_4^{3-}$-P removal.

Statistical analysis

Mann–Whitney U test

In this study, the removal of various water pollutants during treatment using different CVFWs was considered to see whether seasonal variance has any impact on them or not using the “Mann–Whitney U test,” and the variations are shown (Table 7, supplementary file). Significant ($p<0.05$) dye removal was observed for CVFW-1
Similarly significant COD removal was observed for control (summer-monsoon), CVFW-1 (summer-monsoon and monsoon-winter), CVFW-2 (summer-monsoon and monsoon-winter), and CVFW-3 (summer-monsoon and monsoon-winter). Significant differences were observed in the case of dye, COD, and PO$_4^{3-}$-P removal, highlighting the impact of seasonal variation, whereas NH$_4^+$-N removal is independent of meteorological factors.

**Principal component analysis**

The PCA used in the present study helped to concise the information collected to a lesser set of critical, independent variables (Fig. 5). It was used to establish the relationship within the experimental variables (air temperature, pH, air humidity, COD, dye, DO, NH$_4^+$-N, and PO$_4^{3-}$-P) during the treatment. All the above variables were described with three components. Component-1 describes 28.09 of the cumulative variance with an eigenvalue of 2.24. It comprises of variables like air temperature, pH, air humidity, and dye, showing a positive correlation and highlighting the dye removal dependency on meteorological factors. Similarly, component-2 describes 46.29 of the cumulative variance and eigenvalue of 1.45. Here it comprises variables like COD and dye, highlighting the COD value that includes dye. Component-3 contains DO, NH$_4^+$-N, and PO$_4^{3-}$-P, which shows the dependency of NH$_4^+$-N removal on DO and PO$_4^{3-}$-P uptake by Dracaena and media adsorption.
FTIR spectral analysis

By analyzing both inlet and outlet samples of different CVFWs, i.e., control, CVFW-1, CVFW-2, and CVFW-3, by FTIR, we observed the presence of various functional groups and their intensities (Table 4). The comparative study of inlet and outlet of the wastewater (dye mixture) of concentration 5 ppm treated by control and CVFW-1, as shown in Fig. 6 (supplementary file), stated a remarkable change in the intensity of the functional group. A great shifting in intensity was noticed for the peak azide (2160–2120 cm⁻¹) in CVFW-1 compared to control. This better result in CVFW-1 may be due to phyto-accumulation and media absorption. From FTIR peak at 3340.92 cm⁻¹ of the outlet of control, i.e., N–H stretching, primary amine, we may predict that the formation of primary amine, a byproduct of the azo group, prevents further degradation process of dye.

By analyzing FTIR peaks of both inlet and outlet of CVFW-2, we observed no significant change in intensity of the azide group. But the peak at 1262.87 cm⁻¹ (alkyl aryl ether, aromatic ester) found in the inlet was absent in the outlet and the peaks at 1159.89, 1087.48, 1017.86, 887.84, 819.03, 755.55, 687.62, and 621.97 cm⁻¹ were found in the outlet. We may predict that the functional group alkyl aryl ether

![Fig. 4 Variation of NH₄⁺-N and PO₄³⁻-P concentrations in different CVFWs](a) summer; (b) winter; (c) summer; (d) monsoon; (e) winter)
| Seasons | Wetland types | Parameters | $C_{in}$ (mg/l) | $C_{out}$ (mg/l) | $K_A$ (m/d) |
|---------|--------------|------------|----------------|----------------|------------|
| Summer  | Control      | Dye        | 5.51           | 3.08           | 0.139      |
|         |              | COD        | 32.41          | 32.09          | 0.002      |
|         |              | $PO_4^{3-}$-P | 3.13          | 1.78           | 0.135      |
|         |              | $NH_4^+$-N | 3.25           | 0.11           | 0.813      |
|         | CVFW-1       | Dye        | 5.51           | 1.37           | 0.334      |
|         |              | COD        | 32.41          | 12.38          | 0.231      |
|         |              | $PO_4^{3-}$-P | 3.13          | 1.31           | 0.209      |
|         |              | $NH_4^+$-N | 3.25           | 0.11           | 0.813      |
|         | CVFW-2       | Dye        | 52.21          | 12.47          | 0.344      |
|         |              | COD        | 68.29          | 20.18          | 0.293      |
|         |              | $PO_4^{3-}$-P | 3.13          | 1.34           | 0.204      |
|         |              | $NH_4^+$-N | 3.25           | 0.11           | 0.813      |
|         | CVFW-3       | Dye        | 107.06         | 57.65          | 0.148      |
|         |              | COD        | 113.12         | 45.97          | 0.216      |
|         |              | $PO_4^{3-}$-P | 3.13          | 1.37           | 0.198      |
|         |              | $NH_4^+$-N | 3.25           | 0.18           | 0.694      |
| Monsoon | Control      | Dye        | 5.48           | 3.24           | 0.13       |
|         |              | COD        | 32             | 32             | 0          |
|         |              | $PO_4^{3-}$-P | 3.12          | 2.51           | 0.052      |
|         | CVFW-1       | Dye        | 5.48           | 2.01           | 0.24       |
|         |              | COD        | 32             | 15.79          | 0.169      |
|         |              | $PO_4^{3-}$-P | 3.12          | 1.8            | 0.132      |
|         | CVFW-2       | Dye        | 50.66          | 24.45          | 0.175      |
|         |              | COD        | 68.32          | 29.16          | 0.204      |
|         |              | $PO_4^{3-}$-P | 3.12          | 1.62           | 0.157      |
|         | CVFW-3       | Dye        | 101.45         | 63.55          | 0.112      |
|         |              | COD        | 113.79         | 55.68          | 0.172      |
|         |              | $PO_4^{3-}$-P | 3.12          | 1.68           | 0.148      |
| Winter  | Control      | Dye        | 5.52           | 3.3            | 0.123      |
|         |              | COD        | 33.22          | 32.89          | 0.002      |
|         |              | $PO_4^{3-}$-P | 3.14          | 1.86           | 0.125      |
|         |              | $NH_4^+$-N | 3.24           | 0.22           | 0.645      |
|         | CVFW-1       | Dye        | 5.52           | 1.48           | 0.315      |
|         |              | COD        | 33.22          | 11.89          | 0.246      |
|         |              | $PO_4^{3-}$-P | 3.14          | 1.76           | 0.138      |
|         |              | $NH_4^+$-N | 3.24           | 0.12           | 0.791      |
|         | CVFW-2       | Dye        | 55.24          | 12.8           | 0.351      |
|         |              | COD        | 68.22          | 18.89          | 0.308      |
|         |              | $PO_4^{3-}$-P | 3.14          | 1.45           | 0.185      |
|         |              | $NH_4^+$-N | 3.24           | 0.14           | 0.754      |
|         | CVFW-3       | Dye        | 106.59         | 60.97          | 0.134      |
|         |              | COD        | 113            | 42.56          | 0.234      |
|         |              | $PO_4^{3-}$-P | 3.14          | 1.66           | 0.153      |
|         |              | $NH_4^+$-N | 3.24           | 0.12           | 0.791      |

$A$, area, i.e., 0.0081 m$^2$, $C_{out}$, outlet concentration, mg/l, $C_{in}$, inlet concentration, mg/l, $q$, hydraulic loading rate, m/d, $K_A$, decomposition constant, m/d, $Dye$, azo dye metanil yellow, acid yellow 36, $COD$, chemical oxygen demand, $PO_4^{3-}$-P, phosphate phosphorous, $NH_4^+$-N, ammonium nitrogen.
and aromatic ester has got transformation during treatment to produce the alcohol, alkenes, aliphatic ethers, and various fluoro compounds.

By investigating the FTIR peak of both inlet and outlet of CVFW-3, we may state that a slight shift in intensity for the azide group has occurred (Fig. 7, supplementary file). Besides it, peaks (1260.71, 1021.81, 867.02, 806.61, 751.51, 632.99 cm⁻¹) disappeared in the outlet.

Elemental and oxide accumulation by Dracaena

The potential of Dracaena concerning elemental and oxide accumulation during treatment was observed in the present study while treating 262 l of wastewater from summer to winter, where composite samples were considered for analysis of root and stem. Metallic elements, viz., Al, Ti, Cr, Mn, Fe, Co, Ni, Cu, Zn, Mo, Ru, Pd, V, and W, and non-metallic elements, viz., Na, Mg, Si, P, S, Cl, K, Ca, Br, and Sr, were detected from root and stem of CVFW-1, CVFW-2, and CVFW-3, respectively (Table 5). Metallic element accumulation was observed for Mn (root—48%, stem—75.1%), Co (root—100%, stem—100%), Cu (root—30.3%, stem—7.7%), and Mo (root—100%, stem—100%) in CVFW-1, respectively. Accumulation in roots was observed for Cr (61.6%) and Ni (31.3%), whereas Al (25.7%) accumulation was observed in the stem. Similarly, nonmetallic element accumulation was observed for Na (root—34.5%, stem—89.4%), Mg (root—32.3%, stem—50.4%), Si (root—8.6%, stem—4.7%), S (root—28.1%, stem—65.3%), and Br (root—41.7%, stem—100%) in CVFW-1, respectively. Accumulation in stem was observed for P (58.3%), Cl (69.2%), K (5%), and Ca (63.7%). CVFW-1 accumulated oxides in both roots (CaO, MgO, Na₂O, K₂O, P₂O₅, MnO, SO₃, V₂O₅, SrO, CuO, Cr₂O₃, NiO, MoO₃, and CoO) and stem (SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO, Na₂O, TiO₂, P₂O₅, MnO, SO₃, V₂O₅, SrO, CuO, ZnO, MoO₃, CoO), respectively (Table 5). Similarly, the elements and oxides for CVFW-2 and CVFW-3 are shown in Table 4. Overall in CVFW-2, the accumulation was observed to be more than CVFW-1 and CVFW-3. Moreover, the element accumulation was observed to be maximum in the stem compared with roots for all the Dracaena-based wetlands. For oxides, accumulation was observed to be more in roots. The source of these elements and oxides may be largely from the media used in the wetlands, and some might be from the chemicals used to prepare the synthetic wastewater. The accumulation by Dracaena proves to be a potential plant species, which may be used in treating real textile dye wastewater (that contains both dye and other toxic elements).

Wastewater effect on Dracaena

The biochemical components of plants were studied as they played a vital role in textile dye wastewater treatment and taking nutrients (nitrogen, phosphorous). The growth of the Dracaena plant was monitored in terms of ash content, chlorophyll (a, b, and total), and inorganic salts (nitrogen and phosphorous) within a gap of 9 months, from summer to winter (Table 6). A substantial increase in chlorophyll concentrations was observed for CVFW-1 and CVFW-2 with no physical stress on plant growth. In contrast, decreased chlorophyll in CVFW-3 shows plant stress imposed due to higher inlet dye concentration. The root ash content has increased for all CVFWs, whereas stem ash content is only observed to be decreased in CVFW-3.

Fig. 5 Principal component analysis highlighting the relationship within the experimental variables (air temperature, pH, air humidity, COD, dye, DO, NH₄⁺-N, and PO₄³⁻-P) during the treatment
### Table 4  Infrared frequencies and identified functional groups from FTIR spectra

| Wetland types | Inlet                          | Outlet                          | Inlet                          | Outlet                          |
|---------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|
|               | Frequency (cm⁻¹) | Possibility of functional groups | Respective functional groups | Frequency (cm⁻¹) | Possibility of functional groups | Respective functional groups |
| Control       | 3855.54           | O–H stretching                  | Alcohol                       | 3984.96           | O–H stretching                  | Alcohol                       |
|               | 3391.42           | O–H stretching                  | Alcohol                       | 3340.92           | N–H stretching                  | Aliphatic primary amine, secondary amine |
|               | 2127.93           | N = N = N stretching            | Azide                         | 2132.71           | N = N = N stretching, N = C = N stretching, CΞC stretching | Azide, carbodiimide, alkyne |
|               | 1871.37           | C–H bending                     | Aromatic compound             | 1642.96           | C = N stretching, C = C stretching | Imine/oxime, alkene, conjugated alkene |
|               | 1644.2            | C = C stretching, N–H BENDING   | Conjugated alkene, alkene, amine, cyclic alkene, alkene, imine/oxime | 1262.93           | C–O stretching                  | Aromatic ester, alkyl aryl ethers |
|               | 625.18            | C–Br stretching                 | Halo compound                 | 700.13            | C = C bending                   | Alkene                         |
|               | 413.84            |                                |                               | 412.61            |                                |                                |
| CVFW-1        | 3372.66           | O–H stretching, N–H stretching  | Alcohol, aliphatic primary amine | 3294.5            | O–H stretching, C–H stretching | Carboxylic acid, alcohol, alkyne |
|               | 2127.53           | N = N = N stretching, N = C = N stretching | Azide, carbodiimide | 2131.79           | CΞC stretching, N = C = N stretching, N = C = S stretching, N = N = N stretching, N = C = S stretching | Alkyne, carbodiimide, azide, isothiocyanate |
|               | 1643.87           | C = C stretching, C = N stretching, C = C stretching | Conjugated alkene, imine/oxime, alkene | 1642.98           | C = N stretching, C = C stretching | Imine/oxime, alkene, conjugated alkene |
|               | 731.55            | C–H bending                     | Mono substituted              | 700.8             | C = C bending                   | Alkene                         |
|               | 412.48            |                                |                               | 413.33            |                                |                                |
| Wetland types | Inlet | Possibility of functional groups | Respective functional groups | Outlet | Possibility of functional groups | Respective functional groups |
|---------------|-------|---------------------------------|-----------------------------|--------|---------------------------------|-----------------------------|
| CVWF-2        | 3934.91 | O–H stretching                  | Alcohol                     | 3614.9 | O–H stretching                  | Alcohol                     |
|               | 3467.72 | O–H stretching                  | Alcohol                     | 2127.13| N=N=N stretching, N=C=N stretching, C=C=N stretching, N=C=S stretching | Azide, carbodiimide, alkyne, isothiocyanate |
|               | 3263.87 | O–H stretching                  | Carboxylic acid             | 1651.18| C=N stretching, C=C stretching  | Alkene, imine/oxime         |
|               | 2131.49 | N=N=N stretching, N=C=N stretching, C=C=N stretching, N=C=S stretching | Azide, carbodiimide, alkyne, isothiocyanate | 1159.89| O–H bending, C–F stretching, C–O stretching | Fluoro compound, tertiary alcohol |
|               | 1642.65 | C=C stretching                  | Alkene, conjugated alkene   | 1087.48| C–O stretching,                | Aliphatic ether, secondary alcohol |
|               | 1262.87 | C–O stretching                  | Alkyl aryl ether, aromatic ester | 1017.86|                                  |                             |
|               | 698.2   | C–Br stretching                 | Halo compound               | 887.84 | C=C bending                     | Alkene                      |
|               | 412.12  |                                 |                             | 755.55 | C–H bending                     | Mono substituted            |
|               |         |                                 |                             | 687.62 | C–Br stretching                 | Halo compound               |
|               |         |                                 |                             | 621.62 | C–Br stretching                 | Halo compound               |
|               |         |                                 |                             | 557.77 | C–I stretching                  | Halo compound               |
|               |         |                                 |                             | 489.12 |                                  |                             |
|               |         |                                 |                             | 435.34 |                                  |                             |
| Wetland types | Inlet | Outlet |
|---------------|-------|--------|
|               | Frequency (cm\(^{-1}\)) | Possibility of functional groups | Respective functional groups | Frequency (cm\(^{-1}\)) | Possibility of functional groups | Respective functional groups |
| CVFW-3        | 3928.44 | O–H stretching | Alcohol | 3937.15 | O–H stretching | Alcohol |
|               | 3900.77 | O–H stretching | Alcohol | 3543.17 | O–H stretching | Alcohol |
|               | 3647.53 | O–H stretching | Alcohol | 3262.99 | O–H stretching | Alcohol, carboxylic acid |
|               | 3565.23 | O–H stretching | Alcohol | 2129.62 | N = N = N stretching | Azide |
|               | 2126.5 | N = N = N stretching, N = C = N stretching, CΞC stretching, N = C = S stretching | Azide, carbodiimide, Alkyne, isothiocyanate | 1642.47 | C = N stretching | Imine/oxime |
|               | 1651.86 | C = N stretching, C = C stretching | Imine/oxime, alkene | 701.25 | | Benzene derivative |
|               | 1260.71 | C-O stretching | Aromatic ester, alkyl aryl ether | 553.31 | | |
|               | 1021.81 | | | | | |
|               | 867.02 | | | | | |
|               | 806.61 | C = C bending, C–Cl stretching | Alkene, halo compound | | | |
|               | 751.51 | C–Cl stretching | Halo compound | | | |
|               | 632.99 | C–Br stretching | Halo compound | | | |
|               | 474.93 | | | | | |
Table 5  Elemental and oxide accumulation by *Dracaena* in the wetlands during the study period

|          | Element | Summer | Winter | Accumulation (%) |
|----------|---------|--------|--------|------------------|
|          |         | Root   | Stem   | CVFW-1 Root   | CVFW-1 Stem |
| Elements | Na (ppm)| 1310   | 284    | 2000          | 2690        | 34.5 | 89.4 |
|          | Mg (ppm)| 1130   | 1220   | 1670          | 2460        | 32.3 | 50.4 |
|          | Al (ppm)| 408    | 1100   | 549           | 942         | 25.7 | n/a |
|          | Si (ppm)| 1600   | 4070   | 1750          | 4270        | 8.6  | 4.7 |
|          | P (ppm) | 1490   | 830    | 1180          | 1990        | n/a  | 58.3 |
|          | S (ppm) | 3090   | 1560   | 4300          | 4490        | 28.1 | 65.3 |
|          | Cl (ppm)| 12,700 | 4470   | 11,700        | 14,500      | n/a  | 69.2 |
|          | K (ppm)| 27,400 | 6250   | 6750          | 6580        | n/a  | 5.0 |
|          | Ca (ppm)| 17,300 | 8640   | 14,600        | 23,800      | n/a  | 63.7 |
|          | Ti (ppm)| 194    | 489    | n/d           | 300         | n/a  | n/a |
|          | Cr (ppm)| 96.7   | 116    | 252           | n/d         | n/a  | n/a |
|          | Mn (ppm)| 156    | 96.7   | 300           | 389         | 48.0 | 75.1 |
|          | Fe (ppm)| 3450   | 7820   | 2230          | 4230        | n/a  | n/a |
|          | Co (ppm)| 112    | 104    | 163           | 93.9        | 31.3 | n/a |
|          | Ni (ppm)| 154    | 190    | 221           | 231         | 30.3 | 17.7 |
|          | Cu (ppm)| 187    | 209    | 177           | 219         | n/a  | 4.6 |
|          | Zn (ppm)| 186    | n/d    | 319           | 414         | 41.7 | 100.0 |
|          | Br (ppm)| 725    | 331    | 598           | 111         | n/a  | n/a |
|          | Sr (ppm)| 725    | 331    | 385           | 423         | 100.0 | 100.0 |
|          | Mo (ppm)| 420    | 583    | 421           | 524         | 0.2  | n/a |
|          | Ru (ppm)| 186    | 459    | n/d           | 915         | n/a  | 49.8 |
|          | Pd (ppm)| n/d    | n/d    | n/d           | 829         | n/a  | 100.0 |
|          | W (ppm) | n/d    | n/d    | n/d           | 127         | n/a  | 100.0 |
|          | V (ppm) | n/d    | n/d    | n/d           | 127         | n/a  | 100.0 |
| Oxides   | SiO₂ (ppm)| 9100 | 3060  | 3790          | 9480        | n/a  | 67.7 |
|          | Al₂O₃ (ppm)| 2050 | 882  | 1220          | 1777        | n/a  | 50.4 |
|          | Fe₂O₃ (ppm)| 10,900 | 4820 | 3270          | 5730        | n/a  | 15.9 |
|          | CaO (ppm)| 12,400 | 24,100 | 20,200        | 33,300      | 38.6 | 27.6 |
|          | MgO (ppm)| 2200   | 1910   | 2820          | 4230        | 22.0 | 54.8 |
|          | Na₂O (ppm)| 387   | 1810   | 2850          | 3940        | 86.4 | 54.1 |
|          | TiO₂ (ppm)| 758   | 413    | 184           | 527         | n/a  | 21.6 |
|          | K₂O (ppm)| 7400   | 33,100 | 8130          | 7760        | 9.0  | n/a |
|          | P₂O₅ (ppm)| 1170  | 3270   | 2540          | 4480        | 53.9 | 27.0 |
|          | MnO (ppm)| 162    | 163    | 360           | 488         | 55.0 | 66.6 |
|          | SO₃ (ppm)| 3800   | 7550   | 10,800        | 10,700      | 64.8 | 29.4 |
|          | V₂O₅ (ppm)| 99.8  | n/d    | 150           | 244         | 33.5 | 100.0 |
|          | SrO (ppm)| 379    | 851    | 766           | 1230        | 50.5 | 30.8 |
|          | CuO (ppm)| 208    | 213    | 246           | 276         | 15.4 | 22.8 |
|          | Cr₂O₃ (ppm)| 49.5 | n/d    | 250           | n/d         | 80.2 | n/a |
|          | ZnO (ppm)| 287    | 218    | 220           | 284         | n/a  | 23.2 |
|          | NiO (ppm)| 88.6   | 125    | 189           | n/d         | 53.1 | n/a |
|          | MoO₃ (ppm)| n/d   | 592    | 538           | 635         | 100.0 | 6.8 |
|          | CoO (ppm)| n/d    | n/d    | 68.1          | 18.1        | 100.0 | 100.0 |
### Table 5 (continued)

| Elements | Summer | Winter | Accumulation (%) |
|----------|--------|--------|------------------|
|          | Root   | Stem   | Root   | Stem   | Root   | Stem   |
| Na (ppm) | 1310   | 284    | 743    | 2690   | n/a    | 89.4   |
| Mg (ppm) | 1130   | 1220   | 1590   | 2460   | 28.9   | 50.4   |
| Al (ppm) | 408    | 1100   | 2080   | 942    | 80.4   | n/a    |
| Si (ppm) | 1600   | 4070   | 4040   | 4270   | 60.4   | 4.7    |
| P (ppm)  | 1490   | 830    | 672    | 1990   | n/a    | 58.3   |
| S (ppm)  | 3090   | 1560   | 9190   | 4490   | 66.4   | 65.3   |
| Cl (ppm) | 12,700 | 4470   | 3930   | 14,500 | n/a    | 69.2   |
| K (ppm)  | 27,400 | 6250   | 1810   | 6850   | n/a    | 8.8    |
| Ca (ppm) | 17,300 | 8640   | 16,500 | 23,800 | n/a    | 63.7   |
| Ti (ppm) | 194    | 489    | 997    | 300    | 80.5   | n/a    |
| Cr (ppm) | 96.7   | 96.7   | 687    | 389    | 77.3   | 75.1   |
| Mn (ppm) | 156    | 96.7   | 687    | 389    | 77.3   | 75.1   |
| Fe (ppm) | 3450   | 7820   | 17,000 | 4230   | 79.7   | n/a    |
| Co (ppm) | n/d    | n/d    | n/d    | 18.9   | n/a    | 100.0  |
| Ni (ppm) | 112    | 104    | 232    | 93.9   | 51.7   | n/a    |
| Cu (ppm) | 154    | 190    | 308    | 231    | 50.0   | 17.7   |
| Zn (ppm) | 187    | 209    | 279    | 219    | 33.0   | 4.6    |
| Br (ppm) | 725    | 331    | 704    | 1110   | n/a    | 70.2   |
| Sr (ppm) | 725    | 331    | 704    | 1110   | n/a    | 70.2   |
| Mo (ppm) | n/d    | n/d    | 425    | 423    | 100.0  | 100.0  |
| Ru (ppm) | 420    | 583    | 554    | 524    | 24.2   | n/a    |
| Pd (ppm) | n/d    | 459    | 594    | 915    | 100.0  | 49.8   |
| W (ppm)  | n/d    | n/d    | n/d    | 829    | n/a    | 100.0  |
| V (ppm)  | n/d    | n/d    | 111    | 127    | 100.0  | 100.0  |
| Oxides   |        |        |        |        |        |        |
| SiO\textsubscript{2} (ppm) | 9100   | 3060   | 19,500 | 1800   | 53.3   | n/a    |
| Al\textsubscript{2}O\textsubscript{3} (ppm) | 2050   | 882    | 4190   | n/d    | 51.1   | n/a    |
| Fe\textsubscript{2}O\textsubscript{3} (ppm) | 10,900 | 4820   | 24,100 | 2580   | 54.8   | n/a    |
| CaO (ppm) | 12,400 | 24,100 | 22,700 | 22,300 | 45.4   | n/a    |
| MgO (ppm) | 2200   | 1910   | 2760   | 1550   | 20.3   | n/a    |
| Na\textsubscript{2}O (ppm) | 387    | 1810   | 967    | 3850   | 60.0   | 53.0   |
| TiO\textsubscript{2} (ppm) | 758    | 413    | 1640   | 230    | 53.8   | n/a    |
| K\textsubscript{2}O (ppm) | 7400   | 33,100 | 2170   | 8810   | n/a    | n/a    |
| P\textsubscript{2}O\textsubscript{5} (ppm) | 1170   | 3270   | 1300   | 1300   | 10.0   | n/a    |
| MnO (ppm) | 162    | 163    | 880    | 365    | 81.6   | 55.3   |
| SO\textsubscript{3} (ppm) | 3800   | 7550   | 9780   | 4400   | 61.1   | n/a    |
| V\textsubscript{2}O\textsubscript{5} (ppm) | 99.8   | n/d    | 249    | n/d    | 59.9   | n/a    |
| SrO (ppm) | 379    | 851    | 755    | 789    | 49.8   | n/a    |
| CuO (ppm) | 208    | 213    | 378    | 191    | 45.0   | n/a    |
| Cr\textsubscript{2}O\textsubscript{3} (ppm) | 49.5   | n/d    | 265    | n/d    | 81.3   | n/a    |
| ZnO (ppm) | 287    | 218    | 344    | 137    | 16.6   | n/a    |
| NiO (ppm) | 88.6   | 125    | 239    | 93.5   | 62.9   | n/a    |
| MoO\textsubscript{3} (ppm) | n/d    | 592    | 603    | n/d    | 100.0  | n/a    |
Table 5 (continued)

| Elements | Summer | Winter | Accumulation (%) |
|----------|--------|--------|------------------|
|          | Root   | Stem   | Root             | Stem   | Root   | Stem   |
| Na (ppm) | 1310   | 284    | 958              | 5710   | n/a    | 95.0   |
| Mg (ppm) | 1130   | 1220   | 1650             | 3720   | 31.5   | 67.2   |
| Al (ppm) | 408    | 1100   | 1630             | 585    | 75.0   | n/a    |
| Si (ppm) | 1600   | 4070   | 6350             | 3530   | 74.8   | n/a    |
| P (ppm)  | 1490   | 830    | 1060             | 4470   | n/a    | 81.4   |
| S (ppm)  | 3090   | 1560   | 8780             | 6100   | 64.8   | 74.4   |
| Cl (ppm) | 12,700 | 4470   | 8550             | n/d    | n/a    | n/a    |
| K (ppm)  | 27,400 | 6250   | 1550             | 24,800 | n/a    | 74.8   |
| Ca (ppm) | 17,300 | 8640   | 19,400           | 39,100 | 10.8   | 77.9   |
| Ti (ppm) | 194    | 489    | 818              | 220    | 76.3   | n/a    |
| Cr (ppm) | 96.7   | 96.7   | 786              | 473    | 80.2   | 79.6   |
| Mn (ppm) | 156    | 361    | 13,400           | 3520   | 74.3   | n/a    |
| Fe (ppm) | 112    | 104    | 213              | n/d    | 47.4   | n/a    |
| Ni (ppm) | 154    | 190    | 395              | 219    | 61.0   | 13.2   |
| Cu (ppm) | 187    | 209    | 387              | 361    | 51.7   | 42.1   |
| Zn (ppm) | 186    | n/d    | 348              | 620    | 46.6   | 100.0  |
| Br (ppm) | 194    | 331    | 691              | 1660   | n/a    | 80.1   |
| Mo (ppm) | 420    | 583    | 500              | 702    | 16.0   | 17.0   |
| Ru (ppm) | 420    | 459    | 220              | 398    | 100.0  | 100.0  |
| Pd (ppm) | n/d    | n/d    | 453              | 82.4   | 100.0  | 100.0  |

**Oxides**

| Oxides  | Summer | Winter | Accumulation (%) |
|---------|--------|--------|------------------|
| SiO₂ (ppm) | 9100   | 3060   | 14,100           | 7620   | 35.5   | 59.8   |
| Al₂O₃ (ppm) | 2050   | 882    | 3000             | 1340   | 31.7   | 34.2   |
| Fe₂O₃ (ppm) | 10,900 | 4820   | 18,400           | 4810   | 40.8   | n/a    |
| CaO (ppm)  | 12,400 | 24,100 | 26,500           | 53,900 | 53.2   | 55.3   |
| MgO (ppm)  | 2200   | 1910   | 2820             | 6620   | 22.0   | 71.1   |
| Na₂O (ppm) | 387    | 1810   | 1190             | 8450   | 67.5   | 78.6   |
| TiO₂ (ppm) | 758    | 413    | 1100             | 268    | 31.1   | n/a    |
| K₂O (ppm)  | 7400   | 33,100 | 1920             | 14,200 | n/a    | n/a    |
| P₂O₅ (ppm) | 1170   | 3270   | 2360             | 10,700 | 50.4   | 69.4   |
| MnO (ppm)  | 162    | 163    | 1030             | 602    | 84.3   | 72.9   |
| SO₃ (ppm)  | 3800   | 7550   | 21,800           | 14,900 | 82.6   | 49.3   |
| V₂O₅ (ppm) | 99.8   | n/d    | 754              | n/d    | 86.8   | n/a    |
| SrO (ppm)  | 379    | 851    | 776              | 1780   | 51.2   | 52.2   |
| CuO (ppm)  | 208    | 213    | 503              | 319    | 58.6   | 33.2   |
| Cr₂O₃ (ppm) | 49.5   | n/d    | 503              | n/d    | n/a    | n/a    |
| ZnO (ppm)  | 287    | 218    | 469              | 480    | 38.8   | 54.6   |
| NiO (ppm)  | 88.6   | 125    | 279              | n/d    | 68.2   | n/a    |
| MoO₃ (ppm) | n/d    | n/d    | n/d              | 430    | n/a    | 100.0  |

Accumulation observed while treating 262 l of wastewater from summer to winter

n/d not detected, n/a not applicable
Conclusions

In this study, the performance of different “constructed vertical flow wetlands” treating textile dye wastewater (metanil yellow as dye) is investigated for 9 months (covering three seasons). The CVFWs planted with *Dracaena* efficiently removed contaminants like dye, COD, NH₄⁺-N, and PO₄³⁻-P from the wastewater and the removal performance largely depends on meteorological factors. The CVFWs’ overall performance is similar for summer and winter, and least in monsoon. Significant dye removal was observed during the study period, maximum in summer (control, 44.3%; CVFW-1, 75.1%; CVFW-2, 76.1%; CVFW-3, 46%), but lesser in winter (control, 45; CVFW-1, 73.1%; CVFW-2, 76.8%; CVFW-3, 42.6%) and the least in monsoon (control, 40.8%; CVFW-1, 63.5%; CVFW-2, 51.6%; CVFW-3, 37.1%), whereas COD removal was observed to be highest in winter (64.4%, CVFW-1; 72.3%, CVFW-2; 62.5%, CVFW-3) followed by summer (61.8%, CVFW-1; 70.5%, CVFW-2; 59.4%, CVFW-3) and monsoon (50.5%, CVFW-1; 57.2%, CVFW-2; 51%, CVFW-3). Nutrients ranged between 52.1 and 64.4% (PO₄³⁻-P) and 56.6 and 71.6 (NH₄⁺-N). CVFW-1 and CVFW-2 performed well, showing no stress on *Dracaena*, whereas CVFW-3 showed lesser performance, which may be due to plant stress resulting from a higher inlet concentration of dye. Dye removal was achieved due to phytoremediation activities and media adsorption. *Dracaena* proved to be efficient in dye removal and other pollutants; however, exceeding dye concentrations (> 50 mg/l) may pose stress. The first-order kinetic model was used to evaluate the decomposition rate constant. Higher $K_A$ values were achieved for dye removal in summer for all CVFWs. Various functional groups were characterized using FTIR from the inlet and outlet water samples of different CVFWs. The pollutant removal efficiency concerning seasons was validated statistically. Dye, COD, and PO₄³⁻-P removal showed significant differences, highlighting the impact of seasonal variation, whereas NH₄⁺-N removal is independent of meteorological factors. The *Dracaena* of the wetlands accumulated various elements and oxides with no stress on its health. Apart from wetland species, there are various robust ornamental plants that can be tested for textile dye wastewater treatment.

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Table 6 Biochemical characteristics of *Dracaena* of CVFWs

| Wetland types | Parameters | CVFW-1 | CVFW-2 | CVFW-3 |
|---------------|------------|--------|--------|--------|
| Summer        | Root ash content (%) | 0.96   | 0.96   | 0.96   |
|               | Stem ash content (%)  | 4.90   | 4.90   | 4.90   |
|               | Ammonia (mg/l), root  | 0.82   | 0.82   | 0.82   |
|               | Ammonia (mg/l), stem  | 0.82   | 0.82   | 0.82   |
|               | Phosphate (mg/l), root | 0.02   | 0.02   | 0.02   |
|               | Phosphate (mg/l), stem | 0.03   | 0.03   | 0.03   |
|               | Chlorophyll a (mg/ml) | 1.48   | 1.48   | 1.48   |
|               | Chlorophyll b (mg/ml) | 0.95   | 0.95   | 0.95   |
|               | Total chlorophyll (mg/ml) | 2.42   | 2.42   | 2.42   |
| Winter        | Root ash content (%) | 1.73   | 1.25   | 1.60   |
|               | Stem ash content (%)  | 5.16   | 6.97   | 3.17   |
|               | Ammonia (mg/l), root  | 1.16   | 1.03   | 0.90   |
|               | Ammonia (mg/l), stem  | 0.98   | 1.04   | 0.98   |
|               | Phosphate (mg/l), root | 0.05   | 0.03   | 0.03   |
|               | Phosphate (mg/l), stem | 0.06   | 0.03   | 0.03   |
|               | Chlorophyll a (mg/ml) | 2.84   | 3.29   | 3.25   |
|               | Chlorophyll b (mg/ml) | 1.30   | 1.53   | 1.35   |
|               | Total chlorophyll (mg/ml) | 4.01   | 4.81   | 4.24   |
Author contribution Monali Muduli: conceptualization, data curation, and writing—original draft. Meena Choudhary: data curation, review writing, visualization. Soumya Haldar: review and editing. Sanak Ray: conceptualization, visualization, review, supervision, editing, and fund acquisition.

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Data availability Data are available from the authors upon reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

References

APHA. (2017). Standard methods for the examination of water and waste water (23rd ed.). American Public Health Association.

Ali, Y., Shafida, A. H., & Rashid, U. (2018). Biomedical applications of aromatic azo compounds. Mini Reviews in Medicinal Chemistry, 18(18), 1548–1558. https://doi.org/10.2174/138955751866618052413111

Anjaneya, O., Souche, S. Y., Santoshkumar, M., & Karegoudar, T. B. (2011). Decolorization of sulfonated azo dye metanil yellow by newly isolated bacterial strains: Bacillus sp. strain AK1 and Lysinibacillus sp. strain AK2. Journal of Hazardous Materials, 190(1–3), 351–358. https://doi.org/10.1016/j.jhazmat.2011.03.044

Benkhaya, S., M’rabet, S., & El Harfi, A. (2020). Classifications, properties, recent synthesis and applications of azo dyes. Helikon, 6(1). https://doi.org/10.1016/j.helikon.2020.e03271

Chung, K. T. (2016). Azo dyes and human health: A review. Journal of Environmental Science and Health - Part C Environmental Carcinogenesis and Ecotoxicology Reviews, 34(4), 233–261. https://doi.org/10.1080/10590501.2016.1236602

Dadrasnia, A., & Pariatamby, A. (2016). Phyto-enhanced remediation of soil co-contaminated with lead and diesel fuel using biowaste and Dracaena reflexa: A laboratory study. Waste Management and Research, 34(3), 246–253. https://doi.org/10.1177/0734242X15621375

Dogdu, G., & Yalcuk, A. (2016). Indigo dyeing wastewater treatment by eco-friendly constructed wetlands using different beddng media. Desalination and Water Treatment, 57(32), 15007–15019.

Gajewska, M., Skrzypiec, K., Jó, K., Mucha, Z., Karczmarczyk, A., & Bugajski, P. (2020). Kinetics of pollutants removal in vertical and horizontal flow constructed wetlands in temperate climate. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2020.137371

Ghosh, D., Singha, P. S., Firdaus, S. B., & Ghosh, S. (2017). Metanil yellow: The toxic food colorant. Asian Pacific Journal of Health Sciences, 4(4), 65–66. https://doi.org/10.21276/apjhs.2017.4.4.16

Guerrero-Coronilla, I., Aranda-García, E., & Cristiani-Urbina, E. (2019). Biosorption of metanil yellow dye from aqueous solutions by the entire water hyacinth plant (Eichhornia crassipes) and its vegetative organs. Environmental Engineering and Management Journal, 18(8), 1671–1682. https://doi.org/10.30638/eemj.2019.157

Haddadi, D., Ghnabi-Gammar, Z., Hamed, K. B., & Bousselmi, L. (2019). A re-circulating horizontal flow constructed wetland for the treatment of synthetic azo dye at high concentrations. Environmental Science and Pollution Research, 26(13), 13489–13501.

Hussein, A., & Scholz, M. (2018). Treatment of artificial wastewater containing two azo textile dyes by vertical-flow constructed wetlands. Environmental Science and Pollution Research, 25(7), 6870–6889. https://doi.org/10.1007/s11356-017-0992-0

Indian Meteorological Department. (2020). Retrieved 2 March 2020 to 24 November 2020, from https://mausam.imd.gov.in/

Kourani, K., Kapoor, N., Badiye, A., & Shukla, R. K. (2020). Detection of synthetic food color “metanil yellow” in sweets: A systematic approach. Journal of Planar Chromatography - Modern TLC, 33(4), 413–418. https://doi.org/10.1007/s00764-020-00046-9

Ladwani, K. D., Ladwani, K. D., Ramteke, D. S., & Deo, S. (2016). Detection and identification of organic compounds in wastewater of final effluent treatment plant by FTIR and GC-MS. Journal of Advanced Chemical Sciences, 2(2), 246-247.

Lee, J., Lee, S., & Yu, S. (2016). Relationships between water quality parameters in rivers and lakes: BOD 5, COD, NBOPs, and TOC. Environmental Monitoring and Assessment. https://doi.org/10.1007/s10661-016-5251-1

Li, Y., Yang, H. Y., Shen, J. Y., Mu, Y., & Yu, H. Q. (2016). Enhancement of azo dye decolourisation in a MFC-MEC coupled system. Bioresource Technology, 202, 93–100. https://doi.org/10.1016/j.biortech.2015.11.079

Matyszczak, G., Sędkowska, A., & Kuś, S. (2020). Comparative degradation of metanil yellow in the electro-Fenton process with different catalysts: A simplified kinetic model study. Dyes and Pigments, 174(July). https://doi.org/10.1016/j.dyepig.2019.108076

Mohanty, A., Ray, S., Yadav, A. K., & Chaudhury, G. R. (2015). NH3 and COD removal from wastewater using biological process: Kinetics with optimization studies. Desalination and Water Treatment, 53(3), 658–670.

Muduli, M., Sonpal, V., Ray, S., & Haldar, S. (2022). In-depth performance study of an innovative decentralized multistage constructed wetland system treating real institutional wastewater. Environmental Research, 210, 112896. https://doi.org/10.1016/j.envres.2022.112896

Nandakumar, S., Pipil, H., Ray, S., & Haritash, A. K. (2019). Removal of phosphorus and nitrogen from wastewater in Brachiaria-based constructed wetland. Chemosphere, 233, 216–222.

Oon, Y. L., Ong, S. A., Ho, L. N., Wong, Y. S., Dahalan, F. A., Oon, Y. S., et al. (2020). Constructed wetland–microbial fuel cell for azo dyes degradation and energy recovery: Influence of molecular structure, kinetics, mechanisms and degradation
pathways. *Science of the Total Environment*, 720, 137370. https://doi.org/10.1016/j.scitotenv.2020.137370

Ramadhani, P., Chaidir, Z., Zilfa, Z., Tomi, Z. B., Rahmiarti, D., & Zein, R. (2020). Shrimp shell (Metapenaeus monoceros) waste as a low-cost adsorbent for metanil yellow dye removal in aqueous solution. *Desalination and Water Treatment*, 197, 413–423. https://doi.org/10.5004/dwt.2020.25963

Ray, S., Mohanty, A., Mohanty, S. S., Mishra, S., & Chaudhury, G. R. (2014a). Optimization of biological elimination of ammonia and COD from waste water using response surface methodology. *Clean-Soil, Air, Water*, 42(12), 1744–1750.

Ray, S., Mohanty, A., Mohanty, S. S., Mishra, S., & Chaudhury, G. R. (2014b). Removal of nitrate and COD from wastewater using denitrification process: Kinetic, optimization, and statistical studies. *Clean Technologies and Environmental Policy*, 16(2), 291–301.

Ray, S., Scholz, M., & Haritash, A. K. (2019). Kinetics of carbon and nitrogen assimilation by heterotrophic microorganisms during wastewater treatment. *Environmental Monitoring and Assessment*, 191(7), 451.

Tee, H. C., Lim, P. E., Seng, C. E., Mohd Nawi, M. A., & Adnan, R. (2015). Enhancement of azo dye acid orange 7 removal in newly developed horizontal subsurface-flow constructed wetland. *Journal of Environmental Management*, 147, 349–355. https://doi.org/10.1016/j.jenvman.2014.09.025

Yaseen, D. A., & Scholz, M. (2017). Comparison of experimental ponds for the treatment of dye wastewater under controlled and semi-natural conditions. *Environmental Science and Pollution Research*, 24(19), 16031–16040. https://doi.org/10.1007/s11356-017-9245-5

Yin, H., Yan, X., & Gu, X. (2017). Evaluation of thermally-modified calcium-rich attapulgite as a low-cost substrate for rapid phosphorus removal in constructed wetlands. *Water Research*, 115, 329–338. https://doi.org/10.1016/j.watres.2017.03.014

Zou, H., & Wang, Y. (2017). Azo dyes wastewater treatment and simultaneous electricity generation in a novel process of electrolysis cell combined with microbial fuel cell. *Bioresource Technology*, 235, 167–175. https://doi.org/10.1016/j.biortech.2017.03.093

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