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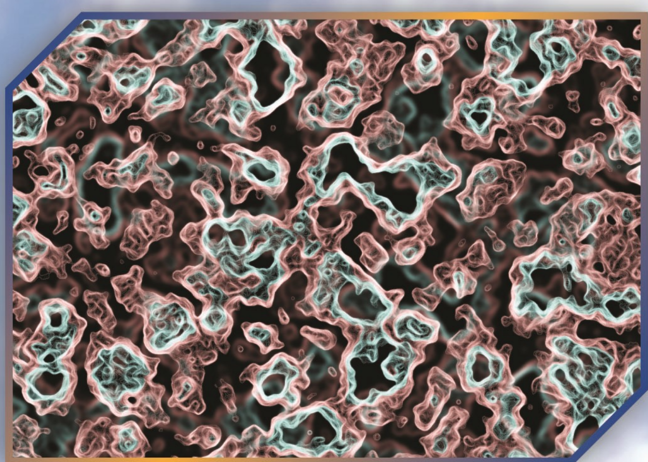

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RESEARCH ARTICLE

Waste characterization in Istanbul and a proposal for biodegradable solid waste management

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ABSTRACT

The concept of integrated solid waste management is based on the strategies of waste prevention, waste reduction, reuse, recycling (including composting), incineration and disposal at existing landfills. Solid waste characterization is the basis for integrated solid waste management. It is important to identify the solid waste composition for the determination, planning and implementation of any solid waste management system. In order to ensure a cleaner environment and lower greenhouse gas emissions; Turkey requires more robust and coherent strategies regarding the solid waste management system. In order to plan an efficient integrated solid waste management system and ensure a circular economy, it is necessary to include all the materials and production resources in the solid waste stream. The first step in waste management studies is to determine the waste characteristics. The characterization study performed by ISTAC includes the determination of the timing and the selection of neighborhoods of the waste to be collected, collection of representative samples of unprocessed waste, manual sorting of the waste into individual waste components, data collection, laboratory analysis and reporting of the results. The characterization results have been analyzed and suggestions on the sustainable management of biodegradable waste have been introduced. This paper focuses primarily on Biodegradable Municipal Waste (BMW), which is produced largely by households and commerce.

The National Strategy on Biodegradable Waste has to set out and enforce a range of measures to meet EU's ambitious diversion targets. The key to success is for all involved– local authorities, waste operators, businesses and householders – to play their part in the successful implementation of the full range of integrated waste management options. Even though there are legislations, broad support in their implementation should be provided by the Government.

Keywords: Biodegradable waste, Istanbul, municipal solid waste

1. INTRODUCTION

The first step in waste management studies is to determine waste characteristics. According to the waste characterization, the facilities to be included in the solid waste management system and the capacities of these facilities are decided. It is also important to monitor the variation of solid waste characterization over certain periods. Solid waste characterization varies according to season, region and socio-economic situation.

Sufficient and representative samples are required for solid waste characterization analysis and testing. Solid wastes to be analyzed are in different environments and physical conditions. However, each sample taken should be consistent with these physical conditions and the waste to be characterized. Solid wastes are usually inhomogeneous mixtures and are in different forms. Thus, taking representative samples requires careful and well-planned work [1].

The municipal solid waste (MSW) characterization studies of Istanbul are performed by Istac. This study introduces the results of the 2017 summer and winter MSW characterization studies of Istanbul. The characterization results have been analyzed and suggestions on the sustainable management of biodegradable waste have been proposed.

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2. MATERIALS AND METHODS

In the characterization study, the standard named "ASTM D5231 Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste" and the methodology named "European Commission-Methodology for the Analysis of Solid Waste (SWA-Tool)" were taken as the basis [2]. The Ministry of Environment and Urbanization's "Solid waste characterization and solid waste disposal facilities information update" circular (dated 15.10.2007) and "Solid waste characterization analysis method (analysis of material groups)" booklet has also been taken into account. This method describes procedures for measuring the composition of unprocessed MSW by employing manual sorting. This test method applies to the determination of the mean composition of MSW based on the collection and manual sorting of a number of samples of waste over a selected time period. This method includes procedures for the collection of a representative sorting sample of unprocessed waste, manual sorting of the waste into individual waste components, data collection, laboratory analysis and reporting of the results. The samples were manually sorted into waste components. The weight fraction of each component in the sorting sample was calculated from the weights of the components. The mean waste composition was calculated using the results of the composition of each of the sorting samples.

In a characterization study, a zoning study should be performed before taking samples. Parameters like socio-economic effect, collection system, urban structure etc. are effective in zoning studies (SWA-Tool). In order to determine the solid waste content in Istanbul, waste characterization studies were carried out in different times, during summer and winter time from 2005 to 2017. The study conducted for the 39 district municipalities of Istanbul has considered three main socio-economic conditions: low income, high income and the commercial region. For the low and high level zones to be taken from the districts during the planning phase, the samples for the neighborhoods are determined by coordinating with the district municipalities on which days and from which vehicles the samples will be taken. It should be noted that the samples for the characterization study were collected from the trucks at the transfer stations, hence the possible minimizing effect of scavengers could not have been taken into consideration.

Prior to the study, the regions of the samples to be collected were identified and samples were sent to the site according to the specified work schedule. Routine collection procedures were carried out in the identified areas. The information about the area and the amount of waste collected for each vehicle was recorded accordingly. Waste loaded vehicles were weighed before sending to the region where the characterization study was performed.

All of the waste in the vehicles were emptied for sampling and mixed with the work machine (scoop). The waste piles were then laid out with a work machine and made suitable for sampling. It is important to note that the surface of the area of sampling should be impermeable. A sample specimen of 0.5 m^3, resistant to infiltration and flow, and recommended in the ASTM standard was used for the characterization sample as it complies with the criteria for working in 91-136 kg specimens. During sampling the specimen was filled with waste without any compression so that there is no space left. 2 kg of samples were sent for laboratory analysis per each vehicle.

To obtain representative min. 91 kg samples, ASTM recommends quartering and coning. Quartering is the separation of a truckload of waste into successive quarters after thoroughly mixing the contents with a front-end loader. The samples are then coned again and quartered again until they are about 91 kg [3]. After the quartering, the samples are mixed diagonally, ie. 1 and 3 or 2 and 4. Fig 1 depicts an example of quartering.

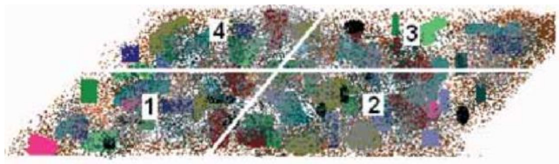

Fig 1. Quartering

It is important to determine how many categorical (group) batches are to be included in the sampling programs, in order to decide what to measure. The SWA-Tool, contains 13 compulsory primary categories and 35 recommended secondary waste categories and it encourages adjustments according to every country's local waste information requirements. For Istanbul, in the separation process, wastes are classified into 14 categories with reference to "Methodology for the Analysis of Solid Waste" (SWA-Tool) prepared by the European Commission for urban wastes and waste disposal technologies. The waste components for the Istanbul municipal solid waste characterization study are given in Table 1.

After the classification, the samples are taken to the laboratory. In the laboratory, followed by weighing and air drying; analysis of moisture content, ignition loss, calorific value, total nitrogen, total carbon, carbon nitrogen ratio, ash analysis were conducted.

2.1. Analysis of municipal solid waste in Istanbul

The municipal solid waste characterization of Istanbul was carried out in all 39 districts of the city. Istanbul is a 1900 km^2 city which spreads over two continents, Europe and Asia. Within the scope of the study, samples were collected and characterized from solid waste collection vehicles from 25 districts on the European side and 14 on the Asian side for winter and summer seasons. In order to make the planning better, 39 districts were separated as Asian Side and European Side and studies were carried out accordingly. The names of the 14 districts on the Asian side are; Adalar, Ataşehir, Beykoz, Çekmeköy, Kadıköy, Kartal, Maltepe, Pendik, Sancaktepe, Sultanbeyli, Şile, Tuzla, Ümraniye and Üsküdar. And the names of the 25 districts on the European side are; Arnavutköy, Avcılar, Bağcılar, Bahçelievler, Bakırköy, Başakşehir, Bayrampaşa, Beşiktaş, Beylikdüzü, Beyoğlu, Büyükçekmece, Çatalca, Esenler, Esenyurt, Eyüp, Fatih, Gaziosmanpaşa, Güngören, Kağıthane, Küçükçekmece, Sarıyer, Silivri, Sultangazi, Şişli, Zeytinburnu.

The municipal solid waste characterization results for Istanbul of 2017 are summarized in Fig 2. It can be clearly seen that almost 2/3 of the waste is biodegradable. Considering the daily amount of municipal solid waste is over 18000 tons in Istanbul, the amount of biodegradable municipal waste (BMW) is very high and actions should be taken immediately. It should be noted that the contamination over any waste composition was negligible.

Table 1. Waste Composition

No	Waste Composition	Content
1	Paper-Cardboard	All kinds of paper, corrugated cardboard
2	Glass	All kinds of color-colorless bottles, jars
3	Pet	Water and beverage bottles
4	Nylon bags	Any kind of grocery bags
5	Plastics	Any kind of plastics waste except PET
6	Textile	All kinds of textile materials
7	Composite	Fruit juice boxes, milk boxes
8	Diapers	All kinds of diapers
9	Metals	All kinds of metal materials
10	Electronics	Computer, telephone, radio, etc.
11	Hazardous waste	Battery, detergent boxes, medicine boxes, paint boxes
12	Biodegradable waste	Food waste, vegetables, fruit, park-garden wastes
13	Other Combustible	Shoe, carpet, bag, foam, food packaging, board
14	Noncombustible	Ash, stone, rubble, ceramic, dust

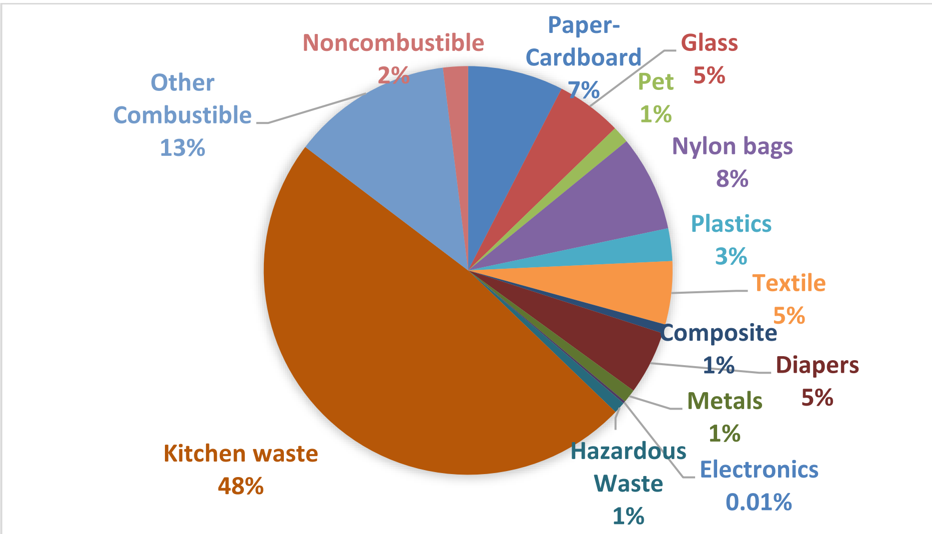

Fig 2. The municipal solid waste characterization results for Istanbul in 2017

The recyclable packaging waste content (glass, paper-cardboard, metals, plastics, PET, composite etc.) is over 15% in Istanbul. In order not to ignore the potential of the street collectors, waste samples should not be taken only from the garbage collection vehicles. The content of biodegradable waste (kitchen waste, park-garden wastes) was found to be 48.17%. It should be noted that even though the park-garden wastes are collected separately, some negligible amount of trimmings have been encountered in the study.

There is a significant difference, especially in terms of the recyclable waste content, between the waste samples taken from the commercial area and the high income areas and the samples taken from the low income areas in 2017 (18.12 %, 15.04 % and 13.73%, respectively). The results of characterization of municipal solid waste in Istanbul from years 2005 to 2017 are shown in Table 2.

The waste characteristics vary remarkably over long periods (10-15 years). However, it may also vary considerably due to some factors (changes in consumption habits, changes in income level, migration, etc.) in shorter periods. In this respect, monitoring waste characteristics is a necessity in terms of effective waste management. It is most advisable to perform the waste characterization process in 5-year periods unless there are major changes in social, socio-economic, urban structuring etc. When the results of the characterization studies are evaluated, they should be based on the cause-effect relationship.

Table 2. Istanbul municipal solid waste characterization results for years 2005-2017

Period	2005 Summer	2006 Winter	2007 Summer	2009 Winter	2010 Summer	2017 Winter	2017 Summer
Material				%			
Paper-Cardboard	13,30	12,06	12,37	15,57	11,05	10,32	4,79
Glass	5,82	5,93	3,97	3,03	3,72	4,67	5,72
Pet	1,52	1,21	1,02	1,13	1,36	1,45	1,24
Nylon bags	9,48	7,83	8,42	9,96	9,47	9,67	5,50
Plastics	3,39	2,56	2,60	2,62	2,28	2,60	2,56
Textile	5,28	1,93	4,08	3,42	5,74	4,89	5,11
Composite	0,64	0,77	0,49	0,86	0,66	0,88	0,54
Diapers	3,90	4,19	4,49	5,45	5,03	5,17	4,90
Metals	1,63	1,49	0,66	1,12	1,10	1,01	1,13
Electronics	0,15	0,01	0,00	0,03	0,17	0,17	0,19
Hazardous Waste	0,01	0,02	0,00	0,01	0,31	0,94	0,90
Kitchen waste	50,22	56,34	59,75	54,09	51,71	47,93	48,36
Other Combustible	2,97	2,00	2,14	2,09	6,16	8,31	17,09
Noncombustible	1,70	3,66	0,01	0,63	1,23	1,99	1,96

According to the laboratory analysis, the waste moisture content is 61.22 % for the winter season and 51.03 % for the summer season in 2017. Even though the difference seems to be high, these results are expected as the sampling was conducted during the wet season. The high calorific value within the municipal solid waste is around 4000 kcal kg^{-1}. The lower calorific value, which is a function of the waste moisture content, is 1558 kcal kg^{-1} on average during the winter season and is the value that needs to be taken into consideration in the case of precipitation especially in terms of thermal disposal methods. In the summer season, the lower calorific value was calculated as 1587 kcal/kg. The values of ignition loss are calculated as 84.62% in the winter season and 79.36 % in the summer season, which represents thermally loss of mass. Calorific value should be monitored in terms of thermal methods if the moisture content is around 55% or lower as minimum calorific value should meet certain requirements depending on the technology and operation efficiency. 80% of the heat loss values indicate that the volatile organics are high, which emphasize biological and thermal methods. This value represents the amount of ash which will be transferred to the landfill after thermal processes.

2.2. *Recommendations on the management of biodegradable waste of Istanbul*

Considering the amount of waste produced in Istanbul is over 18000 tons day^{-1}, approximately 9000 tons of kitchen waste is disposed at the landfills daily. It is important to note that the samples for the characterization study were collected from the transfer stations, thus the minimizing effect of scavengers could not have been taken into consideration.

This study focused on the roadmap of the management of biodegradable solid waste management. A pilot district of Istanbul shall be selected and biodegradable bags are to be proposed to be distributed to each household in that pilot district as a suggestion for collecting biodegradable waste separately. Istorba is suggested to be the name of the biodegradable bags. Regulatory framework should make separate collection compulsory at a household level. Waste separation not only increases the quality of produced compost and recyclables, and optimizes incineration but also enables better financing of waste management activities and minimizes the energy and labor inputs to any downstream processes [4].

The presentation of the bags in addition to the importance of separate collection will be promoted by the media. Public education will put emphasis on the separate collection of biodegradable municipal solid waste. Five biodegradable bags will be distributed for each household/week. In case extra bags are required, Istorba, which come with a grid imprint, will be available at retailers and the disposal of biodegradable waste using another kind of bag will be strictly prohibited.

Two different types of bins will be distributed for each building where applicable; and as frequent as possible elsewhere. The size of the bins will be depending on the number of inhibitants for every building. There will be one container for organic material and one container for recyclables in front of the buildings. The organics will be collected seperately and will be stored at the Istorba and will be thrown at the bin, the recyclables will also be collected seperately and be thrown at the respective bin.

The scavangers will be employed by the local municipalities and are going to collect the waste from the bins to the community bins. One scavenger will be assigned for a neighborhood of 500 inhibitants. A new-design truck will be provided for every scavenger. The scavenger will be in charge of taking the trash to the community bins and the fate of the recyclables will be under the scavenger's responsibility. The scavanger can either transfer the recyclables to the community recylable bin or sell them directly to the stakeholders.

The public shall be informed by reminders about the use of Istorba and shall be asked to collect their waste separately at home. By collecting biodegradable waste separately, the amount of trash in the Istorba will decrease. Thus the inhibitants will need fewer bags, which has a noticeable impact on their wallet.

Each neighborhood shall be informed about the collection times of the trucks. As meat and fish wastes quickly turn into bad odors; people shall be asked to place these in the biodegradable waste container just before the container is emptied at the collection time off the truck. In order for the biodegradable waste to attract fewer flies; the container should be emptied and washed on a regular basis. As the lack of ventilation sets off the fermentation process, biodegradable waste in the collection bin or container should not be compressed. To absorb moisture, wet biodegradable waste should be dried or wrapped in ordinary newspaper and the bottom of personal collection bins should be lined with a layer of paper towels or newspaper.

3. RESULTS AND DISCUSSION

There are some difficulties in the separate collection of waste and some factors have been mentioned in the literature. It has been indicated that, socio-economic characteristics, behavioural attitudes, peer influence and institutional arrangements; in detail; gender, peer influence, land size, location of household and membership of environmental organization explain household waste utilization and separation behaviour [5]. Moreover, good moral values and situational factors such as storage convenience and collection times are also mentioned to have encouraged public's involvement and consequently, the participations rate and local authorities should take into consideration of individuals personal beliefs about the moral correctness and incorrectness of performing waste separation and factors that may motivate and inhibit waste separation behaviour [6]. Inconvenience has always been cited as a major barrier toward recycling and convenience as a major motivator [7].

Biodegradable waste, which can 'biodegrade' by natural processes, accounts for approximately three quarters of the municipal solid waste produced by homes and businesses and comprises 'organic' or natural materials which will break down over time. The principal 'biodegradable' components of municipal waste are paper and cardboard, food wastes and garden wastes.

The European Union (EU) Directive 'Landfill Directive' (2018/850) dealing with the landfilling of waste, imposes that the restrictions should be strengthened in order to move to a circular economy [8]. The Directive imposes restrictions on the consignment of certain waste materials to landfill. Although Directive 1999/31/EC already sets landfill diversion targets for biodegradable waste, it is reasonable to put in place further restrictions on the landfilling of biodegradable waste by prohibiting the landfilling of biodegradable waste that has been separately collected for recycling in accordance with Directive 2008/98/EC [9, 10]. To drive policy reforms, the EU Commission shall organise high-level exchanges on the circular economy and waste and step up cooperation with Member States, regions and cities in making the best use of EU funds and where necessary, the Commission shall use its enforcement powers [11].

4. CONCLUSIONS

This paper not only included the characterization of municipal solid waste in Istanbul but also provided suggestions biodegradable municipal solid waste for Istanbul, as a pilot city for Turkey. The proposal for the improvement of biowaste management following the authors' research for ISTAC was introduced. It is important to suggest the employment of the scavengers to the waste collection system legally by the local municipalities. The proposal of biodegradable bags is also a promising solution to increase the rate of source separation of organic waste.

The suggested solution consists of a logistically interconnected integrated biowaste management system of technologies that would manage optimally the specifications of individual groups of biological wastes, the needs of customers, and the possible sale of the final products and/or energies.

The separate collection of organic waste at source not only will increase the quality of product at the composting and biomethanization facilities, but also will improve the efficiency of the incineration plant. In the recent years, more emphasis was placed on the recycling of packaging waste. With the decline of the packaging waste with respect to the overall waste, the importance of focusing on the management of biodegradable waste has emerged. Success stories regarding the separate collection of organic waste should be deliberately examined and must be adopted to the national conditions. With the necessity of mandatory organic seperation at household level, each local authority will require to adapt to its own socio-economic conditions; thus, it is not possible to develop one recycling system that can be adopted by all. However, in order to establish a sustainable biodegredable solid waste management system, general principles have to be identified, restrictions should be appplied.

Further studies such as the implementation of campaigns on environment awareness from the earliest years of school, to spread and improve recycling habits at the household level, reforming the current tax-deductible system that incentivizes reusing solid waste at the household level should be implemented. The recommendations could be applied by other countries as well.

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RESEARCH ARTICLE

Synthesis of copper particles and elimination of cupric ions by chemical reduction

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ABSTRACT

Development of enhanced methods for copper particles synthesis is crucial for the improvement of material science and technology. Therefore, in this study a successful synthesis of copper metal was achieved by chemical reduction. Ascorbic acid was used as a reducing agent. In the presence of soda, copper sulphate pentahydrated ($CuSO_4$, $5H_2O$) with acid ascorbic at 60 °C of temperature produced metallic copper powder with the total degradation (100%) of copper ions (Cu^{2+}). The presence of hydroxide ions (OH^-) is necessary to achieve and improve the chemical reduction reaction. Several parameters, as reducing agent volume, reaction temperature and soda quantity were investigated and checked their impact in this research study. The obtained powder was washed and dried in the fresh air then analysed by X-ray diffraction.

Keywords: Ascorbic acid, chemical reduction, ions, copper metal, copper sulphate, sodium hydroxide

1. INTRODUCTION

Water pollution by heavy metals has got a serious toxicological impact. For this reason, it is necessary to monitor industrial wastes contents as well as water designated for domestic consumption [1]. Among these metals, we find copper, which is an essential trace element for human metabolism. However, in small quantity, where the daily adult need for copper is about 0.2 mg [2]. WHO recommended a provisional guide value of 0.2 mg L^{-1} of copper concentration in domestic water [2]. Copper can be found in some natural water sources under ionic or complex forms at low concentrations less than 0.1 mg L^{-1} [2]. It can be also found as metallic deposits, electric and electronic household wastes and leachates of minerals. In addition, water piping corrosion generates from 0.5 to 0.1 mg L^{-1} of copper in water [2] [3] [4].

It already exists several methods of aqueous copper separation solutions. These methods are based on chemical precipitation phenomenon [5], ions exchange [6], biosorption [7], extraction [9] [10] or membrane separation [11].

Reduction method is largely used for metallic nanoparticles synthesis and in particular for copper. Different reducing agents have been used as sodium borohydride [12] and hydrazine [13]. Natural agents as ascorbic acid are used for copper ions (Cu^{2+}) reduction to metallic copper [14]. Reduction method has got a big advantage of cleaning up water from dissolved copper ions and transforming them to metallic particles that can be easily separated after settling.

2. MATERIALS AND METHODS

2.1. Preparation of solutions

Prepared solutions were made at the basis of distillate water of pH between 5.5 to 6.8 and conductivity from 3 to 5 µS cm^{-1}. In this study, the mass molar of the two prepared solutions are 249.69 g mol^{-1} and 176.13 g mol^{-1} for copper sulphate solution ($CuSO_4$, $5H_2O$) 0.2 M and ascorbic acid ($C_6H_8O_6$) consecutively.

A defined volume of acid ascorbic was heated to 60 °C in a laboratory bain-marie. Once the ascorbic acid was preheated, 10 mL of copper sulphate was added drop by drop agitated with a mechanical stirrer as shown in the scheme in Figure 1.

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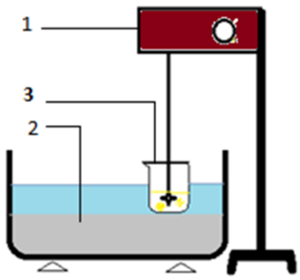

Fig 1. Experimental dispositive of the research study. 1: Mechanical stirrer 2: Laboratory bain-marie 3: Beaker (reactor)

The series of reactions of ions copper reduction until obtaining metallic copper are represented in the three following reactions (1), (2) and (3).

$$Cu^{2+} + C_6H_8O_6 \rightarrow Cu^{+} + C_6H_6O_6 + 2H^{+} \quad (1)$$

$$Cu^{+} + 2OH^{-} \rightarrow Cu(OH)_2 \quad (2)$$

$$Cu(OH)_2 + C_6H_8O_6 \rightarrow Cu + C_6H_6O_6 + 2H_2O \quad (3)$$

2.2. *Analytical methods*

During reaction and every 10 min, a sample was taken to determine copper ions concentration. The concentration was determined by calorimetric dosage with Titriplex III and the presence of Murexide ($C_8H_8N_6O_6$) as colour indicator. After 0.1 hr of reaction, the final solution was centrifuged at 6000 rpm for 5 min. The deposited solid was washed by distillate water then filtrated by standard paper filter. The obtained solid was dried in the open air. During drying process, the obtained powder was visually monitored. It did not show any sign of oxidation and the final obtained powder is illustrated in Figure 2.

For the optimal conditions, the prepared or obtained solid sample was analyzed by X-Ray Diffraction (XRD) for different solids characterization.

Fig 2. Metallic copper powder obtained after copper ions reduction

3. RESULTS AND DISCUSSION

3.1. *Effect of acid ascorbic volume*

In this section of the study, the variation of reducing agent volume was investigated and studied its impact on the copper ions production efficiency. Three different volumes of ascorbic acid were used 20, 50 and 60 mL. The attained results are represented in Figure 3.

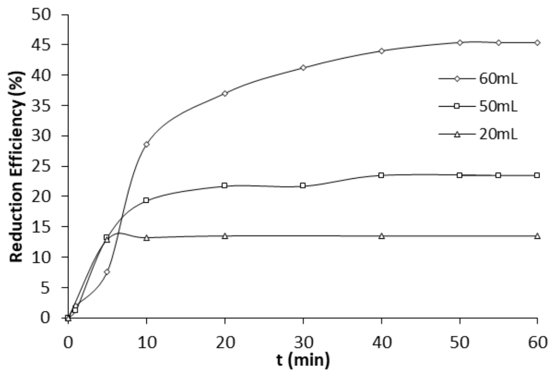

Fig 3. Copper ions reduction efficiency in function of ascorbic acid volume

The results show that 45.5% of copper ions were generated at 60 mL of ascorbic acid after about 60 min of reaction. The weakest efficiency was noticed at 20 mL of ascorbic acid. According to the obtained results, it can be seen that the copper reduction efficiency increases with the increase of reducing agent volume. This improvement of copper reduction can be explained by more ascorbic acid molecules which are available for reducing the same quantity of copper ions containing in the aqueous solution [15] [16].

The dried solid sample obtained at 60 mL of ascorbic acid was analysed and XRD results are illustrated in Figure 4, where it is clear that the two significant spectres correspond to pure metallic copper.

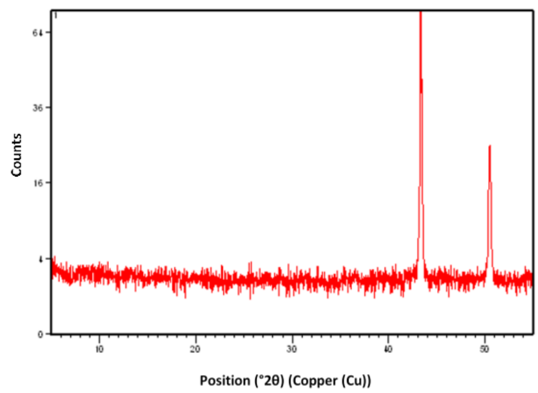

Fig 4. XRD Spectre obtained after copper ions reduction with 60 mL of ascorbic acid volume

3.2. *Effect of temperature*

To study the impact of temperature on the copper ions reduction, the same procedure was followed. However, the laboratory bain-marie temperature was varied.

The investigated temperatures were: 27, 40, 60 and 70 °C. The achieved results are summarised in Figure 5.

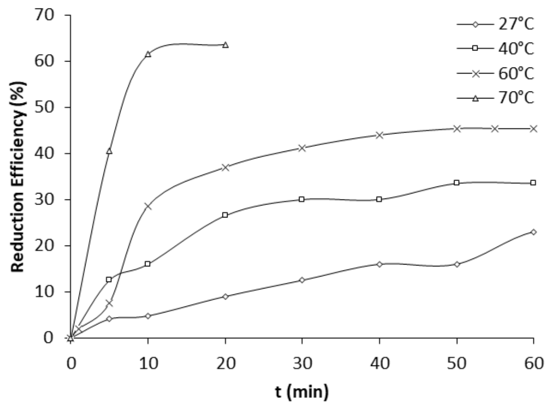

Fig 5. Copper ions reduction efficiency in function of bain-marie temperature

The results illustrated in Figure 5 show that the ions copper reduction is favoured by increasing temperature. In fact, the reduction efficiencies obtained after 60 min of reaction were 23, 33.5 and 45.4% at 27, 40, and 60 °C subsequently. The energy required to trigger copper ions reduction into copper particles declines with the temperature. Additionally, at higher temperatures, the probability of one molecule colliding and reacting with another increases [15]. In this study, the increase of temperature to 70 °C allowed having 63.6% of ions copper reduction efficiency after just 20 min of reaction confirming what was found in the literature [15]. However, under this temperature, water started to evaporate which leads to a decrease in treated water quantity and eventually the studied concentration of ascorbic acid as a reducing agent will be different from its initial value. For such reasons, the experiment was stopped once water evaporation started and it was judged that 60°C is the optimum temperature of copper reduction using 60 mL of ascorbic acid. In all tests, colour indicator gave pink colour indicating that the reaction has taken place.

3.3. Effect of copper ions reduction in an alkaline environment

According to ions copper reduction reactions (2) and (3), reduction can happen in an alkaline environment. Thereby for such reason, it is studied how much is affected reduction efficiency according to the volume of sodium hydroxide added. The experimental procedure was altered this time, where initially 10 mL of copper sulphate was mixed with 10 mL of sodium hydroxide of the same concentration 0.2M to form copper hydroxide ($Cu(OH)_2$). The measured pH of solution was 12.7. The mixture is then added to the preheated 60 mL of ascorbic acid drop by drop and agitated with a mechanical agitator as done in the first experiments. The results are shown in Figure 6.

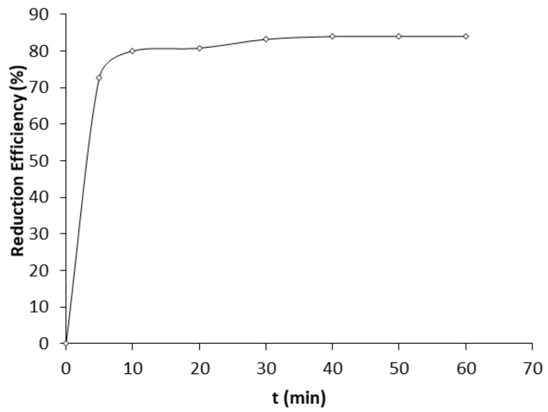

Fig 6. Copper ions reduction efficiency for 60 mL of ascorbic acid in an alkaline environment at 60 °C

As expected and with compliance with other researches, the addition of NaOH solution has dramatically impacted on the progress of copper chemical reduction reaction [16] [17] [18]. After 30 min of reaction, 84% of ions copper were reduced. However, according to Figure 3 and under the same conditions of ascorbic acid volume and temperature, reduction efficiency was only 41.2% after the same period of reaction without alkaline solution.

3.4. Effect of sodium hydroxide volume

To determine how the volume of sodium hydroxide can alter the reduction efficiency, many volumes were taken in consideration (10, 20, 30 and 40 mL) and the rest of conditions kept constant as in the previous section. The obtained results are illustrated in Figure 7.

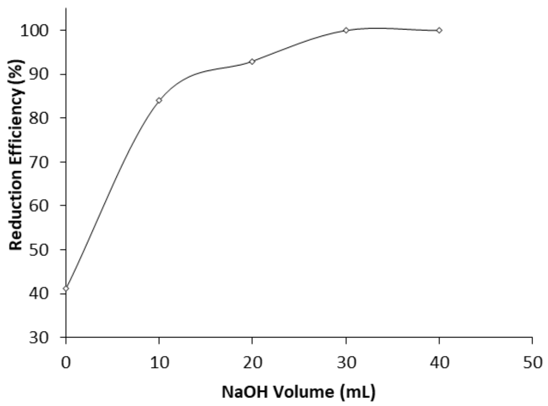

Fig 7. Copper ions reduction efficiency in function of sodium hydroxide volume for 60 mL of ascorbic acid volume at 60 °C of temperature

The results represented in Figure 7 indicated that a complete ions copper reduction was achieved with addition of 30 mL of NaOH. Therefore, it is definitely, ions copper reduction is better in an alkaline pH. However, it is difficult to explain the cause. Actually, no explanation was found in the literature. Probably, it can be explained by the initial transformation of copper ions to hydroxide particles which gives the advantage of their transformation to reduced particles.

4. CONCLUSION

The main objective of this research work was about investigation the possibility of copper elimination by chemical reduction using ascorbic acid as a reducing agent. This experimental study allowed to note that the chemical reduction of copper hydroxide can be achieved at 100% of removal efficiency using 60 mL of ascorbic acid and 30 mL of sodium hydroxide at 60 °C

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RESEARCH ARTICLE

Construction waste management practices on-sites: A case study of Istanbul city

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ABSTRACT

Increasing construction activities put enormous stress on waste generation in Turkey. Therefore, to manage all these construction wastes by setting effective waste management strategies becomes more significant day by day. Although there is a rising interest in waste management issues, there are not enough studies in Turkey. The lack of data is a prominent obstacle for the researchers. Addressing this research gap, an explanatory multiple-case study was conducted to reveal the waste management practices (waste generation, collection-sorting, storage-disposal, and recovery) on-sites. Unstructured interviews were conducted with different 13 experts working at different construction sites in Istanbul. According to the qualitative study results, there is usually no waste management plan on-sites. Project revisions and cutting of materials for sizing, storage problems are the most emphasized causes of waste on-sites. Wastes are mostly collected and disposed of by the contractors and there is a tendency to collect wastes in mixed on-site and later partly sort. Collection-sorting and storage-disposal practices on-sites are affected by the quantity of waste, site facilities, storage opportunities, scale of the contractor and economic value of waste. The recovery facilities are mostly depending on the economic gain to be obtained from waste. In this context, the recycling and reusing of steel waste is given the best importance. There are not enough networks for recovery of cardboard/paper-plastic wastes on-sites. There is no illegal dumping among the cases included in this study. However, awareness on special treatment of hazardous wastes has not yet been developed enough on-sites in Turkey.

Keywords: Construction waste, waste management, on-site waste management

1. INTRODUCTION

Increasing industrial production activities as parallel to the increase in the world population, alienates human to nature, and causes various environmental impacts such as depletion of natural resources, global warming, non-renewable energy consumption, and waste generation. All these environmental impacts force human to produce solutions and take measures [1, 2]. The construction industry is responsible for an important part of these environmental impacts, such as resource consumption, land use, land deterioration, noise, dust, pollution etc [3]. It is also a major source of urban waste and the most voluminous waste streams generated regularly in urban areas [4]. According to Eurostat data in 2016, construction activities account for approximately 36% of the total waste generated by economic activities and households in Europe [5], In the last decades, construction activities have substantially increased due to population growth, economical factors, urban renewal projects, etc, in Turkey. It is estimated that the amount of Construction and Demolition (C&D) waste in Turkey will reach 300 million tons by 2023 [6].

In 2015, the Republic of Turkey Ministry of Environment and Urbanization, in the process of integrating European Union legislation into national law, published "Waste Management Regulation" according to the European Parliament and Council Waste Framework Directive 2008/98/EC. Today, Waste Management activities are executed in accordance with Waste Management Regulation and carried out under the administration and supervision of the Ministry of Environment and Urbanization, Metropolitan Municipalities and municipalities. To set more effective waste management strategies, existing Waste Management Practices (WMP) in 81 provinces were examined by the Ministry of Environment and

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Urbanization, and the improvement proposals related to waste management and the targets to be achieved by 2023 were put forward in National Waste Management and Action Plan. Some of the proposals are to establish a collection system, to implement a vehicle tracking system on vehicles carrying C&D waste, to make selective demolition compulsory to ensure reuse of C&D waste, to establish material definitions and standards about C&D waste, to set a model for the recovery of excavation waste in landscape arrangements and to increase recovery facilities [6]. However, an effective waste management system could not still been established due to some prominent obstacles in application, such as the fact that waste management issue is not a priority policy area, the absence of an established institutional infrastructure authorized at both national and local levels, lack of proper coordination and cooperation among the authorized organizations in waste management, scarcity of resources, inadequate taxes taken for waste collection services, inadequate and limited infrastructure which need modernization, insufficiency of audit and monitoring activities, etc. [7]. C&D waste management research area, however, recently started to attract researchers' interest. Esin and Cosgun [8], conducted a survey aiming to provide some suggestions about preventing and reducing wastes caused by modifications in residential buildings. Polat et al. [9], conducted a quantitative study through a questionnaire survey among Turkish contractors in order to determine the importance level of the waste causes. According to their results, design and construction detail errors, frequent design changes and change orders, waste from cutting uneconomical shape are at high levels of importance as waste causes. Arslan et al. [10], wrote a book chapter about C&D waste management in Turkey. Salgin [11], conducted a study to reveal the strengths and weaknesses of C&D waste management regulations in Turkey. Salgin et al. [12], investigated the benefits of a flexible design in C&D prevention and reduction through a case of an educational building in Kayseri. Salgin [13], additionally, stated that dimensional coordination between building product and building dimensions has an important effect on waste reduction. There is also a study on C&D wastes generated during urban transformation activities in case of Kayseri which is conducted by Salgin and Cosgun [14]. There are also some conference papers conducted by different researchers [15, 16] about C&D waste management practices. However, more research is needed on C&D waste. Lack of data is one of the most important obstacles for the researchers in Turkey. When examined the literature in the World, it is seen that there are various studies ranging from waste quantification, reduction, recovery (reuse, recycle) or disposal, etc. of C&D waste. Most of them focus on C&D waste quantification, characterization, source identification, and recovery or the other management practices separately. Some of them tend to evaluate management practices of the construction industry induced waste itself as a material. The other issues of waste management vary according to the different interests of researchers. There are not much more studies about WMP during construction process. Considering the situation in Turkey and the World, this study presents a process based approach and examines WMP in the construction process including waste generation, collection-sorting practices, storage-disposal and recovery practices. It also reveals the current applications of CWM practices on-sites and proposes improvement suggestions for the site management practices in Turkey.

2. C&D WASTE

Waste is defined as "any substance or object that the holder discards or intends or is required to discard" [17]. Waste occurs in any industrial production processes. Different production processes cause various types of wastes having different physical, mechanical, chemical, elemental, etc. properties such as being hazardous, inert and non-hazardous. Hazardous wastes are defined as the wastes which have at least one hazard to human health or environment and have the characteristics of hazardous substances such as ignitability, corrosiveness, toxicity or reactivity. Non-hazardous wastes are defined as the wastes having no hazardous features due to the prior physical, chemical and biological transformations. Inert wastes do not experience any physical, chemical and biological transformations [18, 19]. European List of Waste provides a comprehensive classification of wastes according to its compositions and properties [20].

Construction Waste (CW) is defined as "building and site improvement materials and other solid wastes resulting from construction, remodelling, and renovation or repair operations". Demolition waste is defined as "building and site improvement materials resulting from demolition or selective demolition" [19]. CW includes masonry and concrete masonry units, all untreated wood including lumber and finish materials, wood sheet materials, wood trim, metals, roofing insulation carpet and pad, gypsum board, unused (leftover) paint, piping, electrical conduit, packaging such as paper, cardboard, boxes, plastic, sheet and film polystyrene packaging, wood crates, plastic pails, beverage and packaged food containers [19, 21].

Generally, there are produced cleaner materials in the construction process than demolition process [22]. The composition and the effects of C&D waste vary depending on the type of construction and the methods used during construction [23]. According to Gavilan and Bernold [24], the significance of the sources of waste changes depending on the project and material types, and material flow begins with the material delivering process to the disposal of wastes on-site. Approximately 1% to 10% of construction materials on-sites turn into waste [25]. However waste generation rates can be affected different indicators such as the type of building or project being constructed etc. [3]. For instance according to Building Research Establishment's study [26], which was conducted for nine building products at three on-sites (mortar, bricks, concrete roof tiles, concrete blocks, mineral wool, polystyrene, polyurethane insulation panel, plaster and plasterboard), wastage rates differ from 2.1% (mineral wool) to 31.9% (plasterboard).

3. C&D WASTE MANAGEMENT

It is difficult to deal with waste management issues such as collection, storage, transport, treatment, and disposal of wastes, especially in medium and large urban cities. Since 1980, the western world and part of Asia have adopted the waste management hierarchy (WMH) approach [18, 27]. This approach is also known in literature as 3R principle (reduce, recycle, reuse). WMH refers to an order of preference for an action to reduce and manage waste and ranks management activities according to their environmental benefits. Although WMH is a widely used principle, there is no best option from environmental perspective, which has universal consensus [28]. Christensen [27], defined waste management in four phases: Waste generation; Collection and transport; Treatment; Recycling, utilization and land filling (RUL). Waste generation phase consists of waste categories, waste types, waste quantities, and composition. Collection and transport phase includes source separation, collection, transport, and bulk transfer activities. Treatment activities include separation of waste for recovery, incineration, biological treatment, and other operations or processes changing the characteristics of the waste. In the RUL process, waste leaves the system permanently and is recycled, utilized on land (e.g. compost) or in construction, or is disposed of in a landfill [27].

There are many research studies contributed to CW management issues. Gavilan and Bernold [24], conducted a study on categorization and quantification of CW. They classified waste causes into six categories as design, procurement, handling of materials, operation, residual wastes and others not listed. Using the same classification in their study, Bossink and Brouwers [25], conducted a study about causes and generation rates of CW on residential sites. Mcdonald and Smithers [29] studied the construction process through conducting a case study in Australia. They adapted a waste management plan to reduce the quantity of CW sent to the disposal. Faniran and Caban [30] studied about CW minimization strategies and sources of waste on-sites. Poon et al. [21] conducted a research about on-site sorting of CW. They stated availability of site space is the most important factor which affects construction waste sorting methods. They also found management effort, labour and cost interference with normal site activities as major factors. On the other hand, waste sortability, market for recyclables and environmental benefit are the minor factors of construction waste sorting methods on-sites. Poon et al. [31] analyzed the quantities and causes of waste generated during the construction of residential buildings in Hong Kong and examined waste handling methods. Poon et al. [32] searched the recovery rates of various types of demolition wastes. Poon et al. [33] conducted a questionnaire survey and work site visits aiming to find out cause of waste, to estimate material wastage level and the ways to reduce waste on-sites. Kartam et al. [34] studied C&D wastes through focusing on recycling efforts leading to minimize the wastes sent to the landfill in Kuwait. Shen et al. [35] studied waste handling in construction process through six case studies located in Hong Kong city. Tam and Tam [36] studied recycling practices of CW. Begum et al. [37] conducted a case study to reveal economic feasibility of CW minimisation on-sites. Osmani et al. [38] studied architects' and contractors' attitudes on waste minimisation through a questionnaire survey. Tam and Tam [39] carried out a study about CW recycling. Tam [40] searched economic considerations about recycling of concrete waste. Osmani et al. [41] investigated architects' approaches about CW minimization through questioners. They have grouped the waste causes according to the origins of waste as contract, design, procurement, transportation, on-site management and planning, material storage, material handling, site operation, residual and others. Tam [42] researched the effectiveness of WMP in construction. Jaillon et al. [43] conducted a study to reveal the waste reduction potential of prefabrication usage compared the conventional construction and found that the prefabrication supplies benefits in waste reduction (approximately 52%) on-sites. Wang et al. [44] conducted a study aiming to find critical success factors for on-site sorting of CW in Chile. Lu and Yuan [45] studied critical success factors for waste management in Chile. Yuan [46] conducted a strength weakness, opportunity and treat analysis for C&D waste management in China. Yuan [47] studied on social performance of C&D waste management and found 8 affecting indicators as practitioners' awareness, provision of job opportunities, physical working conditions, impacts on long-term health, safety of workers, public satisfaction, social image, and public appeal. Yuan et al. [48] searched on-site CW sorting practices through case studies of 6 construction sites Li et al. [49] developed a model for quantifying waste generation in construction. Saez et al. [50] conducted a study about the effectiveness of C&D waste management practices, and they found that the use of industrialized systems and the contract of suppliers managing waste are highly effective practices. Wang et al. [51] presented the critical factors in CW minimization at design stage. Gangolells et al. [52] analyzed implementation of effective WMP in construction site and projects. Bakshan et al. [53] developed a methodology to quantify waste generated at various construction processes. Ajayi et al.[54] conducted a study about site WMP. Ding et al. [55] developed a system dynamic model for waste reduction in construction process. Li et al. [56] searched effecting factors about CW reduction behaviour of contractor employees. Ding et al. [57] developed a model for construction and design stages about waste reduction.

Waste management is not a significant issue in terms of only environment. It should be considered as an economic issue as well. Reducing the amount of waste which is sent to landfill or sent for incineration may supply economic, environmental and social benefits such as creating employment in the recycling industry, reducing the overall building cost, avoiding transportation, new material purchasing and disposal costs, and reducing related environmental impacts such as resource consumption etc. One of the most important benefits of reusing waste materials is the reduction in resource, energy consumption and new material production [47, 58, 59]. According to Begum et al. [37], waste minimization such as reusing and recycling is economically feasible and plays an important role in environmental management.

According to Marzouk and Azab [60], recycling of C&D waste decreases emissions, energy use, global warming potential and conserves landfill and also reduces the costs of combating air pollution.

The variety in the aforementioned studies reveals that waste management is a comprehensive issue focused on quantification, reduction, recovery or disposal of CW, and should be carefully handled in terms of effectively using national material and energy resources and providing environmental and economic sustainability.

4. METHODOLOGY

This study is an explanatory case study which investigates how WMPs are performed on-sites in Istanbul. Explanatory case studies deal with investigating operational process over time instead of frequencies [61]. To increase validity of results, multiple-case study research was conducted among different experts working at different sites in Istanbul. According to Yin [61], multiple-case studies supply to set general explanations which accommodate with each cases even if the cases vary in detail. Multiple-case studies also aim to see processes and outcomes across many cases to understand how they are qualified by the local conditions [62]. The main research questions of the study are as follows:

- What kind of CW are produced on-sites?
- How CW is collected-sorted and stored-disposed on-sites?
- How the CW is recovered (reuse and recycle) on-sites?

The data belonging the cases was collected through unstructured interviews and site visits. The interviews were conducted using a general interview guide approach. Interview guides include a set of topics to be explored, and question sentences are not preset. The questions are asked by the interviewer as the situation evolves [63]. Thus, an unstructured interview guide, in the study, was designed to gather data in a systematic way. It was filled during the interviews, and handwritten notes were taken. The interviews usually continued between 50-80 minutes. Designed interview guide consisted of 3 main sections according to the determined main research questions;

- Main Causes of Waste on-site;
- Collection-Sorting, Storage -Disposal practices of CW on-site;
- Recovery (reuse and recycle) practices.

Data gathering process was completed at two steps:

Firstly, to obtain insights on CWM practices and to reveal the general tendency about CWM practices in Istanbul, a pilot study was conducted through unstructured interviews with 3 different experts working for different sites. The profession and experience of the respondents are given in Table 1.

Table 1. Profession and experience of respondents

Respondent Name	Profession	Site Experience (years)
RA (LsC)	Architect	16
RB (SsC)	Civil engineer	21
RC (LsC)	Architect	28

*R: Respondent, (A, B, C): The codes of the respondents, SsC: Small Scale Contractor, LsC: Large Scale Contractor.

Purposive sampling technique, which means selecting the people, groups or categories on the basis of their relevance to the research questions [64], was used to determine the respondents of the pilot study. To increase generalizability, the respondents were chosen from the experts who have the experiences in small scale construction sites consisting one to three building blocks and large scale construction sites consisting more than three building blocks.

Secondly, the interview guide were updated and detailed according to the pilot study results, and the interviews were conducted with ten different experts for ten different construction sites located in Istanbul. During the interviews, descriptive questions were asked according to the flow of the speech, which facilitated the data acquisition. Seven of the sites were also visited. Interviews and site visits were conducted from May 2018 till April 2019. To overcome the difficulties in finding the respondents willing to attend to the study and to ensure that the respondents involved in the study are at the level of sufficient knowledge and experience, besides purposive sampling, snowball technique was applied. Snowball is a sampling technique which the researcher starts with one sampling category (usually a person) and asks her/him for a new contact to others of a similar or known type [64]. Thus, the respondents working at different construction sites and the different cases have been determined. Of these cases, different types of projects i.e. residential, mixed use, transportation and museum were selected. The cases consisted of three mixed used (office, residential and commercial) projects, five residential projects, one airport project and one museum renewal project. Three of the cases were defined as small scale sites and the remaining cases were defined as large scale sites. General information about the cases and the respondents included in the study is presented in Table 2.

The interviews were conducted with the experts working on totally 10 different cases. The sample size, 10 cases, was decided according to 'theoretical saturation', which means stopping data collection when similar instances are found and there is no new data to reach for the researcher [65].

Additionally, the statements on sample size of the following researchers were also supported this decision. According to Stake [66], the efficiency of the study will be decreased if the number of cases is less than 4 or more than 10. Less than 4 cases do not supply sufficient interactivity whereas 15 or 30 cases show more uniqueness of interactivity which will not be enough clear to understand for researcher team and readers. Guest et al. [67], found data saturation had occurred by the time. They had analyzed twelve interviews. According to them, a sample of twelve will likely be sufficient to reach saturation. According to Creswell [68], it is typical to study few cases in qualitative research. In some cases, researchers may study a single site and in other cases, the case number may range 1 or 2 to 30 or 40 cases. Creswell [68] emphasized that a larger number of cases may become unwieldy and time-consuming in terms of collecting and analyzing.

Table 2. General information about the cases and respondents included in the study

Construction Site Number	Function of Construction	Type of Construction	Profession and Site Experience of Respondent (years)
S1*/LsC	Residential-Office (6 Residential Block -8-9 floors, 3 Office Blocks -18 floors)	RCS Façade: Silicon glass and flexible ceramic	Architect 15
S2*/LsC	Residential-Office-Commercial (2 blocks forty-five storey and 1 block with six-storey)	RCS and steel structure	Architect 22
S3*/LsC	Residential (10residential, 1parking and 1social centre blocks)	RCS Façade: Silicon glass and flexible ceramic, aluminium curtain wall system and PVC window frames	Architect 20
S4/SsC	Museum renovation project	Existing museum building constructed as RCS in 1957. Existing building were partly destroyed and RCS and steel beams, composite flooring, strengthening applications in the foundation are applied.	Architect 50
S5*/LsC	Residential (472 villas blocks)	RCS Façade: Heat insulation and plaster	Civil engineer 11
S6/LsC	Airport	Steel Façade: Aluminium panels (The total façade area: 500000 m^2)	Architect 29
S7*/SsC	Residential (3 blocks -14 floors)	RCS Façade: Plaster and paint on rock wool insulation.	Civil engineer 14
S8*/SsC	Residential (1block -14 floors)	RCS	Civil engineer 9
S9/LsC	Residential, 6 blocks	RCS Façade: Aluminium composite panels and stone wool insulation, and plaster	Architect 13
S10*/LsC	Residential-Office-Commercial (9 blocks -15 to 20 floors)	RCS Façade: The precast elements made of glass fibre reinforced concrete and partly ceramic claddings	Chemical engineer 36
Abbreviations	S refers Site, * refers Visited Site, SsC refers Small Scale Contractor, LsC refers Large Scale Contractor RCS refers reinforced concrete structure.		

The analysis of the obtained data was carried out by thematic analysis, which is one of the most common forms of analysis within qualitative research [69]. According to Miles and Huberman [62], data display is "An organised, compressed, assembly of information that permits conclusion drawing and action" According to Alhojailan [70], thematic analysis can be applied to qualitative data when the study aims to reveal the current practices of any individual. According to Braun and Clarke [71], thematic analysis is the process of analysis of qualitative data through determining patterns or themes. In this strategy, tentative answers for the research questions are categorized into themes which is "a simple sentence, a string of words with a subject and a predicate" [72].

5. RESULTS AND DISCUSSION

In this section, the qualitative data (unstructured interview results) gathered during the pilot study and multiple-cases of CWM practices are analyzed and discussed. As mentioned in "Methodology Section", the data analysis is carried out by thematic analysis. According to the thematic analysis, the themes for the data related to the activities carried out during the construction processes of 10 different cases were first determined according to research questions and then given in matrices for all sites. These themes are organized and detailed in relation to waste causes (MC), collection-sorting (C-S), storage (S) and disposal (D), and recovery (R) practices, which are the main sections of the interview guide.

5.1. Main causes of waste on-site

The mostly emphasized waste causes on-sites are presented site by site in Table 3. The interview results and some proposals based on literature review are as follows:

Table 3. Matrix of mostly emphasized waste causes (MC) on-sites

Themes: MC on-sites	Cases (Sites)									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
MC1. Revisions during construction		■	■	■	■		■		■	
MC2. Intrinsically reasons of the construction process										
(a) Cutting of the materials for sizing	■	■	■	■	■	■	■	■	■	■
(b)Temporarily surface protection		■		■		■	■		■	■
(c) Non-consumables (pallets, packaging)	■	■			■	■				■
MC3. Design and detailing decisions										
(a) Material selection	■		■							
(b) Detailing errors				■					■	
MC4.Workmanship, assembly and application errors				■		■	■		■	
MC5. The work coordination and supervision problems	■			■	■					
MC6. Site specific causes				■		■				
MC7. Storage conditions and organization problems	■			■	■			■	■	
MC8. Mobilization (handling) errors	■			■	■		■			
MC9. Procurement (over-ordering etc.)			■							
Affecting Factors: User wishes, Low material resistance, Applied surface area, Project specific orders (Project sized), Designing with standard products, Building in-situ models, Scale of contractor.										

• The main causes of waste in Table 3 were determined and coded considering the interview findings and the classifications of Gavilan and Bernold [24], Bossink and Brouwers [25], Osmani et al. [41]. Special construction projects, however, may cause special wastes, such as the wastes emerged as a result of the protection of some work of art in Site-4. For this reason, unlike other studies, site specific causes (MC6) were handled as another waste cause in this study.

• Project revisions (MC1) and cutting of materials for sizing (MC2-a), storage conditions and organization problems (MC7) are the mostly emphasised causes of wastes on-sites by the respondents. Fig 1 illustrates the waste formed due to cutting of steel reinforcement. According to Polat et al. [9], design and construction detail errors, frequent design changes and change orders, waste from cutting uneconomical shape are at high levels of importance as waste cause. In parallel with the results of Polat et al. [9], project revisions (MC1) and cutting of materials for sizing (MC2-a) are the mostly emphasised causes of wastes on-sites by the respondents. Faniran and Caban, [21]; Osmani et al., [38] and Poon et al. [33] also confirmed that MC1 and MC2-a are the main generators of waste on-sites.

• In residential projects, MC1 are generally made due to the customer's esthetical wishes such as a change in the floor or wall finishing materials etc. On the other hand, in commercial spaces, MC1 can be mostly due to the spatial change needs. In addition, some architectural project problems can cause the revisions as well. According to Poon et al. [33], Osmani et al. [38], revisions are made due to last minute client requirements, complex designs, lack of communication between designers, contractors and engineers, lack of design information, unforeseen ground conditions and long project duration. MC1 could be prevented or reduced by developing the coordination between designers and users in design process. Thus users can select themselves finishing materials such as floor coverings, kitchen cupboards etc., in design process and so waste can be avoided.

Fig 1. Waste generation during cutting of steel reinforcement for sizing (Site-8)

• According to Poon et al. [33], designing with standard sized building materials avoids cutting, and also design for flexibility reduces the generation of construction waste. Designing more flexible spaces, especially for commercial spaces, could be another measure to reduce MC1 for Istanbul. To reduce MC2-a, the use of standard products could be widespread for Istanbul.

• There may occur various types of MC2 in relation to construction method (such as in-situ, prefabricated, etc.). According to Jaillon et al. [43], wet trades, such as concreting, masonry etc. usually accounts for 20% of the total wastes on-sites. According to Tam et al. [42], and Jaillon et al. [43], one of the ways of reducing waste due to MC2 is to use prefabricated building components instead of wet trade.

• Usage of materials for temporarily surface protection purposes (MC2-b) is another prominent waste cause. There is usually a tendency on that cardboard, paper and plastic materials to be used for protection purposes are supplied by purchase. However, such materials could be provided from the packaging waste on-sites. According to Jaillon et al. [43], temporary works generate prominent amount of waste on construction sites.

• Non-consumable materials such as wood pallets (M2-c) which is used during transportation of materials, parts or components (MPCs) to site usually turn into waste on-sites. It is possible to reuse these pallets or to recycle in production of different products such as furniture production, etc.

• None of the respondents emphasized use of materials not complying with specifications as an effective waste cause. However, Polat et al. [9] stated that use of materials not complying with specifications is a waste cause at high-medium importance level. According to respondents, if the resistance of selected material is low, there occurs waste due to damage of material during application. However, importance level of material selection (MC3-a) as a waste cause, changes depending on the surface area on which it is applied. For example on Site-1 and 3, there were applied flexible ceramic (having low material resistance) on facade which made MC3-a a prominent waste cause as covering the big surface areas of the buildings. MC3, as proposed in the study of Faniran and Caban [30], can be avoided through some applications such as reviewing of the project specifications by the contractor at the construction stage, defining the specifications clearly, paying the relevant attention to detailing, design and planning, etc.

• Insufficiency in the supervision of the applications and the change of sub-contractor which causes adaptation problems are the factors affecting the waste generation due to MC4. Following a well-planned work schedule may prevent waste on-sites. Building a model of the detail which will be produced on-sites is another application to prevent waste generation due to MC4. On sites-1, 3, 5, 6 and 9, the models were built in 1/1 scale and applied in situ (Fig 2a-b).According to Yuan [47], practitioners' attitudes directly affect waste generation on-sites, so raising practitioners' awareness is an effective factor in avoiding CW generation due to MC4.

• The work coordination and supervision problems (MC5), such as missing of MPCs on-site and usage of MPCs for different purposes, also cause waste on-sites.

• Waste can occur due to site specific causes (MC6). For instance, on Site-4, during renovation process, some of the paintings exhibited in the museum were temporarily stored on the basement floor and a briquette wall was built around for protection. These walls were then destroyed and turned into waste. The other example is on Site-6. The project delivery time were moved earlier which caused the number of workers working on the roof to increase (200-250 people has reached to 1650 people), and the extra strain on the roof damaged the application. Thus, the application on the roof had to be renewed.

• MC7 is one of the most emphasized waste cause on-sites. To reduce waste resulting from this cause, storage conditions and organization disorders should be avoided. MPCs can deteriorate as a result of storage in unsuitable conditions in the construction site such as high temperature and humidity, windy weather, etc. For instance, gypsum boards may be broken due to the improper storage; insulating boards may be skipped if the prevailing wind direction is not taken into consideration. Storage disorders also may cause waste. For instance, the insulation materials should be placed upright not to be crushed. Mobilization errors (MC8) such as damage to MPCs during horizontal mobilization or damage to MPCs during shipment to the construction site, etc. can cause waste. As parallel to the proposal of Poon et al. [33], it could be said that supplying coordination between suppliers, designers, manufacturers and contractors could be an effective way to avoid MC8.

• Procurement (MC9) is the least effective waste cause on-sites. As proposed by Poon et al. [33], clear records of purchase, delivery, usage and payment can avoid over-orders and supply material control.

(a) (b)

Fig 2. In-situ sample application on Site-1(a)and sample application on Site-3 (b)

5.2. Collection-sorting (C-S), storage (S) and disposal (D) practices on-sites

Collection-sorting (C-S), storage (S) and disposal (D) practices on-sites are presented site by site in Table 4. The interview results and some proposals based on literature review are as follows:

• Wastes are mostly collected and disposed by the contractors (R-a) and there is a tendency to collect waste in mixed on-site and later partly sorted (C-S-b) according to their type (steel, paper, plastic and wood wastes are usually separated). That the contractors are more effective than sub-contractors in waste handling is beneficial in terms of coordination and supervision of the actors involved in the construction process as mentioned by Shen et al. [35]. However, according to respondents, contractors sometimes cause errors during sorting of waste, such as disposing by mistake of any equipment or materials belonging to sub-contractors. According to respondents, C-S is affected by site facilities, storage opportunities, scale of construction, quantity of waste, and economic value of waste.

• LsC firms tend to collect the waste separately or to sort the waste. The quantity of waste is an important factor for waste sorting, especially in small construction sites. If the quantity of waste is little, the constructors usually ignore waste sorting.

• According to the respondents, the economic value of waste is the most substantial factor affecting on CW sorting, differing from Poon et al. [21] which state that availability of site space is the most important factor. For instance, as being a valuable material with high recycling rate, steel waste is the mostly separated waste type on-sites. CS practices of other wastes should be encouraged as well in Turkey. Sorting practices can be increased by educating workers and sub-contractors on waste and these practices, as stated in the study of Poon et al. as well [31], should be a legal or contractual obligation on-sites.

• R_C stated that waste collection period changes site-to-site depending on the production process on-sites, site facilities, and storage opportunities. It should be well planned and organized not to obstacle working conditions. For instance, on-Site-6 (airport), the wastes were sent to the collection area in every 3-4 days. On the other hand, during the production of the roofs, there were generated too much packaging and protection waste (the foils on the aluminum panels caused too much paper and plastic waste.). During the application of the aluminum panels, a team of 100 people collected the wastes to prevent clogging of the gutters.

• Waste storage-disposal practices also changes depending on the site facilities. If there is no place for storage on-site, wastes are sent to landfill without temporarily storage on-site. According to R_C, since the wastes occupy space on-sites, they sometimes make the works difficult. For this reason, the contractor firms generally want the removal of waste from site as soon as possible. This case is similar to the research finding of Poon et al. [31] saying that congested site areas cause obstacles to waste sorting practices on-sites.

• R_A stated that there is a charge of damping of the waste to landfill determined by the municipalities. The charges are calculated as the cost per a track load. The wastes on all construction sites involved in this study are transferred to the landfill determined by the municipalities (D-a). Hazardous wastes such as bituminous insulating material, and their boxes are usually separated by LsC (S4, 7, 8). SsC generally do not give enough importance to the sorting of hazardous waste. Yuan [47] stated that, illegal dumping of C&D waste also badly affects the city image. However, there is no illegal dumping among the cases included in this study. This shows that there is considerable control mechanism in practice regarding the illegal disposal of waste. On the other hand, any control mechanism on proper disposal of hazardous wastes has not yet been developed enough.

• According to R_A, there are some applications of the burial of the ceramic and concrete wastes on-sites. Burial should be avoided in environmental burden. Incineration (D-b) is forbidden in only two sites included in the study. Incineration activities should also be avoided in environmental burden on-sites.

Table 4. Collection-sorting (C-S), storage (S) and disposal (D) practices on-sites

Themes: (C-S), (S) and (D) practices on-sites	Cases (Sites)									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
R. Responsibility										
(a) Waste is collected and disposed by contractor.	■			■	■	■	■	■	■	■
(b) Waste is collected and disposed by subcontractors.		■	■							
C-S. Performing way of waste collection										
(a)Wastes are separately collected and sorted.		■			■	■				■
(b) Wastes are collected and later partly or fully sorted.	■		■				■	■	■	
(c) Wastes are collected in mixed on-site and not sorted.				■						
S. Performing way of storage										
(a) Wastes for disposal are temporarily stored.	■		■	■	■	■				■
(b) Wastes for disposal are directly sent to landfill.		■					■	■	■	
D. Performing way of disposal										
(a) Wastes are sent to determined landfill areas.	■	■	■	■	■	■	■	■	■	■
(b) Incineration of wastes are forbidden.						■			■	
(c) Special treatment is applied to hazardous wastes.		■	■		■	■			■	■
Affecting Factors:Quantity of waste, Site facilities, Storage opportunities, Scale of the Contractor, Economic value of waste.										

5.3. Recovery Practices On-Site

Matrix of mostly applied recovery practices (RP) on-sites are presented site by site in Table 5. The interview results and some proposals based on literature review are as follows:

• Waste Management Plan supplies various benefits such as reducing/preventing waste generation, supplying cost savings, reducing risks on-sites, etc. [42]. According to R_A-B-C, there is usually no WMP and RP are usually applied in an unsystematic way on-sites.

• There may be various types of wastes which have the potentiality of reuse and recycling. According to Peng et al. [58], scale of project determines the material reuse and recycling potentiality from economical perspective. According to the interview results; in terms of recovery, the economic gain to be obtained from waste is primarily important for contractors. In this context, recycling of steel waste is given the best importance (RP-a). There are also reuse activities; for instance, steel waste is used in the parapet production on Site-7. According to R_C, any length of steel reinforcement longer than 100-120 cm is suitable for use on-sites. As another example, on Site-1, oriented strand boards which were used in the production of site perimeter were reused as roof sheathing. Similarly, the metal work safety nets were reused in the production of metal profiles. To increase recovery, MPC's that are temporarily used on-sites should be designed as reusable on same site after the completion of its function. Additionally, the steel beams that were removed from the entrance canopy due to the project revisions were used for floor construction on Site-1 (Fig 3a). On Site-3 (Fig 3b), after the application of floor covering, the remaining cuts of polyethylene sheeting used on slabs were used on window frames as filling materials. The other example is that the aggregate inside the concrete waste was separated, washed and reused in the concrete production on Site-10. Wood pallets were reused through sending back to the supplier on Site-10.

• Wood wastes are generally used as firewood by workers at their home (RP-g, RP-j). However, incineration may cause various impacts threating human health such as hydrogen chloride, sulphur dioxide, heavy metals (lead, cadmium, dioxins, and particulates) [58]. Incineration applications on-sites should be avoided, and reusing or recycling of wastes should be ensured in environmental burden.

• Cardboard/paper (RP-k), plastic wastes (RP-l) are also among the wastes recycled on-sites. According to R_B, however, there is usually no network for recycling of plastic wastes except municipalities. The recovery of plastic wastes should also be expanded through supplying relevant network.

Table 5. Matrix of mostly applied recovery practices (RP) on-sites

Themes: Recovery Practices (RP) on-sites	Cases (Sites)									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
RP. Recovery of waste materials										
(a) Steel reinforcement waste is recycled.	■	■	■		■	■	■	■	■	■
(b) Steel reinforcement waste is reused.							■			
(c) Metal pallets are recycled.						■				
(d) Aluminium waste is recycled.	■				■	■				
(e) Galvanized material sheet waste is recycled.						■				
(f) Ceramic/brick/concrete waste is used as a filling.										■
(g) Wood pallets are used for heat recovery.	■	■	■		■	■				
(h) Wood pallets are reused (sent back to the supplier).										■
(J) Wood formwork wastes are used for heat recovery.										■
(k) Cardboard/paper wastes are recycled.	■	■	■		■	■			■	■
(l) Plastic wastes are recycled.	■	■			■	■				■
(m) Polyethylene sheeting waste is reused on windows.			■							
(n) Recovery facilities of waste are ignored.				■						
(o) Excavation waste is used for site arrangements.	■				■					
(p)The aggregate in excavation waste is recovered.							■			
(s) The aggregate inside concrete waste is reused.										
(t) Excavation waste is sent to different sites for reuse.	■									
(u) Over-ordered MPC is sent to different sites for reuse.	■	■					■			
(v) Temporary MPC are used in different productions.	■									
(y) Concrete waste is used temporary site arrangements.										
Affecting Factors: Network with the recycling firms and contractors, Lack of information about recovering potentiality of wastes, Coordination between the sub-processes of construction, Technical teams' and workers' awareness, eagerness and creativity, and Vision and strategy of the contractor firm, Economic gain.										

(a) (b)

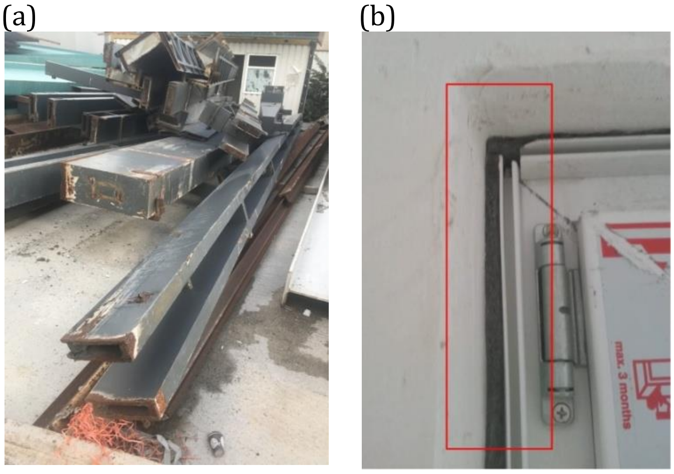

Fig 3. Reused steel beams (Site-1) (a) and polyethylene sheeting used on window frames (Site-3) (b)

• According to R_A, generally, packaged over-ordered MPCs are returned to the supplier. However, it is not possible to return the MPCs ordered in project-specific or block formed materials such as marble. These products usually become directly waste or are kept in the warehouses by the contractor to reuse at different sites (RP-u). In this case, there may be difficulties about the process of finding and using products from storage, due to the lack of a recording system.

• According to the respondents, although there is usually cooperation between the sites constructed by the same contractor firm, there is not any cooperation among different contractors, which causes a prominent obstacle for recovery of CW on-sites. R_A stated that, recovery of wastes in the construction process where they are produced is very difficult, because the work processes generally do not overlap in construction works. This makes corporation with different sites and contractors important in terms of recovery of waste on-sites.

• Adding to economic value of waste, there are some affecting factors (see Table 5) which may decrease or increase recovery facilities on sites. These are inadequate connections (network) with the recycling firms and contractors, lack of information about recovering potentiality of wastes, coordination between the sub-processes of construction, technical teams' and workers' awareness, eagerness and creativity, and the vision and strategy of the contractor firm. In order to evaluate the reusability of the wastes, (i) a system or network between construction sites and different industries should be developed; (ii) practitioners' (constructors, technical team, workers etc.) awareness should be raised about recovery potentiality of wastes; (iii) coordination between the sub-processes of construction should be supplied. Using this coordination system, the possibility of reuse on the same site (in order to avoid transportation), the possibility of reuse on a different site close to the site and the possibility of reuse in a different production process should be examined and evaluated in environmental burden.

6. CONCLUSIONS

In this study, an overview on C&D waste and waste management was provided and explanatory research was conducted through interviews and site visits to reveal CWM practices on-sites in Istanbul. The study is important in terms of revealing management practices and addressing the issue in a holistic approach, which makes it more prominent from collection to disposal on-sites, differing from many other studies in the literature. The interview results are grouped according to the main sections of the interview guide as; main causes of waste, collection-sorting practices, storage-disposal practices, and recovery practices on-sites. There is usually no waste management plan and management practices are usually applied in an unsystematic way. Project revisions and cutting of materials for sizing and storage conditions and organization problems are the mostly emphasized waste cause on-sites. Coordination between designers and users could be developed and the use of prefabricated components and design with standard sized building materials could be widespread for Turkey. Wastes are mostly collected and disposed by the contractors and there is a tendency to collect waste in mixed on-site and later partly sorted. Well planned and organized separately collection-sorting practices of wastes on-sites should be encouraged for environmental burden. Burial and incineration activities on-sites should be avoided. There is no enough network for recovery of cardboard/paper plastic wastes on-sites, which needs to be developed in Turkey. There is no illegal dumping among the cases included in this study. However, awareness and control mechanism on special treatment of hazardous wastes has not yet been developed enough on-sites. The economic gain to be obtained from waste is most important factor for contractors. In this context, recycling of steel waste is given the best importance. There are also some reuse activities for steel waste on-site. Besides economic gain, the re-use and recycling of different waste types should be evaluated to achieve environmental benefits. To increase recovery, educational activities for practitioners (constructors, technical team, workers, etc.) should be organized. MPC's that are temporarily used on-sites should also be designed as reusable on same site after the completion of its function.

The construction process consists of different sub-processes. Therefore, different sub-contractors are involved in this process, which makes WMP difficult on-sites. WMP should be applied in a systematic way. To implement more effective WMP for construction sites in Turkey, a holistic approach should be developed which allows all stakeholders assess and decide collectively.

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RESEARCH ARTICLE

Comparative analysis of nutrients composition in biochar produced from different feedstocks at varying pyrolysis temperature

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ABSTRACT

Biochar has proved to be effective in improving soil fertility and it is important to know its nutrients variability as influenced by pyrolysis temperature and feedstock type for optimum agricultural productivity. In this experiment four different feedstocks from animal and plant sources were selected and pyrolysed at four different temperatures of 300, 400, 500 and 600 °C for 3 hours at a heating rate of 10 °C min^{-1}. The feedstocks were Corn cob (CC), Poultry litter (PL), Cow dung (CD) and Peanut shell (PS). The results showed that increase in pyrolysis temperature led to decrease in the concentration of many of the parameters analysed in the biochar. At the lowest temperature of 300 °C the highest contents of (0.62 %) N in CD, (66.4 mg g^{-1}) P in CC, (8.38 mg g^{-1}) K in CD, (16.2 mg g^{-1}) Ca in CC, (4 21 mg g^{-1}) Mg in CC, (0.28 %) S in CC, were observed. On the other hand, increase in temperature resulted to increase in C, pH, Ash content and the highest pH value of 10.17 was found in CD. From this study, it can be deduced that feedstocks from animal source shows a high range of nutrient when compared to feedstocks from plant source and likewise increase in temperatures led to decrease in some essential nutrient needed by plant for growth and stability in the soil.

Keywords: Biochar, pyrolysis, temperature, feedstock, nutrients

1. INTRODUCTION

It is no longer news that our dear world is being faced with so many factors which could either be man-made or naturally occurring, whose detrimental effects on the environment has led to great climate change globally. According to IPCC [1], it is proposed that if bold steps are not taken to combat these depleting factors then we might be greatly endangered in our environment, society and the world at large. According to Lal [2], the world population which is currently 6.7 billion, may increase to 9.2 billion by year 2050, thereby increasing these factors which pose harm to the world. Generally, daily human activities give birth to harmful substances which in turn depletes our earthly composition. Some of these harmful substances include excessive carbon dioxide (CO_2) produced from burning of fossil fuels, methane gas released from landfills and from the digestive tract of grazing animals, nitrous oxide from fertilizers, gases from industries, deforestation and lots more. Although, many global warming gases are more harmful than CO_2, but they are not as abundant as CO_2 in the atmosphere [1], this is why CO_2 is regarded as the major greenhouse gas known to man. Concentration of CO_2 in the atmosphere has increased from 280 ppm as at year 2009 [3] and is presently increasing at a rate of 2 ppm $year^{-1}$ (0.5% per year) [4]. According to Lal [3], the concentration of CO_2 amongst other greenhouse gases (GHGs), has led to increase in frequency and intensity of extreme events such as drought, decrease in rainfall effectiveness, decrease in crop yield etc. In other to reduce the GHGs in the atmosphere, two key activities are relevant, which are reduce the emission of CO_2 into the atmosphere and the second option proposes increase the storage of atmosphere carbon in the soil and its added advantage it provides is the potential for enhancement in agricultural production. The primary way in which carbon can be stored into the soil is as soil organic matter, a complex mixture of carbon compounds consisting of decomposing plant and animal tissue, microbes and carbon associated with soil minerals. Soil amendments such as compost, animal and poultry manures have played a huge

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contributing factor to increasing soil organic matter to enhance soil fertility in the past. Although, various limitation have been attributed to the use of animal manure and compost [5]. Therefore, there is need to consider the use of alternative such as biochar, a potential for enhancement of agricultural productivity through soil improvement, environmental sustainability through waste reduction, water resource protection and carbon sequestration [6]. Biochar is a carbon rich product obtained by thermal decomposition of biomass with little or no oxygen at low temperatures [7]. According to research, biochar amendment has been reported to enhance soil physical, chemical, hydrological and biological properties [8-12]. From research, application of biochar to soil increases plant growth since biomass itself is a load of nutrients, Lehman and Rondon [13] reported significant high plant productivity from increase in soil nutrient as a result of the biochar applied. The effectiveness of biochar on crop growth depends on the biochar quality, application rate, soil type and crop species [5]. However, the feedstock and temperature of which a biochar is produced determine the chemical composition and nutrient present in a biochar [14-17]. In addition, Atkinson et al. [18] and Igalavithana et al. [5] reported that biochar produced at low temperature ≤ 300 °C are richer in nutrients and suitable for agricultural soil compared to those produced at higher temperature ≥ 600 °C. Kolton et al. [19] reported that efficiency of biochar can be attributed to its large surface area and pore space which makes it favourable for soil organisms that aid nutrient uptake by the plants. However, study and investigation on different pyrolysis temperature influencing the nutrient composition of biochar produced from different agricultural feedstocks including plants and animal sources have not fully gained much recognition. Therefore, this study investigates the effects of different pyrolysis temperature of 300, 400, 500 and 600 °C on nutrient composition of biochar produced from cow dung, poultry litter, peanut shell and corn cob feedstocks.

2. MATERIALS AND METHODS

2.1. Feedstock collection and biochar production

Feedstock materials from two plant and two animal sources were used for the purpose of this experiment. These feedstocks were Peanut shell (PS), Cow dung (CD), Poultry litter (PL) and Corn cob (CC). All the feedstock were sourced from different local farms in Akure, Southwestern, Nigeria. 10 kg each of CC, PL, PS and CD were cleansed, sundried, and the corn cob reduced into sizes ≤ 5 cm. Thereafter, the feedstock were pyrolysed in a muffle furnace at four different temperatures of 300 °C, 400 °C, 500 °C and 600 °C respectively for 3 hours at a heating rate of 10 °C min^{-1}. After pyrolysis, the biochar yield was determined mathematically by dividing the mass of the biochar produced by the mass of feedstock pyrolysed. In addition, the biochar produced were weighed using a weighing balance and finally sieved with a 2mm sieve in other to obtain uniformity. The sieved biochar samples were packaged in a plastic container and labelled for further analysis.

2.2. Determination of biochar nutrient composition

The chemical and nutrient analysis of the biochar were determined using standard methods and procedures described by International Biochar Initiative [20]. The parameters determined in the samples were: pH, Nitrogen (N), Potassium (K), Phosphorus (P), Calcium (Ca), Sulphur (S), Magnesium (Mg), Carbon (C), Hydrogen (H), Iron (Fe), Aluminum (Al), Zinc (Zn), Copper (Cu), Sodium (Na), Ash content, Cation Exchange Capacity (CEC) and Volatile Matters (VM). The pH was determined using 1:20 w/v biochar to water suspension ratio according to Rajkovich et al. [21] and measured using a portable pH meter (HANNA 016). Also, CEC was determined using ammonium acetate method as illustrated by Rajkovich et al. [21]. Cu, P, Mg, Ca, S, Na, K, Zn, Al and Fe were extracted from biochar samples by digestion in hydrogen peroxide (H_2O_2) and sulphuric acid (H_2SO_4) according to Wolf [39], thereafter, their concentrations in the biochar digest were determined on an atomic absorption spectrophotometer (AAnalyst 100, Perkin-Elmer, USA). C, H, N were determined through extraction using analytical techniques from the solution of biochar mixed into 1M HCl and allowed to stand overnight followed by mechanical shaking [22]. Volatile matter and ash content were determined using methods ASTM D1762-84 recommended by IBI [20].

3. RESULTS AND DISCUSSION

3.1. Effects of pyrolysis temperature on biochar yield

The biochar yield from all the pyrolysed feedstock ranged between 5.0 ± 0.02 – 58.0 ± 0.06 % and there was a decreasing trend in yield with increasing temperature as shown in Table 1. This is similar to the findings of many researchers as they also reported decrease in biochar yield with increasing temperature [23-26]. According to Sarfraz et al. [26] and Katyal et al. [27], high biochar yield at lower temperature could be attributed to partial combustion of biochar feedstock while a complete combustion at higher temperature, hence its lower yield. Also, lower yield at high temperature could be as a result of greater losses of volatile components at the higher pyrolysis temperatures [28] and the depolymerisation of compounds like cellulose and hemicellulose as well as combustion of organic materials [29, 17]. The highest biochar yield of 58.0, ± 0.06, 39.5 ± 0.6, 12.0 ± 0.04 and 7.5 ± 0.02 % were obtained at the lowest temperature of 300 °C from CD, PL, CC and PS feedstocks respectively while the lowest yield of 46.0, 36.5, 5.0 and 5.0 were obtained at the highest temperature of 600 °C from the respective feedstocks. The yield of biochar produced from each of the feedstock at the same temperature differ from one another because of the difference in the composition and properties of their feedstock.

Table 1. Biochar yield from different feedstocks pyrolysed under different temperatures

Biochar	Yield			
	Temperature (°C)			
	300	400	500	600
CD	58.0 ± 0.06	54.0 ± 0.2	50.0 ± 0.4	46.0 ± 0.46
PL	39.5 ± 0.6	38.5 ± 0.49	38.0 ± 0.05	36.5 ± 0.31
CC	12.0 ± 0.04	10.0 ± 0.02	6.0 ± 0.04	5.0 ± 0.05
PS	7.5 ± 0.02	6.0 ± 0.02	5.5 ± 0.05	5.0 ± 0.02

Values are mean ± Standard deviation
CD = Cow Dung, PL = Poultry Litter, CC = Corn Cob, PS = Peanut Shell

3.2. Effects of pyrolysis temperature on the physicochemical properties of biochar

From Table 2a, increase in temperature led to decrease in nitrogen concentration of biochar derived from all the feedstocks. This is also similar to Naeem et al. [23], Nwajiaku et al. [25], Sarfraz et al. [26], where the lowest temperature of resulted to higher N value. The highest average N content of 0.62 % was found in CD at the lowest temperature of 300 °C while the lowest average N content of 0.20 % was found in PS at the highest temperature of 600 °C. Decrease in N content could be attributed to its transformation and loss during pyrolysis process as temperature increases [25], this is as a result of volatilization of N during pyrolysis where N is removed through the loss of ammonium and nitrate [25]. Also, increase in pyrolytic temperature resulted to decrease in the phosphorus content present in all the biochars. The highest P content of 66.40 mg g^{-1} was found in CC at the lowest temperature of 300 °C while the lowest P content of 15.9 mg g^{-1} was found in PL at the highest temperature of 600 °C. However, this was different to the findings of Sarfraz et al. [26] and Naeem et al. [23] where the highest temperature recorded the highest P value. In the same manner, increase in pyrolytic temperature decreased the concentrations of K, Ca, Mg, H and S present in the biochars derived from all the feedstocks, this therefore showed that these elements were lost by volatilization. The highest values of 8.38 mg g^{-1} K content, 16.2 mg g^{-1} Ca content, 4.21 mg g^{-1} Mg content, 14.8 % H content and 0.28 % S content at the lowest temperature of 300 °C were found in CD, CC, CC, PL and CC, respectively, with their lowest values found in the highest temperature of 600 °C. The findings is similar to Nwajiaku et al. [25] where increase in pyrolysis temperature decreased K and Mg. However, Sarfraz et al. [26]; Naeem et al. [23] and Gaskin et al. [30] reported increase in temperature with increase in K, Ca and Mg contents. Nelissen et al. [31] and Al-Wabel et al. [32], differently reported decrease in H content and H and S contents respectively with increase in temperature. However, increase in pyrolytic temperature led to increase in the content of C, this is similar to the findings of Sarfraz et al. [26], Nwajiaku et al. [25] and Naeem et al. [23]. At a temperature of 600 °C, biochar derived from CC had the highest C and content of 31.4 % while the lowest temperature of 300 °C recorded the lowest values of C to be 3.8 % in PL. Moreover, this increase in carbon with increase in temperature shows that pyrolysis promotes carbonization [33] and this could be as a result of high degree of polymerization which makes carbon structure to be more condensed in the biochar [7].

From Table 2b, increase in pyrolytic temperature led to decrease in the contents of Fe, Al, Zn, Na, CEC and VM found in the biochar derived from some of the feedstocks. However, this was different to the findings of Sarfraz et al. [26], where increase in temperature resulted to increase in Fe and Zn. The highest Fe content of 18.40 ppm was found in CC at the lowest temperature of 300 °C while the lowest Fe content of 3.02 ppm was found in CD at the highest temperature of 600 °C. Al content decreased with increase in temperature in biochars derived from PS and PL but had fluctuations of values in CD and maintained equal but lowest content of 1.00 mol kg^{-1} at 500 °C and 600 °C while it exhibited the highest value of 2.32 mol kg^{-1} in CD at a temperature of 500 °C. Zn and Na and VM contents in biochar derived from all the feedstocks decreased with increase in temperature, with the highest values of 9.64 ppm of Zn, 2.91 mg g^{-1} of Na found in PL respectively and 96 % of VM in CD all at 300 °C. Similar to the findings of Sarfraz et al. [26], Naeem et al. [23], and Gaskin et al. [30], CEC decreased with increase in temperature with the highest value of 25.10 mol kg^{-1} at 300 °C in PS but only exhibited differently in PL with the temperature of 500 °C higher than 600 °C. However, the findings of Nelissen et al. [31] reported increase in CEC with increase in temperature. Decrease in CEC with increase in temperature could be attributed to degradation in volatile organic compounds and acid functional groups associated with negative surface charge of biochar [26]. Also, Jindo et al. [34] and Nelissen et al. [31] reported decrease in VM content with increase in temperature. Cu, pH and Ash contents increased with increase in temperature and these findings are similar to that of [23-26, 34]. The highest Cu content of 1.28 ppm was found in CD at 300 °C and lowest value of 0.04 ppm in PS at 600 °C. Increase in pyrolytic temperature led to increase in pH content as the level of acidity decrease and increase basicity of the biochar [35, 36], this could be attributed to the relative concentration of non-pyrolyzed inorganic elements, situated in the original feedstocks [28], and as a result of higher ash contents present at higher temperature [23] and hydrolysis of salts of Ca, K and Mg [30]. The highest pH value of 10.17 was found in CD at 600 °C while the lowest biochar pH was 7.11 at 300 °C in CC. Also, the ash content of 98 % at 600 °C was found in PS and the lowest was found at 300 °C in PL. Peng et al. [37] reported increase in ash content and decrease in volatile matter with increase in temperature. In this study, biochar produced at low temperature showed higher nutrients from all the elements analysed and they can be referred to as agricultural soil amendment [14, 18].

Table 2a. Elemental composition of biochar derived from different feedstocks at different pyrolysis temperatures

Biochar Feedstock	Temp °C	N (%)	P mg g^{-1}	K mg g^{-1}	Ca mg g-1	S %	Mg mg g^{-1}	C %	H %
PS	300	0.3 ± 0.02	23.4 ± 0.36	2.85 ± 0.02	13.11 ± 0.02	0.25 ± 0.02	2.14 ± 0.03	13.4 ± 0.1	6.7 ± 0.04
	400	0.24 ± 0.02	22.2 ± 0.25	2.75 ± 0.05	6.21 ± 0.03	0.20 ± 0.01	1.86 ± 0.06	16.10 ± 0.2	4.32 ± 0.04
	500	0.22 ± 0.03	20.3 ± 0.55	2.51 ± 0.03	3.11 ± 0.04	0.18 ± 0.02	1.76 ± 0.04	21.1 ± 0.9	3.84 ± 0.05
	600	0.20 ± 0.02	17.50 ± 0.05	2.44 ± 0.05	2.00 ± 0.03	0.10 ± 0.02	0.70 ± 0.02	23.4 ± 0.1	2.1 ± 0.03
CC	300	0.59 ± 0.07	66.40 ± 0.58	2.01 ± 0.06	16.2 ± 0.02	0.28 ± 0.04	4.21 ± 0.03	15.7 ± 0.04	14.18 ± 0.1
	400	0.50 ± 0.02	66.3 ± 0.23	1.84 ± 0.01	9.30 ± 0.03	0.22 ± 0.04	3.18 ± 0.03	25.30 ± 0.07	12.24 ± 0.05
	500	0.42 ± 0.04	66.2 ± 0.17	1.67 ± 0.03	8.10 ± 0.04	0.16 ± 0.04	3.14 ± 0.05	29.1 ± 0.13	8.60 ± 0.1
	600	0.38 ± 0.04	65.0 ± 0.02	1.52 ± 0.06	7.90 ± 0.1	0.08 ± 0.00	2.91 ± 2.03	31.4 ± 0.07	4.49 ± 0.05
CD	300	0.62 ± 0.02	24.1 ± 0.02	8.38 ± 0.07	4.28 ± 0.05	0.06 ± 0.01	2.36 ± 0.04	12.6 ± 0.56	7.8 ± 0.1
	400	0.50 ± 0.01	22.8 ± 0.03	6.0 ± 0.03	2.14 ± 0.03	0.03 ± 0.00	1.06 ± 0.09	21.1 ± 0.19	4.17 ± 0.28
	500	0.42 ± 0.01	21.0 ± 0.05	3.52 ± 0.03	1.96 ± 0.05	0.02 ± 0.00	0.62 ± 0.05	24.5 ± 0.06	3.12 ± 0.13
	600	0.38 ± 0.03	19.75 ± 0.05	2.68 ± 0.04	1.86 ± 0.03	0.02 ± 0.00	0.58 ± 0.04	27.2 ± 0.62	2.46 ± 0.07
PL	300	0.36 ± 0.06	19.1 ± 0.98	4.13 ± 0.09	2.56 ± 0.23	0.03 ± 0.00	1.21 ± 0.03	3.80 ± 0.02	3.4 ± 0.04
	400	0.34 ± 0.03	17.4 ± 0.09	4.02 ± 0.11	2.46 ± 0.41	0.03 ± 0.00	1.06 ± 0.07	9.8 ± 0.16	2.68 ± 0.06
	500	0.32 ± 0.03	17.2 ± 0.21	3.76 ± 0.05	1.78 ± 0.10	0.01 ± 0.00	0.62 ± 0.04	19.3 ± 0.17	1.15 ± 0.07
	600	0.30 ± 0.01	15.9 ± 0.18	3.45 ± 0.06	1.16 ± 0.05	0.01 ± 0.00	0.58 ± 0.04	27.2 ± 0.21	1.01 ± 0.06

PS = Peanut Shell CC = Corn Cob CD = Cow Dung PL = Poultry Litter
Mean Values ± Standard deviation

Table 2b. Elemental composition of biochar derived from different feedstocks at different pyrolysis temperatures

Biochar Feedstock	Temp °C	Fe ppm	Al mol kg^{-1}	Zn ppm	Cu ppm	Na mg g^{-1}	pH	Ash %	CEC mol kg^{-1}	VM %
PS	300	9.25 ± 0.02	1.50 ± 0.02	1.61 ± 0.03	0.04 ± 0.00	0.90 ± 0.02	8.41 ± 0.04	90.40 ± 0.41	25.10 ± 0.06	92.60 ± 0.51
	400	8.06 ± 0.07	1.46 ± 0.02	1.33 ± 0.1	0.09 ± 0.01	0.76 ± 0.04	8.46 ± 0.07	96.1 ± 0.25	24.26 ± 0.04	66.11 ± 0.04
	500	7.88 ± 0.1	1.36 ± 0.01	1.15 ± 0.05	0.10 ± 0.02	0.74 ± 0.03	8.75 ± 0.04	97.5 ± 0.5	23.34 ± 0.05	62.22 ± 0.1
	600	6.81 ± 0.09	1.24 ± 0.07	1.1 ± 0.07	0.15 ± 0.02	0.52 ± 0.05	8.79 ± 0.06	98.0 ± 0.02	22.06 ± 0.08	34.22 ± 0.02
CC	300	18.4 ± 0.03	1.24 ± 0.05	7.88 ± 0.05	0.56 ± 0.06	1.23 ± 0.04	7.11 ± 0.04	53.5 ± 0.05	22.14 ± 0.05	85.60 ± 0.06
	400	13.56 ± 0.03	1.02 ± 0.08	7.59 ± 0.03	0.45 ± 0.02	1.20 ± 0.02	7.13 ± 0.03	68.2 ± 0.04	21.20 ± 0.03	52.90 ± 0.02
	500	13.45 ± 0.05	1.00 ± 0.02	6.96 ± 0.06	0.40 ± 0.03	0.98 ± 0.02	7.54 ± 0.04	80.4 ± 0.02	20.16 ± 0.04	49.00 ± 0.76
	600	13.25 ± 0.02	1.00 ± 0.02	6.91 ± 0.1	0.37 ± 0.05	0.96 ± 0.02	7.86 ± 0.04	89.6 ± 0.07	20.00 ± 0.16	38.90 ± 0.08
CD	300	8.15 ± 0.07	2.30 ± 0.16	7.59 ± 0.05	1.28 ± 0.07	2.32 ± 0.1	9.90 ± 0.17	17.9 ± 0.18	22.14 ± 0.15	96.00 ± 0.06
	400	4.57 ± 0.34	2.14 ± 0.01	5.51 ± 0.47	0.21 ± 0.05	2.16 ± 0.18	10.02 ± 0.17	26.7 ± 0.96	21.20 ± 0.18	84.30 ± 0.53
	500	4.20 ± 0.12	2.32 ± 0.09	4.48 ± 0.09	0.19 ± 0.02	1.82 ± 0.07	10.05 ± 0.08	30.0 ± 0.55	20.16 ± 0.11	80.62 ± 0.34
	600	3.02 ± 0.06	2.14 ± 0.08	2.19 ± 0.08	0.14 ± 0.01	1.66 ± 0.12	10.17 ± 0.03	44.6 ± 0.55	20.06 ± 0.12	68.48 ± 0.12
PL	300	6.59 ± 0.07	1.86 ± 0.02	9.64 ± 0.07	0.27 ± 0.06	2.91 ± 0.04	9.39 ± 0.06	15.8 ± 0.22	22.14 ± 0.06	80.90 ± 0.18
	400	5.45 ± 0.1	1.65 ± 0.04	2.20 ± 0.03	0.17 ± 0.02	1.35 ± 0.04	9.57 ± 0.09	21.6 ± 0.34	20.33 ± 0.09	60.11 ± 0.3
	500	5.08 ± 0.11	1.56 ± 0.07	1.12 ± 0.06	0.12 ± 0.04	1.31 ± 0.08	9.77 ± 0.06	36.0 ± 0.05	17.26 ± 0.06	39.70 ± 0.27
	600	5.10 ± 0.15	1.46 ± 0.1	0.78 ± 0.04	0.04 ± 0.00	1.17 ± 0.04	9.96 ± 0.07	66.7 ± 0.3	18.33 ± 0.1	29.63 ± 0.08

PS = Peanut Shell CC = Corn Cob CD = Cow Dung PL = Poultry Litter
Mean Values ± Standard deviation

3.3. Effect of feedstock on nutrients composition of biochar

In addition to analyzing the effect of temperature, this study also analyzed the effect of feedstocks on nutrient composition of biochar. The N and Cu contents followed a descending order of CD>CC>PL>PS. Also, P and Mg contents followed the order of CC>CD>PS>PL. Concentrations of Ca, S, Fe and H followed the order of CC>PS>CD>PL with the two plant sources biochar having the highest concentrations of these nutrients. However, K, Al and pH exhibited the highest concentrations in the two biochars from animal sources in the order of CD>PL>PS>CC. The two animal sources CD and PL exhibited the highest pH compared to the other plant sources, this could be due to the higher amount of basic salts found in their feedstocks [9]. Biochars derived from plant sources exhibited higher concentrations of Ash, CEC and C while the animal sources exhibited higher concentrations of Na, Zn and VM. Comparing PL and PS both from two different sources, PL exhibited the highest concentration of N, K, Al, Zn, Na, Cu, pH and C than PS, while for P, Ca, Fe, S, Mg, Ash, CEC, VM and H the opposite was the case. Gaskin, et al. [30] reported higher concentrations of `N, P, K, Ca, Mg, Cu, Fe, Na, and Zn in Poultry Litter than in Peanut Hull (PN). PS and CC both from plant source exhibited the higher ash content than the other biochars from animal sources, this was different to findings of Koutcheiko et al. [38] who reported high ash content in biochar derived from manures.

Also, CC showed had higher nutrients (P, Ca, S, Mg, H, Fe, Zn, Cu and Ash) concentrations than CD, while the concentrations of K, C, Al, Na, pH, VM were higher in CD. However, there was no significant difference in the concentrations of N and CEC present in both biochars.

4. CONCLUSIONS

From this research it can be concluded that pyrolysis temperature and feedstock have significant effect on the nutrient composition of biochar which in turn affects their suitability as soil amendment. The yield of biochar decreased while ash content increased with increasing pyrolysis temperature. The pH of all biochar was found to increase with increasing temperature while CEC decreased. The concentration of N decreased with increasing temperature and a high proportion of N was conserved in the biochar at lowest temperature. However, other elements such as P, K, Mg and Ca decreased with increasing pyrolysis temperature and therefore this indicates a tendency of these elements to become less available to the soil. Therefore, the suitability of biochar for optimum soil fertility should be pyrolysed at lower temperature with feedstock properly considered.

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RESEARCH ARTICLE

Investigation of the use of photovoltaic solar water pump by occupants of residential buildings in Ile-Ife, Nigeria

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ABSTRACT

The study examined the types of pumps used in supplying water to buildings, assessed the factors affecting the adoption and use of photovoltaic solar water pump and the perception of stakeholders on the use of the photovoltaic solar water pump in the study area. These were done to assess the effectiveness of the use of photovoltaic solar technology to improve the availability of water for the use of the building occupants. The study was carried out in Ile-Ife Region, Osun State, Nigeria. Stratified random sampling was used to categorize the selected residential buildings based on their distance limits to the locations of boreholes, 1-300m, 301-700m, and 711-100m respectively. Systematic sampling was further used in the selection of residential buildings and respondents in the study area. A total of 125 questionnaires were administered on the respondents and the data collected were analyzed using both descriptive and inferential statistical methods. The result shows that a very significant proportion of the respondents, 83.33% depended on wells and boreholes while 73.33% of the wells/boreholes used in the study area had pumping facility. A large proportion of the boreholes in the study area had photovoltaic facilities and were majorly (60%) donated by the government. The most significant factor that influenced the adoption and use of photovoltaic solar water pumps was the level of technical know-how (mean score of 4.1167) and the most ranked benefit had from the use of the facility was less time spent in collecting water (mean score of 4.3583). To foster the availability of quantitative and qualitative water for the use of the building occupants through the provision of photovoltaic water supply, efforts are direly needed to take advantage of the tropical environment of the study area, to ensure optimum performance and security of the facility to drastically reduce dependence on the national grid.

Keywords: Availability, buildings, energy, occupants, photovoltaic, pump, water supply

1. INTRODUCTION

According to [1-3], water occurs in various sources which are rainwater, spring water, groundwater, and surface water. Rainwater is described to be one of the reliable sources of water during rainy seasons in which water is collected and stored from the run-off from roofs after much rain has fallen and used for drinking purposes. Springwater, on the other hand, is derived from aquiver sources found underground and has travelled a short distance when it would come out to the surface for collection. Water gotten from spring is usually of good quality for drinking unless it is contaminated by either human or animal faces [4]. Groundwater is always found mainly in the sub-surface core spaces under the earth's surface, starting from the water table level and is appreciably difficult to extract through some measures put in place. Hence, adequate technology and energy are needed to bring the water from the ground to the surface for collection [5].

Water has always been documented for playing crucial roles in various aspects of people's activities, maintains the ecosystem that provides and gives valuable services to both the environment and human beings [6-7]. Since water is demanded in high proportion all over the world to meet the different needs of the ever-growing population, about 884 million people lack access to potable water supply [8]. The need for sustainable water supply for the use of the households and other occupants of buildings of different types have been increasing pressures on domestic, industrial, and agricultural activities. Many people in developing countries, especially rural areas, lack access to safe and clean drinking water. This may

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further result in water-related diseases and various health implications which will further lead to either skin or eye diseases [9-11].

There is a need to ensure the availability of safe and hygienic water to meet the goals of the World Health Organisation (WHO) and Sustainable Development Goals (SDGs) [12]. Given this, energy is needed to drive the availability and supply of water to households and other occupants of buildings. It has been posited that there is dire need to take the issue of the source of energy that will make water available very seriously because it is one of the fundamental components needed in addressing physical water scarcity [13-14]. Different energy sources; fuel, electricity, and associated facilities are used to ensure water availability amidst physical difficulties like gradient, the height of buildings, and other operating factors. Due to this, manual pumping of water has become more difficult; while diesel and petrol are being used to power the generators, used to pump water into buildings or storage facilities, and energy efficiency of water supply system in buildings thus becomes a point of concern for sustainable development nowadays [15-16]. These fuels are used to pump water from deeper levels, but with innovations in technology globally, solar photovoltaic pumps are increasingly getting more popular because they are more environmentally friendly than other energy sources. Thus, the availability of safe and useable water in a suitable quantity has been a major problem in both urban and rural areas across the globe [17].

Water generation involves collecting water from the best available sources and thus subjecting it to processing, which will ensure availability of water of good physical quality, free from the unpleasant taste of odour and containing nothing which might be detrimental to health. Studies of [18-19] showed that potable water source in a community improves the overall well-being of residents in a particular place. Hence, there is a need to assess the effectiveness of the use of the photovoltaic solar method of pumping water into buildings. Also, photovoltaic solar energy has been documented as a renewable source that is generated from sunlight [20]. Various studies have indicated different advantages that solar energy has over other sources. Photovoltaic solar energy is provided as free, needs no fuel, and produces no waste or pollution [21]. Photovoltaic solar electricity has proved to be an alternative way of power to buildings where there is a poor supply of electricity. Its benefits of the use of solar energy to pump water and produce no waste or pollution in buildings and settlements informed this work.

The aim of the study is therefore to assess the effectiveness of the use of photovoltaic solar technology for pumping water to improve the availability of water to buildings. While the specific objectives of the study are to identify and examine the types of pumps used in the Ile-Ife region; assess the factors influencing the adoption and the use of photovoltaic solar water pump, and examine the perception of stakeholders on the use of photovoltaic solar water pump for domestic water consumption.

2. LITERATURE REVIEW

2.1. Water availability and quality

The world is striving to meet the requirement of the 'Sustainable Development Goals' (SDGs) target on how groundwater supplies, energy, and other necessary resources can be improved to provide a sufficient amount of water needed for the use of householders amidst scarcity of water [22]. The rapid expansion of housing development over time has made public water provision not to be adequate in meeting the current demands of water by building occupants [23]. Given the expected urban population growth rates; and because of some climate change issues, groundwater expansion is considered as one of the preferred responses in areas of Africa where suitable aquifers are present [24]. There is no single and common definition of water quality because it depends on the intended use. However, different methods are used for determining water quality, and each measures a definite variable of water with different accompanying processes [25-26]. In most countries the quality of drinking water is subject to extensive quality standards, regulating the maximum allowable levels of contaminants.

2.2. Water distribution process

Nowadays, the water distribution system consists of methods that collect, treat, store, and distribute water from its various sources to different buildings where it will be consumed [27]. This is needed to distribute and deliver water to consumers with certified pressure, quality, and quantity. This demands to have an effective distribution system that comprises the facilities, such as pump and its accessories meant to supply water from its source to the point of usage [16]. The water pump lifting devices that are used to lift water to a level or height allow users to have easy access to water and make it to flow at an increased pressure [10]. Water available from wells or boreholes lifted for direct distribution or re-distribution to buildings and storage units uses pump facilities [28]. Pumps generally require power to work and it can come from the steam engine; diesel engine, gasoline engine; or electric motor and this helps to distribute water into buildings [29]. Solar energy has also evolved to generate electricity to power the motorized pumps and helps to distribute water into buildings [30].

2.3. Types of water pump

There are a large number of pumps meant for different uses and in different areas. According to [31, 27, 29], two types of pumps commonly used for water pumping are surface and submersible type They can also be seen in the aspect of centrifugal and helical rotor pump. The centrifugal pump uses centrifugal force to increase the velocity of the water. When water enters the pump, it transmits through the impeller unit and thus makes the water to spin. This further makes the water pick up the speed which transforms the required pressure, makes the water leave the pump facility, and be distributed [32, 28-29]. The centrifugal surface water pump is the most popular choice used where the water source is shallow or found above the pump while the maximum suction lift is limited by the atmospheric pressure. The centrifugal submersible pump is installed completely underwater where the motor and the pump are connected as a one-single unit. The type used in wells and boreholes are often long, narrow cylinder-shaped and installed vertically. This type of pump's singular benefit of not relying on external air pressure, makes it a better option, particularly where the water source is below the suction limit and high heads conditions are needed. Its core demerit is that it has disadvantages of access to it for maintenance when faulty [28].

2.4. Processes of powering a water pump

There are various means in which a pump can be powered based on the various types comprising a hand pump, diesel-powered pump, electric driven pump, and solar-powered pumping system. According to [33-34], a hand pump comprises a pumping arm, a piston or plunger, valves, pump rods, and pump cylinder. The arm is pumped by hand and drives the piston and pump rods up and down within the pump cylinder causing different valves positioned above and below the piston to open and close, depending on whether water is being pulled in or pushed up. The diesel or petrol-powered pump employs fuel to drive the water pump operation. So, the total cost of the system includes the fuel cost, the diesel/petrol units, the cost of replacements, and mechanical operation. Pumps driven by diesel or gasoline engines are utilized when larger volumes of water are needed and/or significant depths are involved. The principles of operation and maintenance are similar regardless of the mode. According to [35], a solar-electric powered water pump makes use of electricity by a photovoltaic process. This makes a pump to lift water from wells, boreholes and is further pumped into buildings and any specially located storage facilities. Photovoltaic is preferable where there are sufficient solar resource, moderate demand, and no access to the electric grid and does not produce noise, carbon emissions, and has low operational and maintenance costs [36]. Stand-alone photovoltaic systems (as opposed to grid-connected systems) usually rely on a set of back-up batteries for night time and outages.

3. RESEARCH METHODOLOGY

The study was carried out in Ile-Ife Region of Osun State, Nigeria. The study area, Ile-Ife, is an ancient city of Yoruba which is in the South-Western part of Nigeria. The city is located in the present day of the State of Osun. Ile-Ife is about 218 kilometres (135 miles) Northeast of Lagos which has a population of 509,813 [37]. Ile-Ife is governed by Obas with Ooni of Ife as the title. The city had a substantial size between the 12th and 14th centuries with houses featuring potsherd pavements. The main city of Ife is divided into two Local Government Areas: Ife East, with its headquarters at Oke-Ogbo and Ife Central with its secretariat at the Ajebandele area of the city. Both local governments are composed of a total of 21 political wards and they both have an estimated population of 355,813 people [38].

It is located at the coordinates; latitudes 7°31′N and 7°34′N and longitudes 4°30′E and 4°34′E as shown in Figure 1; and is situated on an elevation ranging between 240 metres and 270 metres above the sea level [37]. Ile-Ife is a rural area with settlements where agriculture is the native occupation of the residents. The city has an undulating terrain under-laid by metamorphic rocks and characterized by two types of soils, deep clay soils on the upper slopes and sandy soils on the lower parts. It has an average rainfall of 1,000 –1,250 mm (39–49 in) usually from March to October and a mean relative humidity of 75% to 100%. Ife is east of the city of Ibadan and connected to it through the Ife-Ibadan highway (Department of Geography, OAU, Ile-Ife). Ile-Ife is also 40 km (25 mi) from Osogbo and has road networks to other cities such as Ede, Ondo, and Ilesha. There is an Opa river which is a perennial stream that flows within Ile-Ife and serves as water supply to the Obafemi Awolowo University, Ile-Ife [39].

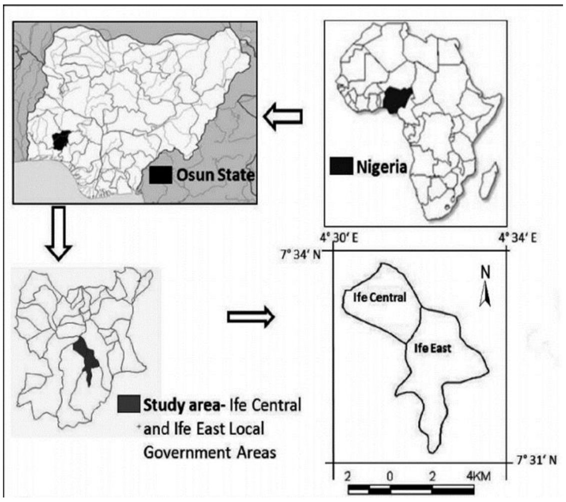

Fig. 1. Map showing Ife East and Ife Central Local Government Areas, Osun State of Ife, Nigeria [40].

Statistics usually provide the researcher with an array of methodologies to select the design of an efficient and cost-effective data collection scheme [41] and to provide answers to research problems, various research designs according to [42] are available. Hence, the survey research design was adopted by the use of the questionnaire to collect the data needed. The questionnaire was designed in a multiple-choice type on a 5-point Likert scale. Population study according to [43] is defined as the total number of persons, objects, or events whose behaviours are being studied. Thus, it defines the limit within which the research findings are applicable such that the result of the investigation is generalized into it. The study is designed to cover primarily, people living in Ife Central and Ife East Local Government Areas, Ile-Ife, and also part of the people living in the Area Office Council of Ife East, Modakeke. This is because; the two Local Governments form the blend of underdeveloped, developing, and developed residences. Therefore, the primary people of these areas are considered as the target population for this study.

The study area according to [44] is divided into 21 wards. The wards include Moore, Ilode I, Ilode II, Okerewe I, Okerewe II, Okerewe III, Yekemi, Modakeke I, Modakeke II, Modakeke III, Ilare I, Ilare II, Ilare III, Ilare IV, Iremo/Ajebandele, Iremo II (Eleyele), Iremo III, Iremo IV, Iremo V, Akarabata, Moore Ojaja. Purposive sampling method was used to select six areas in the study area where solar water pump facilities were installed. These areas are Ilare I, Iremo II (Eleyele), Moore Ojaja, Moore, Modakeke II, and Modakeke III respectively. Stratified random sampling was used to stratify the residential buildings in the selected areas into three, based on maximum proximity of 1000 metres to where the solar water pump was installed in the area. Therefore, buildings located within 300 metres to the point of installation of the solar water pump formed the first part of the stratum; those between 301-700m formed the second stratum while the third stratum formed consists of buildings within 701-1000m (Table 1). The choice of this stratification is based on the proximity of the residences to the solar water pump. The stratification enabled the study to determine the level at which the residents make use of the solar water pump as a means of getting water for domestic use. The systematic sampling method was further employed to select residential buildings from each stratum as one resident was chosen in a building for questionnaire administration. Twenty-five to Thirty houses as shown in Table 1 were selected in each ward for investigation and which informed the administration of 125 questionnaires on the respondents comprising 20, 15, 20, 30, 25, and 15 in Ilare I, Iremo II (Eleyele), Moore Ojaja, Moore, Modakeke II, Modakeke III respectively.

Table 1. Total number of selected buildings in the study area

Areas	0-300m	301-700m	701-1000m	Total No. of Sample
	Sample size			
Ilare I	5	7	8	20
IremoII (Eleyele)	3	5	7	15
Moore Ojaja	5	7	8	20
Moore	7	10	13	30
Modakeke I	5	7	13	25
Modakeke II	3	5	7	15
Total	28	41	56	125

3.1. Sources of data and analysis

The sources of data employed for this study were primary and secondary data respectively. The primary data was obtained through the use of a structured questionnaire that focused on issues relating to the quality of water supply, the type of distribution used, the type of pump used for lifting water, how reliable is the pump, the likely uses of the solar water pump, the factors that influenced the use of solar water and the perception of the stakeholders on the use of solar water pump. A face to face interview was also used to complement questionnaires that were administered on the respondents. The self-completion of the questionnaire method was adopted for this study where the respondents answered the questions by completing the questionnaire themselves and were interpreted if the respondent was illiterate with appreciable illustrations where necessary. The questionnaire was also framed in simple words that conveyed the exact meaning of all the words used. The secondary data was obtained from the review of related textbooks and any other publications on the effective use of the solar water pump. The data collected were analyzed with the use of both descriptive and inferential statistical methods.

4. RESULTS AND DISCUSSION

A total number of 125 questionnaires were administered, 120 were retrieved, and found useful for the analysis. The background information on the profile of the respondents shown in Table 2 indicates that the majority, (68.33%) of the respondents were females while males contributed to 31.67%. This is a fair representation of gender on the level by which water is collected for household use. About 35% of the respondents were between ages 20-29; 23.33% aged from 30-39 years, 12.5% were aged between 40-49 years, 17.5% were aged between 50-59 years, 5.83% were aged between 60-69, while 5.83% of the respondents were of age 70 and above. It was revealed that 45.83% of the respondents were married while 33.3% were single and 8.33% divorced or separated. This indicated that the use of water was mostly by the married individuals who are the majority living in buildings where the solar-powered borehole facilities were installed. It was also shown that 43.33% of the respondents had primary school leaving certificate, while 48% had a secondary school certificate, 16.67% had tertiary education while none of the respondents had no formal education. The indigene nature of the respondents indicated that 79.17% of the respondents were native of the study area while 20.83% are non-indigenes of the study area. This assisted majority of the respondents to have a deep understanding of the environment, the study area, while it was also obtained during the interview process that the non-indigenes have equally had a long period of stay in the area, which equally gave them the opportunity of the knowledge of events in the area. The Table also shows that 40% of the respondent lived in face-to-face (bungalow) building, 44.17% lived in face-face (storey building), 4.17% lived in flat (bungalow), 9.17% lived in flat (storey building) and a paltry 2.5% lived in duplex houses.

4.1. Preliminary assessment of the sources and availability of water consumed in the study area

Preliminary information on the nature, type, and uses of water available in the study area was carried out to determine the need to improve on the water to be supplied for the use of the building occupants. As depicted in Table 3, it was shown that tap water (83.33%), rainwater (83.33%), well water (79.17%) and sachet water are the common sources and types of water available for use in the study area. However, river water (12.50%) and stream water (8.33%) were less available, and this was justified as obtained during the interview process, on the ground that, there was no proximity of the respondents sampled to rivers and streams courses in the study area.

Table 2. Profile of respondents sampled in the study area

Gender Group of the Respondents in the Study Area		
Gender	Frequency	Percentage
Male	38	31.67
Female	82	68.33
Total	120	100.00
Age Group of the Respondents in the Study Area		
Gender	**Frequency**	**Percentage**
20-29	42	35.00
30-39	28	23.33
40-49	15	12.50
50-59	21	17.50
60-69	7	5.83
Above 70	7	5.83
Total	120	100.00
Marital Status of the Respondents in the Study Area		
Status	**Frequency**	**Percentage**
Married	55	45.83
Single	40	33.33
Widowed	15	12.50
Divorced/Separated	10	8.33
Total	120	100.00
Educational Qualifications of the Respondents		
Qualification	**Frequency**	**Percentage**
Primary	52	43.33
Secondary	48	40.00
Tertiary	20	16.67
No formal education	-	-
Total	120	100.00
Indigene Status of the Respondents		
Status	**Frequency**	**Percentage**
Yes	95	79.17
No	25	20.83
Total	120	100.00
Occupancy Status of the Respondents		
Status	**Frequency**	**Percentage**
Face to face (Bungalow)	48	40.00
Face to face (Storey Building)	53	44.17
Flat (Bungalow)	5	4.17
Flat (Storey Building)	11	9.17
Duplex	3	2.50
Total	120	100.00

The study sought to determine the overall satisfaction of the respondents with the general hub of sources of water available in the study area. As shown in Table 4, it was revealed that the majority (83.33%) of the respondents were satisfied with the quality of water gotten from the different sources of water in the study area while a paltry, 16.67% claimed that they were not satisfied. This helped to know if the quality of water sources in the study area is good enough and could pose a threat to the comfort and health of the building occupants. The differential level of satisfaction derived from the consumption of the different sources of water in the study area as shown through the ranking process in Table 5 revealed that borehole water had the highest level of satisfaction with a mean score of 4.20 followed by well water (4.12) while river water had the least level of satisfaction with a mean score of 2.0167. This was also attributed to its challenging proximity to the respondents sampled and the likelihood of having impurities in its raw form.

4.2. Assessment of the availability and use of water pumping facilities

From the fore-going on both bore-hole and well water as the most commonly available water sources that the building occupants in the study area depend on for consumption, it depicts the need to have facilities like the pump and its interrelated appurtenances to supply and distribute water in the buildings occupied by the respondents. It is shown in Table 6 that 73.33% (88) of the boreholes of the respondents used pumping facilities while 26.67% (32) did not have the pumping facilities system installed. It is indicated that a larger proportion of the respondents have the pumping facilities to facilitate water supply to buildings. It is shown in the Table that centrifugal submersible pump is the most commonly used type in the study area with 59.09% (52) response rate, while 40.91% (36) of the respondents used centrifugal surface pump and none used the helical rotor pump; as they claimed that they did not know of it. Furthermore, Table 7 indicated the performance level of the types of pumps used in the study area. It shows that the respondents were more satisfied with the performance of the centrifugal submersible pump with a mean score of 4.625 while the centrifugal surface pump had a lower mean score of 3.909.

In furtherance of the earlier results, Table 8 shows that either of the types of pumps used has been replaced, as 55% (66) of the respondents noted they replaced the pump every 10 years while 10% maintained that they replaced the pump every 5 years. However, 25% (30) indicated that they replaced the pump every two years while 7.5% maintained that their pump is replaced yearly. The remaining 2.5% (3) replaced the pump half a year to keep it in the optimal performance level. Generally, all these responses were found to be due to different performance levels of the installed pump facilities. The Table indicated the possible use of the photovoltaic facilities by the pumps installed in the study area. It is shown that about 93.33% (112) of the respondents claimed that their boreholes used photovoltaic facilities while a paltry figure, 6.67% noted that their water sources did not use photovoltaic facilities. It was also revealed in Table 8 that 60% of the solar water boreholes used in the study area were installed by the government at different tiers/levels, while 31.67% of the facilities were installed by individuals living in the study area, and 4.17% were installed by the Non-Governmental Organisations (NGOs). This implies that the tiers of government are the major organization that installed the solar water borehole for people in the study area.

Table 3. Sources of water available in the study area

Sources, Count (%)	Yes	No	Total
Tap source of water	100 (83.33)	20 (16.67)	120 (100.00)
Rain source of water	100 (83.33)	20 (16.67)	120 (100.00)
River water	15 (12.50)	105 (87.50)	120 (100.00)
Stream source of water	10 (8.33)	110 (91.67)	120 (100.00)
Well source of water	95 (79.17)	25 (20.83)	120 (100.00)
Borehole source of water	70 (58.33)	50 (41.67)	120 (100.00)
Sachet source of water	100 (83.33)	20 (16.67)	120 (100.00)

Table 4. Satisfaction on the sources of water available in the study area

Are you satisfied with the water gotten from the above?	Frequency	Percentage
Yes	100	83.33
No	20	16.67
Total	120	100

Table 5. Level of satisfaction derived from the available sources of water

Source of water	Mean	SD	Rank
Borehole water	4.2	1.1576	1
Well water	4.12	1.164	2
Sachet water	4.08	1.1121	3
Tap water	3.77	1.3886	4
Table water	3.517	1.2963	5
Rainwater	3.3917	1.3886	6
Stream water	2.35	1.3575	7
River water	2.0167	1.4684	8

Table 6. Availability and use of water pumping facilities

Does the Well/Borehole Used Have Pumping Facilities		
Description	Frequency	Percentage
Yes	88	73.33
No	32	26.67
Total	120	100.00
Type of Pumping Facilities Used		
Description	Frequency	Percentage
Centrifugal surface pump	36	40.91
Centrifugal submersible pump	52	59.09
Helical rotor pump	-	-
Total	120	100.00

Table 7. Level of performance of the pumping facilities used

Type of Pump	Mean	SD	Rank
Centrifugal submersible pump	4.625	0.4862	1
Centrifugal surface pump	3.909	1.3273	2

On the assessment of the type of solar-powered system used by the water pump in the study area, Table 8 shows that the respondents noted that that 47.5% of the borehole used 4-solar panels while 37.5% of the borehole used 5-solar panels. The other borehole used 3 and 2 solar panels which are 10% and 5% respectively. Equally, on the type of solar-powered system, it is shown in Table 8 that the battery coupled system with a 65% response rate is the major type of solar-powered system used, while 22.5% of respondents used the hybrid type solar-powered system and 12.5% used the direct-coupled system.

4.3. Factors affecting the adoption and use of photovoltaic solar water pump

The study also sought to determine the factors that might have affected the possible use of the photovoltaic solar water pump in the study area. The factors in the body of literature assessed were considered in assessing the indicators examined. The result shows that many of the respondents noted that consideration of technical know-how with a mean score of 4.1167 is the most significant factor why the photovoltaic solar water is being adopted and used as a measure to power the pump facility. It is because, often, its installation does not require extensive technicality and it also enjoins the availability of solar energy readily from the sun that is needed to power the panel. Other issues raised in the order of ranking were environmental factors (mean score of 3.9583) level of operations and maintenance (mean score of 3.7917) while the performance of the pump had the lowest mean score of 2.8583 and ranked the least (Table 9).

Table 8. Associated issues on the performance and use of the pumping facilities

How often is the Pump Replaced		
How Often	Frequency	Percentage
Half a year	12	10.00
Yearly	7	5.83
Every two years	10	8.33
Every five years	40	33.33
Every ten years	51	42.50
Never replaced it	-	-
Total	120	100.00
Does the Borehole/Pump Have Photovoltaic Facilities		
Does it have photovoltaic facilities	Frequency	Percentage
Yes	112	93.33
No	8	6.67
Total	120	100.00
Which Body Facilitated the Installation of the Photovoltaic Solar Water Pump		
Body	Frequency	Percentage
Government	72	60.00
Individual	38	31.67
NG.O	5	4.17
Community through donations	3	2.50
District assembly	2	1.67
Total	120	100.00
Number of Solar Panels Used by the Borehole		
Number	Frequency	Percentage
2	6	5.00
3	12	10.00
4	57	47.50
5	45	37.50
Total	120	100.00
Type of Solar Powered System of the Borehole		
Type	Frequency	Percentage
Direct-coupled system	15	12.50
Battery coupled system	78	65.00
Hybrid system	27	22.50
Others	-	-
Total	120	100.00

Table 9. Factors affecting the adoption and use of photovoltaic solar water pump

Factors	Mean	SD	Rank
Technical know-how	4.1167	1.124	1
Economic and environment factor	3.9583	1.148	2
Level of operations and maintenance	3.7917	1.377	3
Socio-cultural factor	3.5083	1.609	4
Performance of the pump	2.8583	1.1249	5

4.4. *Perception of stakeholders on issues associated with the use of photovoltaic solar water pump*

The study also assessed the likely perception of the respondents on the performance and use of the photovoltaic solar water pump in the study area because of different indicators extracted from the body of literature. As shown in Table 10, it was revealed that the most ranked benefit that the respondents obtained from their dependence on the photovoltaic solar water pump was the less time, spent in collecting water with a mean score value of 4.3583, cost of making the water available on the fuel or energy used with a mean score of 4.0667, while the reduction in the occurrence of water-borne diseases was rated least with a mean score of 3.4667.

Table 10. Perception of the respondents on the benefits derived from dependence on the use of photovoltaic solar water pump

Benefits	Mean	SD	Rank
Less time spent in collecting water	4.3583	0.9419	1
Lower cost of making the water available	4.0667	1.2816	2
Shorter distance from the water source	3.9333	1.2751	3
Enough water is available for domestic use	3.6833	1.2635	4
Reduction of water-borne diseases	3.4667	1.3530	5

Table 11. Complimentary issues associated with the use and performance of photovoltaic solar water pump

Issue of Theft and Vandalism		
Have you experienced theft/vandalism in the course of the use of solar water pump	Frequency	Percentage
Yes	58	48.33
No	62	51.67
Total	120	100.00
Measures Employed to Curb Theft and Vandalism		
Measures Employed	Frequency	Percentage
Employing the security guard	8	13.79
Construction of perimeter fence around the borehole	45	77.59
Community to stay at alert at night	5	8.62
Total	58	100.00
Problems Encountered During the Use of Solar Water Borehole		
Types of Problem	Frequency	Percentage
Failure of the pump	38	31.67
Bad weather	30	25.00
Theft	32	26.67
Vandalism	20	16.67
Inadequate water supply	-	-
Total	120	100.00

The other complimentary issues on the perception of the stakeholders on the availability and use of photovoltaic solar water pump comprising possibility of theft and vandalism cum any measures used to curb the menace and problems faced from the use of the facility were shown in this sub-section. Table 11 indicates that a lower proportion, 48.33% of the respondents had experienced cases of theft and vandalism of the facility and its complementary accessories at one time or the other; while a sparingly higher proportion, 51.67% had not had the experience. This indicates that a sizeable number of the solar water pumps used in the study area were fairly secured. The Table also reveals that 77.59% of respondents provided perimeter fence structure around the facility while 13.79% engaged services of the security guard. These were to ensure continuous supply and availability of water for different uses by the building occupants. Conclusively, Table 11 indicates that in ensuring the dependence of the respondents on the use of the solar-water pump, the greatest challenge faced was the failure of the pump (31.67%), theft (26.67%), bad weather (25.00%) and vandalism (16.67%) respectively.

5. CONCLUSION AND RECOMMENDATION

In the light of the myriad of challenges associated with the provision of tap water for the convenience and use of the building occupants in the study area by the government, various water sources such as wells and boreholes were significantly explored as alternatives for the quantitative and qualitative supply of water by the respondents. The wells and boreholes that were mostly used inevitably deserved the installation of pumping facilities to ensure the availability of water indoor for the use of the occupants. The study shows that the photovoltaic solar water pump is an effective facility that can be used to provide water for the occupants of buildings particularly in settlements where there is a poor supply of electricity and generally in areas, where there is an advantage of tropical environmental conditions with the abundance of sunlight. It shows that different operating factors such as technical know-how, economic and environmental factor amongst others influenced the use of the photovoltaic solar water pump; while the stakeholders also had varying levels of benefits derived from its adoption. The study also indicates that in the course of the use of the facility, various operational faults and challenges were faced and these were addressed with relevant strategies to ensure continuous use of the facility, supply, and distribution of water to be consumed by the building occupants. Based on the results of the study, there is a need to take good advantage of the tropical environment of the study area, so that any photovoltaic solar water pump to be installed must have a satisfactory number of solar panels that would have the required capacity to drive its efficient operation. This would help to drastically reduce, the likely impact of much dependence on the national grid to power facilities and appliances used in buildings. There is a need for the financiers or donors and the users, to jointly ensure its due use by ensuring that tight security provisions are made to safeguard the photovoltaic water pump facility from misuse and vandalism as may be applicable.

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REVIEW ARTICLE

A review on promising strategy to decrease sludge production: Oxic-settling-anoxic/anaerobic process

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ABSTRACT

Recently, as environmental regulation for the removal of nutrients and excess sludge produced through wastewater treatment has become more restricted, many wastewater treatment plants face serious challenges in terms of waste production. Nowadays, the issue of excess sludge production has received considerable critical attention. Recent developments in sludge treatment technologies have heightened the need for more promising strategies to reduce sludge levels in a cost-effective and environmentally friendly manner. The purpose of this paper is to review recent research into the oxic-settling-anaerobic/anoxic (OSA) technology for sludge minimization. The OSA process is a modification of a conventional activated sludge system with the addition of interchange bioreactor parallel to recycled activated sludge line. The OSA process seems to be a revolutionary and cost-effective alternative for sludge reduction approach in the future. It is hoped that this research will contribute to a deeper understanding of the OSA process in terms of sludge reduction efficiency, carbon and nutrient removal, operational parameters, possible reduction mechanisms and microbial community changes after the implementation of the OSA system and applied in the treatment of real wastewater at full-scale.

Keywords: Activated sludge, OSA process, sludge reduction

1. INTRODUCTION

In addition to demographic growth and increased sludge generation in sewage facilities, considerable attention has been paid to sludge management and new sludge reduction technologies developed in recent years to minimize sludge production in wastewater treatment plants (WWTPs). Sewage sludge arises as a by-product of wastewater treatment. The increase of the annual sewage sludge worldwide production is expecting to exceed 13 million tons of Dried Solids (DS) in 2020 [1]. As has been previously reported in the literature, European Union targets to reduce final waste disposal by 50% by the year 2050 comparing it to the amount of the sludge to be wasted in 2000 [2]. Treatment and disposal of excess sludge require significant amounts of energy and chemical agents, which result in significant increases in the carbon footprint and resource consumption of the wastewater treatment process [3]. The waste sludge treatment and disposal represent one of the major operating costs in a WWTP, which can vary depending on local conditions and size of the treatment plant. It is well known that land use of sewage sludge can greatly reduce the cost of disposal of sludge, but because it can contain high concentrations of metals, pathogens and trace organic pollutants and due to restricted land usage, tightening goals have been set to reduce landfilling [4]. For instance, Europe, North America, and East Asia are the main sludge producers in the world. The previous study by Kelessidis and Stasinakis [1] has emphasized that the European Union alone is generating around 50 million tons of sewage sludge annually. Moreover, Turkey has the most wasteful residents in Europe, actively disposing 32.3 million tons of household and industrial waste straight into landfills, therefore national waste management strategies should be improved and strengthened to protect environmental and human health. For example, as there are many health and environmental issues presented by landfill waste, land application as the major route for the use of sewage sludge has now been banned in several countries (Germany, Netherlands).

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Various technologies can be applied in the wastewater treatment chain to reduce net partition of carbon in sludge, including physical (mechanical, thermal, electrical), chemical (adding oxidizer or uncoupler) [5], [6], and biological (with bacterial predator) [7] methods. A major issue of these processes is the high cost that should be very precisely considered during the implementation of one of these technologies. Even though anaerobic digestion is the most commonly used sludge stabilization method, it is generally limited by the poor biodegradability of waste activated sludge [8].

As the amount of excess sludge produced continues to rise throughout the world and has become a major problem for many wastewater treatment plants, a new approach is needed to develop more promising strategies to reduce sludge levels in a cost-effective and environmentally friendly manner. Minimization of sludge production in the wastewater treatment is better than the post-treatment of the sludge produced to solve sludge-associated problems [9]. An ideal approach to overcoming the excess sludge problems would be to reduce excess sludge in existing wastewater treatment plants. One of the possible solutions to create a feasible engineering approach to this problem is the modification of a conventional activated sludge process – an oxic-settling - anoxic/anaerobic process (OSA). Although this process was firstly discovered in 1964 by Westgarth et al. [10] it can be considered as new technology as we know from the recent laboratory-scale works and a few full- scale applications in the United States of America and only one in Turkey. Commercially OSA process is called the Cannibal process. As an example, the sludge reduction is up to 80 % in Rock Springs WWTP (USA) [11], in Oak Lodge Sanitary District (USA) the plant with a capacity of 40000 m^3 d^{-1} reduces sludge production by 65% [12] with Cannibal implementation. This process, in which Siemens Water Technologies' system of OSA is used (Inegöl, Turkey), the amount of excess sludge is also significantly reduced. This revolutionary technology reduces excess sludge in a significant way, offers great saving possibilities based on operational cost aspects in the wastewater treatment plant, has a simple design, flexible operation and presents no risk to the environment. From an engineering perspective, sludge can be substantially reduced with minimal management process configuration in the conventional activated sludge process.

The goal of this research study is to develop a more rigorous understanding of a new technique - oxic-settling-anoxic/anaerobic (OSA) process, that significantly minimizes the amount of produced sludge from municipal/industrial wastewaters. Starting with a description of the oxic-settling-anaerobic/anoxic process (OSA), following by operating parameters influencing the performance, different explanations for the sludge reduction mechanisms that are still very unclear between the researchers, pollutant removal, and microbial community is going to be presented in this review paper. This paper ends with directions for the research that must be considered in the future.

2. CONCEPT OF OSA PROCESS

The OSA process is a modification of a conventional activated sludge system with the addition of interchange bioreactor parallel to recycled activated sludge line. In this system solids that would be normally wasted from the conventional system are sent to anaerobic/anoxic sludge interchange bioreactor inserted in the return activated sludge loop to minimize sludge generation and increase process reliability as shown in Fig.1.

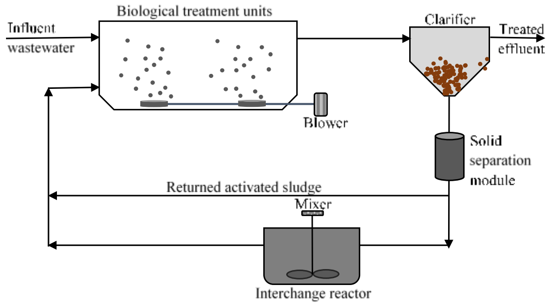

Fig 1. Schematic representation of OSA process

Once sludge is settled, a required volume of it is being sent to interchange anaerobic/anoxic reactor and held under a unique conditioning environment (no oxygen and substrate supply) for specified detention of time. Because there is no oxygen supply in the interchange reactor, the conditions can range from anoxic to anaerobic. The same volume of sludge is then recirculated back to the main aerobic bioreactor. Normally about 50% of return activated sludge passes through solid separation unit (containing ultra-fine mesh screens and hydrocyclones) in full-scale Cannibal process to remove grit, trash, and inert solids content. This content typically constitutes up 20% to 25% of the mixed liquor solids. OSA cycles equal volume of sludge between rich conditions (aeration tank) and deficient (external anoxic/anaerobic reactor/s) in oxygen and substrate [13]. During this process, greater solids destruction is achieved as the overall observed biomass yield is reduced.

There have been various configurations of OSA applications including the attachment of interchange bioreactor to the main conventional activated sludge (CAS) [21], [33], membrane (MBR) [14] or sequencing batch reactors (SBR) [19], [34] reactors presented in the literature. SBR-OSA configuration has advantages over the CAS-OSA or MBR-OSA applications due to the lower space requirement in the waterline due to the absence of the secondary settling and the intermittent sludge cycling.

2.1. The potential of the OSA process in terms of observed sludge yield

Many researchers use the observed yield (Fig. 2), and it has been recognized as an effective marker for sludge reduction [14]-[19].

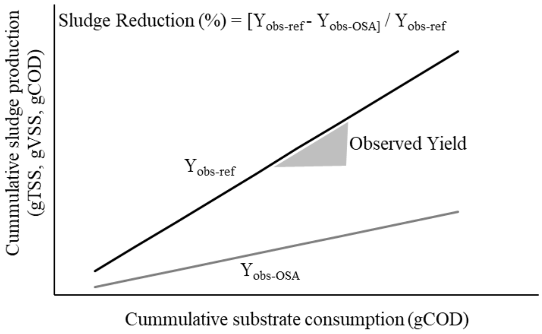

Fig 2. Determination of observed yield

Observed yield is a ratio of the amount of biomass produced to the amount of substrate consumed [20]. The slope of the linear regression is used to determine Y_{obs}, then the ratio of observed sludge yield values of reference and OSA systems are used to calculate sludge reduction using the equation below:

$$Sludge\ reduction(\%) = \frac{Y_{obs-ref} - Y_{obs-OSA}}{Y_{obs-ref}} \times 100 \qquad (1)$$

Previous studies have emphasized, that application of the OSA process can reduce solids up to 87% more than the conventional activated sludge process [14], [21]-[25]. For instance, the following study conducted by Chudoba et al. [22] demonstrated that observed yield in the SBR-OSA system was 3 times lower, which resulted in 60% less biosolids production compared to SBR. This view has also been supported by Novak et al. [21], who reported observed yield in OSA system to be lower (0.13 to 0.29 gVSS/gCOD) than that in a conventional activated sludge process (0.28 to 0.47 gVSS/gCOD) and achieved 39% of sludge reduction of sludge yield. Comparative research by Ye et al. [23] showed biosolids reduction of 14–33% with shorter sludge age (5.5-11.5h) compared to ones applied in the study of Saby et al. [14]. In 2010, Semblante et al. [25] by increasing sludge cycling from once to four times in a day, reported a sludge reduction of 53-77%, whereas Semblante et al. [25] noted that sludge yield of OSA system was 24.8% lower than in reference system without any $FeCl_2$ addition to the systems at a sludge age of 10 days. Other observations indicated that sludge yield can be reduced up to 87% in the OSA system (SRT=10 days) when the highest tested ferric iron concentration of 16.05 mg L^{-1} was present in the influent [26]. In the study of Rodriguez-Perez and Fermoso [27], the OSA system (SRT=14 days) achieved a 51.7% reduction of sludge yield, reducing the excess sludge production by 52.9% compared with the control system.

However, previous studies mentioned above can only be considered the first step towards a more profound understanding of the OSA process, because these studies reported the feasibility of an OSA process related to synthetic wastewater. This has been previously assessed only to a very limited extent because synthetic wastewater strongly differs from real wastewater due to the lack of inert organics and non-volatile solids. Recently, there has been a slight increase in studies focusing on the OSA process using real wastewater. Coma et al. [28] obtained a maximum reduction of 18.3% of the observed yield treating the whole sludge return line treating real wastewater in a UCT pilot plant. For instance, 35% of sludge reduction at the sludge age of 20 days was achieved by using real wastewater by reference [18] and his co-workers. Vitanza et al. [29] evaluated 16 months of performance of an OSA pilot plant fed with real municipal wastewater. The observed yield varied between 0.112 and 0.465 gTSS/gCOD, showing that the excess sludge reduction due to the insertion of the sludge holding tank was 49.6 ± 20.7% compared to the conventional CAS system. Apart from this, a recent study by Karlikanovaite-Balikci and Yagci [19] evaluated simultaneous sludge reduction and in an oxic-settling-anoxic (OSA) system fed with real domestic wastewater at different sludge ages. The greatest corresponding sludge reduction was achieved as 58% operated at an interchange ratio of 7.7% (1/13) in the OSA system. Recent work by Sodhi et al. [30] demonstrated the mechanism of excess sludge disruption from real tannery wastewater feed. The oxic-settling anaerobic coupled conventional activated sludge configuration confirmed around 52% of bio-sludge reduction. These results demonstrate a strong effect of the use of real wastewater, since it is more complex, therefore it showed lower sludge reduction compared with a study including synthetic wastewater (Table 1).

No less important is the manipulation of operational parameters that have a very strong impact on OSA process optimization and performance in terms of solid destruction and pollutant removal.

2.2. Carbon and nutrient removal efficiency in the OSA process

The OSA process has an impact not only on reducing sludge but also on carbon and nutrients removal (Table 1). Unfortunately, a lot of wastewater treatment plants do not meet the discharge requirements of 10 mg TN and 1-2mg/L TP and are facing real problems because of tighter discharge regulations. Simultaneous nutrient removal and excess sludge in biological wastewater treatment processes are closely related to the microbial population composition in treatment processes [31]. Most studies indicated that the phase of OSA does not adversely affect the removal of COD and total nitrogen performance [19], [30], [32], [33]. For example, data from the 2019 study by Karlikanovaite-Balikci and Yagci [19] showed that efficiency in the removal of nitrogen was approximately the same in SBR and SBR-OSA control systems with a slightly smaller concentration of oxidized nitrogen in the OSA process. The efficiency in COD removal was around 85% in CAS systems and slightly higher in OSA systems, approximately 90%. The findings are consistent with findings of past studies by Datta et al. [32], where ammonia (100%) and phosphorus (90%) removal efficiencies were found to be nearly the same as in control system and as in [30] in which COD removal efficiencies were very close in control An-CAS and CAS-OSA systems and slightly higher TN removal in CAS-OSA (74%) compared to An-CAS (81%) was found. Khursheed et al. [34] and Ye et al. [23] have also found nearly equal efficiencies in terms of COD and TN removal.

Table 1. The operating conditions and the removal of pollutants in OSA applications

Process	Wastewater type	SRT (d) in the whole system	ORP (mV)	Temperature (°C)	IR (%)	Y_{obs}	Sludge reduction (%)	COD removal (%)	TN removal (%)	TP removal (%)	Reference
CAS-OSA	synthetic	5 12	-250	18±5 20±2	100	0.21 gTSS/gCOD 0.25 gTSS/gCOD	50% no reduction	82-99	n.a	19-42[5]	Chudoba et al.,1992
MBR-OSA	synthetic	19.5 25.9 30.4	+100 -100 -250	20	100	0.29 gTSS/gCOD 0.21 gTSS/gCOD 0.17 gTSS/gCOD	28 48 58	93-98	n.a	28-63[5]	Saby et al., 2003
SBR-OSA	synthetic	80	n.a	20	10 7 4	0.11gVSS/COD 0.15 gVSS/gCOD 0.21 gVSS/gCOD	60	96-97	n.a	n.a	Novak et al., 2007
CAS-OSA	urban	37-406	-248±133	11.5-27.7	n.a	0.112- 0.465gTSS/gCOD	49.7±20.7	84.9	63.8 ± 11.4[1]	5.1[4]	Vitanza et al., 2019
CAS-OSA	synthetic	n.a	-128±10	25±5	200	0.20 gTSS/gCOD	51.7	n.a	n.a	n.a	Rodrigues-Perez et al, 2016
SBR-OSA	synthetic	n.a	n.a	n.a	12.5 25 37.5 50	0.193-0.267 gVSS/gCOD	3-51	96.4-96.9	70.9-80.6[1]	42.6-76.1[4]	Khursheed et al., 2015
SBR-OSA	a mixture of urban and glucose	n.a	n.a	20	7.7 5.9 5	0.104 gVSS/gCOD 0.117gVSS/gCOD 0.111gVSS/gCOD	52 37 35	90.95 90.18 88.64	85.2[1] 90.4[1] 92.1[1]	n.a	Karlikanovaite and Yagci, 2019
CAS - OSA	urban	60	-150 to -100	n.a	100	0.212 gTSS/gCOD	30.4	85	88[1] 51.4[1]	33.6[4]	Zhou et al., 2015
SBR-OSA	synthetic	n.a	n.a	20	10	0.08 gVSS/gCOD 0.13 gVSS/gCOD 0.23 gVSS/gCOD 0.05 gVSS/gCOD	38 – 87	n.a	n.a	n.a	Yagci et al., 2015
CAS-OSA	synthetic	n.a	n.a	25 ±1	100	n.a	14-33	91	28-30[1]	49-58[4]	Ye et al., 2008
SBR-OSA	synthetic	100	n.a	n.a	10	0.17 gTSS/gCOD	63	-	100[2]	90[5]	Datta et al., 2009
CAS-OSA	synthetic	n.a	n.a	15-35	100 50	0.25 gTSS/gCOD 0.10 gTSS/gCOD	45-80	70-99	50-85[3]	60[5]	Corsino et al., 2020
CAS-OSA	industrial	23-36	-246 and +72	n.a	12-15	0.42-0.87 gVSS/gCOD	40.2-52.3	91.7	81[1]	n.a	Sodhi et al., 2020

[1] TN removal; [2] NH3-N removal; [3] NH_4-N removal; [4] TP removal; [5] PO_4-P removal

However, Saby et al. [14] observed smaller COD concentrations in the effluent of the OSA system stating that the insertion of anoxic tank favors higher COD removal. Zhou et al. [33] and Cantekin et al. [35] also clarified that due to more carbon source present, a high COD/N ratio resulted in greater TN removal output in OSA systems compared to control system. The presence of higher temperatures in the anoxic/anaerobic interchange reactor also can improve COD removal efficiency [36].

In regards to phosphorus removal, Chudoba et al. [21] pointed out that phosphate removal in the OSA type system could not be expected to exceed 50%. At the same time, Vitanza et al. [29] also found phosphorus removal at very low rate 5.1 % whereas [33] also reported phosphorus removal to be lower in A+OSA (33.6%) than in the control system (43.9%). Temperatures over 30°C also lowers the metabolic activity of PAO [38], therefore no PO_4-P release was observed in the anaerobic reactor and PO_4-P removal entirely due to the heterotrophic biomass synthesis resulted in poor removal efficiency close to 60% throughout experiments in the study carried out by [36]. This view is also supported by Corsino et al. [36] who stated that SBR-OSA should not be considered a good candidate for phosphorus removal. These findings suggest that, in general, the addition of interchange bioreactor to recycled activated sludge line can worsen phosphorus removal. On the other hand, these studies cannot be considered as conclusive because further evidence against [21], may lie in the findings of [34], who reported TP removal to be 76.1% and 30% higher than control reactor, when recirculation ratio was increased from 0 to 6.4 and then to 8.2gVSSrecycled/gVSS present at average C/P ratio around 50. Phosphorus removal enhancement (48-58%) over the control reactor (48. 9%) was also noticed in the study of [23] with higher substrate loading.

More information on the OSA effect on phosphorus removal would help us to establish a greater degree of accuracy on this matter. A better understanding of optimization of operational conditions that could enhance phosphorus removal needs to be developed in the future.

2.3. *Operational parameters associated with OSA efficiency*

Sludge interchange ratio

The sludge interchange ratio (IR) is defined to be a critical key design parameter, which strongly influences the sludge reduction mechanism and operational costs. Sludge interchange rate is the number of volumetric interchanges per day between the main and interchange (OSA) reactor.

Many studies ([22], [24], [26], [38]-[40]) applied the interchange ratio of 10% of biomass per day for OSA process, which was defined as the most optimal by Novak et al. [22]. Sun et al. [24] achieved an enhanced sludge reduction (from 53% to 77%) by increasing the frequency of return from once per day to four times per day while maintaining the IR between an SBR and an external anaerobic reactor at 10%. Semblante et al. [18] investigated the impact of IR on sludge reduction by the OSA process using unsettled and settled sewage. IR was varied from 0% to 22% and showed the highest sludge yield reduction (53%) in OSA-SBR comparing to reference SBR at an IR of 11%. Conceptually similar work has also been carried out by [19] in which it was found out that IR of 8% was the most optimum level resulting in 58% sludge reduction treating real domestic sewage. IRs of 5.9% and 5% revealed lower sludge reduction of 37% and 35%, respectively. This study seems to validate the view that IR of 8%, which is lower than in most studies with 10% IR, is an excellent fit for the OSA process thereby more cost-efficient. Although the above investigations examined the effect of IR varying 0%-22%, and mostly 10%, few studies ([23], [33] and 50% [36]) in the literature systematically used IR of 100%. According to Zhou et al. [33], 30.4% of sludge reduction was observed when IR was 100%, whereas 14%-33% sludge reduction was found by Ye et al. [23] and 80% was observed in Corsino et al.'s [36] study, where OSA process was combined with thermal treatment. In our view, a lot of interesting results have been reported regarding IR and this operational parameter should still be of central importance, as it is very uncertain if 10% of IR is the most optimal one.

Redox potential

Oxidation-reduction potential (ORP) is a measure of the ability of the solution to oxidize or reduce another solution. It is a widely used parameter for the on-line monitoring of characteristics reflecting many chemical and biological oxidation processes [41]. In biological wastewater treatment systems, it is often necessary to know the ORP of the various treatment basins to optimize the system. Redox potentials of less than −150 mV indicate anaerobic environments, while values greater than 100 mV indicate aerobic environments [42]. It has been suggested that the ORP level below -100 mV stimulates excess sludge reduction in the anaerobic/anoxic tank [43]. A study investigating the ORP effect on sludge reduction in the OSA process has been carried out by [14]. Authors have applied +100mV, -100mV and -250 mV of ORP values. Anaerobic ORP value of -250mV resulted in the lowest Y_{obs} value of 0.18 gMLSS/gCOD. Sludge reduction in the OSA system can be explained by sludge decay, which is accelerated effectively under low oxidation–-reduction potentials (ORP) in the anoxic/anaerobic tank [14]. Li et al. [44] suggested that proper regulation of ORP from -120 to – 250 mV can effectively reduce sludge by 30-60%. The findings by [16] are in contrast with the previous studies where two ranges of ORP were established for an equal period: firstly, from -400mV to -200 mV and secondly, from -200 to +50mV. Despite prior shreds of evidence, this study resulted that alternation redox conditions from anoxic and anaerobic caused remarkable low observed growth yield of 0.13 kgTSS/kgCOD, which was 45% lower from the yield of 0.24 kgTSS/kgCOD found by [21] and 27% lower than the one (0.18 kgTSS/kgCOD) found by [14] where ORP of -250 was kept constant. A research finding by [18] also pointed out that intermediate ORP range (-50 mV) can facilitate sludge reduction.

Therefore, it is reasonable to expect that alternation anoxic and anaerobic phases are more favorable than ORP at a certain value.

Sludge retention time

Sludge retention time is also another very important key parameter affecting the efficiency of sludge reduction in the main and the interchange OSA bioreactors. The sludge age of the system is defined as the SRT of the main reactor. The sludge retention time in the anaerobic/anoxic reactor depends on the volume fraction interchanged between the main reactor and side-stream reactor and not associated with the total SRT of the system [19]. Semblante et al. [13] reported the sludge yield values as a function of SRT. The same researcher and his colleagues in 2016, determined the effect of SRTs varying from 10 to 40 days on OSA interchange bioreactor. Novak et al. [22] operated an SBR-OSA configuration with an SRT nearly 80 days, achieving a 60% percent reduction in sludge, but also stated that the solid loss in the SBR-OSA system was not due to the high SRT of the entire system. It has conclusively been shown that SRT varying from 10-20 days favored the destruction of the solid whereas SRT of 40 days was not effective in terms of sludge reduction. SRT of 20 days showed the highest sludge minimization with more than 35%. It is consistent with literature stating that employing long SRT in biological wastewater treatment systems can negatively impact the aerobic digestibility of activated sludge by increasing the fraction of non-biodegradable sludge [45]. The study carried out by [14] concentrated on the influence of sludge age in the MBR-OSA reactor interchange over a period of 11.1-17.4d. and there was a 23–58% drop in excess sludge compared to the MBR control system. Ye et al. [23] tested different values of SRT (of 5.5 h, 7.6 h, and 11.5 h) in the ASSR and contrasted the CAS-OSA system's Y_{obs} with a CAS control system. The lowest sludge production was achieved with HRT of 7.6 h.

Temperature

Most processes of biological wastewater treatment are temperature sensitive and higher process temperatures are more effective in reducing sludge. Temperature can influence the overall rate of hydrolysis in the reactions [46] and the increase in temperature allows for greater biomass activity. However, studies on temperature effects on the OSA process are rare to find in literature. Most of the experimental studies regarding OSA process were operated under room temperature [22], [26], [28], [29], [35]. The recent study [36] explored the impact of temperature on sludge stabilization, where the OSA process was coupled with thermic treatment at moderate temperature (35°C) resulting in high sludge reduction (80%), as well as improving sludge settling properties. Realizing the gap in the extant literature, more research is needed for exploring temperature levels and its' impact on the OSA sludge reduction process.

3. POTENTIAL SLUDGE REDUCTION CAUSES IN OSA PROCESS

The mechanisms of this biological sludge reduction method remain unclear. The key mechanism that induces sludge reduction in the OSA process remains highly controversial among researchers in the current literature. The mechanisms involved in reducing sludge yield are linked to uncoupling metabolism, enhanced endogenous decay, the domination of slow-growing microorganisms and destruction of EPS [13].

3.1. Enhanced biomass endogenous decay

Conventionally endogenous decay is used to account for the cell biomass loss that is due to the oxidation of internally stored products for energy, cell death, and predation [20]. The endogenous decay phenomena result in the release of free energy from the biomass which itself becomes substrate [47]. Biomass is concentrated when it is recycled from the clarifier which contributes to the starvation, death, and lysis of some microorganisms therefore starved conditions that encourage cannibalism are created.

Karlikanovaite-Balikci and Yagci [48] used a modified version of the ASM1 model to compare and stoichiometric and kinetic coefficients with control systems to investigate the key mechanism contributing to sludge reduction in OSA systems. After a series of respirometric tests and model calibration results, it was found that the decay rate was the most vital kinetic parameter showing a significant increase after introducing the side-stream reactor into a conventional activated sludge system. The higher sludge decay coefficient in the anoxic/anaerobic OSA system suggests that low sludge production in the OSA system was due to the increased sludge decay rate in the anoxic/anaerobic OSA tank. Moreover, since not all biomass present in the reactor is active biomass, the active biomass ratio in the control SBR reactor was found to be around 75%, whereas in the side-stream reactor it was nearly twice lower. All the findings have brought a point that the OSA process is encouraging endogenous decay, ultimately decreases the viability of the biomass in the reactor and ensures excess sludge reduction in the system. This is supported by [43] who also evaluated four different (energy uncoupling, the domination of slow growers, soluble microbial products (SMPs) effect and sludge decay) possible scenarios for sludge reduction mechanism responsible for sludge reduction in MBR - OSA process. They compared the number of total bacteria and respiring bacteria before and after anaerobic treatment. The main findings from this study indicated that active biomass was reduced by sludge decay processes and it was determined to be the main cause of the sludge reduction. This kinetic coefficient was observed to be accelerating in the MBR- OSA interchange bioreactor under ORP levels lower than -100mV. Wang et al. [49] showed that cell decay contributed to 66.7% of sludge reduction in the OSA process.

3.2. Uncoupling metabolism/spilling

Energy uncoupling/spilling is characterized as a discrepancy in the energy balance between catabolism and anabolism [15]. Uncoupling metabolism can be accomplished by different methods: by the addition of chemical uncouplers [50]-[52], high S_0/X_0 [53] or oxic-settling-anoxic/anaerobic (OSA) process [43]. Ye and Li [51] investigated the potential of the oxic-settling-anoxic (OSA) process with the addition of 3,3,4,5-tetrachloro salicyl anilide (TCS) to reduce excess sludge production. Although a higher dosage of TCS resulted in a higher reduction rate of excess sludge production. 3,3,4,5-tetrachloro salicyl anilide is proven to be xenobiotic organic matter and toxic to the microorganism and environment therefore it should be used with caution. Low sludge production can be achieved with a high S_0/X_0 ratio, but in this case, additional treatment of organic pollutants would be required to meet effluent discharges.

Cycling from anoxic/anaerobic to an aerobic environment, microorganisms are exposed to stress conditions, facilitating the uncoupling of catabolism and anabolism [54]. The uncoupling approach is to improve the energy difference (ATP) between catabolism and anabolism to limit energy supply to anabolism. Consequently, the obtained growth yield of biomass is decreased therefore when the energy uncoupling takes place. Consumption energy for anabolism without decreasing the removal efficiency of organic pollutants in biological wastewater treatment may accordingly supply a direct method for minimizing sludge generation [55]. The phenomenon of uncoupling metabolism in CAS- OSA systems was detected by [49] although it was not significant (7.5%). With the same objective, Chen et al. [43] performed numerical experiments on possible sludge reduction mechanisms and concluded that energy uncoupling was not the case leading to sludge minimization.

3.3. Domination of slow-growing organisms

Few authors have controversial views as to whether slow-growing bacteria could influence the process of sludge reduction. Slow growth rate and high maintenance energy requirement can result in low biomass yield. The early study by [21] stated that around 60% of the total bacterial population was low yield having PAOs (phosphorus accumulating organisms) in the CAS-OSA system. However, interestingly, this is contrary to a study conducted by [43], who studied the mechanism of selection of slow growers and reported that sludge reduction cannot be due to slow growers' dominance.

3.4. Destruction of EPS

A complementary sludge fraction to the active cellular biomass is the extracellular polymeric substances (EPS). Extracellular polymeric substances (EPS) are a complex mixture of high molecular weight polymers, consisting of protein, polysaccharides, humic acids, lipids, and nucleic acids [56], [57] that serve as the structural framework of sludge flocs. Among them, 70%–80% of EPSs are proteins and polysaccharides [58]. The structural framework of EPS is responsible for intercellular adhesion, communication, and propagation. EPS provides physical protection from bactericides and physical stresses [59]. For instance, it is proposed that the destruction of extracellular polymeric substances (EPS) under anaerobic conditions eventually lead to sludge reduction [60]. The remnants of EPS could also serve as a substrate in the aerobic reactor, which further minimizes sludge yield [55]. In that case, EPS destruction and aerobic endogenous decay contribute to sludge reduction. The mechanism of EPS degradation is unclear, but the findings of [61] showed that the addition of α-amylase and β-glucanase improved the hydrolysis of EPS, which led to floc destruction [62]. Extracellular enzymes could play an important role in the degradation of particulate biomass and especially for EPS degradation since hydrolysis of particulate organic matter is usually the rate-limiting step in sludge degradation processes [22].

Some research offer suggestions that sludge reduction in sludge cycling schemes is rooted in the anaerobically-driven degradation of EPS into smaller forms, which are easily degraded when sludge is recycled back to the aerobic reactor [22]. Analysis of protein concentration and OUR tests on control and OSA systems was carried out by [22] resulting in higher OUR profiles in the OSA system due to higher content of readily biodegradable material.

As being a possible explanation of sludge reduction in MBR-OSA system, effects of soluble microbial products (SMP) which are a soluble portion of EPS was also studied by [43] and it was concluded that SMPs could not be the reason of sludge reduction due to no variations in $Y_{s}/_{x}$ found between the MBR-OSA and CAS systems.

Novak et al. [22] also showed moderate concentrations of soluble proteins (81 mg L^{-1}) in an anaerobic SSR. However, the estimation of EPS solubilization rate in the anaerobic SSR based on the soluble protein measurement is very unprecise, because the concentration of proteins is affected not only by the solubilization process but also by transformation and transportation processes. Sludge degradation extent under anaerobic conditions was increased for increased ratios of iron/sodium [60]. Park and Novak [63] showed that EPS extractible with base, thus presumably EPS attached to iron, were more solubilized than other EPS fractions during anaerobic digestion.

4. VARIATION OF MICROBIAL CULTURE POPULATION IN OSA PROCESS

Various specific molecular methodologies have been applied to document and compare the microbial culture structure and population dynamics in control and OSA process systems [21], [26], [33] , [36], [64], [65]. Microbial communities can be strongly affected by diverse factors [66]. Alternating anoxic/anaerobic and aerobic environments play an important role in microbial community composition and shifts. The first serious discussion and analyses of microbial community emerged during the 1990s when [21] stated that OSA biomass contained 50-60% polyphosphate-accumulating bacteria. Despite prior evidence, a decade later, in 2003, [43] pointed out that slow-growing bacteria may not be the reason for solid destruction in the OSA process. In 2015, [33] and co-workers applied 454-high throughput pyrosequencing to investigate microbial community structure in A+OSA and AO systems. They identified that *Proteobacteria, Bacteroidetes, Chloroflexi, Planctomycetes*, and *Actinobacteria* were the dominant phyla. During this research, that has conclusively been shown that classes such as *Anaerolineae* and *Actinobacteria* played a major part in sludge minimization in the A+OSA process. Similarly, using the DGGE fingerprint technique it was shown that *Proteobacteria* and *Bacteroidetes* species were the most abundant in the OSA process [66]. The finding is consistent with findings of the later study by [64] using Next Generation Sequencing (NGS) of bacterial 16S rRNA gene amplicons, which showed that *Proteobacteria, Actinobacteria, Bacteroidetes,* and *Chloroflexi* were also predominant phyla in OSA systems in which their proportions in the microbial community distinguished due to the different IRs applied during the operation period. But surprisingly, *Thiotrichaceae* (phylum: *Proteobacteria*) species were not detected in the seed sludge sample, the majority of the total sequences were represented by *Thiotrichaceae* at the family level in all OSA systems and the genus level, *Thiothrix* was the predominant one. *Thiothrix* species are filamentous bacteria usually found in wastewater treatment plants associated with bulking problems, but during this study bulking problems were not faced. The dominance of *Thiotrix* species possibly could be caused by glucose addition to the influence of real domestic wastewater. A study carried out by [25] determined the microbial community structure in $SBR_{control}$ and SBR_{OSA} systems conducting Illumina sequencing analysis. *Proteobacteria, Bacteroidetes* was the most dominant phylum and *γ-*, *β-*, and *α-Proteobacteria*, *Sphingobaceriia* as the predominant classes in both systems. Predatory (e.g., orders *Myxobacteriales* and *Bdellovibrio*), fermentative (e.g., orders *OP8, Firmicutes, WS3*, and *Spirochaetae*) and hydrolyzing (e.g., phyla *Bacteroidetes* and *Chloroflexi*) bacteria enriched in SBR_{osa} reactors. This observation indicated that these bacterial species were very likely responsible for lower sludge production. *Proteobacteria* members can contribute to release intracellular compounds and then *Bacteroidetes* may use the secondary substrate produced by those species for hydrolytic fermentation to boost their abundance [67].

Moreover, during the OSA process sludge settleability is improved [14]. Rodriguez-Perez and Fermoso [27] investigated the impact of the OSA process on protozoa diversity and filamentous bacteria. Based on the results, while the increase in floc-forming bacteria was detected in the control reactor, there was none in the OSA process. The study has shown that an improvement in a decrease in protozoa diversity, stable development of filamentous bacteria and better sludge settling can be achieved by the OSA process. Corsino et al. [36] investigated the feasibility of couple a of conventional OSA process with a thermic treatment at moderate temperature using acetate-based synthetic wastewater. When the OSA process was operated at room temperature, the amount of filamentous bacteria *Thiothrix* and *Type 0914* significantly increased compared to seed sludge. When the temperature was increased to 35°C, the amount of these types of bacteria was significantly suppressed and better sludge settling properties detected.

5. CONCLUSIONS

The study has gone some way towards enhancing our understanding of sludge reduction by simply modifying a conventional activated sludge system with the insertion of interchange bioreactor into a sludge return line. To summarise, this review paper has shown the overall performance of the OSA program from various aspects: sludge reduction, pollutant removal, microbial population changes and dominance, operational parameters associated with OSA efficiency and future research directions. The OSA process seems to be a revolutionary and cost-effective alternative for sludge reduction approach in the future. There are only a few real full-scale applications right now in the World and limited data in the literature, future research must be undertaken to understand the mechanism and modeling of the process using real wastewater. Besides, the fate and removal efficiencies of some pollutants such as nitrogen, phosphate, and sulfate are needed to be investigated. The information provided in this paper could be helpful for evaluating different possibilities for the realization and management of a wastewater treatment plant's entire strategy, in estimating costs and besides, environmental impacts and benefits.

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BOOK REVIEW

Resilient Water Services and Systems: The Foundation of Well-Being

by Petri Juuti, Harri Mattila, Riikka Rajala, Klaas Schwartz, Chad Staddon, (Eds.), 2019
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The concept of resilience has been in focus of the international community for about 25 years, although the obvious need for it has been indirectly addressed by societies since the birth of larger cities, maybe starting with Rome 2400 years ago. When man was forced to sustain all needs based on subsistence, resilience equalled survival. But with the growth of more complex resource sharing in a money-based economy, the dependence on others to survive and even thrive became obvious. Since water is essential for life, a functional and resilient water service in society is central for the function of it. When writing this review, the world experiences a pandemic challenge from the SARS Covid – 19 viruses. The first recommendation from WHO to reduce infection risk is to wash your hands with soap and water regularly. This presupposes access to safe and clean water. The water service is as always essential for life.

In the book Resilient Water Services and Systems: The Foundation of Well-Being, edited by Petri Juuti, Harri Mattila, Riikka Rajala, Klaas Schwartz and Chad Staddon, researchers and scholars from several universities and countries have contributed with 15 chapters on what constitutes a resilient water services and system (WSS), how the water sector in urban areas has developed the last 150 years and what measures are needed in terms of policy development, organisation and technology to guarantee the sustainability of the WSS in the future. The book consists of an introduction, 13 case studies from Africa, Asia, Europe and North and South America presenting perspectives of resilience from around the world, and a concluding chapter of what the book highlights as essential for WSS to offer resilience in practice. The chapters can be read independently, but to gain full understanding of how resilience in the WSS can be interpreted and achieved, I would recommend the reader to enjoy all chapters as in-depth reading.

The etymology of resilience is from Latin re- (back) and salire (jump). The physical meaning of the word as an action or an act of rebounding or springing back; rebound, recoil, seems to have been in use at least since the seventeenth century. The Oxford English Dictionary lists another three meanings of resilient, where the last is the robustness or adaptability for a person or an organization to recover quickly or easily from, or resist being affected by, a misfortune, shock, illness, or similar events. The word in this meaning has been used in written form in English since at least 1857. This latter meaning is the most common meaning when discussing resilience in the WSS.

When reading the 13 case studies, it becomes clear how different countries and traditions have emphasised different aspects of resilience work. Examples from Finland, the Netherlands and Sweden illustrate a close link between WSS resilience and civil defence contingency and emergency planning. Another, more actor-centred approach, discusses the general need for organisations and individuals to engage in cross-boundary collaborations and by-pass traditional silo-based structures to enhance resilience in the WSS. The ability and capacity of staff and organisations are key parameters for long-term provision of safe and reliable water services. The need for policies and mandates from directors and managers to work with resilience in organisations are also emphasised.

Public institutions, such as municipalities, own 90% of the urban water utilities, 95% of the wastewater and close to 100% of stormwater systems in the world. The role of the municipality in the resilience planning and implementation must be explored and must not be omitted. Several of the chapters discuss the need to enter an age of replacement when the service lifetime of the underground water infrastructure, the pipes and pumping stations, reach their endpoints.

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I think the book deserves to be summarised to a 10 pages executive summary for the ministries of the world responsible for national water planning. When all countries which can afford it now announces large and previously unseen subsidies to the contracting economy during the Covid-19 pandemic period, it is timely for the municipalities to invite governments to launch re-investment programmes for the water sector and suggest a 10-year period for measures in network refurbishments.

What is not emphasised in the book is the economic value of WSS. This is trivial, but for decision makers, the money will always matter, and an additional chapter on the value of a sustainable WSS and the alternative costs for societies when the WSS does not function, could be relevant to add in the second edition of this book.

I recommend both scholars and practitioners to read the book and discuss its message broadly. Historic and contemporary evidence are presented in a concise and clear way supporting the fact that resilience in the WSS is central for a functioning society. It is important at present and will be increasingly relevant in the coming decades.