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Efficiency of a developed wastewater treatment model for smallholder swine production systems

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Abstract
The present study analyzed the efficacy of a wastewater treatment model developed with a four-stage treatment system consisting of storage, sedimentation, filtration and chlorination as independent treatment units. Samples at periodical intervals were subjected to water quality parameter analysis viz. pH, colour, turbidity, total dissolved solids (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD), total coliform count and *E. coli* count. It was observed that pH, color, turbidity, TDS, BOD, total coliform count and *E. coli* count were within the standard limits, whereas COD level of chemical treated water was observed to be higher than the standards. The results of present study proved that wastewater which has passed through all the four treatments had a quality standard comparable to Indian Standards. It can be concluded that the four-stage treatment system was effective for water recycling in small holder pig production systems.

Keywords: Pig farms, water recycling, water quality standards, effluent treatment

1. Introduction

Swine husbandry is an important facet of rural economy in many developing countries, as it is a low-input, demand-driven production system. It generates employment, provides food security and financial safety to the farmers (Chauhan *et al*., 2016) [1]. Pigs are mostly reared by under-privileged, seasonally employed, resource poor farmers for bolstering their livelihood. Due to rapid population growth, there is a phenomenal increase in demand for livestock products all over the world. This situation has led to changes in the farming system from 'subsistence farming' to 'commercial and intensive farming', which causes adverse impacts on the environment. In many developing countries, the majority of small holder swine farms directly release the waste water without any treatments causing serious environmental concerns (Zhou *et al*., 2013) [18]. The deficiency of knowledge in modern husbandry practices lead to improper livestock waste management methods leading to environmental pollution and other related problems.

There is growing concern about the environmental hazards from livestock enterprises, especially swine production systems (Zhang *et al*., 2017) [16]. Pig farms require large amounts of water for effective management. The waste water which accumulates in vats carry pathogens such as Corynebacterium and Salmonella, pharmaceuticals like antibiotics and antimicrobials, metals like copper, iron and zinc, and eco-toxic chemicals like nitrogen, potassium and phosphorus, that pollute the soil and the environment. These wastes leach below the surface polluting the soil and trickles down into the water table polluting the ground water (Jensen *et al*., 2006) [4]. The farm effluents lead to water eutrophication and elevated nitrate levels in ground water and also cause spread of zoonotic diseases (Khurana and Aulakh, 2010) [5]. The resulting wastewater containing high concentration of organic matter, dissolved and suspended solids, and pathogenic microorganisms pose serious threat to the environment (Velho *et al*., 2012) [14]. Pollution of the environment has a significant impact on all living organisms, especially human beings. Environmental protection and regulatory bodies in various countries has set management plans and measures on agricultural wastewater control.

Though it is believed that the smallholder pig production systems do not cause deleterious effects on the environment to a great extent, the changing nature of production systems and the scope of expansion pose serious environmental concerns. The water otherwise let out for irrigation and into streams and canals cause environmental pollution and adds to the amount of wastewater.

The major problem with pig farms is that they require large amounts of water for effective management. In the scenario of water scarcity, there is need for conservation of water. Hence, essential steps have to be adopted to formulate effective wastewater recycling protocols. The present study was carried out to analyse the effectiveness of a developed model of wastewater treatment in pig sties and to analyse the quality of the water at various points of the treatment cycle.

2. Materials and Methods

2.1 Study location and management practices

The study was conducted at the Center for Pig Production and Research, Mannuthy, Kerala, India (longitude 76°, 05” to 70° 45” E, at latitude 10°, 20” to 10°, 56” N) at an altitude of 22.25 m above mean sea level. The location of study was endowed with a humid tropical climate with maximum rainfall by the south west monsoon from June to August and north east monsoon from September to October.

The pig farm wastewater treatment model was developed at the Centre for Pig Production and Research which has an area of fifteen hectares with sufficient infrastructure to house 1500 pigs. All the sheds have asbestos roof, concrete walls and flooring. The shed chosen for the present study was a farrowing house with twenty sows with a litter of 125 piglets. The farrowing house had twenty farrowing pens. The floor was concrete and partially slotted above the drain. Drinking water was provided through separate nipple drinkers for sows and piglets. The shed was well ventilated and animals were not apparently under any stress during the period of study. Multi-phase feeding was practiced in the farm and sows were fed compounded mash feed containing 18 per cent crude protein along with calcium supplements. The feed waste along with dung, urine and biological waste after farrowing was flushed down the drain from the shed.

Animals were washed and sty was cleaned daily from 8.30 am to 10 am in the morning. Water was also used to mix the mash feed for sows and to clean the shed from 3 to 4 pm. The quantity of tap water used for washing the shed, animals and mixing the mash feed in the farrowing shed were recorded and evaluated.

2.2 Treatments adopted in the pig shed wastewater recycling

The wastewater treatment was done as per the wastewater treatment standard being followed in the water treatment plants. The sloppy terrains near the farrowing house were selected for constructing the waste water treatment plant and was built adjacent to the drainage of the shed. The different treatments given are explained below.

2.2.1 Screening*:* The flow of wastewater to the slurry tank was blocked in the drain using a metal shutter so that a wastewater pool was formed in the drain. This wastewater was diverted to the wastewater treatment plant and subjected to different treatments. The effluent was screened using an improvised sieve of $0.4mm^2$ in the drain and another sieve of $0.2mm^2$ in the intake pipe of the wastewater treatment plant. The effluent after screening flowed to the storage tank.

2.2.2 Storage*:* A linear low-density polyethylene (LLDPE) tank of 1000 litre capacity was used for storage. The land was excavated to a depth of four feet to hold the storage tank so as to maintain the gravity flow from the drain. The plumbing work was done using two-inch diameter polyvinyl chloride (PVC) pipes for collecting the wastewater. The tank was provided with a sludge removal pipe of 1.5-inch diameter connected with a PVC ball valve to control the sludge removal. Six hundred litres of the screened effluent was collected in the storage tank and left in quiescent condition for eight hours for gravity settling.

2.2.3 Sedimentation: The supernatant effluent was subjected to alum (hydrated potassium aluminum sulphate) treatment. LLDPE tank of five hundred litre capacity was used for alum treatment. This tank was placed at a height of 8 feet above the storage tank so as to facilitate the gravity flow to the other treatment tanks. The wastewater was pumped to the alum tank using 1-inch suction hose and ½ HP motor. The tank was provided with pipe of 1.5-inch diameter connected with a PVC ball valve to control the removal of flocculent from the tank. Five hundred liters of the supernatant wastewater was pumped to the sedimentation tank. Two hundred gram of alum dissolved in one litre of tap water was added and stirred for fifteen minutes for uniform mixing.

The standard jar testing procedure was employed to find minimum concentration of aluminum sulphate that had good sediment and clear supernatant liquid using pig farm wastewater. The wastewater was allowed to coagulate and settle in a quiescent condition for sixteen hours. For undertaking standard jar test one liter of settled wastewater was collected in eight glass beakers. Alum was added at the rate of 0.24 gm, 0.28 gm, 0.32 gm, 0.36 gm, 0.4 gm, 0.8 gm, 1.2 gm and 1.6 gm, respectively to each beaker, rapidly mixed to disperse the chemical and allowed to settle under quiescent condition. Visual evaluation of coagulation process of examined wastewater samples was focused on flocculent formation and sedimentation. The influence of coagulant both on wastewater colour as well as removal of turbidity was also studied using turbidimeter (*Eutech*). The minimum concentration of alum that had good sediment and clear supernatant liquid was chosen as the concentration of alum for the study.

2.2.4 Slow sand filtration: The supernatant of alum treated wastewater was subjected to slow sand filtration. The supernatant from alum tank was transferred to the sand filter tank using 1.5-inch diameter PVC pipe with ball valve to control the flow of wastewater by gravity flow. The rate of filtering through the filter bed was maintained at the rate of 0.02 liters/minute/ cm^2 by adjusting the valve.

An LLDPE tank of five hundred litre capacity was used as a slow sand filter. Initially, a bed of wash dried gravel (20mm size) about eighty kilograms was provided at the bottom followed by washed and dried coarse gravel (5mm) sixty kilogram, washed and dried charcoal fifteen kilogram and fine sand (2 mm) five kilogram at the top (Fig. 1). The filter bed had a height of forty centimeters from the base of the tank. The sand filter tank was filled with three hundred litre of wastewater and retained for seven days prior to wastewater treatment for biomass formation in the sand filter.

2.2.5 Chlorination: LLDPE tank of five-hundred-liter capacity was used for disinfection of treated wastewater. The filter tank was connected to this tank with a 0.75-inch PVC pipe with PVC ball valve to control the flow of filtered water to the chlorination tank. 100 ml of twelve per cent sodium hypochlorite was used in 500 litres of treated wastewater for disinfection. The level of chlorine in the treated wastewater was maintained at 0.2 ppm (parts per million) of residual chlorine for the proper chlorination. The level of chlorine in the treated wastewater was analyzed using chloroscope (Ltek systems) for proper chlorination.

2.2.6 Storage of the reclaimed water: LLDPE tank of 500 litre capacity was used for the storage of reclaimed water. Four hundred liters of reclaimed water was stored in the tank and pumped to the shed using ½ HP motor and 1-inch suction hose. The tank was provided with a PVC pipe of 1.5-inch diameter connected with a PVC ball valve to control the water removal after cleaning the tank.

The sludge in the sedimentation tank and alum treatment tank was removed daily. All the tanks were washed and cleaned weekly with tap water. During the study period, all the tanks were covered with plastic net for air circulation. Solid waste from the shed and the wastewater were used as slurry for land application in the pig farm.

The water treatment system adopted is graphically represented in Figure 1.

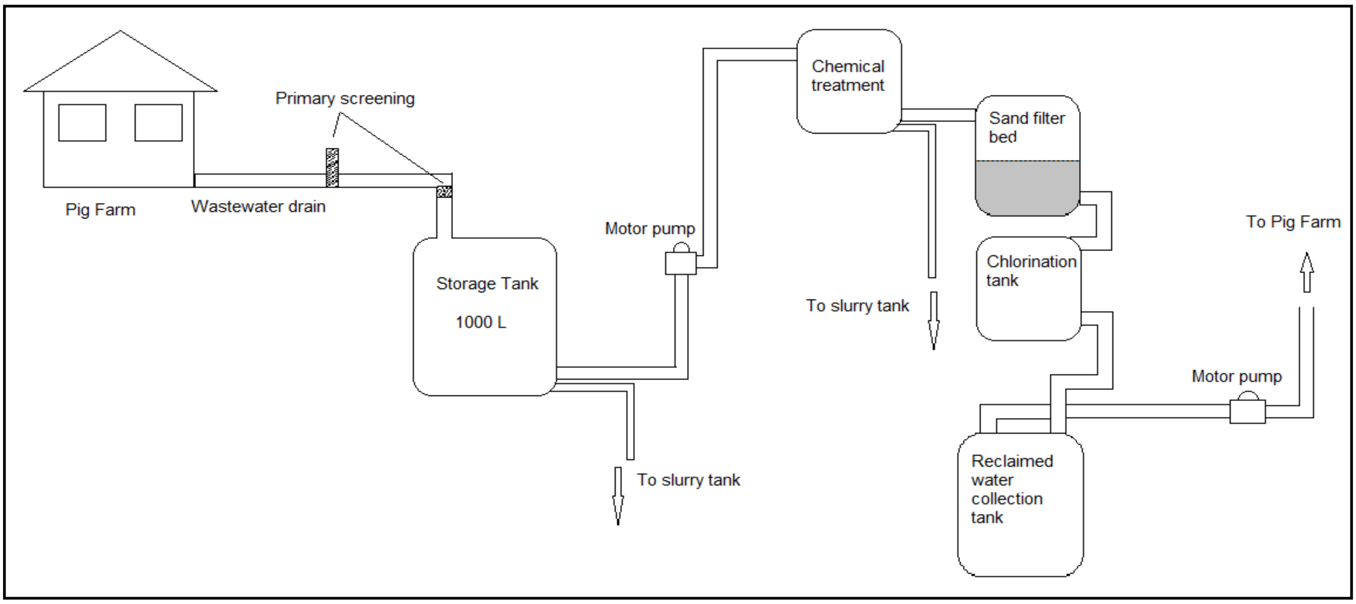

Fig 1: Graphical representation of the water recycling system developed for the study

2.3 Analysis of water quality at various points of treatment

The water quality at various points of the treatment were analysed to find out the efficacy of procedures. For this, the five experimental groups were created as follows. T1 (control) - Tap water used for washing the shed and sows (n=8); T2 –Wastewater from the farrowing shed (n=8); T3 – Wastewater (T2) treated with Alum (n=8); T4 - Wastewater (T3) passed through sand filter (n=8); and T5- Wastewater (T4) treated with sodium hypochlorite (n=7)

Wastewater treatment was done for a period of eighty days and samples were analyzed at ten days interval. One litre of the sample was collected at 9 AM in the morning in a sterile container for the estimation of physical and chemical parameters and 100 ml sample was collected in a sterile container for bacteriological analysis. Samples were kept under refrigeration at 4ºC until analysis. Samplings were done at 10 days interval for eighty days. The usual feeding and management practices prevailing in the farm were followed throughout the treatment period.

The quality of water was assessed as per standards prescribed by the Central Pollution Control Board, for reusing in the pig sty.

Physical, chemical and microbial characteristics of pig farm wastewater were analyzed as per Standard Methods for the Examination of water and wastewater APHA, 2005. The parameters analyzed were pH - The pH was recorded using a digital pH meter (*Eutech*, USA), Colour- Analyzed using instrument NOVA 60 (Merck photometer, Germany); Turbidity - Analyzed using Nephloturbidimeter (*Eutech*, USA); Total Dissolved Solids (TDS) - Analyzed using TDS Tester (*Eutech*, USA); Biological Oxygen Demand (BOD) 5 days - Analyzed using Winkler Method; Chemical Oxygen Demand (COD) - Analyzed using Open Reflux Method; and total coliform count and *E. coli*. count - Analyzed using the Three Tubes method (MPN).

The data collected was analyzed statistically as per the methods described by Snedecor and Cochran (1994).

3. Results

Tap water used for different activity in the shed was recorded, and it was observed that the average water utilization was 790.30±5.90 litres per day for twenty sows and 125 piglets.

3.1 Chemical treatment

The observations on the jar test conducted are furnished in the Table 1. The pH of screened wastewater taken for the jar test was found to be eight. Aluminum sulphate 0.40 gm in one-liter (0.04 per cent) concentration was selected as the dose for wastewater treatment.

Table 1: Results of Jar test for determining the concentration of Alum

Jar No.	Concentration of alum	Flocculent formation	Turbidimeter reading
1	0.24 gm	None	14.22 NTU
2	0.28 gm	None	12.59 NTU
3	0.32 gm	None	8.70 NTU
4	0.36 gm	Fair	7.11 NTU
5	0.40 gm	Good	4.24 NTU
6	0.8 gm	Good	1.94 NTU
7	1.2 gm	Good	2.11 NTU
8	1.6 gm	Heavy	1.12 NTU

3.2 Water quality parameters in different treatments

The results of the water quality analysis in different treatments are depicted in Table 2. The mean pH of water from T2 (8.16±0.16) and T5 (8.03 ±0.28) are significantly higher (p<0.05) than that of T1 (6.57±0.21), T3 (6.88 ± 0.49) and T4 (7.39±0.14).

The mean colour value in Hazen units of water from different treatments indicated that T2 (50.13±9.2 Hazen) is significantly higher (p<0.05) than the rest of treatments. There was no significant difference between colour value of water from T-1 (0), T4 (2.88±1.0 Hazen), T3 (9.13±2.1 Hazen) and T5 (11.40±3.6 Hazen) in increasing trend. T1 (tap water) had no colour as it did not have any suspended solids causing opaqueness. T4 (sand filtered water) and T5 (chlorinated water) were clear due to the respective treatments.

The mean turbidity of different treatments showed that T2 (96.47±13.18 NTU) is significantly higher (p<0.05) than the rest of treatments. The mean total dissolved solids of water from treatments T4 (490.25±40.62 mg/l), T2 (565.38±97.34 mg/l), T3 (640±65.79 mg/l) and T5 (670.2±139.7 mg/l) with increasing trend were significantly higher (p<0.05) than that of T1 (61.14±3.4).

The mean BOD_5 of T2 (192.8±41.38 mg/l) is significantly higher (p<0.05) than that of other treatments. There was no significant difference between BOD_5 of T1 (0.81±0.35 mg/l), T5 (17.13±6.10 mg/l) and T4 (26.51±9.90 mg/l). T3 (alum treated water) had significantly lower (p<0.05) mean BOD_5 (105.46±27.86 mg/l) compared to T2.

The mean COD of T2 (645.00±151.83 mg/l), was significantly higher (p<0.05) than that of all other treatments. T5 (624±355.21 mg/l), had higher COD because of chlorine treatment. There was no significant difference between COD of T3 (353.0±118.86 mg/l) and T4 (185.5±59.41 mg/l).

The mean total coliform count of T2 (8325±486.88 MPN/100ml) was significantly higher (p<0.05) than that of all other treatments. There was no significant difference between T4 (7575±528.39 MPN/100ml), T2 (8325±486.88 MPN/100ml) and T3 (8371±187.35 MPN/100ml) in increasing trend. T5 (44.6±39.10 MPN/100ml) had the lowest total coliform count and was significantly different from T1.

The mean *E. coli* count of T1 (57.14±42.85 MPN/100ml) and T5 (0.0), were not significantly different (p<0.05) from each other, but significantly different from that of T3 (7371.43±358.3 MPN/100ml), T2 (7114.29± 639.72 MPN/100ml) and T4 (6075±722.0 MPN/100ml) in decreasing trend (Table 2).

The physical appearance of water samples from different treatment points of the recycling plant are given in Figure 2.

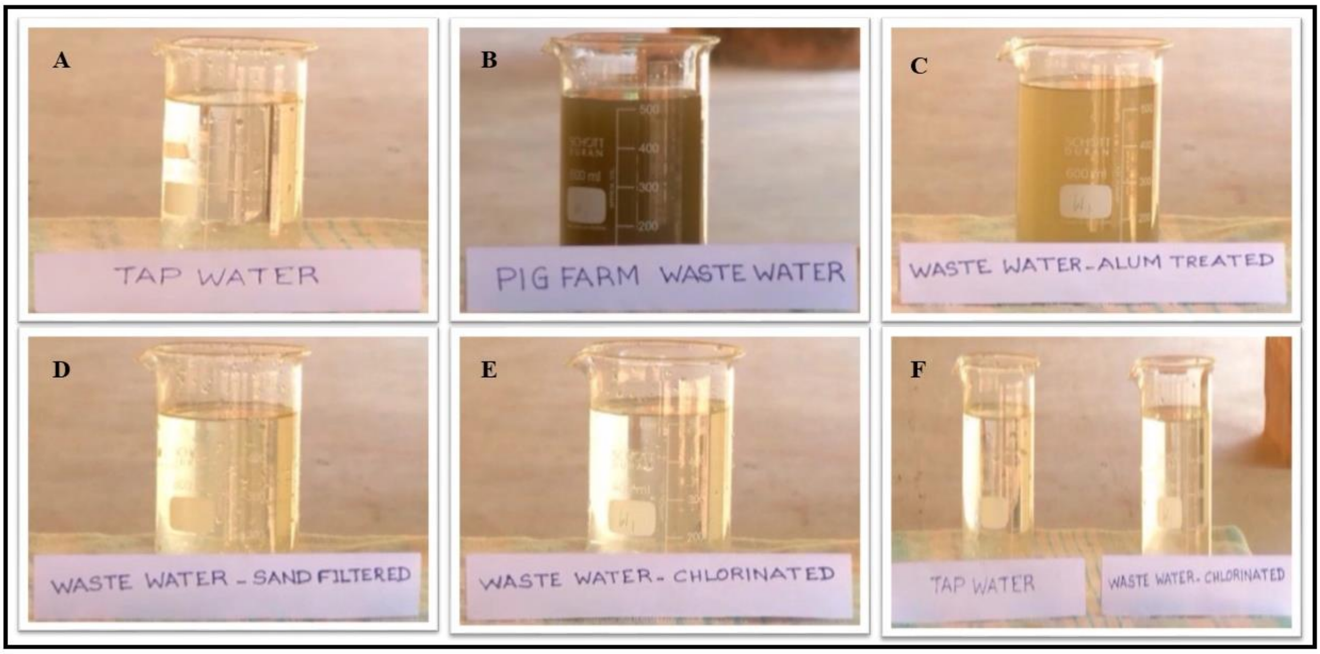

Fig 2: Physical appearance of water collected at different treatment points of recycling plant.

3.3 Indian Standards for quality of drinking water and effluents

The Indian standards for quality of drinking water (IS:10500**)** and effluents (IS:10500, Part A**)** are given in Table 3.

Table 2: Water quality at different treatment points

S. No.	Parameter	Tap water (T1) (Mean ± S.E)	Pig shed Wastewater (T2) Mean ± S.E	Alum treated wastewater (T3) Mean ± S.E	Sand filtered wastewater (T4) Mean ± S.E	Chlorinated wastewater (T5) Mean ± S.E
1	pH	6.57±0.21^{a}	8.16±0.16^{b}	6.88±0.49^{a}	7.39±0.14^{ab}	8.03±0.28^{b}
2	Color, Hazen	0^{a}	50.13±9.2 ^{b}	9.13±2.1^{a}	2.88±1.0 ^{a}	11.40±3.6^{a}
3	Turbidity, NTU	0.48±0.33^{a}	96.47±13.18^{b}	24.71±5.25^{a}	7.36±2.05^{a}	24.42±8.9^{a}
4	TDS, mg/l	61.14±3.4^{a}	565.38± 97.34^{b}	640±65.79^{b}	490.25±40.62^{b}	670.2±139.7^{b}
5	BOD, mg/l	0.81±0.35^{a}	192.8±41.38^{c}	105.46±27.86^{b}	26.51±9.90^{a}	17.13 ± 6.10^{a}
6	COD, mg/l	34.43±12.96^{a}	645.00±151.83^{b}	353.0±118.86^{ab}	185.5±59.41^{ab}	624±355.21^{b}
7	Total coliform, MPN/100ml	2131.86±971.46^{b}	8325±486.88^{c}	8371±187.35^{c}	7575±528.39^{c}	44.6±39.10^{a}
8	E. coli, MPN/100ml	57.14±42.85^{a}	7114.29±639.72^{b}	7371.43±358.3^{b}	6075±722.0^{b}	0.0^{a}

Means bearing the same superscript do not differ significantly (p<0.05)

Table 3: Recommended quality standards for drinking water and effluents

Sl. No.	Parameter	Drinking water (IS:10500)	Discharge of Effluents (IS:10500 Part A)
1	pH	6.5-8.5	5.5-9
2	Colour, Hazen	5-25 (max)	N2
3	Turbidity, NTU	5-10 (max)	-
4	TDS, mg/l	500-2000 (max)	2100
5	BOD_5, mg/l	2	30
6	COD, mg/l	-	250
7	Total coliform, MPN/100ml	0	-
8	E. coli, MPN/100ml	0	-

3.4 Quantity of wastewater reclaimed
Five hundred liters of pig farm wastewater were utilized for the wastewater treatment daily and after different physical, chemical and biological treatment, four hundred liters of wastewater could be reclaimed for reuse in the shed each day (one treatment cycle) for eighty days of the study.

3.5 Special observations on running of wastewater treatment unit
Installation of an initial screen at the outlet of the wastewater from the shed reduced the content of solid waste with higher particle size and helped in operating the unit effectively. The sedimentation process advocated before sand filtration seems to have reduced the chances of clogging in the sand filter unit. Open tanks covered with nets seem to have beneficially contributed to better aeration and access to sunlight thereby increasing the overall efficiency of the unit.

4. Discussion
Though swine husbandry is an integral part of the livelihood and nutritional security of rural households, environmental pollution caused by the disposal of waste water and excreta from pig farms is a matter of concern. The effluent from pig sties may contain various pathogenic organisms which poses a serious threat to public health. Thus, various government agencies have imposed certain restrictions on where and how manure may be land spread and the quality of effluent released. Moreover, swine husbandry requires a large quantity of water for watering the animals and cleaning purposes. It is important have facilities for water conservation in all industries, especially on like swine production. Though water conservation and recycling technologies are available for large scale swine farms, the same is not standardized for small holder production systems, especially in developing countries. Hence, we developed a model comprising various methods like physical, chemical and biological treatments which can be economically affordable for small holder production systems and evaluated the efficiency of the system.

As per Indian standards for water quality, water having a wide range of pH is considered to be safe for drinking purpose (6.5-8.5) and for the effluents (5.5-9). In the present study it was observed that the pH of water at various treatment points lay within the prescribed limits. Previously, Sombatsompop *et al*. (2011) [11] was also reported that the pH of raw wastewater from pig farms as 7.5 to 8.5. Since the pH values of chlorinated wastewater (T5 - reclaimed water) are within the limits of Indian Standards (IS:2296, IS:10500 - Part A), this water can be recommended for use in the pig shed as far as pH was concerned. The mean colour value in Hazen units of water from different treatments indicated that T2 (waste water) was significantly higher (p<0.05) than the rest of treatments. This may be due to dissolved and suspended solids in pig farm wastewater. There colour of water in other treatment points were more or less similar. It was observed that alum treatment and sand filtration considerably bring down the turbidity and colour value to normal range. Since the mean colour values are within the limits of the Indian Standards IS 10500 (Part A) for reclaimed water (T5), this water can be recommended for reuse in the pig shed as far as colour is concerned.

With respect to turbidity, though the turbidity of waste water (T2) was significantly higher than the remaining samples due to high dissolved and suspended solids, the alum treatment and sand filtration helped to keep it within recommended limits. The turbidity after the final treatment was within the limits stipulated by Indian standards, which indicate the effectiveness of respective treatments.

Total-Dissolved Salts (TDS) measure the concentration of inorganic matter like bicarbonates, chlorine, sulphate, sodium, calcium and magnesium dissolved in the water. It is commonly referred as the salinity of the water. Generally, a TDS value of less than 1000 mg/l is considered as ideal for using as drinking water in pig farms (van Heugten, 2010) [13], whereas a value below 2000 is acceptable as per Indian Standards. In present study, it was observed that in all treatment points, the TDS was far less than recommended standards.

Biochemical oxygen demand (BOD) measures the quantity of oxygen required to completely decompose the organic matter present in water. It is mandatory to have reduced BOD levels to the minimum before discharging in to surface waters or recycling. Water with high BOD levels may reduce the oxygen content in water bodies leading to fish kills and other negative effects. As per Indian Standards, maximum permitted BOD level in drinking water is 2 mg/ml and 30 mg/ml in effluent. In the present study it was observed that BOD level of untreated waste water was very high and subsequently reduced to permissible levels while passing through different treatment points. The initial high BOD levels observed in the present study was in the consensus with previous report of Kornboonraksa *et al*. (2009) [6]. It was observed that alum treatment was helpful in considerably reducing BOD levels, due to removal of organic matter during flocculation.

Chemical Oxygen Demand (COD) is the measure of the oxygen required to oxidize soluble and particulate organic matter present in water. The maximum permissible level of COD in effluent is 250 mg/ml as per Indian Standards. It was observed that though the initial COD level of waste water was high, subsequent treatments helped to reduce the levels to the minimum. Though the mechanical and biological treatments helped to reduce the COD levels, it was observed that the chemical treatment considerably increased the COD levels, which might be due to high chlorine content. Previously also, it was reported that high levels of chlorine beyond certain limits, increases the COD of treated water (El-Rehaili, 1995)

[2]. Since the COD values for water from T5 are higher than the limits of the Indian Standards IS 10500 (part A) for discharge of effluents, this water must be treated to reduce the COD before released to public outlets.

The total coliform count is a water quality parameter that monitor the fecal matter contamination and act as an indicator of pathogens that causes various disturbances including diarrhea and typhoid. The sewage generally has a high faecal coliform count ranging from 10^6 up to 10^8 Most Probable Number (MPN)/100ml. Even though coliforms are not a common cause of illness, they indicate the presence of pathogenic organisms originated from fecal matter. As per the Central Pollution Control Board (CPCB) rules, the maximum total coliform count in the initial treatment point of the water recycling plants should be 5,000 MPN/100ml (Seth, 2000) [10]. In present study, it was found that though the total coliform count was significantly higher in the initial sewage water, it gradually decreases and become lowest at the last treatment point. This finding is in accordance with that of Rufete *et al*. (2006) [9], that the pig slurry is a major and pertinent source of faecal coliforms in the soil. The finally treated water had the lowest total coliform count because of disinfection using chlorine. Since the total coliform count values are within the limits of the Indian Standards, this water can be recommended for reuse in pig shed as far as total coliform count was concerned.

E. coli count is considered as the first reference of microbial quality of water and the important indicator of faecal contamination due to their prevalence in digestive tract of animals and human being (Garbow, 2001) [3]. Many strains of E. coli are reportedly pathogenic in nature and adversely affects the health of humans and animals (Rice *et al*., 1996; Wu *et al*., 2011; Soon *et al*., 2013) [8, 15, 12]. Hence it is imperative have the treated water contain E. coli count with in the prescribed limits. The recommended limit for E. coli as per the Indian Standards is zero MPN/100 ml of water. It was observed that the final output after the chlorination met the standard, and there was decreasing trend in the number in successive treatment points. The initial tap water sample reveal the presence of E. coli, which is not fit for consumption, but the result was not surprising, as fecal coliforms and injured coliforms were previously detected in many households tap water samples (Lee and Kim, 2002) [7].

In the present study, four hundred liters of wastewater could be reclaimed from five hundred litres of pig farm wastewater after different physical, chemical and biological treatment for reuse in the shed each day (one treatment cycle) for eighty days of the study. This is in accordance with the finding of Zhang and Lei (1998) [17] who found that 44 per cent of the water can be reclaimed from the original wastewater.

5. Conclusion

The results of present study demonstrated that water undergone the treatments had a quality standard comparable to Indian Standards. Hence the developed low-cost water treatment system can be recommended for recycling waste water in small holder pig production systems.

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