SLUDGE ACCUMULATION AND CHARECTERISTICS IN A WASTEWATER STABILIZATION POND SYSTEM IN VAMVAKOFITO - NORTH GREECE

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ABSTRACT

For the development of Wastewater Stabilization Ponds sludge management, the knowledge of accumulation rates of sludge and its characteristics is required. The sludge removal frequency from the lakes must be determined and incorporated into the pond design, the maintenance schedule and the operation budget of the WSPs system. A better understanding of the sludge distribution in ponds could lead to design improvements in to achieve optimal distribution of the sludge for an improved efficiency, as the amount of the sludge layer can influences the system's performance, as the effective volume and the shape of ponds bottom are impairing. The first objective of this study is to determine the distribution and accumulation rate of accumulation of sludge in a full-scale WSPs system situated in North Greece, treated municipal wastewater of rural settlement Vamvakofito located in latitude φ: 41º 10' 04.79'' N, longitude λ: 23º23΄03.08'' E and altitude 30m. The system consists of one facultative pond, two maturation ponds and a rock filter before the final discharge for algae filtration. The measurements became after 23 years of system operation, without any maintenance. The accumulation rates and distribution of sludge were determined by measuring the thickness of the sludge layer at several locations throughout each pond. The sludge thickness in each pond was measured using the white towel test. It was observed that in the facultative pond, the distribution of sludge was uneven. Whereas in the maturation ponds, especially at the last one, it was fairly uniform. The maximum sludge thickness occurred near the single pond inlet and outlet; higher accumulation also occurred in some of the corners. The average rate of sludge accumulation is 0.09 [m^3.$person^{-1}$.yr^{-1}], the volume of sludge accumulation per wastewater inflow rate per year is equal to 0.002 [m^3 $m^{-3}y^{-1}$] and the sludge thickness is 14 [mm.yr^{-1}] all the values are among the ones reported in the literature. The second objective is to assess the relationship between the annual sludge accumulations with organic load treated by the system. To determinate the BOD_5 and TSS concentration of the system, instantaneous samples were taken from the inflow and the outflow of the WSPs system during the years 2005 over 2007 and 2012. Given the mean annual concentration of TSS, BOD_5 and the annual accumulation of sludge in the WSPs system, simple relationship are generated (R^2>0.85). The third objective is to give some characteristics of the accumulated sludge. Sludge cores were collected at three locations in each pond, near the entrance, in the middle, and near the exit of the ponds. The TSS, FS, VS and F. Coli concentration of sludge cores were determined. The mean TSS concentration is found 184.92 [g.L^{-1}] and the mean VS/FS ratio is equal to 0.45. The higher TSS concentration and the greater thickness of the sludge were found near the inlet in the facultative ponds. No relationship was found between TSS and VS/FS ratio, and TSS and sludge age. In all three ponds the concentration of fecal coliform bacteria decreased with sludge age but, no correlation is founded between the concentration of F. coli and the position in the ponds from inlet to outlet.

Keywords: wastewater, stabilization ponds, sludge accumulation, sludge characteristics

1. Introduction

For the development of Wastewater Stabilization Ponds (WSPs) sludge management, the knowledge of accumulation rates of sludge and its characteristics is required. As well as, the sludge removal frequency from the ponds must be determined and incorporated into the pond design, the maintenance schedule and the operation budget of the WSPs system. Moreover, a better understanding of the sludge distribution in ponds could lead to design improvements in to achieve optimal distribution of the sludge for an improved efficiency (Nelson K. *et al*, 2004). Because the amount of the sludge layer can influences the system's performance, as the effective volume and the shape of ponds bottom are impairing (EPA, 2011). The wastewater treatment by (WSPs) occurs as the removal of several components via sedimentation or transformation of various components by biological and chemical processes. So, at the bottom of the WSPs, a sludge layer is forming due to the sedimentation of the influent's suspended solids and due to the precipitation of algae and bacteria, which grow in the ponds (EPA, 2011). The accumulation rate and the amount and the distribution of sediments depending on the temperature, wind speeds, the age, and the geometry of the pond, as well as the qualitative characteristics of treated wastewater. Thus, more regional data are needed to determine values for sludge accumulation rate. There are a number of researchers having worked with this issue give information about sludge accumulation in several climate conditions (Schneiter R.W. *et al*, 1983; Papadopoulos *et al*, 2003; Nelson K. *et al*, 2004; Mills F. *et al* 2014; Saqqar M and Pescod M.B, 1995). Most researchers mentioned in anaerobic ponds sludge accumulation rate (Peňa M.R,2000; Papadopoulos A. 2003; Salas R. J.J. and Bouza D.R., 2012; Mills F., 2014; Parker CD and Skerry GP, 1968) and little information has been published about the sludge characteristics changes with the time processes and thought the sludge layers (Nelson K. *et al*, 2004). In Greece, only a few WSPs system exist and there are not an adequate number of researches about this issue. The 90% of those systems are situated in North Greece, serving populations ranging from 500 up to 4,000 equivalent populations (e.q.) in rural regions (Chalatsi M. and Gratziou M., 2014). The 76% of them are located in the Region of Serres, where the research reported herein was held.

The first objective of this study is to determine the distribution and accumulation rate of accumulation of sludge in a full-scale WSPs system situated in North Greece, treated municipal wastewater of rural settlement Vamvakofito. The measurements became after 23 years of system operation, without any maintenance. The accumulation rates and distribution of sludge were determined by measuring the thickness of the sludge layer at several locations throughout each pond as the most common method to estimate sludge accumulation is the empirically determination of accumulation rate, volumetric per capita (Mara D. D. and Pearson H., 1998; Mara D.D. *et al*, 1992; EPA, 2011; Nelson K. L. *et al* 2004; Peňa M.R. *et al*, 2000). The second objective is to assess the relationship between the annual sludge accumulations with organic load treated by the system. The third objective is to give the physical and chemical characteristics of the accumulated sludge.

2. Materials and methods

2.1. Data

The WSPs system is situated in latitude φ: 41° 10' 04.79'' N, longitude λ: 23°23΄03.08'' E and altitude 30m. It consists of one facultative pond (Width: 39.5 [m], Length: 62.0 [m], Side slope 45°) two maturation ponds (Width: 29 [m], Length: 61.5 [m], Side slope 45°) and a rock filter before the final discharge for algae filtration. The maximum constructed depth was for the facultative pond 2.40 and for maturation ponds 1.50 [m]. The current depths are from 1.00 to 2.40 [m] and from 1.00 to 2.40 [m] respectively. The total volume is 8.311 [m^{-3}]. It serves 1,061e.p. and the volumetric loading is 3.1 [gr $BOD_5.m^{-3}.d^{-1}$]. The total hydraulic retention time (HRT) is 68.7 days, the inflow rate is 121 [$m^3.d^{-1}$]. The ponds of the system are oriented so that their length is aligned on an east - west axis. The System's operation began in 1989. The sludge thickness layer measuring, at several locations throughout each pond, becomes once a year during the period of the study. The influents entered the ponds continuously through single pipes located, in most cases, in the corner of the pond and the entrance and exit of the wastewater are diagonally. The effluents exit from the upper 0.40 [m] of the last maturation pond.

2.2. Methods

To determinate the BOD_5 and TSS concentration of the system, instantaneous samples were taken from the inflow of the 1st pond and the outflow of the last pond, during the years 2005, 2006, 2007 and 2012, twice a month, at least while meteorological data were recorded (Chalatsi M., 2014**)**. The outflow data have corrected by mass balance method to eliminate errors from atmospheric precipitation, rainfall and evapotranspiration using Thornthwaite method (Chalatsi M., 2014; Giambelluca T., 2003; Alex G. Doll; Black E.P. 2007; Korkusuz E.A., 2004; Breen P.F., 1990; Heliotis F.D. and DeWitt C.B.,1983), as many researchers believe that the mass balance is the most authoritative method to approach mechanisms and parameters that determine the performance of natural systems and the changes occurring in these (Korkusuz E.A.,2004; Breen P.F.,1990; Heliotis F.D. and DeWitt C.B.,1983).

The sludge thickness in each pond was measured using the white towel test as described by Malan (Malan W.M.,1964; Abis K. L. and D. Mara 2005). The intervals of measuring were about 3 [m]. The white towel test was chosen because it was economical, reliable and quite sensitive to the small heights of sludge frequently encountered, and the results were quick and easy to interpret (Abis K. L. and D. Mara, 2005). Attention was given to the days of sampling so that abstain from days there was rainfalls or high winds in the region, to avoid false measurements due to any resuspension of sludge. Average sludge and bottom elevations were determined using the selected data. For each pond a spot soundings was created with the EXCEL aid with a grid size of 1x1 [m]. Based on these new bottom elevations the volumes of pond's present situation were estimated. The difference of the two volumes is the sludge accumulation. Dividing the result by the total years of system's operation the average annual sludge accumulation is obtained.

Sludge cores were collected at three locations in each pond, near the entrance, in the middle, and near the exit of the ponds. The collection was performed after the liquid samples of wastewater were taken; the pond sludge was not dense enough to force open the sediment catch without causing significant vertical disturbance of the sludge layers. At each core location it was assumed that fixed solids were deposited to the sludge layer at a constant rate throughout the operational lifetime of the pond, and that once in the sludge layer they were conserved. The TSS, FS, VS and F. Coli concentration of sludge cores were determined. The average sludge age of each sample was calculated by averaging the age at the top and the bottom of the sample.

Given the mean annual concentration of TSS and the annual accumulation of sludge in the WSPs system, a simple relationship is generated by linear regression. To assess the relationship between the annual sludge accumulations with organic mean annual load BOD_5 and TSS, treated by the system, the multiple regression method is used. For statistic analysis, linear and multiple regression, EXCELL is used.

3. Results and discusion

In Table 1 the statistic elements of TSS and BOD_5 inflow and outflow concentrations are presented.

Table 1: The TSS and BOD_5 annual inflow and outflow concentrations (mg/L)

Pollutant	Max		Min		Median		Mean		STDEV	
	In	Out	In	Out	In	Out	In	Out	In	Out
TSS	115.70	45.00	5.30	0.80	58.30	25.93	62.61	26.68	24.06	8.60
BOD_5	217.00	101.19	110.00	39.99	158.00	66.52	160.68	67.23	28.88	24.38

In Figure 1 the scheme of the bathymetry simulation WSPs system is presented. It was observed that in the facultative pond, the distribution of sludge was uneven. The same conclusions referred in another research, in central Mexico, by Nelson K. *et al* (2004). Whereas in the maturation ponds, especially at the last one, it was fairly uniform. The maximum sludge thickness occurred near the single pond inlet and outlet; higher accumulation also occurred in some of the corners.

From the changes of ponds volumes, were calculated the sludge volume and the amount of sludge accumulation during the years of operation, as well as, the percentage of ponds filling with sludge (r) (Table 2). Moreover, in the same Table (i) the volume of accumulation per ponds area per year [m^3 $m^{-2}yr^{-1}$],(ii) the volume of sludge accumulation per wastewater inflow rate per year [m^3 m^{-3}yr^{-1}], (iii) the sludge accumulation per equivalent capita per year [m^3 p^{-1}yr^{-1}] rate (s), are presented.

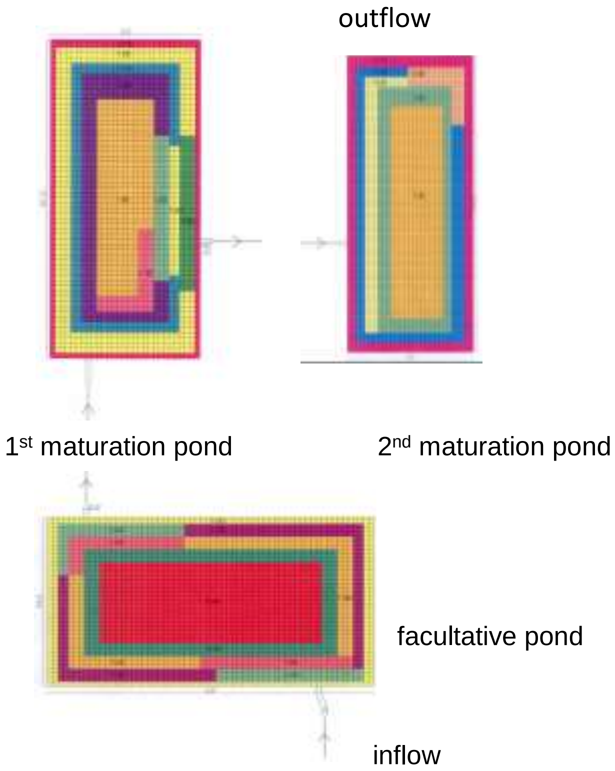

Figure 1: Bathymetry of Vamvakofito WSPs system

Table 2: Accumulation volume and sludge thickness, the percentage of ponds filling with sludge, accumulation volume per ponds area per year, accumulation volume per wastewater annual inflow rate, sludge accumulation per equivalent capita per year.

Accumulation Volume [m^3] (A.V.)	Average Total Sludge thickness [m]	r (%)	Sludge thickness [m.yr^{-1}]	A.V per Q per year	S [m^3 p^{-1}yr^{-1}]
1,951.05	0.322	19	0.014	0.002	0.09

In this research, 19% of the ponds' volume was occupied by solids, resulting in proportional decreases in the design HRT, which was equal to 84.8 [d]. The average, per capita accumulation rates is 0.09 [m^3.person^{-1}.yr^{-1}] (Table 2), whereas in South America ponds these rates were much lower (0.02- 0.04 [m^3.p^{-1}.yr^{-1}]) (Nelson K. L. *et al*, 2004) and in France higher (0.12 [m^3.person^{-1}.yr^{-1}]) (Carrė J *et al*l, 1990). The different accumulation rates may be partly due to different temperatures, the inputs wastewater quality, the stormwaters, and infiltration. The volume of sludge accumulation per wastewater inflow rate per year is equal to 0.002 [m^3 m^{-3}y^{-1}]. The sludge thickness is 14 [mm.yr^{-1}] and is among the values reported in the literature (Nelson K. L. *et al*, 2004; Salas R. J.J. and Bouza D. R., 2012; Peňa M.R. *et al* 2000). This variation is expected because the depth of accumulation is affected by the pond loading rate and treatment efficiency and is thus specific to each WSPs system.

Given the mean annual concentration of organic solids and the annual accumulation of sludge in the three WSP systems, a simple relationship is generated (Eq. 1) by linear regression. According the Eq. 1 the volume of annual accumulation per year can be estimated knowing the mean TSS concentration.

$$S = 256.92 - 214C_{TSS} \quad (1)$$

Where S is the annual sludge accumulation [m^3y^{-1}] and C_{TSS} is the mean annual TSS concentration [mg/L], with $R^2 = 0.8319$ and $5\ mg.L^{-1} \leq C_{TSS} \leq 116\ mg\ L^{-1}$.

The knolling of BOD_5 concentration is an insignificant factor to estimate the annual accumulation of sludge estimation, in this research, as given the mean annual concentration both of TSS and BOD_5 [mgL^{-1}], the estimated annual accumulation volume of sludge (m^3/y), by multiple regression, gives a 1-P value equal to 0.34 for BOD_5. The coefficient of determination R^2 is equal to 0.86.

The TSS sludge's concentration was found to be correlated with depth in the sludge layer with $R^2 = 0.8892$ with the relationship of Eq. 2.

$$TSS = 350\ (Depth)^{0.56} \quad (2)$$

Where Tss in [$g.L^{-1}$] and Depth in [m]. TSS values increase from 3000 [$mg.L^{-1}$] in the interface sludge water up to $370*10^3$ [$mg.L^{-1}$] in the deepest sludge level. No relationship was found between TSS and VS/FS ratio, and TSS and sludge age; usual variables describing the qualitative characteristics of the sludge. The mean TSS concentration in this research is found 184.92 [$g.L^{-1}$] and the mean VS/FS ratio is equal to 0.45 The TSS concentration decreased towards the pond outlets. The higher TSS concentration was found near the inlet in the facultative ponds. In this point it was observed the greater thickness of the sludge too. Therefore, the higher concentration in this point may be due to the greatest compression, as well as, may be affected by a higher fraction of higher density silts and sand that settle out near the inlet. In all three ponds the concentration of fecal coliform bacteria decreased with sludge age. In this research, no correlation is founded between the concentration of F.coli and the position in the ponds (from inlet to outlet).

4. Conclusions

In this research, it was observed that in the facultative pond, the distribution of sludge was uneven. Whereas in the maturation ponds, especially at the last one, it was fairly uniform. The maximum sludge thickness occurred near the single pond inlet and outlet; higher accumulation also occurred in some of the corners. The average rate of sludge accumulation is 0.09 [$m^3.person^{-1}.yr^{-1}$]. The volume of sludge accumulation per wastewater inflow rate per year is equal to 0.002 [$m^3\ m^{-3}y^{-1}$]. The sludge thickness is 14 [$mm.yr^{-1}$] and is among the values reported in the literature. Given the mean annual concentration of TSS [mg/L], the annual accumulation volume of sludge [m^3/y] can be estimated with a simple linear equation with coefficient of determination R^2 equal to 0.8522. The knolling of BOD_5 concentration is an insignificant factor to annual accumulation of sludge estimation. The TSS sludge's concentration was found to be correlated with depth in the sludge layer with $R^2 = 0.8892$. The mean TSS concentration is found 184.92 [$g.L^{-1}$] and the mean VS/FS ratio is equal to 0.45. The higher TSS concentration and the greater thickness of the sludge were found near the inlet in the facultative ponds. No relationship was found between TSS and VS/FS ratio, and TSS and sludge age. In all three ponds the concentration of fecal coliform bacteria decreased with sludge age but, no correlation is founded between the concentration of F. coli and the position in the ponds from inlet to outlet. The estimated parameters can effectively be applied in sizing WSP in similar climate, wastewater quality and treatment conditions especially in Mediterranean countries.

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