Study of Phytotechnology in Sludge Treatment Wetland

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Abstract: Plants are key elements in sludge treatment wetland. The study was conducted to assess the suitability of wetland plants in STW for sludge dewatering and stabilization potential. Pilot-scale study consisting of five units had one control unit i.e no wetland plant. It used species such as Canna indica L, Arundodonax.L, Colocasiaesculanta, Cyprus alopecuroides Rottb and sewage sludge. It maintained sludge loading rate of 70 Kg.TS/m^2.yr treated for 12 months. The suitability of wetland species was assessed on the performance which was based on their survival, sludge dewatering and stabilization potential. The results of the study were based sludge quality such as moisture, total solids (TS) and volatile solids (VS) during sludge feeding and final resting period. The result of sludge dewatering and stabilization showed decrease in moisture by 40% and VS reduction by approximately 15% in planted STW system. Thus, the present study shows the suitability of all wetland plant used in STWs. The result of effect of plant density on sludge dewatering and stabilization were also discussed.

Keywords: **Canna indica L; Arundodonax.L; Colocasia esculanta; Cyprus alopecuroides Rottb; pilot-scale STW; Sludgede watering; Stabilization.**

I. INTRODUCTION

Sludge generated from sewage treatment plant is highly organic and contains a lot of water. Dewatering and stabilization are essential sludge processing techniques that are required to reduce putrescible nature and volume of sludge. The processing required depends on the characteristics of the sludge. Its management is highly complex. Its disposal cost is 20 to 60 % of total operating costs of Wastewater treatment plant (WWTP). The conventional methods of sludge dewatering include centrifugation, pressure filtration, and vacuum filtrations that incur high capital and sustenance cost. Sludge stabilization can be done by aerobic and anaerobic digestion. The conventional dewatering and stabilization processing methods are cost-intensive and require mechanization. In this context, alternative processing methods based on natural mechanisms of purification are required particularly for developing countries. Sludge Treatment Wetland (STW) is an alternative cost-effective method to dewater and stabilize sludge simultaneously with least mechanization and it is most appropriate for the tropical climate. The dewatering performance of STW depends on factors related to the design (substrate type and size, type of plants), the maturity of beds, climatic factors, sludge characteristics, and operational factors (Breen 1997; Prochaska et al. 2007). Wetland vegetation plays an important role in STW, enhancing sludge dewatering and stabilization. The essential nutrients in sludge are converted into a useful end product through biological activity in STW. The presence of plant prevents clogging; favours dewatering and improves mineralization of the sludge (Nielsen 2007). The studies were conducted to highlight the influence of wetland plants on the process of dewatering and mineralization of sludge. The wetland plants used in STW include: Phragmites australis (Nielsen and Willoughby 2005; Giraldi and Iannelli 2009; Peruzzi et al. 2009; Bianchi et al. 2011; Korboulewsky et al.2012; Uggetti et al. 2012; Gagnon et al. 2013); Typha sp.or cattail (De Maeseneer 1997; Panuvatvanichet al. 2009; Korboulewsky et al. 2012;

Uggetti et al. 2012; Gagnon et al. 2013; Wu 2014; Magri et al.2016); Echinochloa pyramidalis (Kengne et al.2011); Cyperus papyrus L (Kengne et al. 2011; Magri et al. 2016); Iris pseudacorus or Canna spp. (Canna Lilies) (Korboulewsky et al. 2012); Zizaniopsis bonariensis (Suntti et al.2010; Magri et al.2016); Scirpus fluviatilis (Gagnon et al.2013); Phragmites karka (Manderia 2012; Pandey and Jenseen 2015).The literature review shows that researchers have used many wetland vegetation to find out its performance in the process of dewatering and stabilization governed by the type of vegetation, local conditions, type of support medium and Solid Loading Rate (SLR). It is also reported that properly selected native plant communities are most tolerant to soils, climatic conditions, and seasonal cycles of inundation and drought (USEPA 2000).In this context, Uggetti et al. (2012), Joceline et al. (2016) have stressed the need of more scientific data on the performance of new wetland vegetation in STW through studies on sludge dewatering and stabilization. In the present study, the locally available wetland vegetation which were not used previously in a tropical climate (like India) were identified and used in pilot –scale study . The wetland vegetation such as Canna indica L., Arundo donax L., Colocasia esculanta, and Cyprus alopecuroides Rottb were used in the study. Colocasia esculenta and Canna indica L are popular plants and these have the ease of cultivation. These used by local people for food, landscape improvement and water purification. Arundo donax L. and Cyprus alopecuroides Rottb are the large and robust grass which are found nearby the study site and have potential to sustain fluctuation in water level, pH variation, high evapotranspiration rate and dense root rhizome pattern. The most common support medium used in STW includes natural sand and gravel. But there is a large scarcity of natural sand and gravel in India, and hence crushed sand was used in the present study. This study aims at assessing the suitability of Canna indica L., Arundo donax L., Colocasia esculanta, and Cyprus alopecuroides Rottb as wetland vegetation in STW. The study contributes to existing knowledge by addition of scientific data on the use of wetland vegetation, and assessment of the use of crushed sand as an alternative support medium for growth of vegetation for sludge dewatering and stabilization. The studies were carried out on pilot- scale STW vegetated with these plants in the crushed sand for sludge dewatering and stabilization potential for a study period of one year and loaded with typical SLR (70kg.TS/m^2.yr). The growth of vegetation and quality of stabilized sludge were monitored throughout the study period.

II. MATERIAL AND METHODS

Source of sludge

Sludge was collected from secondary clarifier of a working Sewage Treatment Plant (STP) treating sewage of Ichalkaranji, Maharashtra (India). STP consists of preliminary treatment (screening, grit removal) followed by secondary treatment based on extended aeration. Fresh sludge was collected from STP as and when required as STP is located near pilot scale STWs.

Study location

The pilot-scale STW systems were constructed in the campus of Sharad Institute of Technology (SIT), Yadrav, Maharashtra, India. The climatic conditions during the study period were from April 2014 to March 2015 .The temperature was from 14 ^{0}C to 40^0 C. The mean annual precipitation was 937.4 mm, with a maximum of 235.51 mm in July, and a minimum of 8.62 mm in May.

Pilot-scale set up

Five pilot-scales STW i.e. S1 (Control with no species), S2 (Canna indica L), S3 (Arundo donax L), S4 (Colocasia esculanta) and S5 (Cyprus alopecuroides Rottb) were designed and developed. Each system was made up of 0.58 m diameter and 0.9 m deep plastic cylindrical tank filled with graded crushed sand as support medium with/without vegetation.

The systems were also provided with ventilation pipe grid and three sampling ports at various levels to sample sludge from different depth thereby enabling assessment of depth-wise variability in sludge quality. The graded sand bed consists of 0.15 m deep stone aggregate at the bottom, 0.23 m deep coarser crushed sand in the middle and 0.10 m deep fine crushed sand at the top. The ventilation pipe grid was made up of the perforated interconnected system of vertical and horizontal plastic pipes of 50mm diameter and was placed above stone aggregate layer. The outlet controlled by a tap at the bottom was provided to collect leachate and drain out the system.

Figure 1 and 2 show typical sketch and photographic view of pilot-scale STW system. The wetland vegetation was collected from the nearby watercourse and transplanted into the system. The plant density of 3.78 to11.36 number/m^2 was adopted (Edwards et al. 2001, Hardej and Ozimek 2002). In the initial period, the plants were given fresh water.

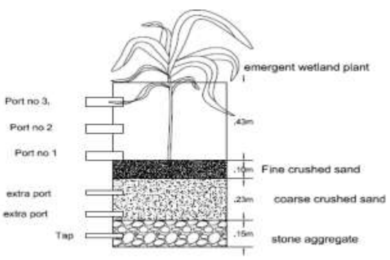


Fig.1 Typical sketch of STW

Fig.2 Photographic view of pilot scale STW

Pilot-scales Operation

The operation of Pilot-scale STW systems was divided into following periods such as initial period, alternate sludge feeding and intermediate resting period and final resting period. The initial period (from February 2014 to April 2014) was observed in which, fresh water was given to the plants and growth of plants was monitored. The alternate feeding of sludge and intermediate resting was adopted during April 2014 to January 2015.The sludge feeding of one week and resting period of one week forms one cycle. The sludge fed to the systems in numbers of cycle's .The final resting period was from February 2015 to March 2015. Thus pilot-scale study was conducted for 12 months which covers all seasons in which plant growth was monitored in sludge environment. Influent sludge was fed to pilot-scale STW after the plants were grown to a height of 0.1m. Sludge was fed to all STW systems simultaneously once a week followed by intermediate resting period of one week. The 319.5 L of sludge was fed to the system in number of cycles during alternate sludge feeding and intermediate resting period (i.e sludge feeding period) to achieve Solid Loading Rate (SLR) of 70kg.TS/m^2.year to assess suitability of wetland vegetation. However, as the study focuses on the performance of wetland vegetation in sludge dewatering and stabilization, it does not deals with efficiency of STW in terms of contaminant removal. Sludge Loading Rate (SLR) was decided on the basis of the values reported in the literature (Burgoon et al.1997; Nielsen 2003;Troesch et al.2009;Uggetti et al.2010;Vincent et al. 2011).However higher SLR'S were also adopted and reported in literature of STW based on the objective of research. The final resting period of two months was adopted during which fresh water was supplied to satisfy the water requirement of the plants.

Sampling procedures and analysis

The residual sludge sample from sampling port 1 (representative of bottom sludge layer) and from surface of sludge layer was collected, just before feeding i.e. at the end of the intermediate resting period. The residual sludge was collected from sampling ports through horizontal scoops and it was mixed to obtain a composite sample. The residual sludge was also collected from four points of the surface layer and mixed to obtain a composite sample.

The residual sludge samples were collected from various ports after accumulation of residual sludge up to the desired levels 1 to 3 of these ports (see fig.1), at the end of the intermediate resting period from pilot-scale STW system. Residual sludge depth was measured above the support /filter media. The volume of residual sludge in each pilot-scale STW system was determined by multiplying surface area of the STW to the sludge depth in the system. The sludge volume reduction was determined by using a ratio of residual sludge volume to total influent sludge in each system. The influent sludge and residual sludge from STW was analyzed for pH, EC, TS, VS, FS, moisture and COD using the standard procedures of APHA 2005. For TP and TKN, a block digester is used to perform kjeldahl digestion. 25 mL sample or standard and 10 mL digestion solution were placed in the digester for 1 hour at 200° C and then for additional one hour at 380°C. Organic matter content (loss on ignition) was obtained by combusting the dried samples in muffle furnace at 550 ± 5 °C for 2 hour. The growth of plants was measured in terms of height in cm and number of shoots obtained and recorded. Also dried leafs of plants were collected and measured in gm to co-relate nutrient removal in the study. The plant density of the species was determined as per the ratio of the number of wetland plants from the surface area. Meteorological data such as, air temperature, atmospheric pressure, air humidity, wind velocity and direction was collected by setting various meteorological observatories at study location.

By comparing residual sludge quality in terms of concentrations of TS, Moisture, and VS in controlled STW system and planted STW system, performance evaluation was investigated to show presence of wetland vegetation, in the process of sludge dewatering and stabilization. The growth of wetland vegetation in sludge environment under repeated sludge feeding in pilot-scale STW systems proves the suitability. Further quality of dewatered sludge produced at the end of final resting period decides its reuse for specific application.

III. RESULT AND DISCUSSION

Sludge dewatering

Figure 3 and 4 indicates the periodical variations of moisture in residual sludge of controlled STW (S1) and planted pilot-scales STW system. The abscissa showed period in days representing, samples collected during last day of intermediate resting period of all cycles of operation. It showed trend in moisture measurement during sludge feeding period and during final resting period to represent surface and bottom layer. Sludge dewatering was assessed by measuring the moisture reduction in the residual sludge, as one of the key aspects of sludge treatment. Refer the results given in table 1 of the pilot-scales STW system. It was observed that average influent moisture concentration (94.21±2.54%) in the system was decreased to 58.72±24.67% in S1;51.6 **±25.95** % in S2; 52.35±27.22% in S3; 50.73± 26.45% in S4; 50.42 ±24.72% in S5, respectively. In the first 3-5 cycles, the filter media performed better to dewater the sludge and separated liquid and solid part of sludge showed effective dewatering process. The solids retained during consecutive feeding cycles showed increase in thickness of sludge accumulated over the filter media. The sludge accumulated in the system undergoes reduction in sludge moisture under the influence of climatic conditions and achieved maximum moisture reduction on account of larger intermediate resting period showing moisture up to 10%. Further sludge feeding in intermediate cycles was responsible to enhance the sludge depth showed effectiveness of dewatering process. Moreover, feeding in intermediate cycle showed increased moisture in residual sludge. The down trend in moisture measurement during 166-204 days shows missed loading and effect of climatic conditions on residual sludge. After a period of 204 days no precipitation occurred but water requirement of wetland species was obtained by wetland plant from the residual moisture of sludge by way of transpiration. The transpiration process was responsible in further reduction of moisture in residual sludge. Overall, result of sludge dewatering shows moisture reduction of 35.49 % in S1(controlled STW system), 42.61 % in S2 by Canna indica L, 41.86% in S3 by Arundo donax, 43.48% in S4 by Colocosia esculanta and 43.79 % in S5 by Cyprus alopecuroides Rottb .

The moisture difference of 7.12, 6.36, 7.98, 8.30% was observed in STW systems of Canna indica L, Arundo donax L, Colocasia esculanta, Cyprus alopecuroides Rottb respectively compared with S1 i.e. Controlled STW system. The moisture difference observed was plant species specific. This shows suitability of Canna indica L, Arundo donax L, Colocasia esculanta , Cyprus alopecuroides Rottb in pilot scale STW system for sludge dewatering . The result indicates better dewatering performance of species used in pilot-scale STW system and showed their effectiveness in STW over controlled STW system.

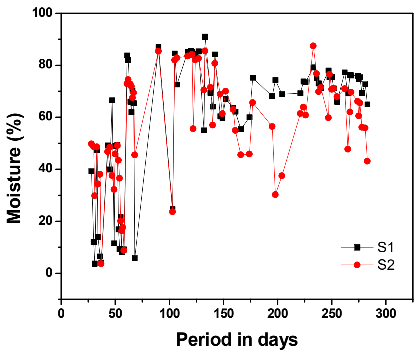
TABLE 1 Characteristics of influent sludge and TS, VS and moisture concentration in pilot scale STW.

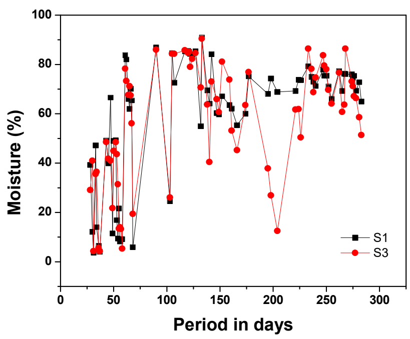
	TS (%)	**VS (%)**	**Moisture (%)**	**Sludge volume reduction (%)**	**Wetland species**
Sludge	5.79 ± 21.17	50.26 ± 16.06	94.21 ± 2.54		
S1	41.28 ± 24.67	39.49 ± 11.32	58.72 ± 24.67	76.78	Controlled STW system
S2	48.4 ± 25.95	36.94 ± 16.93	51.6 ± 25.95	85.08	*Canna indica L*
S3	47.65 ± 27.22	34.5 ± 12.04	52.35 ± 27.22	84.25	*Arundo donax L*
S4	49.27 ± 26.45	34.34 ± 13.16	50.73 ± 26.45	80.93	*Colocasia esculanta*
S5	49.58 ± 24.72	33.21 ± 12.95	50.42 ± 24.72	82.59	*Cyprus alopecuroides Rottb*

The results in table 2 include the values of N, P, K and C: N ratio showing reuse of stabilized sludge for agricultural purpose and used as soil conditioner. The application of stabilized sludge to soil provides potassium, calcium, magnesium, sulfur, and micronutrients for plant growth and showing the increase of water holding capacity of soil which is shown in fig 7.

TABLE 2 Characteristics of stabilized sludge.

Parameter	N (%)	P (%)	K (%)	OC (%)	C/N ratio
Values	2.66	0.78	0.15	28.53	9.95





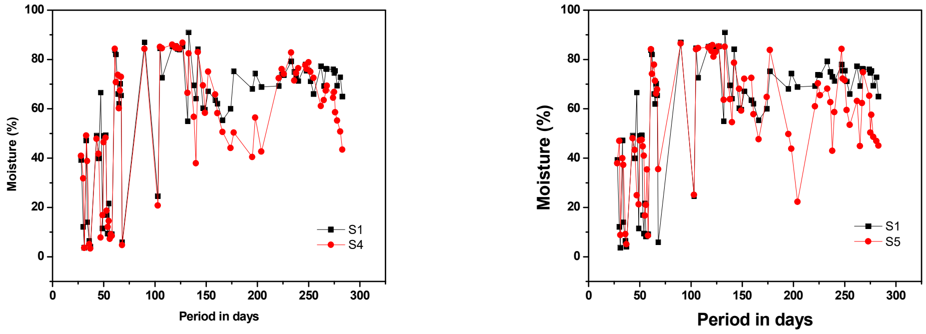


Fig.3 Moisture variation during sludge feeding period in controlled and planted Pilot-scales STW

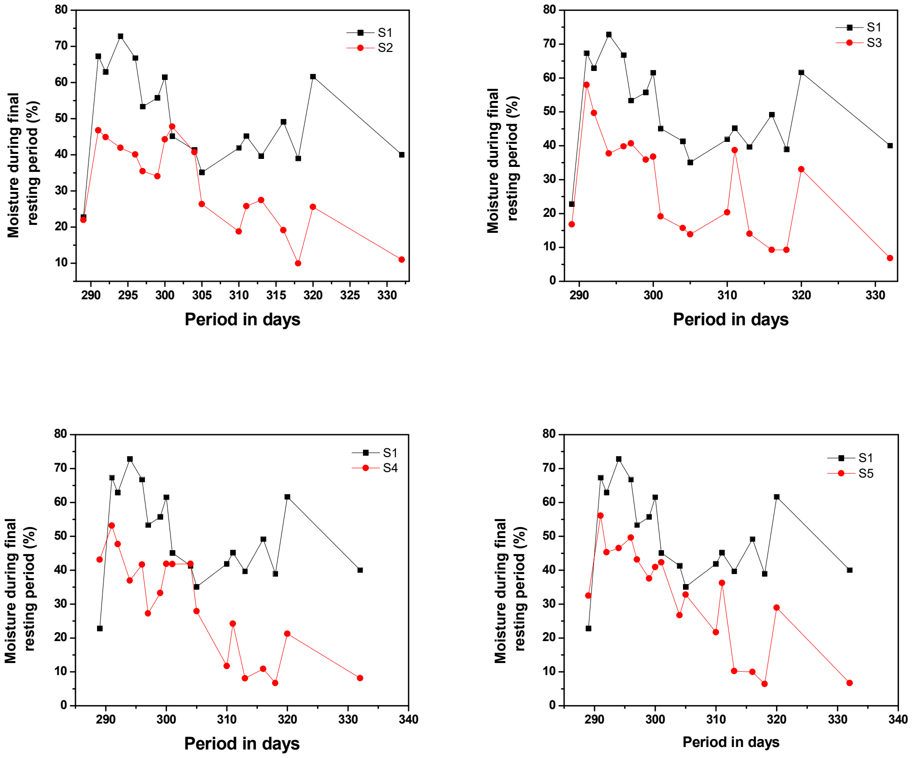


Fig.4 Moisture variation during final resting period in Pilot-scales STW system

The results in fig.4 showed moisture measurements during final resting period in controlled STW system (S1)) and planted (i.e. S2, S3, S4, S5) STW system. Further moisture reduction during final resting period in controlled STW and planted STW system was 47.21% in controlled system, 49.39% in Canna indica L, 49.68% in Arundo donax, 49.57 % Colcocasia esculanta, 50.63% in Cyprus alopecuroides Rottb. The result indicated no significant difference in moisture reduction by plant species but showed suitability in STW as wetland vegetation. The above results suggest that sludge is dry and use of mechanical equipment, such as front-end loaders or shovels required for sludge handling.

Table 1 shows sludge volume reduction in all pilot-scales STW systems. The sludge fed to each pilot-scale STW system was approximately 318.5 L during the sludge feeding period. The residual sludge accumulated at the end of final resting period was 73.54 L in S1 i.e. controlled STW system and 47.53 L in S2, 58.10 L in S3, 50.17 L in S4, and 60.74 L in S5 respectively. It represents gradual Sludge Volume Reduction (SVR) of 76.78% in S1 i.e. controlled STW system and 85.08 % in S2 by canna indica L , 84.25% in S3 by Arundo donax L, 82.59 in S4 by Colocasia esculanta ,80.93% in S5 by Cyprus alopecuroides Rottb.

Higher SVR of 85.08% attained in S2 having wetland specie i.e.canna indica L, followed by arundo donax L followed by cyprus alopecuroides Rottb and colocasia esculanta in treating sludge after final resting period of 2 month. Thus performance of canna indica L was better than other wetland plant species. Further, it was found that difference in SVR varied between 2.91 to 8.38 % in pilot-scales compared with control systems. The results obtained may be because of high dense root system of wetland vegetation used. It aids in draining and better removal of interstitial moisture by transpiration process from residual sludge. The SVR is important parameter considered in reducing handling and transportation cost. In this context, use of Canna indica L, as wetland vegetation will reduce transportation cost and provide pleasing appearance to the surrounding .It will further help in maintaining the biodiversity of plant and thus recommended to use in STW as wetland vegetation.

Sludge Stabilization

Figure 5 and 6 shows variation in the VS in residual sludge of controlled and planted pilot-scale STW systems during the sludge feeding period and final resting period respectively. The abscissa showed period in days representing, samples collected during last day of intermediate resting period of all cycles of operation. The results of sludge stabilization shown in figure 5 and 6 of the pilot-scales STW system were indicated by decrease in volatile solids (VS %) in controlled STW and planted STW system. During the sludge feeding period, influent sludge contained average VS concentration of **50.26 ± 16.06%**.The VS remained in residual sludge was 39.49% in controlled STW system, 36.94% in S2 by canna indica L, 34.50% in S3 by arundo donax ,34.34% in S4 by colcosia esculanta and 33.21 % in S5 by Cyprus alopecuroides Rottb respectively. The VS remained was more controlled STW system than the planted STW system and varied between 2.55-6.28 %. It showed role played by wetland vegetation in sludge stabilization.Further,percentage decrease in VS concentration of 10.77 % in controlled STW system, 13.32% in canna indica L, 15.76% in Arundo donax L, 15.92% in colcosia esculanta and 17.05 % in Cyprus alopecuroides Rottb respectively with respect to influent VS concentration. It shows better performance of Cyprus alopecuroides Rottb followed by Arundo donax L, by colcosia esculanta and canna indica L in sludge stabilization.

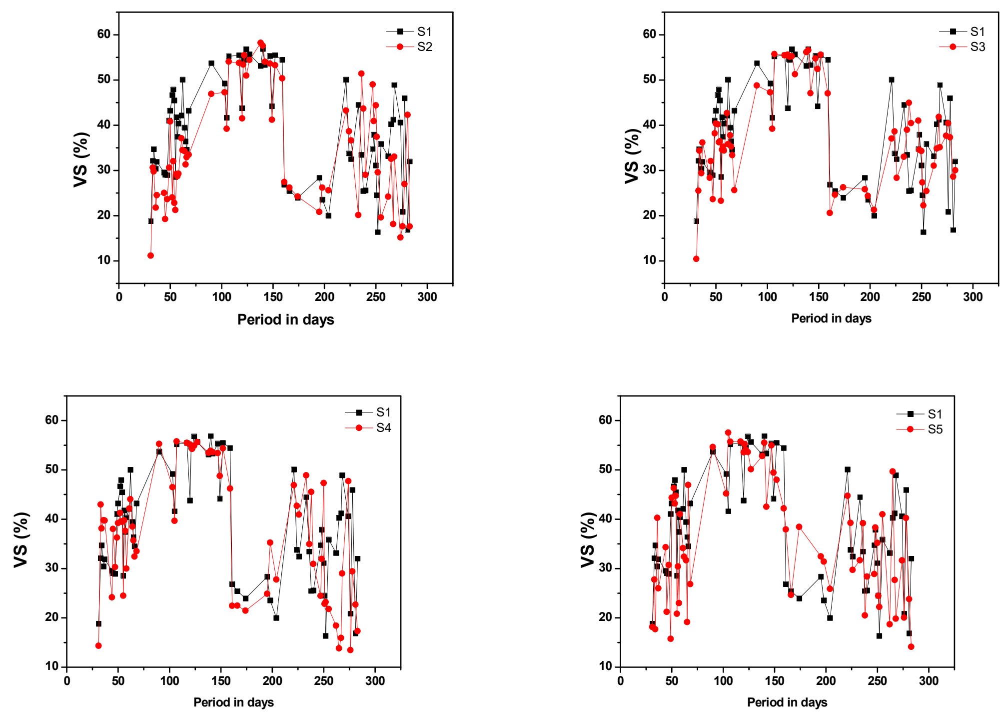


Fig.5 Volatile solids variation during sludge feeding period in Pilot-scales STW system

The results in fig.6 showed VS measurements in residual sludge between the controlled STW system (S1)) and planted (i.e. S2, S3, S4, S5) STW system during final resting period. The difference in values of VS in controlled system and planted STW system at the end of final resting period showed difference of 22.12% between S1 and S2, 20.58% between S1 and S3, 28.86% between S1 and S4, 25.48% in S1 and S5.The results suggest that planted STW system performed better than controlled STW system. The sludge obtained from the controlled system had VS greater than 35 % whereas less than 35% VS in the planted STW system. The VS below 35% is an acceptable level with respect to odour emission. Thus when applied on land, it does not attract flies, mosquitoes, vermin and birds that can carry and spread diseases.

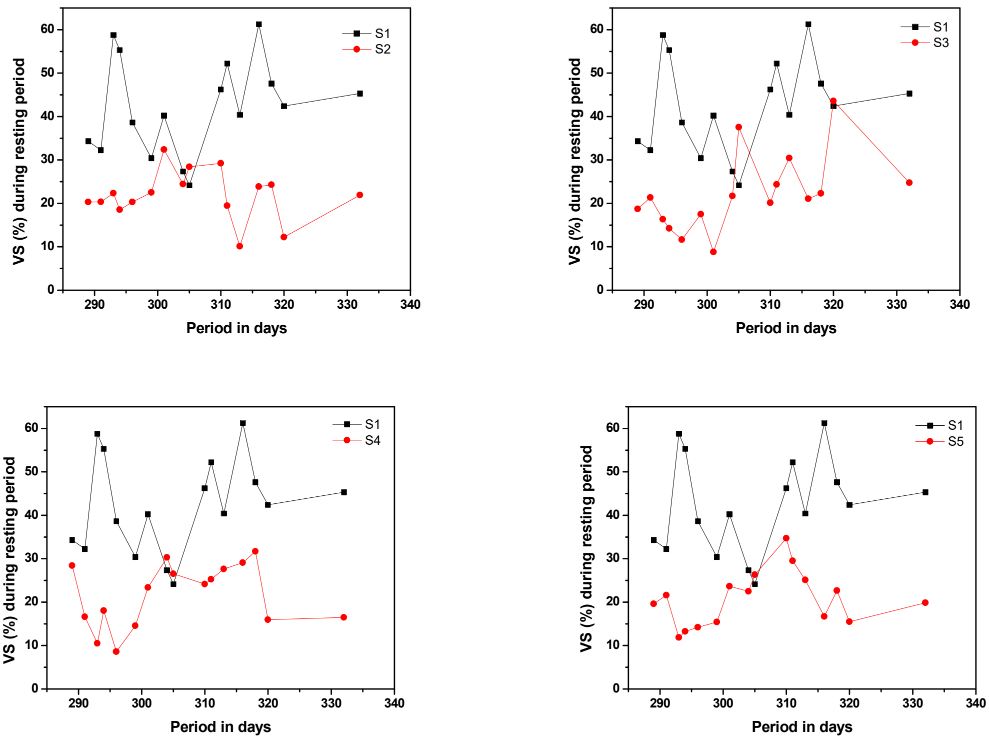


Fig.6 Volatile solids variation during final resting period in Pilot-scales STW system

Plant growth

Figure 7 shows the temporal variation in plant height and density during study period. The growth of wetland plant was observed as increase in height and plant density. The vegetation height increased from 21 to 73 cm, 20 to 111 cm, 11 to 70 cm, 2.5 to 89 cm, for Canna indica L**,** Arundo Donax L, Colocasia esculanta, Cyprus alopecuroides Rottb respectively as shown in Fig.6. The maximum growth in terms of height observed in Arundo donax L was followed by Cyprus alopecuroides Rottb and canna indica L. The plant growth and density was found in the multiple of 7.3 to 23.7 and 5.67 to 20 respectively after 12 months period. It was observed that growth of plant per day was 0.32, 0.4, 0.05, 0.40 cm/day for Canna indica L**,** Arundo Donax L, Colocasia esculanta, Cyprus alopecuroides Rottb, respectively. The wetland plant did not show any stress symptom on account of sludge environment in pilot- scale set up and repeated sludge loading.

In another study conducted for 90 days to assess the effect of plant density on sludge dewatering and stabilization. The study was conducted with final resting period of 58 days and the plant density of 37.9, 75.8 and 113.6 number/m^2 was maintained. It was observed that with increase in drained water that increases TS and reduces VS following increase in the plant density. The range of TS and VS attained were 34.33%, 42.2%, 37.44 % and 38.2, 33.6, 35.94 respectively for plant density of 37.9, 75.8, 113.6 number/m^2.

It looks like that there is significant difference observed in TS value up to plant density of 75.8 number/m^2 and VS reduces to 33.6% with increase in the plant density. The results are indicative of nutrient utilization by the vegetation up to 75.8 number/m^2 or non availability of nutrient in residual sludge for proper growth.

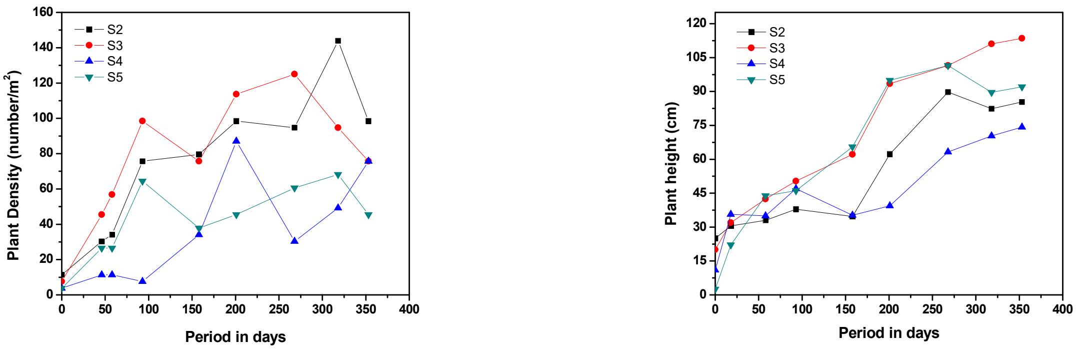


Fig. 7 Temporal variation on plant density and plant height

IV. CONCLUSIONS

The work is related to the design and development of pilot-scales STW systems and suitability of locally available wetland plant and crushed sand as an alternate material in support medium to study sludge dewatering and stabilization potential. The SLR of 70 Kg.TS/m^2.year was found suitable for the local climate to assess the suitability of wetland vegetation in STW. The results of pilot-scales STW system shows total solids more than 40% representing excellent dewatering and VS below 35% helps to avoid odour problem and enhances sludge dewatering and stabilization in STW. Further, more than 80% sludge volume reduction helps to reduce transportation cost. The result of sludge dewatering and stabilization in STW system shows that no need to use mechanical equipment for dewatering process whereas it shows appropriateness of crushed sand in filter media which supported the growth of vegetation and its movement prevented clogging in STW system and enhanced sludge stabilization. Thus this study identifies appropriateness of selected wetland species and filter media as crushed sand in STW. The findings of this study will provide necessary guidance while implementing STW system in the decentralised mode of sludge treatment. The use of crushed sand as supporting media will reduce the cost of construction of STW systems. The use of crushed sand in construction of STW helps to save natural sand and will help to overcome scarcity of sand to small extent. It is the small initiative towards conservation of natural resources.

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Conflict of interest statement

There is no conflict of interest by the authors.

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