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Research article

Recycling of wet grinding industry effluent using effective Microorganisms™ (EM)

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ABSTRACT

A considerable volume of effluent released from the food processing industries, after the extensive use in the products manufacturing and industrial process. Effluents, either without treatment or with improper treatment, released out from the industries would severely damage the environment and human health. An investigation was done by recycling the effluent samples, collected from the wet grinding industry, Madurai, India, which was determined with an acidic pH (5.93), high turbidity (160.78 NTU), high BOD (62.4 mg/l) and COD (274.38 mg/l) and a significantly higher quantity of starch (115.81 mg/l). Biological wastewater treatment method was chosen in this experiment on the basis of the biodegradability index of effluent (3.21–10.75). The main goal of this study was to evaluate the effectiveness of wastewater treatment in a prototype STP utilizing the Effective Micro-organisms™ Consortium application. The US EPA International Water Quality Standards and the Water Quality Index were used to compare the water quality of the recycled effluent with and without the EM application. The effluent from the EM consortium treatment was found to have acceptable levels of pH (7.38), salinity (1.94 ppt) and Conductivity (4.05 mS); and a declining trend found in TDS (1.81 ppt), BOD (24.4 mg/l) and COD (148.83 mg/l) level when the effluent treated using EM. Removal effectiveness of EM significant reduce in the treated effluents starch (85.15%), sulphate (78.42), phosphate (79.60), nitrogen (65.54%), and turbidity (82.73%) level were observed. Which was shown to be comparatively better than employing without EM treatment. This research substantially intends to the best practices, towards sustainable industries through Cleaner Production Mechanism.

1. Introduction

Global food requirement is fulfilled by the food and food product manufacturing and food processing industries, utilizing the agricultural, dairy, meat products. It is estimated that about 50% of natural inland fresh water resources is consumed by these industries for food processing [1,2], and about 60% of food and agro-product industries discharge the effluents, thereby contaminating fresh water resources and oceans [3]. The annual rate of food wastes, generally found with the composition of carbohydrate, protein, lipids, vitamins and organic acids; minerals, synthetic dyes and preservatives and its generation in India is estimated as 350 million tons [4]. The Biodegradable nature makes food industry wastes non-hazardous [5]; however, the proliferating load with organic pollutants discharged to the environment is apparently depends over the nature and quantity of products, manufactured by these industries [6]. Moreover, climatic factor plays a significant role in characterization of the effluents [7].

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Abbreviations

WGI	Wet Grinding Industry
TDS	Total Dissolved Solid
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
SS	Suspended Solid
STP	Sewage Treatment Plant
DO	Dissolved oxygen
ET	effluent Treatment
EM	Effective Microorganisms
AST	Activated Sludge Treatment

Starch based food products industries release effluent, loading with rich organic contents, minerals, oils and low to medium levels of protein, and about 70% soluble solid. Influenced with acidic pH, higher levels of BOD, COD, SS and turbidity in the effluents [8], rich organic materials further causing eutrophication and algal blooms [9]. Hence, the polluted water becomes vulnerable in causing health-hygiene problems, loss of natural biodiversity [10].

Recycling of domestic wastewater as well as the industrial effluent becomes highly essential [11], since they want replenishment of fresh water resources, especially the aquifers to recharge using the safely land-filled recycled wastewaters. Better options with recycling of effluents from food industry include effective recycling through treatment in sewage treatment Plants. Similarly, constructed wetlands have also been employed, experiencing the significant removal of nitrogen and phosphorus removal [12]. Recycling of food industries wastes have been done employing with relatively more expensive physical and chemical treatments [13].

Adoption of different treatment procedures have been followed, using coagulation process in the potato chips industry and rice mills and in cassava products industries [14–16]. Ultra-membrane filtration [17]; nano-absorbent methods [18]; phyto-remediation, using algal treatment [19,20] and anaerobic processes [21] have also been employed in the effluent treatment processes. Chemical treatment in several cases indulges in the incomplete degradation of pollutants [22], also the use of chemical coagulant is found to increase the sludge volume, eventually causing severe environmental contamination [23]. Membrane treatment technology makes excessive contaminants formation leading to clocking of the membrane, thereby filtration gets severe setbacks [24]. The use of synthetic flocculants in the wastewater treatment has a high possibility of mixing up such pollutants with aquifers [25], owing to severe damage to the natural environmental resources. Alternatively, cost-effective biological treatment methods, when they are employed have no severe environmental impacts and by adopting proper recycling using biological treatment, no such adverse affects to environment and the human health impacts.

Use of either single microbial organism [26] or the consortium of microbes [27] have been proved with several benefits, as the microbial activity significantly moderates the levels of BOD, nitrogen, phosphate [28]. Sustainable productivity of the industries could be attained through water-food industries nexus [29,30], through the wise application of suitable treatment technologies, to manage the precious natural freshwater resources. Properly established water quality standards [31,32], would be a pre-requisite for the reuse to crop irrigation [33]. Reusing of food industry effluent, following the proper treatment methods have been demonstrated as they possess advantages including protection of the natural environment from water contamination [34], Moreover, the benefits including the cost effectiveness [35]. Besides the treatment process significantly accomplish water purification, thereby possible promotion of circular economy and sustainable industrial development.

Not much literature is available to show the biological treatment of rice and pulses based product manufacturing wet grinding Industry (WGI) effluent, using microbial consortium. To this context, the research question "What kind of effectiveness in the wet grinding food industry effluent can be done, using the bioremediation method and further, how would be the treatment happens at the different stages of effluent treatment." To address the research question, investigation of this experiment with the objective to determine the effectiveness of processed Effective Microorganisms (EM)™ in the recycling treatment of wet grinding food industry effluent was carried out. Further, the treated water quality in terms of Removal Efficiency (RE), and National Sanitation Foundation (NSF) formulated Water Quality Index (WQI). Treatment efficacy of EM was further analyzed using the statistical procedures viz., ANOVA and Principal Component Analysis (PCA) applied in this experiment. This experiment results would be applicable in the management of precious fresh water resources.

2. Material and methods

2.1. Description of study area and sampling

The food industry situated in Madurai, Tamil Nadu, south India (Latitude 9°55′17.3964″ and Longitude 78°8′49.8444″), manufacturing batter for the popular south Indian food items – *idli, dosai* and black gram *vadai* through wet grinding of rice and polished black lentil seeds. The effluent was collected directly from the industry in clean plastic bottles, during the study period of April 2017 to March 2018, using standard procedure [36], followed by storing at 4 °C in the laboratory, for the further treatment process.

2.2. Effective microorganisms (EM) culture preparation

Commercially available Effective Microorganism™, which comprised of a consortium of *Rhodopsedomonas* sp.*, Lactobascillus* sp., and *Saccharomyces* sp.*,* was used to prepare the extended form of EM culture, to facilitate the fermentation process. The preparatory method reported earlier [37] was followed. The excess gas formed was allowed to escape out to avoid frothing and from the fermented EM culture, mixed with sodium aluminium silicate (zeolite) and kept in dark condition or seven days. This was used in recycling of the wet grinding industrial effluent.

We observed the presence of *Lactobacillus*, *Pseudomonas* and *Yeast* in the EM consortium and generally they have been considered as beneficial population groups and effectively degraded the starch containing effluent [38]. Further, the use of the microbes has no negative effect over the naturally occurring bacteria, as the opportunity of reusing the treated effluent by land refilling [39]. The productivity and quality of agricultural crops are improved by spraying EM culture, as previously reported [40]. Moreover, EM has more function including as a bio-stimulant and effectively involve in bio-sorption of heavy metals from wastewater [41].

In Sago industry effluent treated using microbial consortium reduced only 63% of starch content [42]. Meanwhile, the use of wild microbes could unable to perform or failure in removal of contaminants from wastewater [43]. Therefore an acceptable water quality level attained when using Effective Microorganisms™ (EM), in the recycling of greywater [37,44,45] was tested in this experiment to recycling of WGI effluent.

2.3. Prototype design used in the effluent treatment experiment

The prototype of the Effluent Treatment (ET) system was fabricated with 5ltr capacity as shown in Fig (1). The prototype was designed with the relative dimensions and flocculation and settling tank conditions, available from the standard treatment plant model [46,47]. Raw effluent sample was added with the extended EM *Bokashi* inoculums, in effluent collection tank and then make to flow into mechanical aeration tank for flocculation, using an electric motor to develop 5mpa pressurized aeration (1.25l/min). Then the activated sludge was subjected into secondary sludge removal point, where the suspended solid particles settled down due to gravity force, allowing lighter pure water collected at the top surface. The purified water was allowed to flow through open ended glass tube at the top of the tank, and finally the clarified water was passed through sand filter. Recycled water from this treatment process was collected and stored for laboratory analyses. Similar procedure was employed to the wet grinding industry effluent sample, without adding of EM inoculums for the sludge activation.

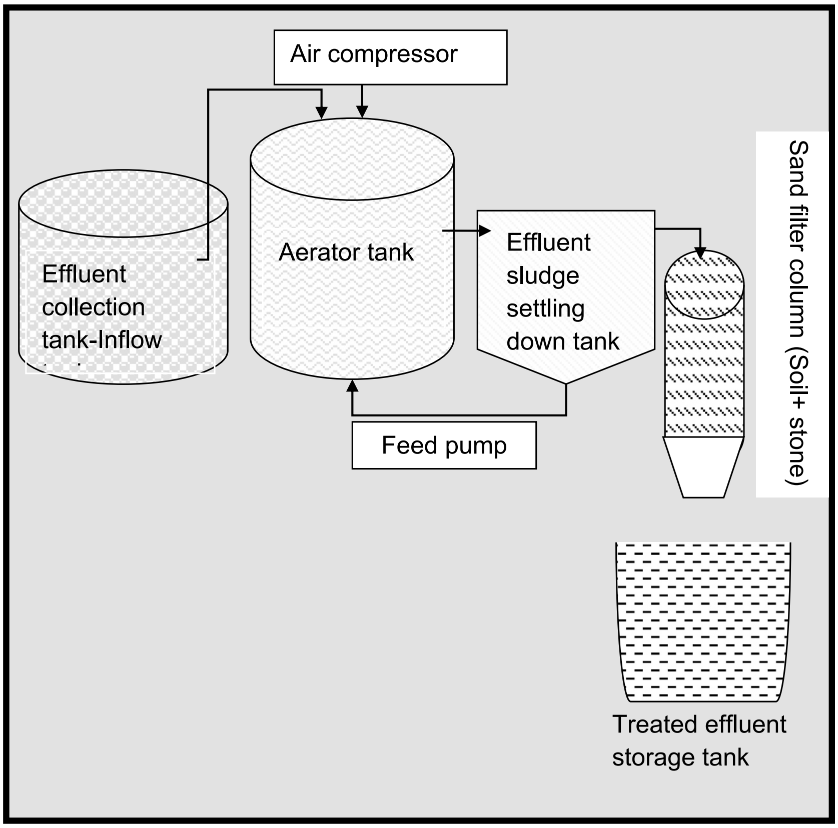

Fig. 1. Scheme of operation for the prototype used in the recycling of wet grinding industry effluent.

2.4. Water quality analysis

Water quality analysis was done in terms of physical nature, water chemistry, using the standard APHA [48], protocols. Temperature, pH, DO, Salinity, Conductivity, TDS, Turbidity using Water Analysis Kit (Systronics Make, No:'371') and BOD, COD, acidity, alkalinity, total hardness, calcium, magnesium, nitrogen, sulphate, phosphate, and starch were determined using wet chemical analysis. Enterobacteriaceae colony was counted by using Colony Forming Unit (CFU) method. Water Quality Index (WQT) of was calculated by the standard method of National Sanitation Foundation (NSFWQT), using the following formula, $NSFWQI = \sum Wiqi$, where qi represents the curved based sub-index value for ith variable, ranged from 0 to 100, and the weight coefficient of ith parameter was estimated to compare the ratio with the standard weight given to denote the water quality

After the treatment procedure was completed, the degradation rate of organic and inorganic compounds was determined through removal efficiency (RE) of contaminants from the recycled water samples.

$$\text{Removal efficiency } \% = \frac{(t_0 - t_1)}{t_0} \times 100$$

Where, t_0 is the analyzed parameter in the raw effluent and t_1 is the same parameter, following recycling.

2.5. Statistical analysis

SPSS software (version16.0) was used to compute the descriptive statistics. One way and two way ANOVA methods used to analyze

Table 1

One way analysis of variance, water quality between the raw wet grinding industry effluent (RWGIE), activated sludge treated effluent (ASTE) without EM and EM treated effluent (EMTE), differentiated with Duncan's Multiple Range Test at $P \leq 0.05$ significant level, and Comparison of water quality with reuses standards (Ref:EnvironmentProtectionRules1986; CPCB2009, US EPA 2012).

Parameters	RWGIF	ASTE	EM TF	Removal efficacy of ASTE (%)	Removal efficacy of EM TE (%)	Agriculture Land Irrigation	Into inland surface
Colour	Milky white	Pale white	Transparent	–	–	–	–
Odour	Strong	Moderate	Less	–	–	–	–
Slurry	222	27	19	82.22	85.58	100	200
Temperature	29±2 °C	28±2 °C	28±2 °C	–	–	45	45
pH	5.93 ± 0.17^c	6.94 ± 0.09^b	7.38 ± 0.08^a	–	–	5–8.5	5.5–9.00
DO (ppm)	4.44 ± 0.31^c	5.44 ± 0.28^b	6.54 ± 0.25^a	–	–	–	4
Salinity (ppt)	3.21 ± 0.61^c	2.87 ± 0.71^b	1.94 ± 0.45^a	10.52	39.44	NS	NS
Conductivity (mS)	5.11 ± 1.31^c	4.94 ± 1.28^b	4.05 ± 1.20^a	3.21	20.76	2.25	–
TDS (ppm)	2.60 ± 0.63^c	2.56 ± 0.67^b	1.81 ± 0.54^a	1.58	30.15	2100	2100
Turbidity (NTU)	160.78 ± 7.07^c	37.74 ± 4.82^b	27.77 ± 4.97^a	76.52	82.73	≤2	≤2
Acidity (mg/l)	66.51 ± 13.61^c	25.66 ± 6.49^b	27.90 ± 6.84^a	–	–	NS	NS
Alkalinity (mg/l)	29.59 ± 9.57^c	30.64 ± 8.10^b	25.11 ± 6.98^a	–	–	NS	NS
Total Hardness (mg/l)	446.67 ± 26.34^c	271.94 ± 22.63^b	155.12 ± 12.04^a	39.11	65.27	NS	NS
Calcium (mg/l)	164.91 ± 9.79^c	92.56 ± 11.56^b	60.81 ± 6.21^a	43.87	63.12	NS	75
Magnesium (mg/l)	173.56 ± 26.69^c	129.10 ± 28.46^b	65.03 ± 13.48^a	25.61	62.52	NS	50
Nitrogen (mg/l)	97.26 ± 13.69^c	44.15 ± 9.60^b	33.51 ± 7.31^a	54.60	65.54	50	50
phosphate (mg/l)	192.17 ± 20.16^c	48.78 ± 4.67^b	39.20 ± 4.10^a	74.61	79.60	–	5
sulphate (mg/l)	73.97 ± 6.48^c	30.18 ± 2.34^b	15.96 ± 1.33^a	59.20	78.42	1000	–
BOD (mg/l)	62.4 ± 0.26^c	61.9 ± 0.13^b	24.4 ± 0.09^a	48.99	60.91	100	30
COD (mg/l)	274.38 ± 13.42^c	194.17 ± 7.30^b	148.83 ± 5.88^a	29.23	45.75	250	250
Starch (mg/l)	115.81 ± 8.52^c	24.23 ± 4.19^b	18.35 ± 2.98^a	79.08	85.15	–	–
TDS/Conductivity ratio	1.87 ± 0.10^c	0.51 ± 0.01^b	0.56 ± 0.11^a	–	–	–	–

*NS not specified in the water quality standards.

the significance between the analyzed variable and treatment effects. Regression analysis was done to determine the extent of correlation among the analyzed variables. Principal component analysis was done using BioVinci software version 3.08.

3. Results and discussion

The water quality of raw effluent was determined from the samples, collected from the wet grinding industry. Treatment of such effluent using Effective microorganisms, which are contained lactic acid bacteria, photosynthetic bacteria and yeast. Among them lactic acid bacteria was efficient in fermentation of grain and pulses [49,50]. Also, the experimental results (Table 1) prove that lactic acid bacteria in the applied EM culture efficiently removed the starch content. Treatment efficacy, in terms of physical attributes and water chemistry was tested for both water samples collected after EM treatment and without EM treatment. Raw effluent was found with a range between 3.21 and 10.75 on Biodegradability Index (BI), during the study period (Fig. 2) and similar values were observed in the previous report of Abdalla and Hammam [51],

3.1. Physical quality

At every time of sample collection, the effluent appeared as a dense milky white liquid with a bad odour, as the effluent was loaded with organic substances and their anaerobic oxidizing nature, a general phenomenon with the food industry effluents [17,52]. Colour removal from the effluent and its appearance like natural water was achieved when the effluent was recycled using EM in this experiment. Colour of effluents may occur due to higher loading of organic compounds in the effluent [6]. Highly significant enhanced dissolved oxygen (DO) level was recorded in EM treated effluent samples, when compared to activated sludge treated effluent, with no EM application (Table 1). Which could be related to the phenomenon of the increased oxidation – reduction in the EM culture applied industrial effluent environment, thereby improves the aerobic activity, eventually facilitated in the organic matter degradation Among the four Principal components with cumulative 77.89% formed. DO was found as the strongest negative dependent parameters segregated as the third component was extracted (Table 2, Fig. 3). This feature could be attributed to the fact supported by Aniyikaiye et al. [53], demonstrating the influential role of excessive biodegradable nutrient contents and their eutrophication effects upon the microbial colonization, further depletes the DO level drastically.

Turbidity level in the water sample is facilitated by the presence of organic and inorganic contaminants [54]. A high amount of turbidity (160.78 NTU) was found in the raw effluent and 82.24% and 78% average turbidity reduction were respectively, made using activated sludge treatment with EM and without EM reduction in the present experimental recycling process (Table 1), due to the settling ability of the suspended solids, as EM treatment was found in the enhancement of flocculation, thereby decreasing the level of suspended solids. Microbial flocculent used in wastewater treatment also reached a similar finding [55]. Turbidity was found segregated with first strongest dependent parameter (Table 2 and Fig. 3). Wastewater generally treated with alum and ferric chloride produced a better form of recycled water using multistage treatment employed in wheat processing industry and also considered to be an efficient method [56]. However, the treatment processes require high-energy consumption, making very high operation and maintenance costs. It was quantified with 0.14% and 0.01% sludge recovery respectively quantified in the secondary sedimentation without and with EM treated effluent. Biological method of wastewater recycling has the advantage of sludge reduction in effluent purification, which is further confirmed through this result and the same is emphasized in a similar finding [57]. Effective

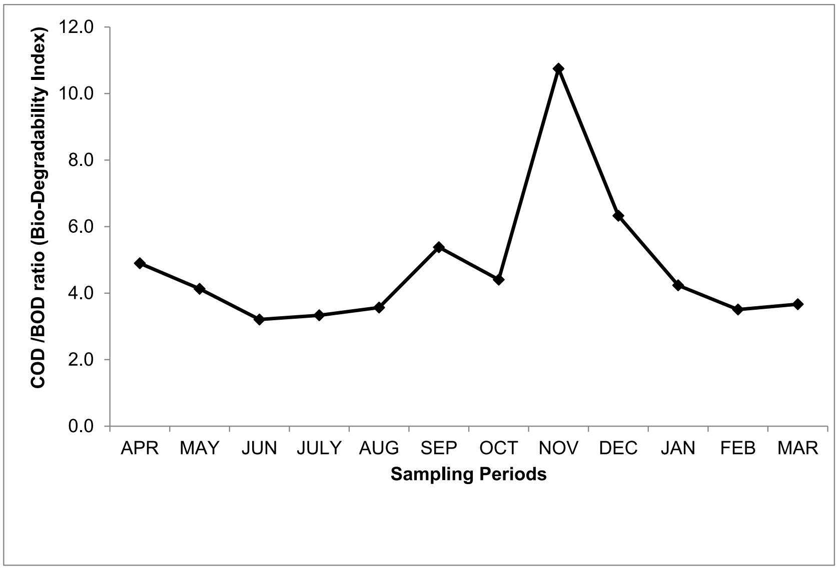

Fig. 2. COD/BOD ratio as the Bio-Degradability Index of wet grinding industry effluent during sampling periods.

Table 2
Principal Component Analysis (PCA) of wet grinding food industry effluent (RE) treated with activated sludge treatment process (ASE) without EM and EM Consortium treatment (EME) were accompanied by Varimax with Kaiser Normalization method.

Rotated Component Matrix[a]				
Parameters	Compound1	Compound 2	Compound 3	Compound 4
pH	−0.598			
DO (ppm)			−0.522	−0.648
Salinity (ppt)			0.793	
Conductivity (mS)		0.872		
TDS (ppm)		0.874		
Turbidity (NTU)	0.889			
Acidity (mg/l)		0.652		
Alkalinity (mg/l)		0.861		
Hardness (mg/l)	0.616			0.527
Calcium (mg/l)	0.722			
Magnesium (mg/l)				0.914
Nitrogen (mg/l)		0.556	0.588	
Sulphate (mg/l)	0.683		0.521	
Phosphate (mg/l)	0.607			
BOD (mg/l)	0.877			
COD (mg/l)	0.732			
Starch (mg/l)	0.875			
Total	**5.43**	**3.76**	**2.12**	**2.01**
% variance	**31.46**	**22.12**	**12.48**	**11.82**
Cumulative %	**31.46**	**53.58**	**66.06**	**77.89**

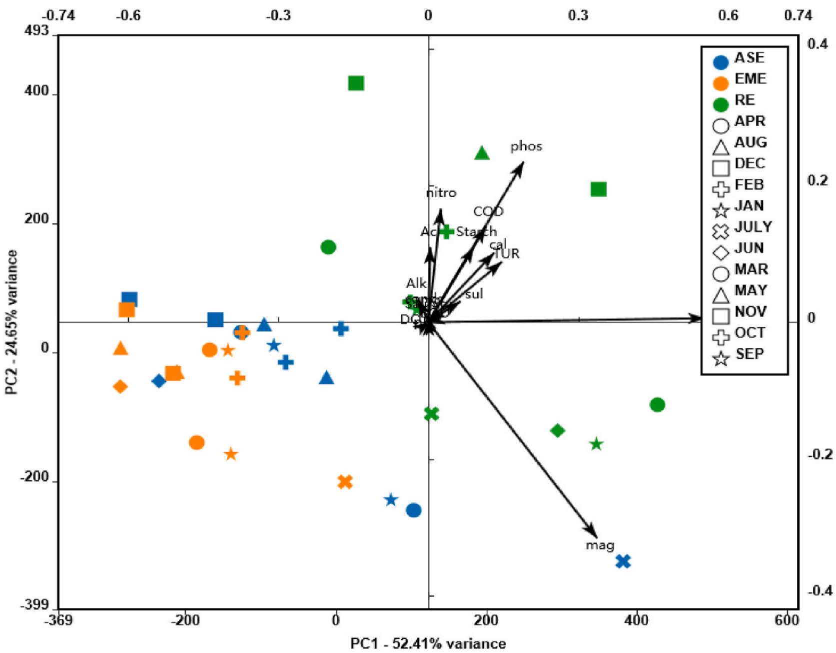

Fig. 3. Principal Component Analysis (PCA) of wet grinding food industry effluent (RE) treated with activated sludge treatment process without EM (ASE) and EM Consortia treatment (EME) were accompanied by Varimax with Kaiser Normalization method, five rotation coverage interactions, four components extracted.

Microorganisms consortium was observed more efficient as its application facilitated a higher rate in the removal of organic and inorganic substances than from the activated sludge treated effluent (Table 1).

3.2. Chemical quality

Raw effluent was found with acidic (5.93 ± 0.17) to slightly alkaline pH range, during the experimental period. Acidic pH of the effluents when it reaches the natural water resources will have an adverse effect on the microbial diversity and their related biochemical reactions [58]. To avoid such conditions, experimental effluent samples treated with activated sludge process, using EM, attained an acceptable limit [59,60], compared to sludge activated without EM treated effluent (Table 1). This result is comparable with the works of Tsolcha et al. [61], on cheese industrial effluent, treated using Choricystis-based microbial consortium. The functional role of enduring microbes with their modified biochemical reactions are tend to be modified with the pH of the aquatic environment [52]. and hence possibly, a conducive environment is developed to the aquatic life.

A high amount of salinity was tested in the raw effluent sample (3.21 ± 0.61 ppt) and its level was considerably reduced by the EM treatment (39.44%) than from the activated sludge (10.5%) treated effluent (Table 1). Moreover, this parameter has segregated as the third strongest factor in PCA (Table 2 and Fig. 3). The raw effluent sample was observed with a fluctuating range of conductivity (5.11 ± 1.31 mS) during sampling periods. It is a common phenomenon of high conductivity, which is indicated by the presence of fairly a larger quantity of ionic forms of inorganic substance [62], which would keep on changing the equilibrium of aqueous solution. Significantly lower conductivity value was detected in the effluent treated using EM consortium when compared with activated sludge treated effluent, without EM application (Table 1). A meager reduction of ionized compounds could be removed in the activated sludge treatment, without the application of EM; whereas in EM applied food industry effluent reduced a high amount of ionized compound. A considerable reduction of conductivity was found in this situation of effluent treatment using constructed wetland system through phyto-remediation [63].

Steepwater of corn meal mill effluent treatment, through physical and chemical treatment were experienced to be ineffective in the removal of contaminants [64]. The divergent nature of contaminating pollutants present in the effluents disrupts the relationship between the conductivity and TDS [65]. EM consortium treated wet grinding industry effluent showed a higher R^2 value, compared to activated sludge treated effluent, without EM consortia (Fig. 4i), revealing the removal of contaminants and regained the low positive relationship between conductivity and TDS. This indicates that using EM consortia in effluent treatment could increase the removal of ionized compounds and restore the relationship between conductivity and TDS (Fig. 4ii). Degrading hydrocarbons and conductivity are the major determinants causing the increase of Total Dissolved Solids (TDS) in contaminated water [66]. A higher rate of TDS in the raw wet grinding industry effluent was able to be reduced moderately using the activated sludge treated effluent without EM (1.58%) in this experiment. EM applied activated sludge treatment was found with appreciable removal of TDS (30.15%) (Table, 1) and from the PCA, it is confirmed as the second strongest loading factor (Table 2 and Fig. 3). Similar to this study results, Uysal and Ekinci [67], demonstrated the reuse water quality standards of photo-bioreactor applied oil effluent treatment.

TDS concentration (2.60 ± 0.63 ppm) in the effluent samples, during the experimental period was found higher than the permitted level, which would cause fluctuating osmotic pressure in crop plants upon irrigation [68]. A higher TDS to Conductivity ratio (2.1) was found in raw effluent and moderate level was reached (0.56), following the EM consortium application (Table 1) which can be considered as the appropriate value [69].

A higher level of acidity determined in the raw effluent samples (66.51 mg/l) could be reduced to a moderate level using activated sludge treated effluent (25.66 mg/l) and EM treatment in the recycling was found with a significant reduction (27.90 mg/l). Subsequently higher level of alkalinity enhances the hardness level [54]. When the pH is too low, the activity of the methanogenic biomass decreases, and the anaerobic digestion process entirely fails [70]. WGI raw effluent was detected to have greater acidity conduction, but the EM consortium was able to withstand it throughout treatment. Meanwhile, a lower amount of alkalinity was noticed in the EM treated effluent (25.11 mg/l), when compared to sludge activation treatment without the addition of EM culture (Table 1). This phenomenon facilitates a stable condition of the syntrophic metabolism, which is essentially required in the effective effluent recycling

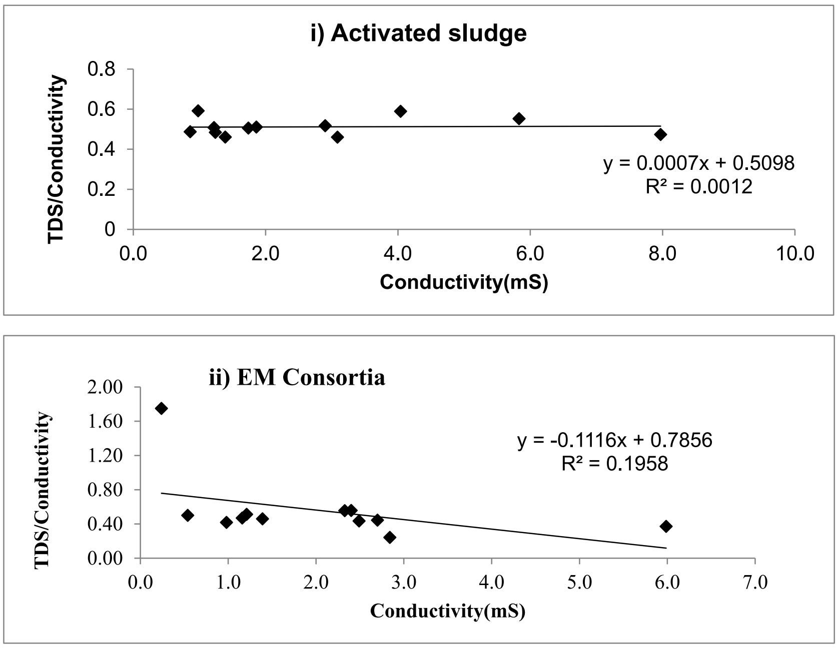

Fig. 4. Relationship between TDS and EC of i) Activated sludge treated effluent without EM and ii) EM consortia treated effluent.

Table 3
Two Factor-analysis for overall treatment efficacy in the raw wet grinding industry effluent (RWGIE), activated sludge treated effluent (ASTE) without EM and EM treated effluent (EMTE) during study period extracted through a water quality parameters at ***Significant level 0.001; **Significant at 0.01 level; *Significant at 0.05 level.

	Df	pH	DO(ppm)	Salinity(ppt)	EC(mS)	TDS(ppm)	Turbidity(NTU)	Acidity(mg/l)	Alkalinity(mg/l)	TotalHardness(mg/l)	Calcium(mg/l)	Magnesium(mg/l)	Nitrogen(mg/l)	Phosphate(mg/l)	Sulphate(mg/l)	BOD(mg/l)	COD(mg/l)	Starch(mg/l)
Month (RE × ASTE × EMTE)	$F_{11,108}$	ns	***	***	***	***	***	***	***	**	**	***	***	***	***	***	***	***
RE	$F_{11,36}$	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
ASTE	$F_{11,36}$	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
EMTE	$F_{11,36}$	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
RE × ASTE	$F_{11,72}$	***	***	***	***	***	***	***	**	***	***	***	***	***	***	***	***	***
RE × EMTE	$F_{11,72}$	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
ASTE × EMTE	$F_{11,72}$	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Treatment (RE × ASTE × EMTE)	$F_{2,108}$	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
RE × ASTE	$F_{1,72}$	***	***	***	***	***	***	***	**	***	***	***	***	***	***	***	***	***
RE × EMTE	$F_{1,72}$	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
ASTE × EMTE	$F_{1,72}$	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Treatment vs month	$F_{11,108}$	***	***	***	***	***	***	***	***	***	***	**	***	***	***	***	***	***
RE × ASTE	$F_{11,72}$	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
RE × EMTE	$F_{11,72}$	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
ASTE × EMTE	$F_{11,72}$	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Error	$F_{11,108}$	0.01	0.29	0	0	0	1.12	2.4	3.94	40.05	4.24	20.55	0.97	0.5	0.62	0.33	3.32	0.71

process.

3.3. Inorganic compounds

A significant reduction of hardness was achieved using EM culture (65.27%) applied in the effluent treatment than using without EM (39.11%). Similarly, calcium and magnesium contents removal efficiency without and with EM application (Table 1). Hardness and calcium were found to a strong determinant factor (Table 2 and Fig. 3), respectively with 0.616 and 0.722.

Nitrogenous compounds loaded with the industry effluent, may have discharged to natural fresh water bodies, including Rivers, accounts about 2% to this pollution effect [71]. About 50% of nitrogenous substances were removed from the effluent samples using the EM consortium in the recycling. However, the present results suggest that recycling WGI effluent using the EM consortium had a positive effect in the reduction of the nitrogenous compounds. Aerobic treatment process improved the dissolved oxygen level of the effluent and was associated with the reduced nitrogen level (Table 1). The result is in accordance with the recycling of food industry effluent using microalgae [72,73], which may be due to the releasing of nitrogenous gases; however the true fact would be revealed, only after the analysis of the emitting gases from the treatment process. Higher carbon to nitrogen level is found to be hampers the proliferation of microbes, thereby nitrogen content could not be removed [60]. Hence, it could be confirmed further, that the microbial activities are favored in the lower or no nitrogen environmental condition.

A higher amount of Sulphate content (78.42%) was removed through the EM consortium application of the effluent treatment, when compared with the activated sludge treatment without EM culture (59.20%). Increased phosphate content was determined in the raw effluent during the study period. From previousreports higher amount of phosphate content was reported due to the subseqent usage of sanitary product [74]. A considerable amount of phosphate reduction was found in the EM treatment, compared to the without EM treatment. Through the process of degradation, beneficial bacteria effectively involving in the removal of organic material from wastewater, and it was earlier reported by Singh et al., [75]. Results from the piggery wastewater treatment using combined algal culture [76] is comparable with the results on the reduction of nitrogen and phosphorus contents along with a considerable reduction of COD, experienced in the present experiment (Table 1). A higher BOD level, detected from the raw effluent sample which could be reduced to 24%, however exceedingly over the permissible limit, using the activated sludge treated effluent without EM. Rifaat and Mohamed [77] illustrated the environmental catastrophes associated with freshwater pollution, which has been estimated by the discharging of food industry effluents to cause more than 50% BOD level raise in the water bodies. In this context, effluent treated with the EM consortium substantially reduced the contaminants level within the permissible limits of Water Quality Standards (Table 1). Following EM application in the sludge activation, a considerable reduction of COD was observed than in the without EM application treatment. Both BOD and COD were segregated into the first loading factor in the PCA (Fig. 3 and Table 2). Effluent treatment experiment, physical and chemical means of treatment effects was found to be inefficient in the removal of COD [78], Ozone based membrane bioreactor, employed water recycling was also found to be reduced to a maximum range of 10–15% COD reduction [79].

Bacterial culture was employed in the treatment of poultry waste to improve the water quality, through the reduction of ammonia form of nitrogen and COD level [80]. Shortfalls in the recycling process due to effluent consisted of non biodegradable substance; using algal culture in COD reduction becomes resilient when the treatment was supplemented using bacterial culture [81]. Hence, the use of Effective Microorganisms consortium in the wet grinding industry effluent treatment, significantly reduced nitrogen, phosphate, and COD level respectively at the rate of 65.54%, 79.60% and 41.75% (Table 1). Similar results were also found with the application of bacterial culture in the treatment of cassava starch effluent recycling by Tosungnoen et al., [82].

The most critical problem in wet grinding industry effluent was its Starch content. EM applied in the sludge activation significantly reduced (85.15%) a higher level of starch found in the effluent compared to sludge activated (79.08%) without EM (Table 1). Potato chips manufacturing industry produced effluent was found with rich source of organic carbon, and starch reduction from effluent by using chemicals. Hence, this process considered to be more expensive [83].

3.4. Biodegradation rate

The degradation rate of organic compound in wet grinding effluent had a significant reduction achieved in nitrogen, phosphate, sulphate and COD, BOD levels at rates of 65.54%, 79.60%, 78.42%, 45.75%, and 60.91% respectively (Table 1). After applying EM consortium to WGI effluent, the inorganic compounds of calcium and magnesium, degradation rates were 63.12% and 62.52% respectively. This high rate of degradation of organic and inorganic compounds in wet grinding effluent was largely attributed by the applied EM consortium in this experiment. Likewise, using of Biological method in starch industry effluent treatment produce a significant effect in the removal of contaminants [9].

3.5. Factor analysis between treatments

The factors of sampling months Vs the analyzed physico-chemical parameters were found with moderately significant reduction of hardness and calcium contents and the remaining parameters were found with a highly significant reduction (Table 3). In the interaction between raw wet grinding industry effluents Vs two different treatments, water quality parameters of pH, DO, TDS, alkalinity, hardness, calcium, nitrogen, sulphate, phosphate BOD and COD were less than the p value and they were considered to highly significant. Likewise, the treatment efficacy compared between Activated sludge treatment and EM treatment, also found with high significant variation (Table 3). Thus, certainly ensured application of EM consortium in wet grinding industry effluent treated effluent has found with a proven effect in recycling compared to sludge activated without EM. Hence, the above results directly showed the treatment beneficial effect using effective microorganisms used in the recycling of the food industry effluent samples (Table 3). Food industry effluents have an advantageous feature in responding to biological recycling, which has confirmed the emphasis laid by Farrajithe et al., [84].

3.6. Water Quality Index (WQI)

Enterobacteriaceae count, nitrogen, and phosphorus, parameters have been applied to determine National Sanitation Foundation's. WQI index is an important inland fresh water quality management assessment tool and therefore it has multiple utility values including in the Policy Decision Making [85,86]. WQI was measured using the results obtained from this experiment and compared with the Water Quality Standards to reveal the weightage ratio (Table 4). The mean value of WQI in the analyzed parameters, were found very low weight over the results obtained from the raw effluent sample and effluent recycled in the sludge activation process, without EM application indicates its poor water quality, indicating from the ratio (Table 4). A higher mean weight of EM consortium treated effluent was found with many parameters among the analyzed variables indicated the recycled industrial effluent using EM application yielded with moderate water quality. A very low range of WQI (31%–42%) was observed in the sludge activated without using EM except September and April months, during the experimental period. EM treated effluent has found with more than 50%–58% of WQI in this experiment (Fig. 5) and from the results, the prudent function of EM consortium in the wet grinding industrial effluent can be recommended. The reusing of industrial production was a great idea for the current situation; also the EM treated effluent further may be used for some other purposes horticulture, building construction work, industries cooling jackets and fire service. According to IWMI [87] reports, the treated wastewater was reused in various parts of India, particularly Kanpur, Nagpur, and Chennai for the improvement of the circular economy. Safe reusing of recycled industrial effluent following proper recycling is essentially required to face the present challenges of climate change [88].

The selected Effective microorganisms are found to be efficiently decomposing organic matter and mineralize pollutants. As a result, it was discovered that the efficacy of the degradation of starch-based waste in the experimental WGI effluent. Microbes have successfully assimilated starch waste as a carbon source in the form of carboxylic acid and nitrogen in the form of ammonia, while simultaneously promoting the growth of other beneficial microbes in a complex environment. This is further attributable to the contaminant removal from the effluent, used in this experiment. Nevertheless, the ability of these microbes to survive in acidic conditions without compromising their efficiency further enhances their effectiveness in wastewater treatment. This EM wastewater technology is feasible to treat starch-based rice mill potato chips and corn industries and municipal wastewater with the compliance of environmental regulations.

Furthermore, the scope of this work has been recommended to wider spatial scales to manage the effluents using the EM consortium in the substantial reduction of pollution and the conservation of natural freshwater resources, as well as improving the water quality, besides in the development of sustainable food industries. Hazardous pollutant reduction using the biological approach, however, requires extensive study to monitor the treatment process and also the modification of microbial organisms with the accumulation of toxic substances with their related metabolic activity and molecular level changes.

4. Conclusion

The current research focuses on the use of EM consortia for recycling wet grinding food industry effluent and their performance as measured by water quality criteria. The most essential harmful element in WGI wastewater is starch content, which was extensively removed by EM consortia up to 85.15% from the raw effluent. The pH of the EM treated effluent was slightly alkaline (7.38) and within the standard effluent discharge limit, however, the pH of the without EM treated effluent was slightly acidic (6.94). The Colour and odour were removed. The removal efficiency of inorganic compounds found in the effluent was nitrogen phosphate sulphate calcium magnesium and their reduction rate respectively 65.54%, 79.60%, 78.42%, 63.12% 62.52%. While, effluent treated without EM showed only 54.60% 74.61%, 59.20%, 43.87%, and 25.61% of inorganic compounds reduction respectively. A considerable amount of reduction was found in salinity (1.94 ppt) Conductivity (4.05 mS), TDS (1.81 ppt), BOD (24.4 mg/l), and COD (148.83 mg/l) using EM-treated effluent compared to without EM treated effluent. However, the effluent treated with activated sludge without EM was found to be above the acceptable limit and had poor WQI quality, therefore it is not recommended for reuse or disposal. The WQI of EM consortium treated effluents exceeded 55% and were in the moderate range, implying either reuse of recycled water or safe land-filling of food industry effluent. Based on the experimental results, it is concluded that the biological treatment technique employing EM consortium application is a sustainable, cost-effective, eco-friendly technology that would be beneficial to such enterprises in terms of Cleaner Production Mechanisms and with sustainable industrial growth, while also safeguarding against environmental degradation and conserving inland freshwater supplies.

Author contribution statement

Lavanya Velmurugan: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.
Kannan Dorai Pandian: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

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Table 4
Water Quality Index (WQI) and weightage determined for the raw effluent samples and treated without and with EM application during the experimental period.

Analyzed WQI parameters	Standard Unit Weight (W_i)	Mean of Per cent Weight co-efficient as compared with standard WQI		
		Raw effluent (W_iq_i)	Activated sludge treated effluent without EM (W_iq_i)	Effective Microorganisms consortium treated effluent (W_iq_i)
DO	0.17	4.3	4.8	5.3
Enterobacteriaceae	0.16	64.5	79.5	89.5
pH	0.11	48.9	80.5	87.3
BOD	0.11	48.4	67.7	73.8
Temperature	0.10	12.4	13.7	14.6
Phosphate	0.10	2.0	2.0	6.1
Nitrogen	0.10	10.3	32.6	38.8
Turbidity	0.08	7.5	53.2	64.0
TDS	0.07	80.0	79.6	95.3
Mean per cent of WQI		30.92	45.95	52.74
Water quality with reference to the WQI weight		Poor	Poor	Medium

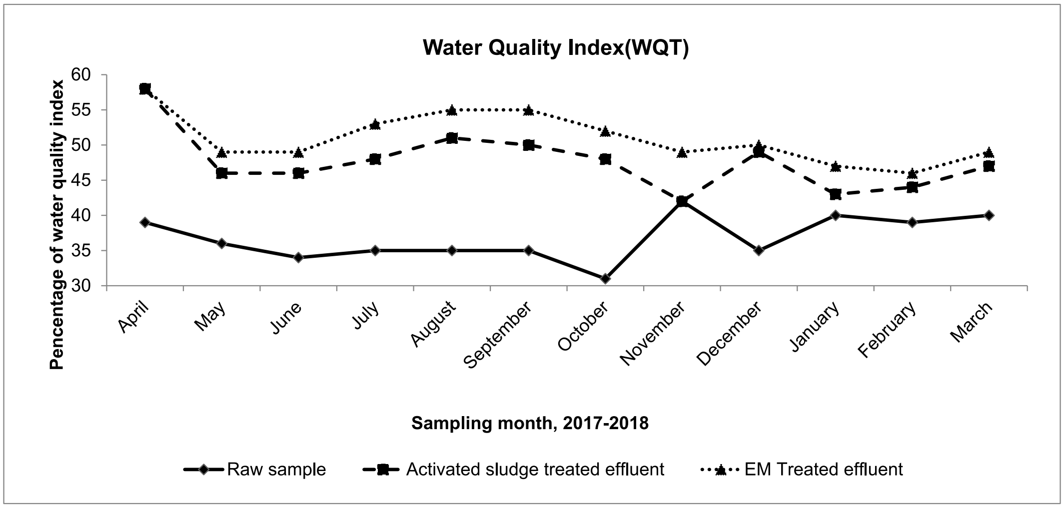

Fig. 5. Water quality Index of wet grinding industry samples, activated sludge treated effluent with and without EM treated effluent, during the experimental period.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no conflict of interests.
Additional information.
The experiment has been further extended by treating the pickle industry effluent using EM.

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