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Sewage treatment in a single pond system at East Kolkata Wetland, India

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ABSTRACT

East Kolkata Wetland (EKW), a Ramsar site, greatly contributes towards purification of city sewage employing single pond system. However, the underlying mechanism remains unknown. Therefore to gain an insight, in this study efforts have been made to understand the rate of biodegradation and the time dependent changes of different physicochemical factors and their interactions that are involved in the process. For this purpose, different parameters such as BOD, COD, faecal coliforms etc. have been measured at different time intervals during the purification process. The results reveal that biodegradation rate at EKW pond is very high and wastewater gets stabilized within 10 days of retention. The higher rate of biodegradation in pond system at EKW ($k = 0.7$ day^{-1}) than in laboratory based in vitro experiment ($k = 0.12$ day^{-1}) reveals the important contribution from other environmental components that are unique for this system. The results also demonstrate the significant influence ($P \leq 0.01$) of temperature, pH and dissolved oxygen on the purification of waste water. Thus the current study provides an insight about the optimal pathway of gradual improvement of wastewater quality in the single pond system at EKW and may serve to explore the inherent mechanism to a great extent.

Key words | biodegradation, East Kolkata Wetland, single pond system, wastewater treatment

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INTRODUCTION

Conservation of natural resources for attaining an environmentally sustainable feature has become an issue of paramount importance in recent years. Enormous amount of wastes of diverse origin should not remain unutilized, but be returned to the ecosystem for various welfare activities. Otherwise, they may prove to be hazardous to biotic life by affecting the biodiversity in the area and may even hamper humans to a great extent. In order to minimize the adverse effect of wastes, public health engineers have provided various waste treatment technologies. However, various informal waste-use practices have been developed in the eastern fringe of Kolkata, India which provide a natural setting for waste treatment and reuse of both solid waste and sewage (Furedy & Ghosh 1984; Mukherjee 1996). For over a hundred year, local farmers, fishermen, scavengers and other groups have been supporting their livelihood from this swampy area, called East Kolkata Wetland (EKW) (Edwards & Pullin 1990). EKW has been designated as Ramsar site, a wetland of international importance as per the Ramsar convention in November 2002 because of its combined role in environment protection and management and thus has been identified as a perfect example of wise use of wetland ecosystem.

The sewage fed fishery ponds at EKW constitute a major component of this natural resource recovery system. The city sewage is stored and treated in these ponds for about a month following some simple and well established steps. Pond preparation constitutes an essential step in water purification at EKW. In this stage, water from a particular pond is removed in the winter months between mid

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November and end of March. Thereafter, the bottom mud is ploughed and treated with lime and left for about a month. Next, the raw sewage from the sewage channels is allowed to enter into the pond to fill up the pond to a depth of about 60 to 90 cm. At this time, the colour of the input water remains deep black (Figure 1) and within 3 to 4 days, the water color starts turning green due to algal growth. Within 7 days algal growth reaches its maximum and algal bloom occurred due to eutrophication (Figure 1). The fishermen then remove the algal mat through netting and the water becomes crystal clear (Figure 1). The water is further left for 20 to 25 days and thereafter is used for fish cultivation, irrigation of the agricultural lands or safely discharged into the surrounding areas.

The quality of sewage is conventionally determined by measuring some important properties such as BOD, COD etc that arises due to complex interaction of physical, chemical (together known as physico-chemical) and biotic components acting on the system. However, these three different types of factors are not functioning independently; rather undergo complex and cumulative interaction to give rise to an ecosystem (Wetzel 2001). In conventional sewage treatment, usually, three ponds are used in a sequential manner: sedimentation (anaerobic), facultative and maturation. Each of these three ponds has different activities to contribute in the purification process. In the present study, focus is laid on an ecology-based technique of the sewage treatment empirically adopted by the local farmers at EKW. The unique feature of this system is that here instead of sequential use of three different ponds, only one pond is used and thus all the physicochemical activities occurring during the purification process are confined within this single pond. Therefore, the interaction between and among the different components of the system and the wastewater purification process must be quite different in this single pond system at EKW from the conventional three ponds system and is truly unknown hitherto.

During the last 20 years several studies have been made on water purification at EKW ponds. However, these studies did not provide any insight either on the purification process or the nature of gradual changes of the physico-chemical components during the treatment process. Those studies were aimed at investigating either the quality of water after the treatment process or products obtained by using the treated effluent (Saha *et al.* 2003; Roy Choudhuri *et al.* 2007). Since sewage consists mostly of organic matter, its degradation is governed by active participation of microbial population within the prevailing environmental niche and is the key driving force in nutrient release and recycling of wastewater. In this context physico-chemical factors like temperature, pH, dissolved oxygen etc. play crucial role to establish the appropriate environmental conditions for biodegradation (Gloyna 1971). Therefore, to unravel the underlying mechanism of wastewater purification at EKW, it is important to know the interactions and the relationships among the various components of the single pond system at EKW and their influence on the purification process.

In the current study, efforts have been directed to determine the biodegradation rate at EKW pond to understand the efficiency of the purification process. Evaluation of the time dependent changes of different physicochemical components of wastewater during the purification regime has also been done. An effort to correlate these

Figure 1 | Gradual changes of wastewater colour at different time points during the purification process at EKW pond. At Day 0, the sewage is deep black in colour with foams floating on surface. At day 7, color becomes green due to intense algal bloom. At day 10, the water becomes transparent and colourless indicating considerable improvement in water quality. Subscribers to the online version of *Water Science and Technology* can access the colour version of this figure from http://www.iwaponline.com/wst.

physicochemical changes to reveal the prevailing interaction between and among these parameters has been made that will serve as a stepping-stone for future study to reveal the exact mechanism of the purification process.

METHODS

The study area

The wetland area lies between latitudes 22° 25″ to 22° 40″ N and longitude 88° 20″ to 88° 35″ E. and the region is suitable for solar radiation. Climate is more or less sub tropical with the annual mean rainfall around 200 cm. The maximum temperature during summer rises to 39°C while minimum temperature during winter is 10°C. The average temperature during the daytime of most of the year is around 30°C with a fall of 5–6°C at night. The region consists of water spread area of 4728.14 ha, degraded water spread area of 1124 ha, agricultural land area of 4959.86 ha, garbage farming area (Dhapa) 602.78 ha and urban and rural settlement 1326.52 ha. The total numbers of fishery ponds (locally called bheries) in EKW are 364 distributed on both sides of the main sewage canals.

Collection of water samples

Water samples were collected from the inlet, middle and outlet of the four different ponds of almost similar size at Day 0, Day 3, Day 7, Day 10, Day 14 and Day 21 of the purification process and were kept in pre washed sterile container. Since in the middle of the day ecosystem becomes most active, all the samples for this study were collected in the middle of the day.

Analysis of water samples

In this study, different parameters were analyzed to monitor the quality of water and all the analysis were commenced on the same day the samples were collected. The non-conservative parameters like pH, and dissolved oxygen (DO) were analyzed onsite during the time of collection by an automatic portable analyzer (WTW Multi 340i). For the analysis of BOD, COD, total nitrogen, NO_3-N, NO_2-N and PO_4-P, water samples were brought to the laboratory in freezing condition and analyzed by standard methods as outlined by American public Health Association (1998).

Determination of BOD kinetic parameter

For BOD kinetic study in laboratory system, the sewage water collected at Day 0 was subjected to BOD analysis at 20°C following the procedure outlined in APHA (1998) for successive days as mentioned in the Figure 2A. For the same experiment at EKW pond set up, water samples were collected at different days and analyzed accordingly. BOD curve is obtained by plotting the BOD values at different time point for both the experimental set up. This curve is described by a first order kinetic equation in integrated form as $y = L_0\ [1 - \exp(-\mathrm{kt})]$, where $y =$ amount of oxygen consumed (or BOD) at time t, $L_0 =$ total amount of oxygen consumed in the reaction (or ultimate BOD), $t =$ time elapsed since the start of the assay, $k =$ rate constant for biodegradation. k and L_0 were calculated by Thomas method (Thomas 1950) based on functions similarity by plotting $(t/y)^{1/3}$ as ordinate Vs. t as abscissa and fitting the points to a straight line with intercept 'a' and slope 'b'. The k and L_0 were calculated as $k = 2.61\,\mathrm{b/a}$ and $L_0 = 1/2.3\,\mathrm{ka}^3$. The k value at ambient temperature is calculated (Metcalf & Eddy Inc 1972) using the formula of $k_\mathrm{T} = k_0 \times \theta^{(\mathrm{T}-\mathrm{T}_0)}$ where $T =$ ambient temperature, $T_0 = 20°\mathrm{C}$ and $\theta = 1.047$ for domestic sewage.

Estimation of faecal coliforms

Enumeration of faecal coliforms was done using multiple tube method following the procedure described in APHA (1998). This method determines the presence of coliform as well as the most probable number (MPN).

Estimation of algal biomass

Since chlorophyll a and chlorophyll b are essential components of algae, algal biomass estimation was carried out indirectly by estimating the amount of chlorophyll a and chlorophyll b. For chlorophyll estimation, the water is filtered through 0.45 μm membrane filter and the biological mass retained in filter paper is extracted with a mixture of acetone and $MgCO_3$ (1% $MgCO_3$ in 90% acetone) and

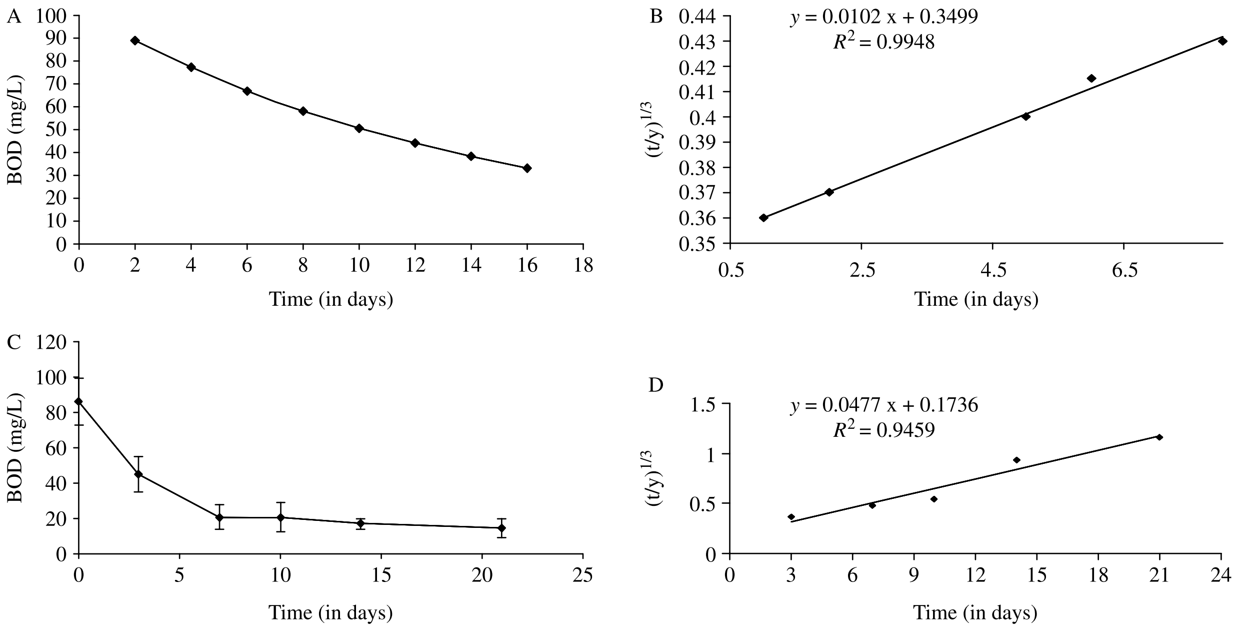

Figure 2 | Biodegradation kinetics of wastewater. A. Change of wastewater BOD with time under *in vitro* condition. B. Determination of K and L from *in vitro* raw- sewage BOD removal kinetics. C. Change of wastewater BOD with time at EKW ponds. D. Determination of K and L from BOD removal kinetics at natural condition at EKW. Error bars represent standard deviations.

allowed for incubation at 4°C for four hours. Optical density (OD) was measured at 663, 645 and 631 nm wavelengths and the chlorophyll content was calculated using a formula as described in Trivedy & Goel (1986).

Statistical analysis

Experimental results were subjected to statistical analysis of Pearson's correlation coefficient as well as one-way analysis of variance (ANOVA). Besides, the Hochberg Multiple Comparison test was also conducted in the present study. All the statistical analyses were carried out using the software SPSS-11 statistical package for windows.

RESULTS AND DISCUSSION

Sewage characteristics

Physico-chemical characteristics of the Kolkata city sewage revealed that the effluent is slightly alkaline in nature with the pH value ranging from 7.2 to 7.6 (Table 1). Higher values of BOD and COD are indicative of significant amount of biodegradable organic matter due to which the effluent is devoid of traces of dissolved oxygen. In addition, the total nitrogen content is considerably higher than the phosphorus and most of them were organically associated. However, the presence of oxidative form of nitrogen, like nitrate nitrogen (NO_3-N) and nitrite nitrogen (NO_2-N), is negligible. The level of reactive phosphate-phosphorus (PO_4-P) in sewage is higher than the combined amount of NO_3-N and NO_2-N that results in very low N/P ratio in the system.

Rate of biodegradation

To better understand the purification process at EKW ponds, the rate of biodegradation of the city wastewater under *in vitro* laboratory condition at 20°C temperature and in the natural set up at EKW has been determined from BOD reduction kinetics as described in methods. The stabilization of waste water is highly complex in nature and it is inappropriate to express the biodegradation rate equation in simple mathematical formula. However, to maintain the simplicity and to make our understanding easy, first order rate equation has been considered for our

Table 1 | Wastewater characteristics at three different time point of purification at EKW and its comparison with Bureau of Indian Standard (BIS 1991)*

Components	Untreated sewage at day 0	Treated effluent at day 10	Treated effluent at day 21	BIS Fishery	BIS Irrigation	BIS Surface water Discharge
Temperature (°C)	31 ± 2.0	32 ± 1.8	35 ± 1.5	–	–	–
pH	7.45 ± 0.31	8.415 ± 0.03	8.51 ± 0.06	5.5–9.0	6.5–8.5	5.5–9.0
DO (mg/L)	0	7.023 ± 1.86	9.6 ± 2.12	–	$\geqq$ 4.0	–
BOD (mg/L)	86.24 ± 13.17	20.74 ± 8.16	14.66 ± 5.12	≤100	–	≤ 30
COD (mg/L)	202 ± 17.74	147 ± 12.35	138 ± 1.63	–	–	≤250
Total nitrogen (mg/L)	55.5 ± 18.57	21.29 ± 5.8	24.71 ± 0.66	–	–	≤100
NH_4-N (mg/L)	5.62 ± 2.08	1.96 ± 0.74	1.11 ± 0.20	–	–	≤50
PO_4-P (mg/L)	1.89 ± 0.26	0.76 ± 0.24	0.86 ± 0.01	–	–	≤5.0
NO_3-N (mg/L)	1.12 ± 0.12	0.58 ± 0.20	0.56 ± 0.08	–	–	≤10.0

*The data represented are average (±SD) of the values obtained from water collected from inlet, middle and out let of four different ponds.

experimental results. Thus the biodegradation rate constant (k) of the wastewater at 20°C under laboratory condition was found to be 0.07 per day, which is however lower than the average k value of sewage water as mentioned in literature (Metcalf & Eddy Inc 1972). In reality, k value largely depends on the composition of the organic matter, which again is known to vary from place to place due to variation in sewage composition that is related to the food habit, life style and economic status of the community in the area. In addition, it is also temperature dependent. In tropical countries normal temperature varies considerably throughout the year and therefore an expression of reaction rate constant at the ambient temperature would be more meaningful and justified. Therefore, a temperature correction factor in the rate equation has been incorporated (see methods) that results in 75% increase in k value (0.12 per day). According to this rate constant, the time required for stabilization of BOD value was calculated to be 19 days. However, in natural open pond system at EKW, the major changes in organic load have occurred within 7 days of retention as evident from Figure 2C. The biodegradation rate at EKW pond system was found to be 0.7 per day (Figure 2D). The marked difference in the biodegradation rate obtained from in vitro laboratory experiment and from natural set up at EKW strongly suggests the contribution from natural factors such as microbial activities that are only present in the natural set up at EKW to this purification process.

Wastewater purification at EKW pond

To understand the wastewater purification process at EKW pond, different parameters like BOD, COD etc. at different time of the purification process have been determined as described in methods. As water samples for these analyses were collected from different location like inlet, middle and outlet of the pond, spatial variation of the values may arise. To test this possibility, statistical analysis of the components of inlet, middle and outlet sections of the pond were carried out and found to be insignificant when they are subjected to one-way analysis of variance (ANOVA) (data not shown) indicating that no considerable changes in wastewater quality take place in any portion of the pond, probably due to thorough mixing by the mobility of the water mass at the influence of air-water interaction and thus represent a homogenous system. Consistent with the previously published data (Ghosh 1983; Ghosh & Sen 1987), the present study also demonstrates that at the end of purification a considerable improvement of water quality with reduction in values of BOD, COD and other parameters were observed (Figure 3). The results also show that within the first 10 days of retention of wastewater at EKW pond, there is a reduction of 75.95% of BOD (Figure 2C), 27.23% of COD, 62% of TN, 65.12% of NH_4-N (Data not shown), 59.5% of TP and 99.9% of faecal coliforms (Figure 3) and attains the standard value as stipulated by Bureau of Indian Standard (BIS) for surface water, fish culture and irrigation

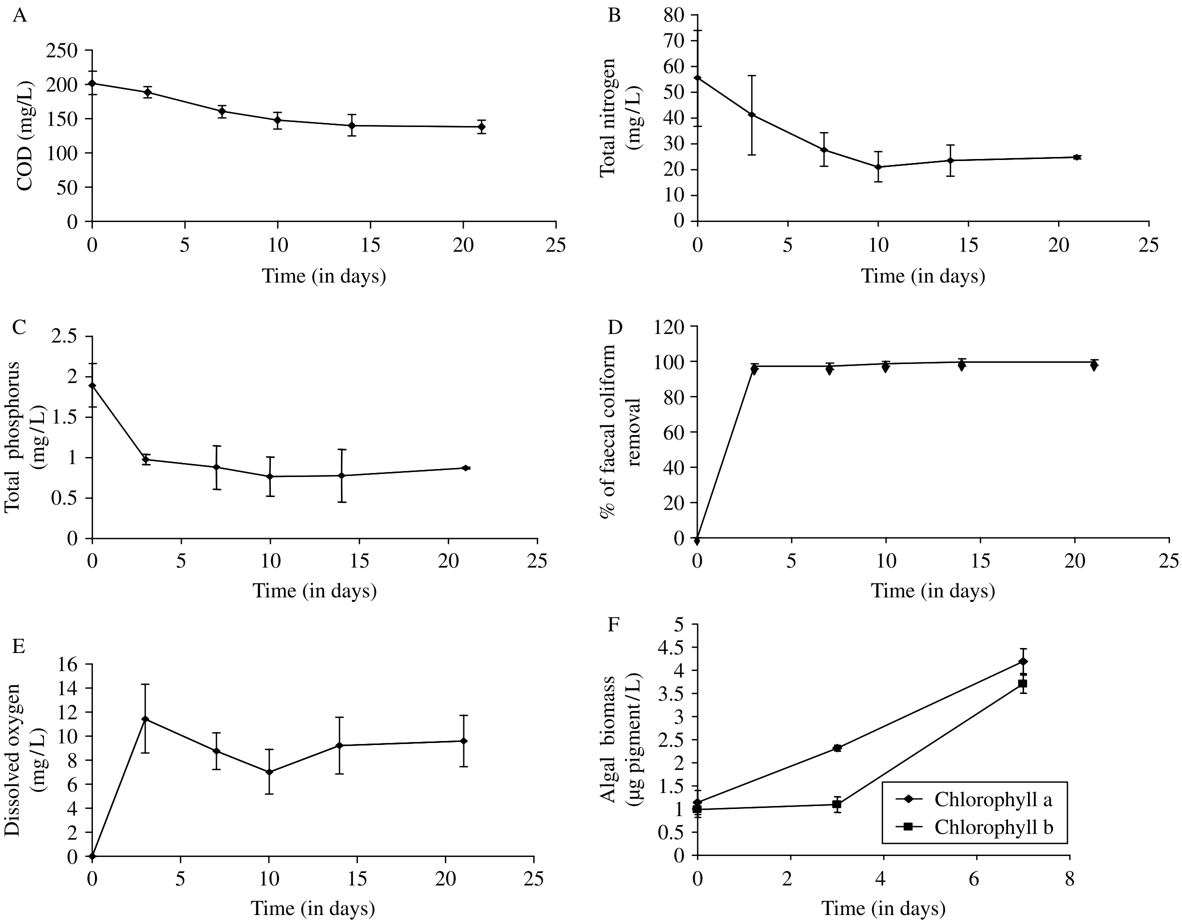

Figure 3 | Time dependent changes of different parameters of wastewater at EKW ponds. COD (A), total nitrogen content (B), total phosphorous content (C), faecal coliform removal (D), dissolved oxygen (E), algal biomass in terms of chlorophyll content (F) were monitored at different time points during the purification at EKW ponds. Each experimental analysis was done at least three times and the average values were plotted against time. Error bar represents standard deviation.

purposes (Table 1) indicating a substantial improvement of the water quality. It suggests that the major events responsible for water purification at EKW takes place within this short period which is congruent with the observed higher biodegradation rate at EKW ponds as described in the previous section.

This faster and efficient biodegradation, as evident from the result, in this unique single pond system can only be explained if the practices adopted by local farmers during pond preparation and treatment tenure can be hypothetically related to the data obtained from our study. In the following section it is explained with appropriate references and reasoning that how the changes in physicochemical properties have helped to develop the appropriate ecological and environmental milieu conducive for the purification of wastewater. During pond preparation, the ponds are made dry and ploughed after the addition of lime. Drying effectively restores the infiltration rate of the soil as a result of intense biochemical decomposition of previous clogged organic layer at suitable pH ranges of soil (Bouwer & Chaney 1974; Smith & Schroeder 1985). Consequently, oxygen enters the soil, which may be utilized for the reduction of the BOD and COD of the anoxic sewage (Idelovitch & Michael 1984; Smith & Schroeder 1985) after its entrance. The fine suspended organic solids of wastewater, such as sludge and bacterial flock, are possibly removed from the water column by settling on the soil surface and thereby acting as a primary clarifier in the system. The gradual accumulation of organic matter probably forms a layer of high hydraulic impedance that reduces infiltration rate (Bouwer 1985) and acts as oxygen sink and thus may create anaerobic condition in soil, which is also known to be effective for BOD removal (Bouwer & Chaney 1974; Bouwer 1985). On the other hand, the shallow depth (60–90 cm), large surface area, abundant sunlight and continuous natural aeration at the pond surface may help the growth of facultative bacteria that can efficiently degrade organic matter present in the wastewater.

After 3 days the water appears green due to algal growth (Figure 3F) and the percentage of dissolved oxygen is increased (Figure 3E) because of the photosynthesis by the algal population as well as the diffusion from air. The greenish colour together with high percentage of oxygen saturation in water are indicative of intense eutrophication in the system (Goldman & Horn 1983) that reaches the maximum on Day 7 (Figure 1). Thereafter, the algal mat is removed by netting. The removal of nutritional elements through plant utilization resembles tertiary waste treatment (Thawale *et al.* 2006). This bio-mineralization process is the key that transforms the complex organic compounds and resulted in reduced BOD and COD values of the treated effluent.

Loss of nitrogen from the system normally takes place in three different ways: through denitrification, through volatilization in the form of ammonia and by biological uptake. Environmental condition prevailing in the pond system, at least during the first few days of retention, may not permit denitrification because of the fact that the sewage is predominantly in organic and ammonium form with negligible amount of nitrate, which is known to be essential (Bouwer & Chaney 1974) for denitrification. Moreover, a good growth of nitrifying bacteria has been reported (Forsberg & Wysocka 1996) under conditions of relatively high temperature, when the ratio of BOD to TN is in between 2 and 3. In the present study, this ratio remained at an average of 2, which indicates that the system favors nitrification rather than denitrification. Therefore, most of the nitrogen removal could be through biological uptake, settlement in the soil and consequent removal by netting from the pond system. However, some loss of NH_4-N as NH_3 due to increase in pH during eutrophication in daytime cannot be ruled out (McLarney 1984). The removal of phosphate from the sewage is also evident from our results that occurred within the first 3 days (Figure 3C). This may be predominantly due to precipitation as calcium salts (Hosni *et al.* 2008) and partly due to incorporation into biotic life (Scinto & Reddyb 2003).

Quick removal of faecal coliform load from the sewage water is also evident from our results (Figure 3D). The large size of the pond provides huge surface area available for adsorption and filtration of the microbial biomass. Large surface area, plenty of sunlight, shallow depth and presence of oxygenated condition may contribute to a great extent in enhanced bacterial removal and results in almost 100% reduction of faecal coliform load within three days.

Time required for the stabilization of wastewater

To determine the minimum time required for waste stabilization process in EKW pond system, a multiple comparison study (ANOVA, Hochberg) was carried out

Table 2 | Probability values of the comparison statistics (Hochburg) of the mean differences between the initial and the successive results of the chemical components

	***P* values**				
Components	**Day 0–Day 3**	**Day 0–Day 7**	**Day 0–Day 10**	**Day 0–Day 14**	**Day 0–Day 21**
pH	0.000*	0.000*	0.000*	0.000*	0.000*
BOD	0.000*	0.000*	0.000*	0.000*	0.000*
COD	0.266	0.000*	0.000*	0.000*	0.010*
TN	0.583	0.021*	0.003*	0.004*	0.009*
TP	0.000*	0.000*	0.000*	0.000*	0.000*
NH_4-N	0.176	0.021*	0.003*	0.000*	0.000*
NO_2-N	0.824	0.017*	0.002*	0.000*	0.001*
NO_3-N	0.336	0.363	1.000	0.999	0.406
DO	0.006*	0.051*	0.187	0.035*	0.001*

*Mean differences are significant at $P \leq 0.05$ levels.

Table 3 | Pearson correlation coefficients of the physico-chemical components during purification process

Temp	Temp	pH	BOD	COD	TN	TP	NH_4-N	NO_2-N	NO_3-N
pH	0.728*								
BOD	−0.794*	−0.946*							
COD	−0.674*	−0.587*	0.681*						
TN	−0.809*	−0.479*	0.623*	0.737*					
TP	0.097	−0.010	−0.019	0.101	0.138				
NH_4-N	−0.640*	−0.746*	0.799*	0.619*	0.696*	0.009			
NO_2-N	−0.618*	−0.634*	0.667*	0.695*	0.703*	0.057	0.660*		
NO_3-N	0.089	−0.02	0.021	0.009	0.126	0.195	0.219	0.416	
DO	0.610*	0.711†	−0.693*	−0.282	−0.290	−0.176	−0.551*	0.387	0.044

*Correlation is significant at $P \leq 0.01$ level.
†Correlation is significant at $P \leq 0.05$ level.

utilizing the data obtained in different phases of purification. This is done using mean difference between the first and consecutive observations to find the time required to obtain the first significant reduction of these components from the wastewater. It is evident from our result that statistically significant changes ($P < 0.05$) for pH, BOD, TP and DO occur within the first 3 days of water retention in the pond, whereas the removal of COD, TN, NH_4-N and NO_2-N was only found significant after 3 days of retention in the pond (Table 2). Multiple comparison analysis between the observations at day 10 and day 14 demonstrates that the degree of changes for chemical components gets stable within first 10 days of retention and remains almost unaltered for the remaining days (data not shown) which is also evident from the Figure 3. It indicates that the aquatic system in the treatment pond attains equilibrium after 10 days of purification. Thus, this result strongly supports that the different reactions responsible for the stabilization of wastewater at EKW occur within the first 10 days of retention. This high efficiency of waste removal can be attributed towards the diverse environmental factors that results in enhanced chemical changes of wastewater in the pond system at EKW.

Relationship among different physicochemical components of water

Considering some important abiotic factors that influence the purification process at EKW pond system, their interaction as well as relationship between and among them have been analyzed employing Pearson Correlation Coefficient Analysis. The result shows that BOD, COD, TN, NH_4-N and NO_2-N are significantly correlated with each other (Table 3). This correlation may be due to the common origin for these components or synergetic effect on the purification process. Strong positive correlation among temperature, DO and pH has also been shown (Table 3). Positive correlation between temperature and DO is possible only when the rate of natural supply of oxygen surpasses the oxygen removal rate in the system. Contribution of this excess supply of oxygen comes from the photosynthetic activity of algal population present in the system. However, these components (temperature, DO and pH) exhibit negative correlation with BOD, COD, TN, NH_4-N and NO_2-N. It indicates that DO, temperature and pH have positive influence in reducing BOD and COD etc. to a great extent. Therefore pH, temp and DO play an important role during the purification process.

CONCLUSIONS

At EKW, with the help of single pond system raw sewage has been found to be purified employing the indigenous practices developed by local farmers. The soil-sewage and their associated ecosystem component act as physico-bio-chemical reactors capable of treating the sewage efficiently. The study reveals that various physico-chemical and biological reactions that occur during first 10 days in soil-sewage system play crucial role in the stabilization of the sewage. This high rate of biodegradation can be attributed to the interaction of several environmental factors of the wetland ecosystem. Temperature, pH and dissolved oxygen have been shown to have positive influence in the improvement of wastewater quality. The results on interactions and relations among different physico-chemical components may provide further insight into the underlying mechanism of this highly efficient wastewater purification process.

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