Comparison of Agro-Wastes For Dewatering Enhancement For Dredged Sludge From Sewers

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Abstract

With the increasing wastewater generation from domestic and industrial activities due to the rapid economic development, the generation of sludge, in particular dredged sludge from municipal sewer system, has been an issue in developing countries. This study evaluated the enhancement of sewer's sludge dewatering via mixing the sludge with different agro-wastes, including corn core powder, rice husk powder, bagasse powder and peanut shell powder. The addition of these agro-waste powders helped decrease the sludge's moisture contents up to 17% after mixing with the ratio of 1:3, 1:5 or 1:7. Statistical analysis revealed the impacts of both additive types and mixing ratio on moisture content reduction. Among the four types of agro-waste, rice husk was shown to be the best additive to dredge sludges with highest reduction of heavy metal concentration and moisture content. The addition of agro-waste powders to enhance the dewatering of sludges is quite promising in the context of promoting waste reuse and energy saving.

Highlights

- The agro-waste powders modified with 2M NaOH solution helped decrease the sludge's moisture contents up to 17%.
- The degree of dewaterability depended on the type of agro-waste powders and mixing ratio.
- The addition of agro-waste increased the organic matters in the sludge from 10% up to 40%.
- Rice husk was proved to be the best additive to dredge sludges from sewers with highest reduction of heavy metal concentration and moisture content.

1. Introduction

One of the big still challenges for developing countries is wastewater and sludge treatment. In most of the countries applying separate drainage and sewerage system, sludge from the sewers is minimal. However, for the combined sewage systems, the sludge or some other papers called "sediment" accumulated within the sewers is more significant (Jiménez et al. 2004). For example, with 3360 km^2 area and 8.05 million inhabitants (in 2019), Hanoi city (Vietnam) generated approximately 186 thousand tons of the total dredged sludge from its combined sewers (HDSC 2019). In general, the sludge cannot be treated by a single process but a combination of processes to address various contaminant problems (Palermo and Hays 2013) and the same requirement occurs with dredged sludge from sewers. It involves pretreatment (physical screening and dewatering) and operational treatment (Bioremediation, Chemical Treatment, Extraction, Thermal Treatment) like sewage sludge in the wastewater treatment plants (WWTPs) (USEPA 2005). In fact, the dredged sludge from sewers is more like the primary sludge in WWTPs. In developing countries, most of the sewer sludge is dried by natural method (i.e., drying beds) or mechanical method (i.e., sludge compression machines) before landfilling. However, there has been no proper treatment for dredged sludges from combined sewers which was only collected and dumped in a contained site. Recently, the dredge sludge from sewers was strongly promoted and encouraged to reuse for different purposes including construction materials (i.e., aggregates, cements, calcined and non-calcined bricks) and fertilizers. Several sludge-to-energy projects have been implemented in the past ten years in Vietnam with an attempt of transferring sludges to construction materials (Hoang and Nguyen 2017).

Sludge dewatering is one of critical steps in sludge treatment as it reduces significant water from the mixed sludge which creates favorable conditions for next sludge treatment process. Studies on dewatering enhancement have been done quite a few and mostly with sewage sludges from WWTPs; such as using chemicals (Guo et al. 2016; Dai et al. 2018; Liang et al. 2018; Rashvanlou et al. 2020), electrochemical Fenton (Liang et al. 2015; Cai et al. 2019; Tao et al. 2019), thermal treatment (Schnell et al. 2020) or combination of hydrothermal treatment and $FeSO_4/Ca(ClO)_2$ oxidation (Chen et al. 2019). Addition of agro-wastes for dewatering enhancement has also been paid much attention from researchers within the past decade (Liang et al. 2018; Wójcik 2019; Guo et al. 2019). This approach is considered attractive as it is quite environmentally friendly, energy saving, and the waste-blended sludge can be reused as great potential materials for composting, or post-treatment by incineration. It was found that several carbonaceous materials from agro-wastes, acting as skeleton builders, have enhanced sludge dewaterability and cake properties (Ramachandra et al. 2020). These materials add more rigid and incompressible structures to the sludge solids providing water passages (Qi et al. 2011). In another study, different doses of walnut shell (0, 50, 100, 200, 400, and 600 mg/g dry sludge) were added into sewage sludge samples conditioned with $Ca(ClO)_2$ and ferric coagulant to evaluate the dewatering enhancement. The combination of all had reduced the moisture content from 90.8–78.6% compared with the raw sludge (Liang et al. 2018). Guo et al. (2019) recently tried waste corn core powder, that was pretreated with 2M NaOH and 0.16M cationic surfactant cetyltrimethylammonium bromide (CTMAB), for sludge dewatering. They found more organic matters were released into supernatant, and more bound water turned into free water phase, thus enhancing sludge dewatering (Guo et al. 2019). It can be seen that physical conditioners, that are rich in hemicelluloses, lignin and other hemicelluloses, are often modified with chemicals such as alkaline solutions. Alkaline hydrolyzation was proved to breakdown the lignin structure, increase the internal surface area (Soccol et al. 2011). The alkaline hydrolysis was also believed to have impact on intermolecular linkage between xylem hemicelluloses and lignin or other hemicelluloses. In particular, the NaOH treatment of ligno-cellulosic material caused swelling, leading to an increase of internal surface area, and separation of structural linkages between lignin and carbohydrates (Soccol et al. 2011). Since agro-wastes such as rice husk, rice straw, peanut shell, corn cob, etc. normally have high percentages of hemicelluloses (20–40%), lignin (10–20%), and carbohydrates components (Zaaba et al. 2016; Punnadiyil et al. 2016; Ma et al. 2016; Ma'ruf et al. 2017; Hoang et al. 2020), the preconditioning of the agro-waste additives is a critical step.

This paper, therefore, focus on the solution for dewatering enhancement of dredged sludges from sewers by appropriate agro- wastes. Four types of agro-wastes such as corn core powder, rice husk powder, sugarcane bagasse powder and peanut shell powder, which are pre-conditioned with NaOH solution, shall be used as additives to blend with dredged sludge for dewaterability enhancement. Understand the impact of agro-wastes on the moisture content and heavy metal reduction shall be rendered as one of the highlight results of this study and for further development of recycling sludge.

2. Materials And Methods

2.1. Sludge for testing

Dredged sludge from sewers were chosen in this study. The sampling sludges, which were taken from Yen So sludge dumping site (Hanoi city, Vietnam), were settled to some extent at the Yen So site before collected in 20-L containers. The sludges were screened on 2.5-mm sieves to remove gravels, debris, grits, leaves or cloths before stored at 4^{o}C for use. In addition, they were analyzed in terms of physical (moisture content-MC, pH, composition) and chemical (heavy metals, thermal energy, organic matters, etc.) characteristics. Details of analytical methods are present in Table 1.

Table 1
Sample analytical methods

No	Parameters	Unit	Analytical methods
1	Moisture content	%	TCVN 4196:2012
2	pH	-	TCVN 4192:2011
3	Composition (sand, limon and clay)	%	TCVN 6862:2012
4	Al_2O_3	%	TCVN 7891:2008
5	Fe_2O_3	%	TCVN 7891:2008
6	SiO_2	%	TCVN 7891:2008
7	CaO	%	TCVN 7891:2008
8	MgO	%	TCVN 7890:2008
9	Cl^-	%	TCVN 6194-1-1996
10	SO_4^{2-}	%	TCVN 6200:1996
11	As	mg/kg	ISO 20280:2007
12	Cu	mg/kg	ISO 11047:1998
13	Zn	mg/kg	ISO 11047:1998
14	Cr	mg/kg	ISO 11047:1998
15	Cd	mg/kg	ISO 11047:1998
16	Pb	mg/kg	ISO 11047:1998
17	Total organic matters	%	TCVN 7376:2004
18	Heat value	kCal/kg	ASTM D240

TCVN: Vietnam national technical standards, ISO: International Organization Standardization, ASTM: American Society for Testing and Materials

Moreover, the samples that presented better dewatering performance were sent for Scanning Electron Microscope (SEM) and X-Ray Diffraction (XRD). The SEM was implemented using the Tabletop Microscope (TM4000plus, Hitachi, Japan) while XRD was conducted using the X-ray machine (Miniflex600, Rigaku, USA). The oxide components were detected using X-ray Fluorescence Spectrometer XRF (JSX 1000S, Jeol, Japan). The total organic matters of sludge samples (thickened sludge) were analyzed using method for soil analysis employing $K_2Cr_2O_7$ solution (national standard TCVN 7376:2004).

2.2. Preparation of agro-waste additives

Four types of agro-wastes (corn core, rice husk, sugarcane bagasse and peanut shell) were collected dry and ground to a size of 100 mesh (i.e., 150 µm). To increase the hydrophilicity of the additives, they were hydrolyzed by soaking individually in 2M NaOH solution > 98% purity (CAS: 1310-73-2, Sigma Aldrich) for 60 min at room temperature, then washed with distilled water until free of foams and put in the oven at $105^{o}C$ until completely dry. Since they were attached together during the hydrolyzation and drying processes, the additives were then ground again into powder and sieved to particle size diameters < 150 µm. Finally, they were stored in sealed bottles and named as CCP, RHP, SBP, and PSP for modified corn core, rice husk, sugarcane bagasse and peanut shell powders, respectively (see Fig. 1).

2.3. Sludge dewatering test

As mentioned above, the testing sludges were those settled for some time at the Yen So dumping site, so the sludges were slightly thickened. The sludges, after screened, were mixed with individual additives with the additive - sludge ratio of 1:3; 1:5 and 1:7 by weight. Each sample was 100 grams in total. The sludge and additive were mixed for 15 min at 100 rpm. After that, the mixture was compressed by hydraulic compression machine (60T, 267/56/21, Leipzig, Germany) with the compression load of 400 kG. The compression time was 15 min for each sample. The selection of dewatering test's conditions was referred from previous studies with some modification to fit with the dredged sludges (Guo et al. 2019; Liang et al. 2018). All the tests were conducted in duplicate. The whole process was presented in Fig. 2.

2.4. Data analysis

The statistical analysis was also conducted to evaluate the impact of additive types or mixing ratio on the decrease in the moisture content. This step was performed by using two-way analysis of variance (ANOVA) in which the variables were the additive types and mixing ratio on the moisture content. The level of significance was $\alpha = 0.05$ in all cases. The software StatPlus:mac LE v7.3.31 (Analyst Soft Inc., USA) was used for this statistical analysis.

3. Results And Discussion

3.1. Characteristics of testing sludges

The characteristics of testing sludges were given in Table 2. The moisture content was quite low as 45.5% as they were settled for some time at the dumping site. Initially, its moisture content could be up to 98% when they were dredged and pumped from the sewers into the trucks. The dredged sludge from sewers had neutral pH condition as the sewers received mostly domestic wastewater, rainwater and maybe some treated industrial wastewater. Besides, due to the urban combined drainage system receives lots of runoff water from the road surface, the sand accounted for majority in the composition (corresponding with highest SiO_2 percentage ~ 72.8%) in the dredged sludge from sewers, while SiO_2 concentration was less than 10% in sewage sludge in WWTP (Palermo and Hays 2013). With high inorganic composition, it is more logical to reuse the dredged sludges for the production of construction materials than for composting purpose.

Table 2
Characteristic of testing sludges

No	Parameters	Unit	Dredged sludge from sewers (DSS)	QCVN 43:2017/ BTNMT
1	Moisture content	%	45.5	-
2	pH	-	7.26	-
3	Compositions			-
4	*- Sand*	*%*	*70.4*	-
	- Limon	*%*	*21.9*	-
	- Clay	*%*	*7.7*	-
	Al_2O_3	%	7.97	-
5	Fe_2O_3	%	5.64	-
6	SiO_2	%	72.86	-
7	CaO	%	6.86	-
8	MgO	%	2.65	-
9	Cl^-	%	0.27	-
10	SO_4^{2-}	%	1.07	-
11	Cu	mg/kg	72.86	197
12	As	mg/kg	50.8	17
13	Zn	mg/kg	1640.8	315
14	Cr	mg/kg	160.5	90
15	Cd	mg/kg	< 2	3.5
16	Pb	mg/kg	108.5	91.3
17	Total organic matters	%	12.3	-
18	Heat value	kCal/kg	1250	-

QCVN 43:2017/ BTNMT: National technical regulation on sediment quality

Furthermore, the dredged sludge from sewers was contaminated with heavy metals such as Zn, Cr, As and Pb. This could be due to the discharge of improperly-treated industrial wastewater into the urban combined drainage system. In terms of organic matters, the dredged sludge from sewers had shown a low concentration of 12.3%. This proved clearly the contrary characteristics of dredged sludge from sewers versus sewage sludge from WWTP. The one from WWTP normally contained higher organic matters (i.e., 20–60%) (Bozym and Siemiątkowski 2018; Ruimin et al. 2021) while the inorganic matters were limited.

3.2. Effect of additive blending on dewaterability

Fig 3 presents the effect of additive types and additive-sludge mixing ratio on the reduction of moisture contents of the testing sludges.

It is clearly seen from Fig. 3 that the blending with additives had substantial impacts on dewatering of dredged sludge from sewers. The moisture contents reduced up to 17% and mostly noticeable with corn core powders, followed by rice husk powder (Fig. 3a). This result was similar to the findings of previous studies (Liu et al. 2019; Guo et al. 2019; Wojcik 2019) even though they used sewage sludges from wastewater treatment plants. Their previous studies also observed a decrease of about 10%-15% in moisture content when mixing with these kinds of agro-wastes. The explanation was partly due to particle charge attraction. Normally, sludge particles were negatively charged, which exhibited mutual repulsion, resulted in a negatively charged stable colloid dispersion. After mixing with NaOH-modified additives, which were positively charged, the additives could play a role of electric neutralization and release of bound water from the dispersion (Guo et al. 2019). Moreover, during the reaction process between sludge particles and modified corn core powder, more bound water turned into free water phase, thus enhancing sludge dewatering.

When discussing about the impacts of these additives to sludge dewatering, some research mentioned about their skeleton building ability. Wallnut shell, as an example, was revealed to be a skeleton builder that formed the rigid skeleton and further increased the deep dewatering of the sludge (Liang et al. 2018). As explained previously, the selected additives had all rich in hemicelluloses, cellulose and lignin. For instance, rice husk contained 40% cellulose, 30% lignin, and 20% silica (Chindaprasirt and Cao 2015), peanut shell had 35.7% cellulose, 30.2% lignin, 18.7% hemicelluloses, and 5.9% ash content (Punnadiyil et al. 2016), while the main components of sugarcane bagasse were cellulose (46.0%), hemicellulose (24.5%), lignin (20.0%) (Hoang et al. 2021), and there were 26.5% cellulose, 13.6% lignin and other compounds in corn core (Xiaofen et al. 2018). Upon NaOH pretreatment, lignin and hemicelluloses were partly removed, the cellulose content and sample porosity, which were increased, were instrumental for the hydrolysis of the additives (Han et al., 2012). Thus, when mixing with the sludges, the additives can absorb water molecules from the dredged sludges more easily.

Due to dredged sludge with high silicate and low organic matters component, it was revealed that only minimal changes of moisture content were observed (Fig. 3b) after compression. In general, sludges with high organic matters tended to hold higher water content and will be more impacted with compression

(Yang et al. 2021). With the purpose of reducing moisture as much as possible to meet the requirement for reuse as construction bricks, it can be initially concluded that the rice husk with mixing ratio of 1:5 was the best additive for dredge sludge from sewers, i.e., moisture content decreasing from 45.5±4.1% to 33.9±1.5% after blending and to 22.7±0.6% after compression.

Regarding to the influence of mixing ratio, there was no obvious impact of the additives on moisture content, except for rice husk powder (Fig. 3b). After compression, the additive blending showed even less influence. While the rice husk powder mixture obtained the best dewatering efficiency at 1:5 (equal to 200 mg/g dosage of rice husk led reduction of moisture contents from 45.75±4.12% to 22.69±0.12%), the remaining (corn core, sugarcane bagasse and peanut shell) mixtures showed the best dewatering performance with mixing ratio of 1:7. The results in this study achieved the better dewatering performance in comparison with previous study with sewage sludge mixing with rice husk additive revealed that increasing dosages of rice husk from 50, 100, 200, and 300 mg/g led to the reduction of moisture content from 72.9–63.4% (Liu et al. 2019). Therefore, the agro-waste additives helped enhance the dewatering performance of dredged sludge from sewers to certain extent, however, the enhancement efficiency was not necessarily proportional to the added quantity.

3.3. Effect of additive blending on organic matters

Organic matters were considered in this study as it relates to the potential application for calcined bricks, the sequential target of this research. Should the dredged sludges be reused for materials for calcined bricks, the organic matters as well as the thermal energy/heating values must be put in consideration. It was claimed that the high content of organic matter in raw sludge caused a decrease in mechanical strength and delay in hydration process (Chang et al. 2020). However, sludge with high content of organic matters can be considered potential fuel with its high calorific value (Zabaniotou and Theofilou 2008), which would be valued during the incineration for producing calcined bricks.

The testing sludges were dredged sludges from the urban combined drainage system, thus, they had some organic matters but at low level (about 12%). The additives employed to enhance the sludge dewatering in this study (corn core, rice husk, sugarcane bagasse and peanut shell) were agro-wastes that were rich in organic matters. As a result, possibly higher organic matters would be expected for the samples (Guo et al. 2019). Nevertheless, it was shown in Fig. 4 that the high mixing ratio of 1:3 for additive and sludge produced significant change in organic content (from 12±0.2% to 39±1.8% after mixing with sugarcane bagasse powder or to 35±6% after mixing with corn core powder). Lower mixing ratio of 1:5 or 1:7 did not increase the organic content in most cases. A trend of decrease in the organic content was observed when reducing the mixing ratio from 1:3, 1:5 and 1:7. In particular for the case of rice husk additive, the organic matters were about 10%, 20% and 30% for the mixing ratio with additives of 1:7; 1:5 and 1:3, respectively. Liang et al. (2018) indicated that the addition of walnut shell biomass significantly promoted the mixed fuel combustion characteristics. Although the presence of organic matters enhanced the combustion capability, they may lead to more μm-scale pores and large macro defects on the surface of brick. Despite these defects, the properties of all brick samples such as compressive strength, water absorption and freeze-thawing resistance still met the standard requirement of brick products (Zhang et al. 2016). Somehow, the porous and lighter bricks are indeed the development trend of construction bricks nowadays, to impose less impact on the building foundation.

3.4. Effect of additive blending on other physical and chemical characteristics

Selected redged sludge from sewers samples (good performance in moisture content reduction) were sent for physical and chemical examination. This was to evaluate the impact of additives on the sludge characteristics as materials for brick production.

Table 3
Physical and chemical characteristics of samples

No	Index	Unit	M1	M2	M3	M4	M5	M6	Standard
1	Al_2O_3	%	7.97	4.58	4.25	4.2	4.18	4.17	-
2	CaO	%	6.86	7.23	6.78	6.58	6.47	6.66	-
3	Fe_2O_3	%	5.64	2.74	2.97	2.89	2.84	2.9	-
4	K_2O	%	1.95	3.33	2.91	1.92	1.88	2.72	-
5	MgO	%	2.65	1.24	1.2	1.07	1.02	1.39	-
6	MnO	%	0.14	0.04	0.04	0.04	0.04	0.04	-
7	P_2O_5	%	1.25	0.87	0.82	0.8	0.93	0.95	-
8	TiO_2	%	0.68	0.38	0.35	0.2	0.29	0.42	-
9	SiO_2	%	72.86	79.59	80.68	82.3	82.35	80.75	-
10	Ag	mg/Kg	< 2	< 2	< 2	< 2	< 2	< 2	-
11	As	mg/Kg	50.8	31.2	34	33.5	32.8	35.1	17
12	B	mg/Kg	62.4	25.2	30	31.1	30.3	40.8	-
13	Ba	mg/Kg	650.5	328	370.5	374.2	369.7	430.9	-
14	Be	mg/Kg	< 5	< 5	< 5	< 5	< 5	< 5	-
15	Bi	mg/Kg	< 10	< 10	< 10	< 10	< 10	< 10	-
16	Cd	mg/Kg	< 2	< 2	< 2	< 2	< 2	< 2	3.5
17	Ce	mg/Kg	65.7	35.7	44.4	45.8	44.7	48.2	-
18	Co	mg/Kg	120.8	18.5	22.1	23.2	22.9	32.5	-
19	Cr	mg/Kg	160.5	140.8	171.1	175.2	171.6	180.1	90
20	Cu	mg/Kg	168.2	70.6	83.7	85.7	84.3	90.8	197
21	Ga	mg/Kg	< 10	< 10	< 10	< 10	< 10	< 10	-
22	Ge	mg/Kg	< 20	< 20	< 20	< 20	< 20	< 20	-

Note: M1: raw DSS; M2: DSS + RHP (1:5); M3: DSS + RHP (1:7); M4: DSS + CCP (1:7); M5: DSS + PSP (1:7); M6: DSS + SBP (1:7). (DSS: Dredged sludge from sewers; CCP: corn core powder, RHP: rice husk powder, SBP: sugarcane bagasse powder, and PSP: peanut shell powders)

Standard: QCVN 43:2017/ BTNMT – National technical regulation in sediment quality. "-": Not applicable.

No	Index	Unit	M1	M2	M3	M4	M5	M6	Standard
23	**La**	mg/Kg	40.4	17.2	23.2	24.3	22.8	27.4	-
24	**Li**	mg/Kg	52.1	23.4	29	29.8	28	32.7	-
25	**Mo**	mg/Kg	< 5	< 5	< 5	< 5	< 5	< 5	-
26	**Nb**	mg/Kg	13.5	5.5	6.2	6.4	6.1	6.5	-
27	**Ni**	mg/Kg	78.2	60.1	73.4	75	72.7	75.1	-
28	**Pb**	mg/Kg	108.5	62.4	80.1	82.4	80.6	83.8	91.3
29	**Sb**	mg/Kg	23.1	14.5	18.1	19.2	18.8	19.2	-
30	**Sc**	mg/Kg	8.5	6.2	6.9	7.1	6.8	7.2	-
31	**Sn**	mg/Kg	< 10	< 10	< 10	< 10	< 10	< 10	-
32	**Sr**	mg/Kg	165.2	155.8	210	214.2	210.5	215.2	-
33	**Ta**	mg/Kg	< 10	< 10	< 10	< 10	< 10	< 10	-
34	**V**	mg/Kg	88.8	48.9	61.8	62.8	60.6	63.6	-
35	**W**	mg/Kg	50.3	30.7	39.2	41	40.3	40.8	-
36	**Y**	mg/Kg	25.7	9.4	12.5	13.2	12.7	13.4	-
37	**Zn**	mg/Kg	1640.8	485.6	630.6	635.7	630	650.1	315

Note: M1: raw DSS; M2: DSS + RHP (1:5); M3: DSS + RHP (1:7); M4: DSS + CCP (1:7); M5: DSS + PSP (1:7); M6: DSS + SBP (1:7). (DSS: Dredged sludge from sewers; CCP: corn core powder, RHP: rice husk powder, SBP: sugarcane bagasse powder, and PSP: peanut shell powders)

Standard: QCVN 43:2017/ BTNMT – National technical regulation in sediment quality. "-": Not applicable.

The changes in physical and chemical characteristics can be seen clearly in Table 3. In terms of oxide components, most of them decreased in concentration (%), except for SiO_2. The same trend was observed for the case of heave metals, except for Sr and Cr. Certainly, the decrease varied with different additives. Because the additives are mostly organic matters, the inorganic concentrations were reduced within the same volume of samples. Moreover, the additives also reduced heavy metal concentrations in dredged sludge from sewers up to 70%, 58% and 42% for the cases of Zn, Pb and Cu, respectively due to their heavy metal adsorption abilities (Nguyen et.al. 2019; Hoang et.al. 2019). The sludge samples blended with rice husk powder (ratio of 1:5) showed consistently the lowest concentration of heavy metals compared with the remaining additives. With the same blending ratio of 1:7, the rice husk and peanut shell powders proved to be more impact than the baggage and corn core powders in term of heavy metals reduction. Besides, the sludge samples blended with rice husk powder (ratio of 1:5) also had the highest moisture reduction (17%) when comparing the moisture content of raw sludge and mixed sludge after compression. Furthermore, the composition of rice husk mixed sample had the highest content of Al_2O_3 and CaO, which had high potential of water absorption.

In comparison with the Vietnamese national standard for *sediment quality*, the presence of heavy metals was still higher than the accepted values mostly. Nevertheless, if the modified dredged sludge from sewers was reused for making calcined brick, it would be recommended to mix maximum 30% by weight of dredged sludge from sewers with clay (Hoang and Nguyen 2017). Thus, the heavy metals would be three times less in concentration in the final brick products, which means their presence in the bricks would be in acceptable range and cause no harm to the environment and human being.

3.5. SEM and XRD results of blended sludges

As mentioned above, selected sludge samples (good performance in moisture reduction) were sent for SEM and XRD examination to see the impact of additives on dewatering.

It can be seen from Fig. 5 that with the same magnification of 1000 times, the surface morphology of sludges before and after treatment was completely different. The additives seemed to bind the sludge and make many big aggregates, leaving more pores on the surface. The pores showed clearest for the case of sludge blended with sugarcane bagasse powder, followed by the ones blended with peanut shell powder and corn core powder. The surface of raw sludge was smoother with tiny particles. It was similar to the findings of Guo et al. (2019); Xiong et al. (2017). They observed small particles in the raw sludge and those tiny sludge particles became large flocs through re-agglomerate, leaving porous and rough surface with macro pores and voids in the treated sludge. The tiny particles were probably inorganic debris (Guo et al. 2018) while the big agglomerates were mostly due to organic agro-waste additives. Even though these agro-wastes were claimed to be skeleton builders and made the sludge more porous after mixing, only in this study, they can be seen clearly different performances under the same condition. While they explained the porous surface formed channels for the outflow of the bound water from sludge, another possible mechanism was suggested, i.e. water absorption ability. Apparently that the additives have absorbed water which made the sludge drier. Bound water from the sludge solids was broken and absorbed by the additives, then released faster after compression. The mechanism can be illustrated in Fig. 6.

In consideration of XRD images, which was used to identify the mineralogical compounds and crystalline phase present in the samples, Fig. 7 rendered different peaks showing the alternation of sludge particle’s surface when mixing with the additives. The major peaks obtained were identified as quartz (SiO_2) and they were shown in all samples. It was consistent with the results on main component of sludges (Table

2). For the sludge without additive (DSS), the major peaks were quartz and iron phosphate. This makes sense as Fe_2O_3, Al_2O_3 and CaO were dominant oxides besides quartz in DSS's characteristics (as seen Table 2). For the sample added with rice husk powder, there was occurrence of Li, Mn, Fe besides quartz. The major peaks, identified in sample with peanut shell powder, were the complex of NH_4^+, Si and F. For the case of sugarcane bagasse-DSS sample, CaO and K_2O were found. It seemed that some elements of additives, indicated in studies of Viruthagiri et al. (2011); Hoang et al. (2020); Ma et al. (2016); Punnadiyil et al. (2016), had deposited on the sludge surface via examination with XRD.

3.6. Statistical analysis

This section will analyze the impact of both types of additives (corn core, rice husk, peanut shell and sugarcane bagasse) and mixing ratio of sludge and additives (1:3, 1:5 and 1:7) in the reduction of moisture contents (MC) after mixing and after compression. The two-way ANOVA from software StatPlus:mac LE v7.3.31 (AnalystSoft Inc., USA) was employed for this purpose. Table 5 presents the analytical results of two-way ANOVA.

Table 5
Two-way ANOVA results (p value, n = 26) showing the impact on MC by different additives and mixing ratio.

		After mixing	After compression
General interaction			
	Type of additives (A)	0.00003	0.00853
	Mixing ratio (B)	0.26849	0.04167
	A x B	0.0044	0.01323
Detailed interaction according to Tukey-Kramer method			
Type of additives (A)	Mixing ratio (B)		
Sugarcane bagasse	(1) vs (2)	0.14379	0.07988
	(1) vs (3)	0.95277	0.73252
	(2) vs (3)	0.22817	0.02087
Peanut shell	(1) vs (2)	0.82725	0.99931
	(1) vs (3)	0.06475	0.57401
	(2) vs (3)	0.02277	0.59637
Corn core	(1) vs (2)	0.45141	0.69127
	(1) vs (3)	0.06844	0.00669
	(2) vs (3)	0.45141	0.02952
Rice husk	(1) vs (2)	0.04961	0.01427
	(1) vs (3)	0.00255	0.92317
	(2) vs (3)	0.25190	0.02827

Note: Mixing ratio 1:3 (1); 1:5 (2) and 1:7 (3), $p < 0.05$: significant impact

It was clearly shown in the Table 5 that each factor had significant impact on the MC either after mixing or after compression. For each individual additive, the impact was shown the most with rice husk powder (*$p < 0.05$*). Specifically, different mixing ratios of rice husk with dredged sludge from sewers would lead to substantial reduction on moisture content, which confirms in the Fig. 3a above.

4. Conclusions

Dredged sludge from sewers was evaluated in term of dewaterability upon mixing with four different agro-wastes, including rice husk, corn core, sugarcane bagasse and peanut shell. Three mixing ratios of

1:3, 1:5 and 1:7 were tried and it was found that the mixing ratio was statistically significant for the case of adding rice husk powders with moisture content decreasing from 45.5±4.1% to 33.9±1.5% after mixing and to 22.7±0.6% after compression. For the others, there was no proportional correlation between mixing ratio and the reduction of moisture content or heavy metal concentrations. The incorporation of these agro-waste additives also increased the organic matters in the sludge up to 40%. With the low cost in enhancing dewaterability and heavy metal reduction of the sludge, these agro-wastes, in particular rice husks, were proved to be a promising raw material for reuse as construction materials in the context of sustainable environmental protection.

Declarations

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Ethics approval and consent to participate

Not applicable

Consent to publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Conceptualization: Khai Manh Nguyen; Thuy Thi Pham; Methodology: Huan Xuan Nguyen, Huyen Thi Thanh Dang, Lan Thi Ngoc Pham; Formal analysis and investigation: Huan Xuan Nguyen, Nga Thi Huyen Tran, Quyen Duc Hoang; Experiment: Quyen Duc Hoang, Anh Thuy Tran; Writing - original draft preparation: Huan Xuan Nguyen, Huyen Thi Thanh Dang; Writing - review and editing: Thuy Thi Pham, Lan Thi Ngoc Pham; Funding acquisition: Khai Manh Nguyen, Thuy Thi Pham; Supervision: Khai Manh Nguyen.

Availability of data and material

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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Table

Table 4 is not available with this version

Figures

Figure 1

Image of testing additives: (a) rice husk powder_RHP; (b) corn core powder_CCP; (c) peanut shell powder_PSP and (d) sugarcane bagasse powder_SBP

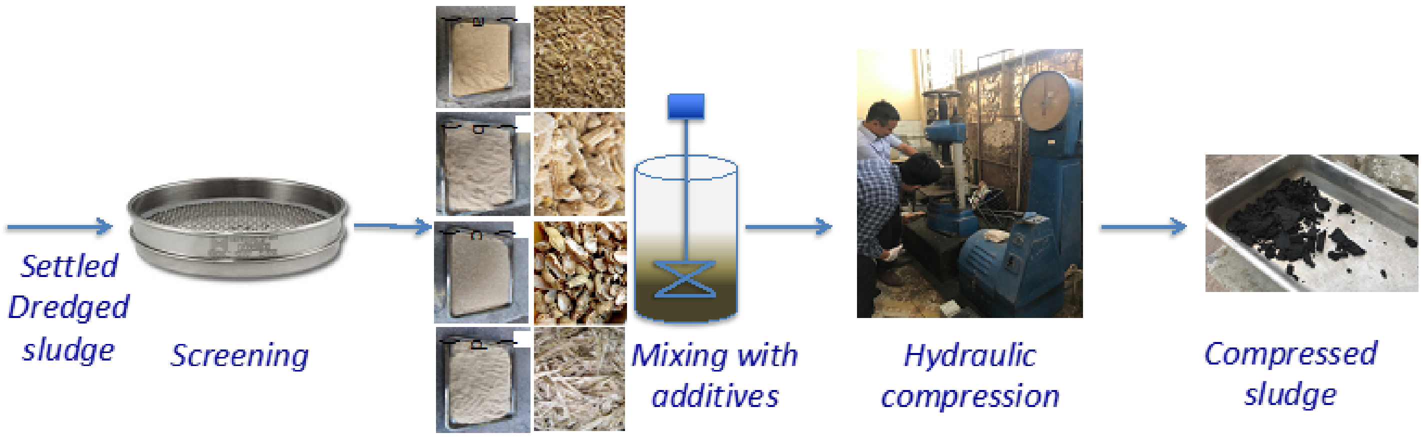

Figure 2

Dewatering procedure in the lab

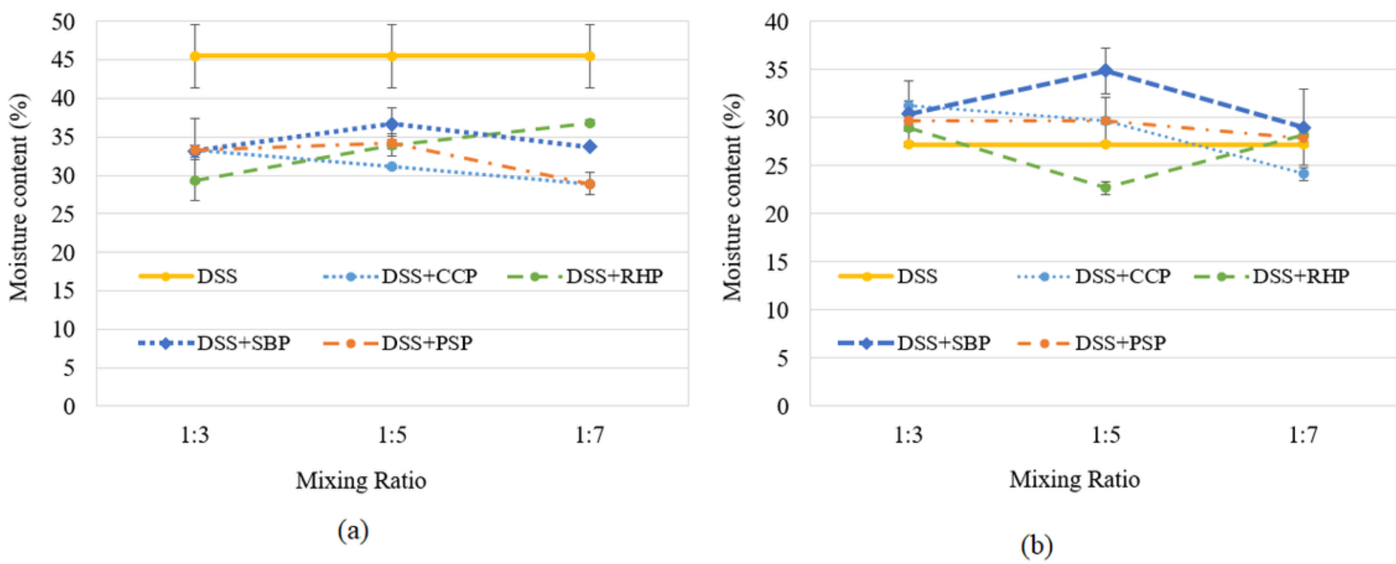

Figure 3

Moisture contents of testing DSS with additives: (a) before and (b) after compression (DSS: Dredged sludge from sewers; CCP: corn core powder, RHP: rice husk powder, SBP: sugarcane bagasse powder, and PSP: peanut shell powders)

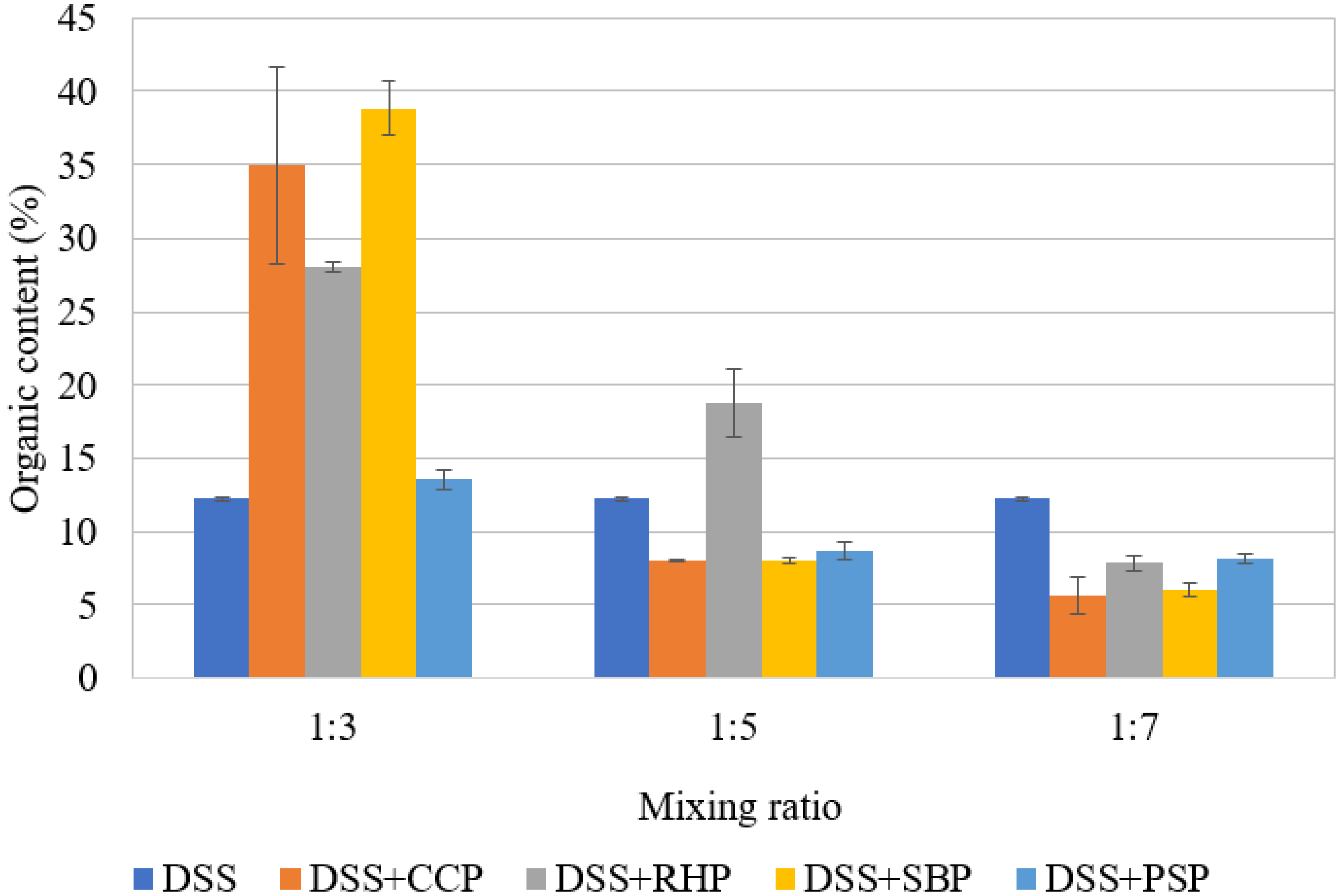

Figure 4

Organic matters in the dredged sludges with and without additives (DSS: Dredged sludge from sewers; CCP: corn core powder, RHP: rice husk powder, SBP: sugarcane bagasse powder, and PSP: peanut shell powders)

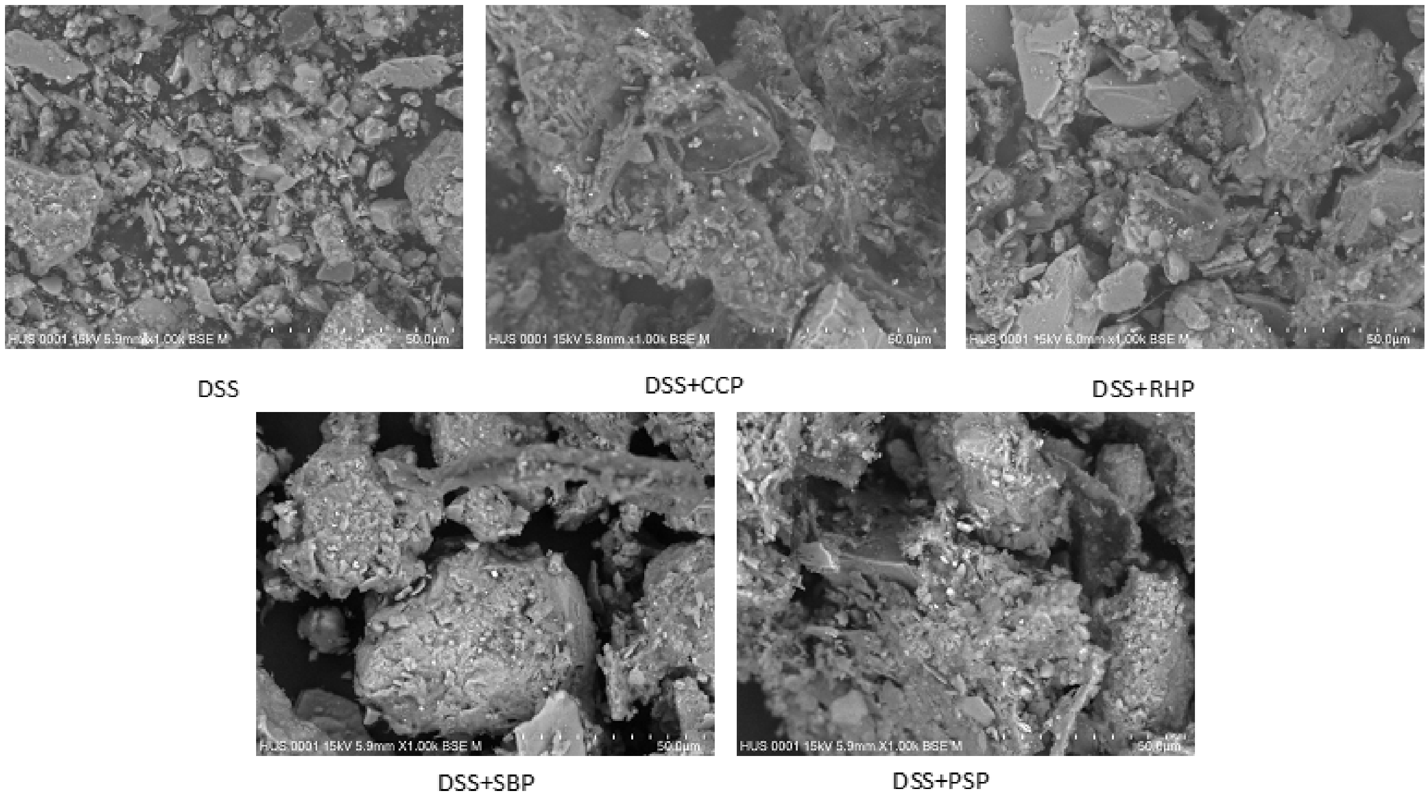

Figure 5

SEM images (magnification of 1000X) of raw and additive-blended dredged sludge from sewers (1:7 mixture ratio). DSS: Dredged sludge from sewers, CCP: Corn core powder, RHP: Rice husk powder, SBP: Sugarcane bagasse powder, PSP: Peanut shell powder

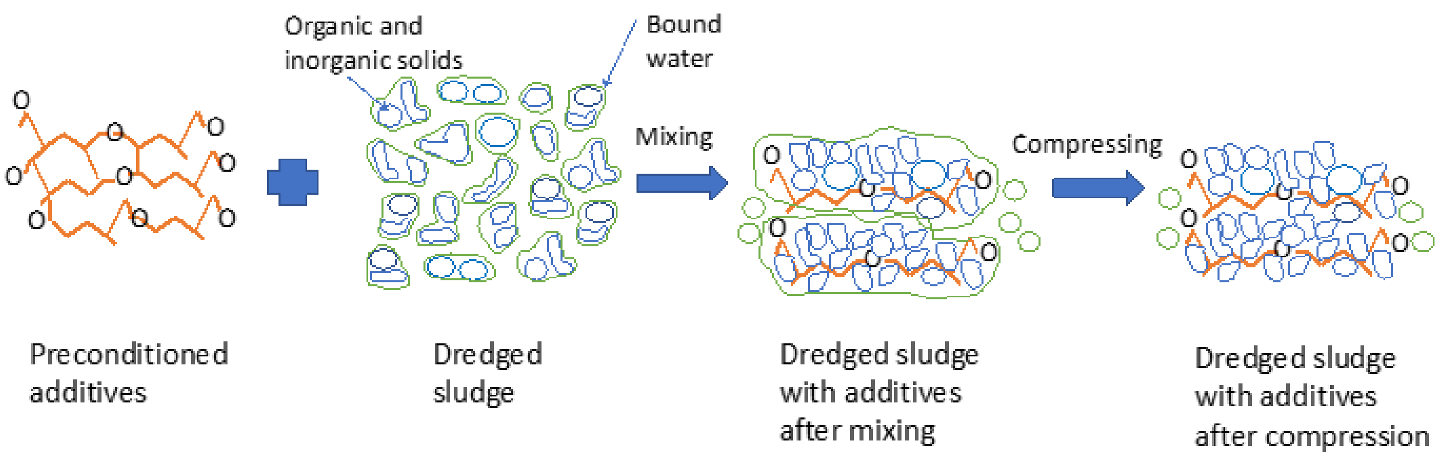

Figure 6

Predicted mechanism after mixing with preconditioned additives and mechanical compression.

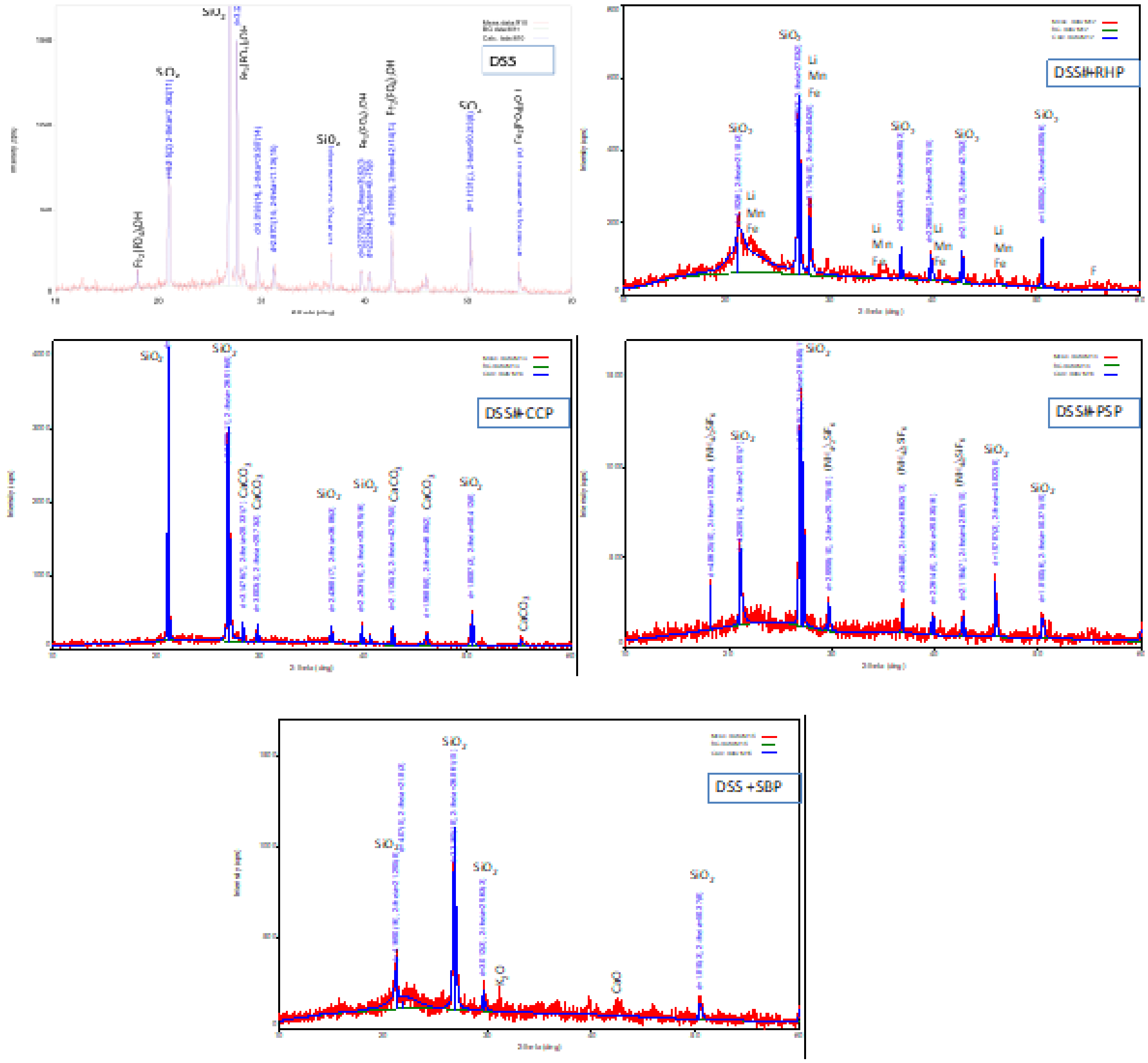

Figure 7

XRD images of sludge samples

Supplementary Files

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