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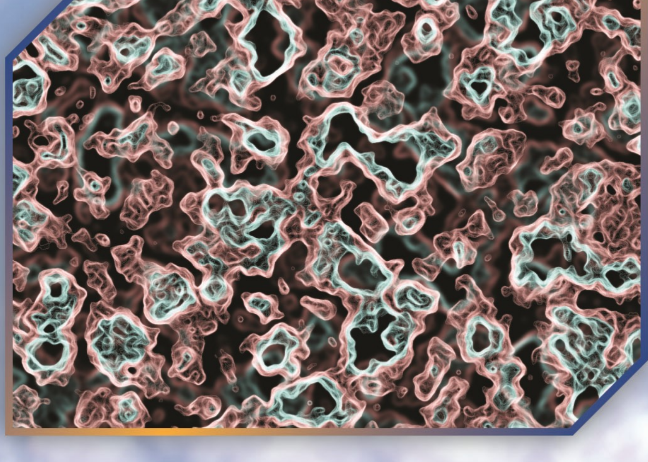

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TABLE OF CONTENTS

Environmental Research & Technology, Vol. 4 (2), pp. 102-107, 2021

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RESEARCH ARTICLE

The state of the art of nuclear energy and its bibliometric analysis

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ABSTRACT

Nuclear power plants, which started to be used in the military field in the 19th century, began to be used in electricity generation due to the oil crisis and increasing electricity need. It has many advantages as well as some disadvantages. Commonly used fossil, hydraulic, wind and solar energy systems likewise have both advantages and disadvantages. The emission of nuclear radiation is the most important risk. If there is no radiation emission, it will cause a less bad impact even if an accident happens. Also, waste management will be easier. With the development of technology, the production of new generation reactors can ensure that some disadvantages are eliminated or minimized. When looking at the studies carried out in WOS, studies on nuclear energy are related to environmental issues (waste management and occupational health). However, more studies should be carried out on two problems (waste management and occupational health) that are important in the operation of nuclear power plants.

Keywords: Advantages, bibliometric analysis, disadvantages, nuclear energy, waste management

1. INTRODUCTION

Nuclear power plants started with the discovery of uranium at the end of the 19th century and are a technology developed and used primarily in the military field. As the infrastructure developed, the high heat energy generated as a result of fission reactions started to be converted into electrical energy. Especially after the oil crisis in the 1970s, interest in nuclear energy has increased. Today, 8.1% of the electricity needs are met in more than 30 countries with nuclear power plants operating over 440. The USA (99), France (58) and Japan (42) are the countries with the most nuclear power plants. Turkey is continuing the construction of nuclear power plants in Sinop and Mersin. It is planned to be built in Kirklareli. Nuclear energy is a method that provides high electrical energy. For example, all of Turkey's electricity can be provided with 26 nuclear power plants and is a technology that requires less space than conventional alternatives. In addition, the amount of waste and emission generated is low. Except that the investment costs of nuclear power plants are high and waste management is difficult, the possibility of being used as a nuclear weapon in the future decreases the confidence in technology. However, despite its negative aspects, it is a technology that continues to be built due to its advantages. Research studies are related to both reactor design and waste management. But especially the accidents in the past (Three Mile Island in the USA in 1979, Chernobyl in the Soviet Union in 1986, Tokai-mura in Japan in 1999, and Fukushima in Japan in 2011) make this technology difficult to accept by the public. In addition, an issue that makes this technology difficult to be desired by the public is waste management. These two issues have caused some countries to abandon the installation of nuclear power plants or to extend the construction period. Despite its negative aspects, various research studies are still being conducted [1].

The aim of this study is to consider the positive and negative aspects of nuclear energy and to compare it with the most widely used power plants. In addition, to present a bibliometric analysis of studies conducted with nuclear energy.

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2. NUCLEAR ENERGY

Nuclear energy is formed as a result of the reaction that takes place between atoms. The first use of nuclear reactors was in 1942. Reactors were first used for military vehicles, submarines, and ships, then began to be used for commercial, power/electricity generation and educational-research purposes. Commercial reactors are divided into two groups as fast and thermal. Thermal reactors are mostly used. Reactors are divided into 3 groups according to whether or not enrichment is made in terms of fuel. The most used reactors in the world are light-water reactors (pressurized water reactor and boiling water reactor). Pressurized water reactor is the most widely used reactor. Its operating conditions are 15 MPa pressure and 320◦C temperature. In these reactors, uranium fuel is enriched by 3-5% and water is used as a retarder/coolant [2]. The fuels used in nuclear power generation are mainly uranium, thorium and plutonium. Uranium and thorium occur naturally, while plutonium is artificially produced from uranium. Plutonium is also a nuclear weapon. Uranium is found in high amounts in Australia, Kazakhstan and Canada. Thorium is highly available in India, Brazil, Australia, and the USA [2].

Nuclear power plants are similar to thermal power plants. The steam formed in both power plants is converted into electrical energy by means of tribunes and generators. The main difference between the two power plants is the way steam is obtained. A nuclear reactor consists mainly of fuel, retarder (moderator), cooler, control rods, reflector, reactor heart (core, boiler heart) and protector [3].

As a result of nuclear energy generation, waste that must be managed is created. Radioactive wastes are found in solid, liquid and gaseous forms. Safe management of nuclear waste; It consists of collection, separation, packaging, conditioning (concentration, solidification, compression, incineration), intermediate storage, transportation, long-term storage and/or disposal. The wastes generated are grouped according to their radioactivity content as very low, low, medium and high levels. Very low-level wastes are the group with activity concentrations less than about 100 times the clearance limits, and disposal of these wastes can be carried out in surface disposal facilities. Low (400-4000 Bq g^{-1}) and medium level wastes can be disposed of in near-surface, medium and deep disposal facilities depending on their radionuclide content. Low and medium level wastes are stored in an abrasion resistant, safe and sheltered structure. High-level wastes are disposed of only in deep disposal facilities. Small volume low and medium level wastes can be disposed of well type, while high level wastes cannot be disposed of well type. Wastes (gas or liquid) below the emission limit to the environment can be released directly into the environment. The volumes of low level solid wastes are reduced by compression and incineration methods, while the volumes of liquid wastes are reduced by evaporation and drying. It is then stored properly and kept waiting to reduce the radioactivity. High level wastes are stored either by dry/wet storage or after vitrification. Continuous control is required in dry or wet storage methods. Vitrification method is a difficult and costly option [2]. Countries such as France, Germany, England, Russia, Canada and Japan have active recycling facilities. Recycled plutonium is a nuclear weapon material. The acquisition of nuclear weapon material is a threat to the world [2].

In nuclear power plants, radiation is mostly emitted from radioactive waste and nuclear equipment rooms. Emitted radiation is a serious danger to human and environmental health. Regular radiation monitoring in reactor, storage units etc. should be done. Mladenov et al. [4] stated that radioactive waste management is technically difficult but can be managed more easily when there is sufficient funding and professional management behavior.

In addition to providing a sustainable electricity source, nuclear power plants will also produce new generation reactors with the rapid development of technology [5]. Of course, the development of the nuclear industry may be slow due to the public reaction. However, necessary support must be provided and qualified personnel must be trained to design, build and operate nuclear reactors. Nuclear energy that has no carbon emissions is a cheap and technologically advanced alternative. Today, 2nd and 3rd generation reactors are operated. 3+. Generation has begun to be used. With the development of 4th generation reactors, or the use of fusion reactors rather than fission, it would be a more attractive alternative. Fusion reactors prevent nuclear weapon.

It is the occurrence of accidents that have a serious impact on the slow development of the nuclear industry [6]. Of course, it is natural for the public to be anxious because of accidents. However, when the literature was searched, it was concluded that accidents occurred as a result of some measures that were not taken or natural disasters such as earthquakes. For example, while the reactors did not have a protective shell in the Chernobyl accident, the Fukushima accident was due to the earthquake. One of the reasons why the earthquake has a great impact is that some reactors do not have refrigerators.

Yes, there is risk. There is nothing in life without risk. Driving, flying, etc. is also a risk. Perhaps the biggest disadvantage of nuclear power plants is that it affects large areas, including where the system is located. But if we think in terms of Turkey, many of our neighboring countries are used nuclear reactors. Many countries have focused on developing their economy and producing their energy needs cheaply without considering this risk. For this reason, it is an alternative to be preferred to reduce its dependence on foreign development and meet the electricity needs of Turkey. Only good management, business plans should be created and qualified personnel should be trained. Nuclear power plants can be dangerous if not managed well and safely from the site selection process to the final stage [7].

The advantages and disadvantages of nuclear power plants are given below:

Advantages;

•It does not cause global climate change [8],

•Approximately 2 million times more energy is produced compared to fossil fuels,

•Less solid waste (300 thousand times by mass) is produced compared to fossil fuels

•Uranium is found in many countries (100-year reserve),

•It has no polluting effects on the environment during normal operation,

•Using less fuel compared to fossil fuels [9],

•Requiring approximately 3.5 times less space compared to thermal power plants,

•It can be operated day and night, regardless of climatic conditions,

•Not affected by fluctuations in fuel prices,

•Has a long operating life

•It can be reused after the radioactivity of the generated waste decreases [10],

•Risk of accident is very low due to the security measures taken.

•Its construction is cheaper than hydroelectric power plants.

•Provides stable energy production throughout the year [11, 12].

Disadvantages;

•Radiation emission harms the environment and people,

•Management is difficult and expensive due to the radiation contained in solid waste [13],

•The storage period of wastes is long and the need for space can be high [14],

•Plutonium produced artificially or as a result of the operation of a nuclear plant can be used as a nuclear weapon,

•More than 50% of the public do not accept it,

•Accidents with serious impact have occurred,

•Having high investment cost [12].

3. NUCLEAR ENERGY VS. OTHER ENERGY SOURCES

The main renewable energy sources used in addition to fossil fuels (coal and natural gas) are hydraulics, wind and solar. Nuclear energy is not a renewable energy source. However, as a result of the reaction, water vapor and H_2 are formed. So there is no greenhouse gas effect. Mainly used energy sources were compared in terms of different criteria (Table 1).

While 7.8×10^{13} J kg^{-1} of energy is released as a result of the burning of uranium used in nuclear energy production, 5×10^{7} J kg^{-1} of energy in fossil fuels is released. In other words, 1.5×10^{6} times more energy is produced from nuclear fuel compared to fossil fuels [17]. When nuclear and thermal power plants are compared in terms of fuel cost and waste amount, a nuclear power plant is both a cheaper and more environmentally friendly method. For a 1000 MW power plant, 25 tons of fuel are required annually for nuclear power generation and 1 ton of vitrified waste is produced annually. In thermal power plants, 3 million tons of fuel are required annually, 7 million tons of gas such as CO_2 and H_2S are emitted and 150-200 thousand tons of solid waste are generated [2]. In other words, 1 ton of uranium is equivalent to burning 16000 tons of coal or 80000 barrels of oil [18].

Energy generation costs are decreasing rapidly due to constantly evolving technologies, economies of scale, competitive supply chains, and increasing developer experience. This is valid for fast-growing alternatives. For example, the costs of solar and wind energy production decreased by 82% and 39% in 2019 compared to 2010, respectively [19]. In the 2020-2050 projection study, while no significant change is expected in the cost of nuclear (79-78 \$ (MWh)$^{-1}$) and coal (71-68 \$ (MWh)$^{-1}$) energy alternatives, it was predicted that there will be a decrease in the cost of solar (51-37 \$ (MWh)$^{-1}$) and wind (39-28 \$ (MWh)$^{-1}$) [19]. Installed capacity (2010-2020) and electric generation (2010-2018) data for renewable energy alternatives used both in the world and in Turkey is shown in Fig 1 [19]. As the installed capacity for all alternatives increased worldwide, electricity generation has also increased. In Turkey, there has been a rapid increase in production in all alternatives, especially solar energy, except hydropower.

Nuclear energy plants should also be established in areas with few fault lines, such as coasts, rivers and lakes. Hydroelectric power is reliable and cheap. However, it is insufficient to meet all energy needs. The yield varies according to the seasons and cannot be installed everywhere. Wind and solar energy are also weather dependent and are not stable alternatives.

In nuclear power plants, technology is constantly improving and safety is increasing. But radiation emissions, fatal accidents have not yet been completely minimized. Although it is a clean and highly efficient energy source, it seriously affects the wide area in a long time for case of an accident. But, according to the statistics obtained from the World Health Organization and other sources, it is seen that approximately 4000 times more people die per unit of energy produced compared to nuclear energy in energy production from coal [8].

4. BIBLIOMETRIC ANALYSIS ABOUT NUCLEAR ENERGY

When Fig 2 is examined, the number of studies on nuclear energy has increased every year. Studies on nuclear energy started in 1975. Until today (20/07/2020) 105505 studies have been carried out. These studies were carried out mainly in the USA, Germany, China, Japan, and France. Environmental studies have been carried out since 1980. 3096 environmental studies have been carried out so far. The top five countries in which environmental studies are carried out are America, England, Germany, Japan and France. 815 of environmental studies are related to occupational health. Studies on occupational health were also carried out by the same countries (USA, France, Japan, England, Germany). The first study about occupational health was carried out in 1980 in the USA. The number of studies that include the words nuclear energy and waste management as a topic in Web of Science (WOS) is 894. 30% of the studies were carried out in the USA. Other top five countries are France, Germany, England, and Japan. The first study was carried out in 1990 in England.

As can be seen in Fig 3, studies have been carried out on many issues. The most intensive studies are related to nuclear science technology, environmental sciences, and energy fuels [20].

Table 1. Nuclear energy vs. other commonly used energy sources [15*, 16]

Criteria	Nuclear	Fossil-Coal	Solar	Geothermal	Wind-Onshore	Hydraulic
Source	Local/Foreign	Local/Foreign	Local	Local	Local	Local
Carbon neutral	Yes	No	Yes	Yes	Yes	Yes
Dispatch	Baseload	Baseload	Intermittent	Baseload	Intermittent	Baseload
Efficiency	High	Medium	Low	Low	Low	Low
Environmtental impacts	High	High	Low	Low	Low	Low
Occupational heath and safety	High	Medium	Low	Low	Low	Low
Pollution	Low	Very high	Low	Low	Very low	Very low
Capacity factor (%)	90-91	66-83	39-68	85-90	38-55	-
Fuel cost ($ $(MMBtu)^{-1}$)	0.85	1.45	-	-	-	-
Total capital cost ($ kW^{-1})	6900-12200	3000-6250	6000-9100	3950-6600	1100-1500	1900-2600*
Fixed O&M cost ($ kW^{-1} yr^{-1})	108.5-133	40.8-81.8	75-80	0	28-36.5	-
Variable O&M cost ($ $(MWh)^{-1}$)	3.5-4.25	2.75-50	-	24-34	-	-
2017 capacity (GW)	11	70	98	-	52	19

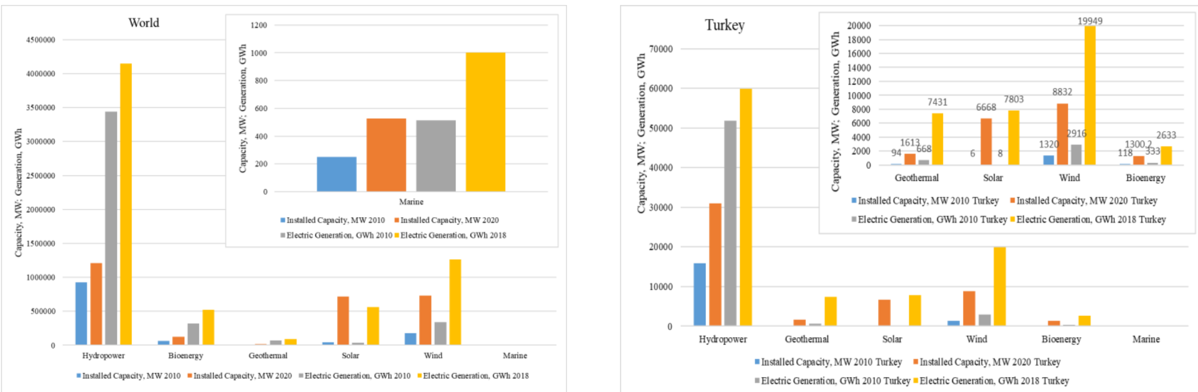

Fig 1. Installed capacity (2010-2020) and electric generation (2010-2018) for renewable energy alternatives used both in the world and in Turkey [19]

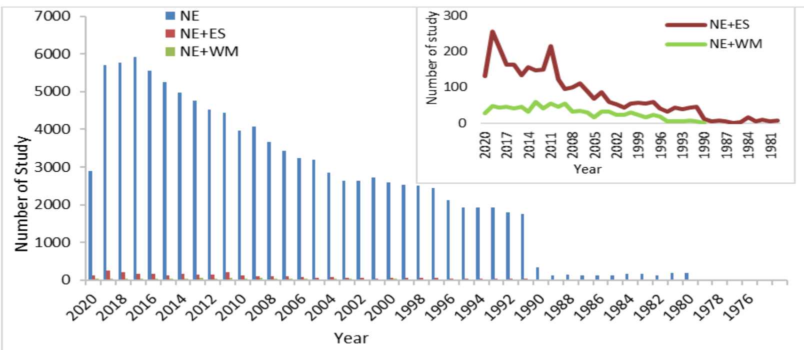

Fig 2. Bibliometric analysis on nuclear energy

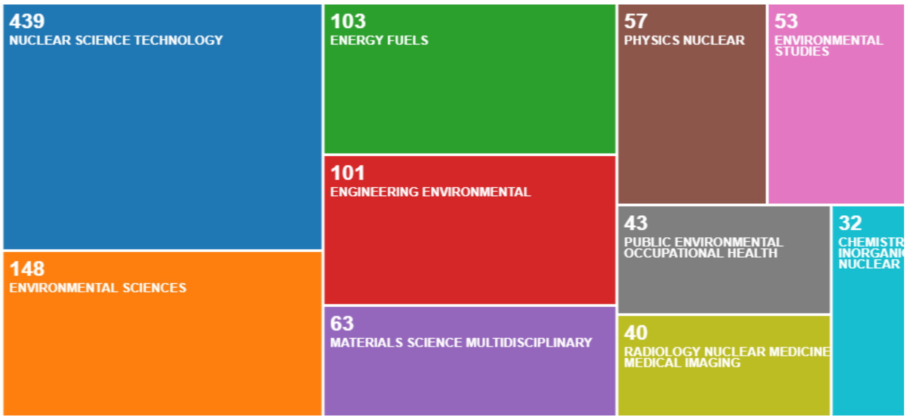

Fig 3. WOS categories in studies on nuclear energy and waste management

5. CONCLUSION AND EVALUATION

Nuclear power is an attractive source of electricity production. However, it is an energy generation system that must be operated with high precautions. It is a technology that can be used for electrical energy production, except that it is not used as a nuclear weapon. Various studies should also be carried out to optimize the negative effects of radiation emissions and waste management. Considering the bibliometric analysis results, it can be said that more attention should be paid to waste management and work safety issues. It is an alternative that can be preferred in terms of reducing dependence on oil and natural gas, reducing greenhouse gas, helping to solve the electrical energy problem, and helping the economy to develop.

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RESEARCH ARTICLE

Recycling of cotton dust for organic farming is a pivotal replacement of chemical fertilizers by composting and its quality analysis

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ABSTRACT

Improper management of cotton dust wastes creates environmental pollution as well as different health problems. Cotton dust waste contains important nutrient elements that can meet the need for micronutrients of crop plants that will be a potential replacement of chemical fertilizers. In this study, it was to produce the cotton dust for further utilization as compost plant raw materials and analyzed and compared various parameters in different maturity days. The cotton dust was produced in compost with different combinations with different materials (cotton dust ash, rice bran, rice bran ash, Urea) by composting pit method. It was analyzed for a wide range of parameters including heavy metals and compared with standard compost parameters. The C:N ratio varies from 18:1 to 58:1 within forty days and 17:1 to 37:1 within fifty days and 17:1 to 31:1 within sixty days. The other specification such as physical condition, color, pH, N(%), P(%), K(%), S(%), were within the standard limits. Therefore, the result of the study suggested, for forty, fifty, and sixty days matured compost, samples 1,3,4,5, samples 1,2,4,5, and samples 1,2,3,5 respectively could be used in the agriculture land for cultivation to reduce the harmful effect of chemical fertilizer in the land. The cotton dust samples 2,3,4 respectively, for forty, fifty, and sixty days should be avoided for a higher value of the C:N ratio. This information could be beneficial for the practical application of cotton dust in agriculture in Bangladesh and can be a sustainable solution in textile spinning pollution.

Keywords: Cotton waste, composting, environmental pollution, waste recycling

1. INTRODUCTION

Bangladesh is an agricultural country, where industrialization is taking place in a gradually increasing phase. Alamin [1] reported that in Bangladesh the important industries are textiles, leather training, fertilizer manufacturing, sugar manufacturing, chemical, pharmaceutical, oil refining, etc. Among these, textile industries are rapidly expanding day by day. There are 394 textile spinning units are established with 9.6 mL. Spindle, 0.23 mL. Rotor and their production capacity are 2000 million Kgs and wastage generation is 20 million kgs, which are polluting the environment by their wastage [2]. The spinning waste management system is not well defined and these wastes are not commercially usable [3]. The open air is polluted by this micro dust and these wastes are using for cooking and burning. As a consequence, the users of this wastage are suffered from different lung diseases as the air is polluted by excess smoke during burning [4]. Sometimes huge amounts of these wastes are dumped in open places that pollute the environment by mixing its micro dust in the open air at a 5% probability level [5]. It is within the range of acceptable limit of the coefficient of variability which is the degree of precision with which the treatments were compared. Users of this waste are suffering from byssinosis which is an acute occupational lung disease often observed among workers exposed to cotton dust [6, 7]. Cotton dust can cause some severe respiratory responses which include chest tightness and bronchoconstriction [8].

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Exposure to cotton dust can also be the cause of non-specific respiratory symptoms, decreasing lung function, and increasing airway responsiveness [9]. The agricultural sector of Bangladesh is destroyed day by day due to the damage friability of our land, the high price of fertilizer, and the polluted environment [10]. Our farmers use more chemical fertilizer for the faster growth of crops and vegetables [11]. But they are not concerned with the hazardous effect of chemical fertilizer on land and the environment. As a result, they can get high production from their land for short time but they can damage their land for the future. Monro [12] stated chemical fertilizers provide short term results yet in the long term damage the soil, groundwater, and our health. The compost fertilizer overcomes the hazardous effect of chemical fertilizer. Compost contains a full spectrum of essential nutrients for plant growth. Although Compost is not a fertilizer, it is a growing medium when used as an amendment to existing soil intended to improve the overall fertility and tilth of the soil [13]. Compost should be analyzed for its nutrient content prior to use so that nutrient levels can be identified and the compost used in the right application [14]. A large amount of cotton spinning wastes is generated in Bangladesh due to a large number of textile industries [15]. The cotton waste contains micro-dust comprises 50-80% fiber fragments, leaf and husk fragments, 10-25 % sand and earth, and 10-25 % water-soluble materials. The high proportion of fiber fragments indicates that a large part of the micro-dust arises in the course of processing. Nearly about 40 % of the micro dust is free between the fibers and flocks, 20-30 % is loosely bound, and the remaining 20-30 % bound to the fibers it has been demonstrated by Kumar [16]. So, this is a great scope to use this unusable waste as compost and solve the spinning waste management problem and also minimize the environmental pollution from chemical fertilizer use. As well as minimize the use of chemical fertilizer and save our land and provide the compost fertilizer to the farmers at low cost and use the non-usable spinning wastes. This research work focuses on developing composting of cotton dust and its quality analysis.

Cotton can be recycled from pre-consumers (post-industrial) and post-consumer cotton waste [17]. Discarded textile products are common source for post-consumers wastes like used apparel and home textiles. During recycling process, the cotton wastes is first sorted by type and color and then processed through stripping machines that break the yarns and fabric into smaller pieces before pulling them apart into fiber [18]. Virgin cotton is often mixed with recycled cotton to improve yarn strength [19]. Since waste cotton is often already dyed, re-dyeing may not be necessary, not more than 30% recycled cotton content is used in the finished yarn or fabric. Cotton is an extremely resource-intense crop in terms of water, pesticides and insecticides, so recycled cotton can lead to significant savings of natural resources and reduce pollution from agriculture [20]. 765 m^3 (202,000 US gal) of water can be saved by one ton of cotton recycling. Two scenarios are also chosen for recycling is incineration and landfill, and subsequently, additional two cases of incineration and landfill but with applied eco-paths are considered in order to assess the environmental improvements of the process [18].

Combining recycle cotton and plastic bottles to make clothing and textiles, creating sustainable, earth-conscious products [21]. Recycled cotton can also be used in industrial settings as polishing and wiper clothes and processing of high-quality paper. Applications like seat stuffing or home and automotive insulation, cotton can be reused. Additionally, cotton waste can be made into a stronger, more durable paper than traditional wood-pulp-based paper, which may contain a high concentration of acids.

2. MATERIALS AND METHOD

2.1. Selection of factory

Since Gazipur is a large industrial area it was convenient to have an industry in the Gazipur zone. In consideration of distance from the compost plant and the availability of raw cotton waste, Gazipur will be the feasible choice. Cotton dust was collected from Matin Limited, Kashimpur, a spinning mill which is situated near Savar, Gazipur, because of only 18 Km distance from the composting plant (Fig 1).

Fig 1. Location of Matin Spinning Mills Limited (Source: Google Earth)

2.2. Samples collection and preservation

120 kg of cotton dust samples were collected in four larger size plastic bags. Each bag contains 30kg cotton dust as in Fig 2, which were carried by a mini truck. To improve the quality of compost various materials were mixed with the cotton dust with a different combination, such materials as cotton spinning wastage ash, rice bran, rice bran ash, and Urea as in Fig 3.

2.3. Construction of shade on composting area

A composting shade was constructed in an open place which is shown in Fig 4. The size of the composting shade was 15'×10'. To protect the composting process from rainwater, the edge of the composting area was elevated of height 6 inches so that no rainwater comes into the shaded area.

2.4. Preparation of composting pit

For running's the composting process, composting pits were made. There were five composting pits. The size of each composting pit was 2'×2'×2' as shown in Fig 5. The longitudinal clear space between the two pits was 1.5' and the transverse clear space between the two pits was 2'.

2.5. composition of different prepared compost samples

Five samples were taken with the different ratios of cotton waste, cotton waste ash, rice bran, rice bran ash, and urea to develop the compost quality. The different combinations of composts are given in Table 1.

Fig 2. Collected cotton dust in plastic bags

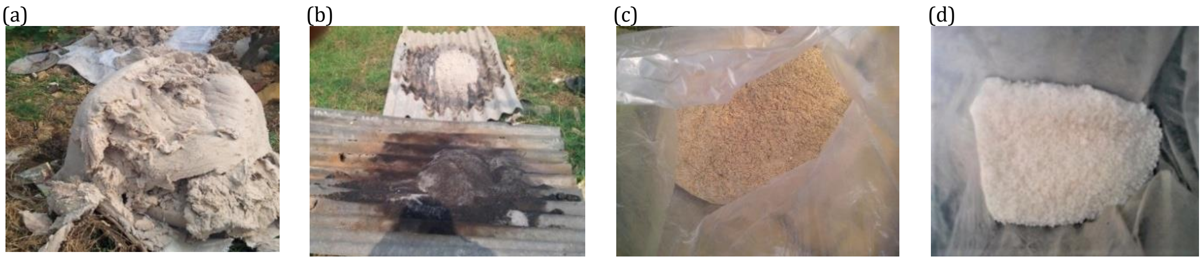

Fig 3. Collection of (a) cotton dust, (b) cotton and rice bran ash, (c) rice bran and (d) urea

Fig 4. Preparation of shade on the composting area

Fig 5. Preparation of composting pit

Table 1. Different combinations of compost samples

Sample No.	Cotton spinning dust in Kg	Cotton spinning dust ash in Kg	Rice bran in Kg	Rice bran ash in Kg	Urea in kg/10kg
1	7	1.5	1	0.5	0.10
2	10	-	-	-	0.25
3	8	2	-	-	0.20
4	8	-	2	-	0.20
5	8	-	-	2	0.10

2.6. Wetting and filling of compost pit with cotton dust mixture

Before mixing all combined materials, compost materials were measured and cotton dust samples were wetted in the water in a plastic drum as displayed in Fig 6. After completing the above-identified work, the compost samples were kept in the pit by three layers, every layer was separated by using a thin soil layer and the remaining portion of the pit was filled up by earthen soil. Fig 7 shows the filling of the composting pit with the sample.

Fig 6. Wetting of the cotton dust

2.7. Remixing and moisture content check in the compost pit

For uniform composting throughout the entire height of the compost pit, the composting materials were remixed in 10 days interval. Moisture content in the compost pit was examined and kept sufficient moisture as it required standard composting of the materials according to the pit testing method recommended by Bangladesh Agricultural Research Institute (BARI), Gazipur. Fig 8 indicates the remixing and moisture content check of the composting pit.

Fig 7. Filling of compost pit with cotton dust mixture

Fig 8. Remixing and checking up of moisture content in the compost pit

2.8. Collection and drying of compost samples

For comparing the maturity and quality analysis, compost samples were collected three times from the pit First samples were collected after forty days, the second samples were collected after fifty days and finally, the samples were collected after sixty days. The sample collection procedure is shown in Fig 9. Fig 10 expresses the drying of collected samples for three days in sunlight before quality analysis.

Fig 9. Collection of samples from the compost pit

Fig 10. Drying of compost materials in sunlight

2.9. Laboratory analysis of compost

Physical condition and color were determined by eye visible condition. pH was determined by a conductivity meter (EC150, HACH). Potassium in the ash solution was determined by using a flame photometer. Available Phosphorous was determined using the Bray P1 method it has been demonstrated by Olsen and Sommers [22]. The Organic Carbon content of compost was determined using the dichromate oxidation method. Total Nitrogen was determined by the Kjeldahl distillation and titration method.

3. RESULTS & DISCUSSION

3.1. Properties of raw micro cotton waste

Table 2 represents the physical condition and chemical properties of raw cotton waste which were analyzed in the laboratory.

3.2. Properties of cotton compost for forty days

Physical, chemical, and nutrients properties of cotton compost

The physical properties of cotton dust compost with individual samples are shown in Table 3. The physical condition of samples was dust and the color is as black as standard compost. So considering these two parameters, samples were used in this study had been a good agreement to produce typical compost. The percentage of moisture of different combinations of cotton compost at forty days samples were varied between the values of 8% to 13% which were within the standard limit.

Table 4 represents the chemical properties of cotton dust compost. The pH of a different combination was varied between 6.3 to 6.9 which were within the standard limit recommended by BARI. The percentages of OC, N, and C:N ratio of cotton compost after forty days samples were varied between the values of 16 to 35, 0.6 to 0.95, and 18:1 to 58:1 respectively, while sample 2 was exceeded the recommended value in the case of OC (10-25) and C:N (maximum 20:1).

Nutrient properties of cotton dust compost are expressed in Fig 11. The percentages of P, K, and S values of all samples were varied between 0.66 to 0.85, 1.30 to 2.05, and 0.29 to 0.41 respectively where all the values are in the standard limits recommended by BARI.

Table 2. Properties of raw micro cotton waste

Specification	Raw material
Physical condition	Fiber
Color	Off white
Moisture (%)	0.121
pH	7.6
Organic carbon (OC) (%)	45
Nitrogen (N) (%)	0.58
Carbon: nitrogen (C:N)	78:1
Phosphorus (P) (%)	0.65
Potassium (K) (%)	1.25
Sulfur (S) (%)	0.2

Table 3. Physical properties of compost at forty days

Parameters	Compost Std. of BARI	Nominated Samples				
		1	2	3	4	5
Physical Condition	Non granular form	Dust	Dust	Dust	Dust	Dust
Color	Dark gray to black	Black	Black	Black	Black	Black
Moisture (%)	Maximum 15	10	12	11	13	8

Table 4. Chemical properties of compost after forty days

Parameters	Compost Std. of BARI	Nominated Samples				
		1	2	3	4	5
pH	6-8.5	6.9	6.9	6.9	6.4	6.3
OC (%)	10-25	18	35	16	18	16
N (%)	0.5-4	0.95	0.6	0.90	0.88	0.90
C:N	Maximum 20:1	19:1	58:1	18:1	20:1	18:1

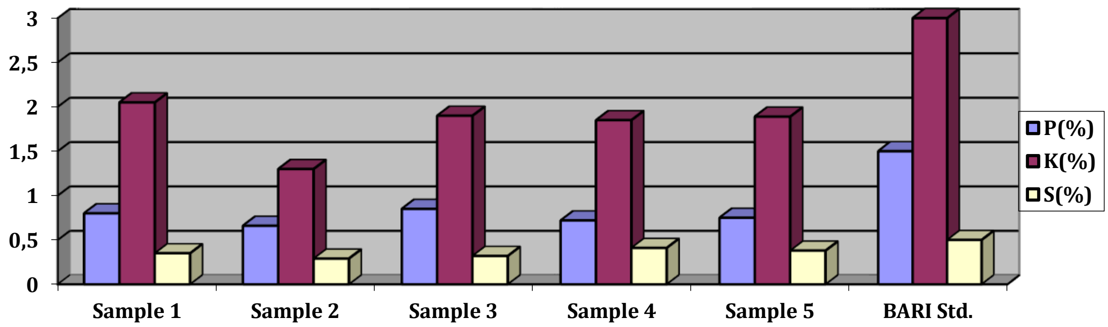

Fig 11. Nutrient properties of compost after forty days

3.3. Properties of cotton compost for fifty days

Physical, chemical, and nutrients properties of cotton compost

Table 5 indicates the physical properties of cotton dust compost after fifty days. The physical condition is dust and the color is as black as standard compost for all samples. These two parameters can be taken into consideration on the basis of using these samples to produce typical compost. The percentage values of moisture for all the samples were varied between 9% to 14% which was not exceed the standard limit.

The chemical properties of cotton dust compost are shown in Table 6. The pH and N values for all samples in case of fifty days compost were within the BARI standard limit. The percentages values of OC and C:N ratio were also within the standard limit except for sample 3, whose OC value is 33, and the C:N ratio is 37:1.

In terms of Nutrient properties of cotton dust compost after fifty days, all the P, K, and S values are within the acceptable limit for compost standard recommended by BARI which is illustrated in Fig 12.

3.4. Properties of cotton compost for sixty days

Physical, chemical, and nutrients properties of cotton compost

The percentage of moisture of different combinations of cotton compost after sixty days of samples were varied between the values of 10% to 14% which was not exceeded the acceptable limit. Besides, the physical condition and the color were also followed by the standard guidance of BARI as presented in Table 7.

Table 5. Physical properties of compost at fifty days

Parameters	Compost Std. of BARI	Nominated Samples				
		1	2	3	4	5
Physical condition	Non granular form	Dust	Dust	Dust	Dust	Dust
Color	Dark gray to black	Black	Black	Black	Black	Black
Moisture (%)	Maximum 15	11	13	14	12	9

Table 6. Chemical properties of compost after fifty days

Parameters	Compost Std. of BARI	Nominated Samples				
		1	2	3	4	5
pH	6-8.5	7.9	7.5	7.1	6.7	7.2
OC (%)	10-25	17	24	33	17	15
N %)	0.5-4	0.93	1.2	0.89	0.89	0.88
C:N	Maximum 20:1	18:1	20:1	37:1	19:1	17:1

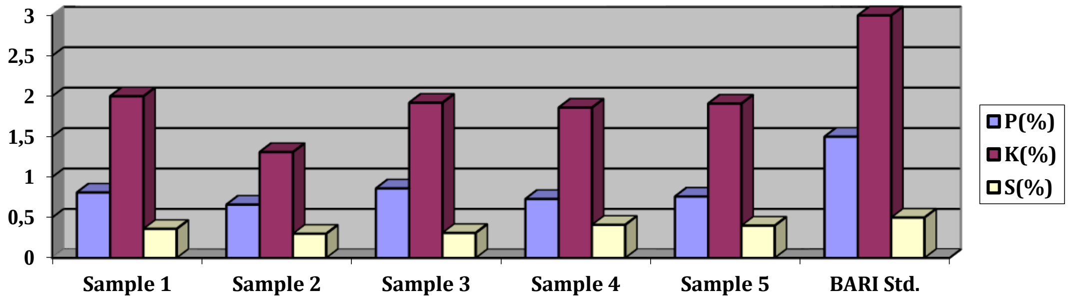

Fig 12. Nutrient properties of compost after fifty days

Table 7. Physical properties of compost at sixty days

Parameters	Compost Std. of BARI	Nominated Samples				
		1	2	3	4	5
Physical condition	Non granular form	Dust	Dust	Dust	Dust	Dust
Color	Dark gray to black	Black	Black	Black	Black	Black
Moisture (%)	Maximum 15	12	11	10	14	10

According to Table 8, the pH and N values of sixty days compost samples were varied between 6.9 to 7.7 and 0.88 to 1.23 respectively. On the contrary, the values of OC and the C:N ratio were in the acceptable limit except the sample 04 having the value out of limit.

The parameters representing the Nutrient properties of sixty days of compost samples are delineated in Fig 13. The maximum value of P, K, and S were 0.87, 2.02, 0.40 had been found in samples 3, 1, and 5 respectively whereas the minimum values of them were found in sample 2. All values of different parameters within the range of BARI guidance.

Table 8. Chemical properties of compost after sixty days

Parameters	Compost Std. of BARI	Nominated Samples				
		1	2	3	4	5
pH	6-8.5	6.9	7.3	7.4	7.7	7.4
OC (%)	10-25	17	22	24	28	15
N (%)	0.5-4	0.92	1.15	1.23	0.89	0.88
C:N	Maximum 20:1	18:1	19:1	19:1	31:1	17:1

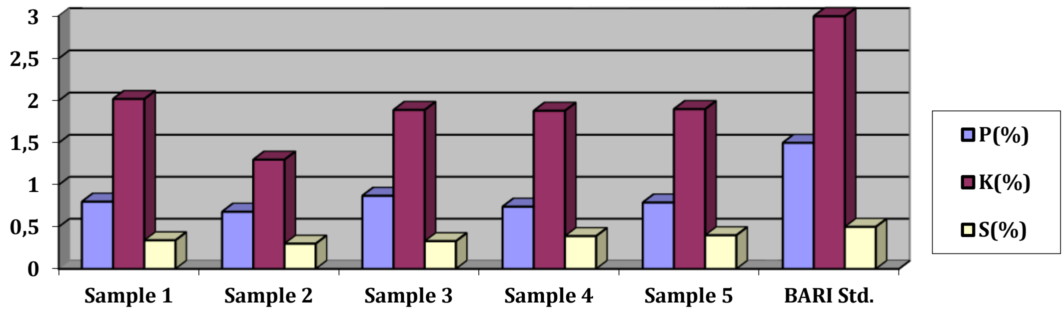

Fig 13. Nutrient properties of compost after sixty days

Optimum compost value (C: N ratio) indicates the rate of decomposition of compost mixtures and most compost is considered finished when C: N ratio is in the range of 12-22. So, in this study, sample 2 for composting after forty days, sample 3 for composting after fifty days, and sample 4 for composting after sixty days except for all other samples for different days of composting are in suitable condition for cotton dust compost. Moreover, those 3 samples have higher C: N ratio than standard values because there is not enough nitrogen for optimal growth of the microbial populations, so the compost will remain relatively cool and degradation will proceed at a slow rate.

4. CONCLUSIONS

Cotton dust compost has been produced with different combinations and compared the compost maturity with different days. The cotton dust compost has been analyzed in different maturity periods and compared different parameters with the standard value requirement of compost according to BARI, Gazipur, Bangladesh. For forty days matured compost, sample 1, sample 3, sample 4, sample 5, for fifty days matured compost, sample 1, sample 2, sample 4, sample 5 and for sixty days matured compost, sample 1, sample 2, sample 3, sample 5 could be used in the agriculture land for cultivation to reduce the harmful effect of chemical fertilizer in the land. The cotton dust sample 2 for forty days, cotton dust sample 3 for fifty days, and cotton dust sample 4 for sixty days should be avoided due to the higher value of the C:N ratio.

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RESEARCH ARTICLE

A study on evaluation of site selection in sanitary landfill with regard to urban growth

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ABSTRACT

Sanitary landfill is a widely used waste disposal method worldwide due to its safe and economic. The most important issue in this storage method is the process of selecting the landfill. This process is one of the critical issues in the urban planning process due to its enormous impact on the region's economy, ecology, and environmental health. At the same time, it is also a great importance for public health. Urban growth is a phenomenon that is difficult to stop or limit in line with economic dynamics and demographic changes. For this reason, site selection in solid waste sanitary landfill is a great importance in terms of ensuring a sustainable urban future. The site selection in sanitary landfill is made conventionally taking into account environmental, social and economic criteria. In this study, the waste disposal facility, which was built according to the mentioned criteria and still in operation, was evaluated in the context of urban growth. In this context, Landsat TM 1989 satellite image for the determination of urban boundaries of the central settlement area of Sanliurfa before the irrigation of the GAP project, and Sentinel-2 satellite image enrichment to determine the urban development boundaries after irrigation was mapped by Screen digitizing. Its spatial evaluation and mapping were performed utilizing ArcGIS software.

Keywords: Sanitary landfill, site selection, socio-economic pressures, urban growth, Sanliurfa

1. INTRODUCTION

Many countries have started to pay more attention to the selection of landfills with the increase in urbanization in recent years. Searching for a new waste site can be a time-consuming process when existing waste disposal sites are full. For this reason, a new field must be determined before these fields are filled. The landfill has been used for years as the most common method of removing solid waste almost worldwide.

Suitable hydrological, geological, and environmental conditions are required for a suitable solid waste sanitary landfill site. For these reasons, waste sanitary landfills should be specially designed and built, and managed strictly to keep them safe during their operation. Scientific studies need to be done to properly select the applicable areas for landfill. In this way, the cost of landfills can be reduced, and possible pollution can be controlled [1]. Many methods such as diagramming, gray clustering, expert systems, geographic information systems (GIS), and analytical hierarchy processes (AHP) are used in the selection of landfills [2]. GIS techniques are a method used effectively to provide solutions for landfill selection [3,4]. The geographic information system (GIS) is a digital database management system designed to manage spatially distributed data from various sources in large volumes. They efficiently retrieve store, analyze and display information according to user-defined indications. In this way, it is an ideal method for advanced site selection studies. GIS is widely used to facilitate the landfill selection process and to reduce its cost [5,6].

In developing countries such as Turkey, landfill or multi-criteria analysis using GIS significant progress was made way relates to the election [7]. However, this method is an advantage for developing countries

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since it does not include financial and economic restrictions. Technological development, globalization, and unavoidable population growth have accelerated the urbanization process in developing countries. Therefore, the selection of suitable solid waste sites should match the rapid urbanization process [8,9].

In this study, the waste disposal facility, which was built according to the mentioned criteria and still in operation, was evaluated in the context of urban growth. In this context, Landsat TM 1989 satellite image for the determination of urban boundaries of the central settlement area of Sanliurfa before the irrigation of the GAP project, and Sentinel-2 satellite image enrichment to determine the urban development boundaries after irrigation was mapped by Screen digitizing. Its spatial evaluation and mapping were performed using ArcGIS software.

2. MATERIALS AND METHOD

2.1. Study area

The province of Sanliurfa is in the center of the Southeastern Anatolia Region, Gaziantep is located in the west, Adiyaman in the northwest, Diyarbakir in the northeast, Mardin in the west, and Syria in the south. It is located between 36° 40'- 38° 02' North latitudes and 37° 50'- 40° 12' East longitudes (Fig 1). Its altitude is 518 m.

Sanliurfa is located on the southern skirts of the central part of the Southeast Taurus Mountains. Mountains and high hills in the north of the province descend towards the south. The great plains are in the southern half. Row hills are quite common. Suruç, Harran, Viransehir plains, which are lined from west to east, are among these mountain ranges. The area of Sanliurfa land is 18,584 km^2. 98.3% of the provincial lands, 61.7% of which are covered with plateaus, 22% by mountains, and 16% by plains, are arable land.

2.2. Methodology

In the analysis of the urban changes of the city of Sanliurfa, Landsat-5 TM and Sentinel-2A satellite data were used in 1989 and 2019, respectively. Landsat-5 TM 1989 satellite image and Sentinel-2A satellite to determine the boundaries of urban development after irrigation was mapped by image enhancement screen digitizing (Fig 2). The Landsat-5 TM sensor, which has been used since 1984, has 6 bands with 30 m resolution and a thermal band with 120 m resolution in the near and middle infrared region. Each Landsat TM image covers an area of approximately 185x185 km^2 [10].

Fig 1. Study area and existing solid waste storage facility

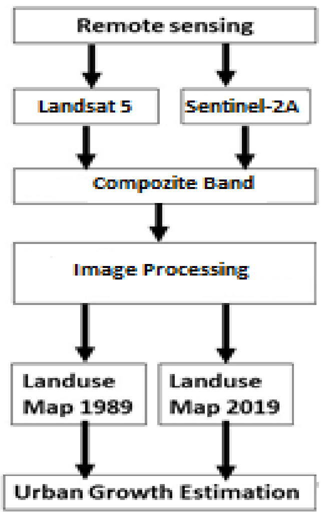

Fig 2. Methodology and flow chart of the study

Studies were carried out on the WGS84 UTM Zone 37N projection system. Image processing and evaluation of multi-time satellite images were carried out using ERDAS Imagine© and ArcGIS© software.

2.3. Urban growth

Rapid urban growth in developing countries contributes greatly to increasing problems related to unemployment, poverty, inadequate healthcare, low quality of life, damage to nature, poor water quality, and deterioration of living environments, especially in rural areas. [11, 12]. Unplanned population growth, together with the inadequacy of basic services; brings along problems especially for rural areas [12]. Recently, urban growth management has become a challenge for urban planners and developers, putting pressure on allocating land suitable for development [13, 14].

Unforeseen environmental threats have started to emerge as a result of socio-economic pressures such as industrialization, urbanization, migration, and population growth, especially in metropolitan settlements. To prevent these problems, central and local government actors must act together with urban growth management units / sub-units and produce results (Fig 3).

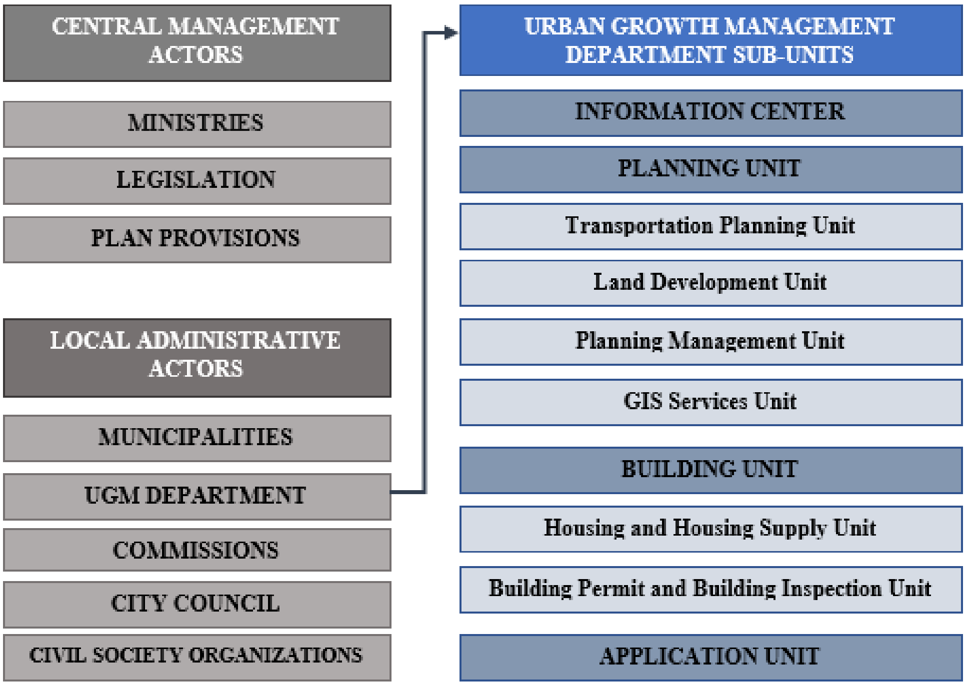

Fig 3. Urban growth management actors and administrative structuring [15]

Unless urban growth is realized in a planned and controlled manner, it leads to various adversities such as environmental pollution, distorted and irregular construction, agricultural land remaining in the city, and losing their qualifications [16]. Analysis of urban growth using past and present spatial and quality data is considered as one of the basic requirements of urban geographic studies, future planning, and political policies for urban development.

Mapping, modeling, and measurements of urban growth can be analyzed using GIS and remote sensing-based statistical models. Thanks to these technological developments, the change in the temporal and spatial scale of complex urban systems and the direction of this change have become analyzable [17].

2.4. Solid waste generation

According to statistical data, people generate 2-5% more solid waste each year compared to the previous year [18]. When the solid waste indicators for 2016 published by TURKSTAT are examined, it has been determined that 1390 of them provide waste service among 1397 municipalities. It is stated in the survey results that a total of 31.6 million tons of solid waste is collected from these municipal services. However, the daily average amount of waste collected by municipalities was determined as 1.17 kg for 2016. This amount was stated as 1.14 kg for Ankara, one of the big cities, 1.30 kg for Istanbul, and 1.32 kg for İzmir [19].

When the 2018 solid waste indicators published by TURKSTAT are examined, it has been determined that 1395 of 1399 municipalities provide waste services. It has been determined that municipalities providing waste services collect 32 million 209 thousand tons of waste. According to the results of the survey, the daily average amount of waste per capita collected by the municipalities was determined as 1.16 kg for 2018. In three major cities, the daily average amount of waste collected per capita was determined as 1.28 kg for Istanbul, 1.18 kg for Ankara, and 1.36 kg for Izmir [19]. 67.2% of 32 million 209 thousand tons of waste collected in municipalities where waste service is provided is sent to regular storage facilities, 20.2% to municipal dumpsites, and 12.3% to recovery facilities. It was stated that 0.2% of it was disposed of by burning in the open, burying, pouring into the stream or land (Table 1).

2.5. Classification of solid waste landfills

Storage areas are divided into two groups as irregular storage areas and landfills [20]. In irregular storage areas, which are used in developing and underdeveloped countries, solid wastes in waste storage areas are discharged irregularly into open land without taking any precautions and removed from the human environment. Since the wastes are not covered, the formation of dust clouds due to the wind effect in irregular storage areas, the resulting gases cause air pollution, and the environmental and visual pollution of solid wastes spread over a wide area cause infectious diseases for animals living in these areas [20, 21].

Table 1. Municipal waste indicators

Municipal Waste Indicators	2016	2018
Total number of municipalities	1397	1399
Number of municipalities providing waste services	1390	1395
The ratio of the municipal population receiving waste services to the total municipal population (%)	98.6	98.8
Total amount of waste (thousand tons)	31584	32209
Average amount of waste per person (kg $person^{-1}$ day^{-1})	1.17	1.16
The ratio of total waste according to disposal and recovery methods (%)		
Sent to landfill facilities	61.2	67.2
Sent to municipal waste	28.8	20.2
Sent to recycling facilities	9.8	12.3
Other disposal methods	0.2	0.2

Landfill facilities (DDT) can be defined as places where wastes are accepted as controlled, wastes are disposed of above ground and underground according to some technical conditions, and the wastes generated as a result of the mechanism formed in the waste after storage are controlled. Although the landfill is at the bottom of the waste management order, it is a widely used disposal method in many countries around the world [20]. In landfilling, solid materials and sewage sludge, which are intended to be disposed of by the producer but need to be removed regularly in terms of environmental protection, should be collected in a certain order by considering the physical, chemical, and biological effects they cause in the environment and stored accordingly [21, 22].

The following principles should be taken into consideration when performing landfill [20]: Regularly covering solid wastes with ground cover; compaction, slope, and subsequent use of vegetation, drainage of water flowing from the surface, control mechanisms to protect ground and surface waters; factors affecting the selection of landfill site location.

In the determination of alternative storage areas, the restrictions set in the Waste Management Regulation used in our country are taken into consideration [23]. The limitations to be used in the location of storage facilities in the Regulation on the Landfill of Wastes are as follows: distance to airports; distance to the forest, afforestation, and protected areas; distance to underground and surface water resources; topographic and geological situation; flood, landslide, avalanche, erosion and high risk of earthquakes; prevailing wind direction and precipitation, natural or cultural heritage situation; absence of pipelines.

Ciritci and Türk emphasized that since determining the location of the storage facility is a difficult and critical stage, solid waste management is not only an environmental issue and should not be ignored in various socio-cultural and economic issues (Table 2) [24, 25].

2.6. Identification of the criteria

Site selection is a complex spatial decision problem that offers many alternatives for decision-makers and carries different preferences. That is, this choice is not easy and unilaterally definable [26]. It is a difficult and long-lasting process to evaluate the existing information regarding the selection of the study area with classical methods [18].

Although current methods consider various objectives and relevant criteria, there is no integrated method to account for the best landfill in all policies [27]. Given these conditions, a model is needed that considers the importance of all three environmental, economic and socio-cultural criteria at the same time (Fig 4).

Table 2. Site selection criteria for sanitary landfills [25]

Dimensions	Criteria	Ideal options	Acceptable range
Economic (D_1)	Land price (C_{11})	1. The suitable site for waste disposal must be inexpensive as much as possible. 2. Land price is determined based on its distance from proximate roads (the closer, the more expensive)	For a distance less than 100 m from the road, the price was IRR 150000 per m^2. - For a distance within 100–400 m from the road, the price was IRR 100000 per m^2. - For a distance more than 400 m from the road, the price was IRR 50000 per m^2.
	Distance from roads (C_{12})	Due to economic constraints in terms of transportation costs, the waste disposal site should not be very far from main roads.	- Reasonable distance: less than 100 m from the road. - Relatively reasonable distance: within 100–1000 m from the road. - Unreasonable distance: more than 1000 m from the road.
Environmental (D_2)	Distance from rivers (C_{21})	The disposal site must be located somewhere far from rivers and flowing surface waters to avoid pollution.	- Unreasonable distance from rivers: less than 500 m - Relatively reasonable distance from rivers: 500–2000 m
	Distance from lakes (C_{22})	The disposal site must be located somewhere far from lakes to avoid pollution.	- Unreasonable distance from lakes: less than 500 m - Relatively reasonable distance from lakes: 500–2000 m
	Distance from grasslands (C_{23})	The disposal site must be located somewhere far from pastures and grasslands to minimize environmental pollution.	- Unreasonable distance from pastures: less than 1000 m - Relatively reasonable distance from pastures: 1000–2000 m - Reasonable distance from pastures: more than 2000 m
	Distance from forest regions (C_{24})	The waste disposed of must be considerably far from forest regions to minimize environmental pollution.	- Unreasonable distance from forests: less than 1000 m - Relatively reasonable distance from forests: 1000–2000 m - Reasonable distance from forests: more than 2000 m
	Distance from agricultural lands (C_{25})	The disposal site must be located somewhere considerably far from farmlands and agricultural areas to minimize environmental and social pollution.	- Unreasonable distance from agricultural lands: less than 1200 m - Relatively reasonable distance from agricultural lands: 1200–2000 m - Reasonable distance from agricultural lands: more than 2000 m
Climatic (D_3)	Climate conditions (C_{31})	The disposal site should be located in arid areas.	- Unappropriated areas: cold and humid - Relatively appropriated areas: cold and dry
	Distance from floodprone areas (C_{32})	The disposal site should not be located near water pathways, flood pathways, and flood-prone areas.	- Unreasonable distance from flood pathways: less than 1000 m - Relatively reasonable distance from flood pathways: 1000–2000 m - Reasonable distance from flood pathways: more than 2000 m
Geological (D_4)	Slope of land (C_{41})	The disposal site should be located, as much as possible, in level and straight areas.	- Reasonable slope: less than 10° - Relatively reasonable slope: 10–40° - Unreasonable slope: more than 40°
	Terrain (C_{42})	This factor has a function similar to that of slope and is calculated through the slope layer in GIS.	Reasonable areas: level lands - Relatively reasonable areas: hill sites - Unreasonable areas: uneven and mountainous regions
	AMSL (C_{43})	The disposal site must be located in places with a low AMSL to keep climatic states and terrains stable.	- Reasonable height: less than 1000 - Relatively reasonable height: 1000-2100 - Unreasonable height: more than 2100
Social (D_5)	Distance from residential areas (C_{51})	Due to social constraints, the disposal site must be located somewhere far from cities, rural regions, and residential areas.	- Unreasonable distance from residential areas: less than 700 m - Relatively reasonable distance from residential areas: 700–3000 m - Reasonable distance from residential areas: more than 3000 m

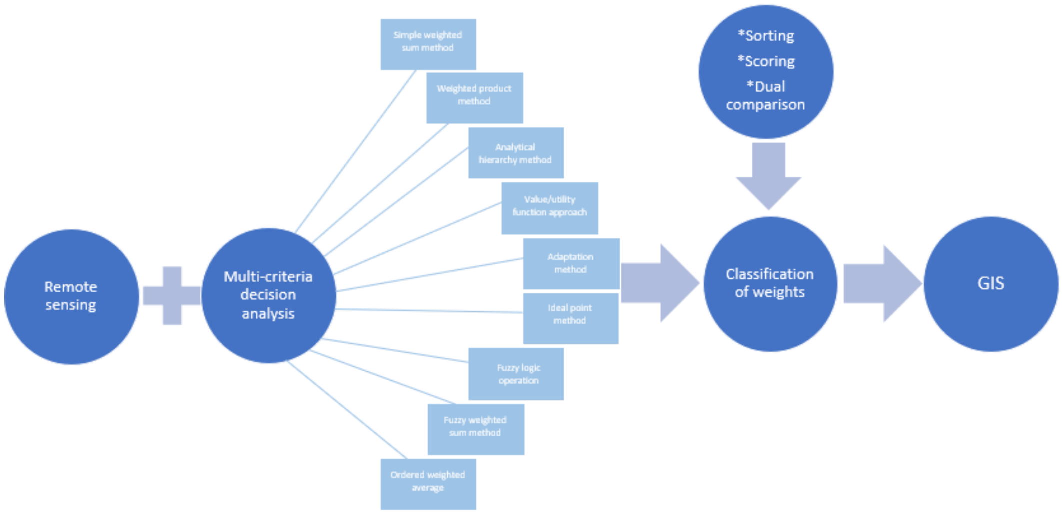

Fig 4. Use of (GIS-MCDV-Remote Sensing) technologies for choosing the appropriate place for waste storage

2.7. Urban growth estimation

Environmental pressures caused by the incorrect use of space on natural resources, both developed and developing countries as one of the important issues on the agenda in Turkey. The most important reason for the emergence of these problems is that the protection-use balance and environmental values are not considered sufficiently [10]. The cities develop, and settlement areas move in different directions with each passing day [28]. Many ecological problems arise when the demographic structure and spatial development of the province are not well followed and balanced with a plan [29].

3. RESULTS & DISCUSSION

Classification results for 1989 and 2019 are shown in Fig 5. Classification results of satellite images differ visually. In these images, mainly green areas are gathered especially in the south of the city. Sanliurfa, which was a small city in 1989, turned into a megacity by 2019. The urban land rate has increased. Urban population growth between these years was faster than urban land growth in the same period.

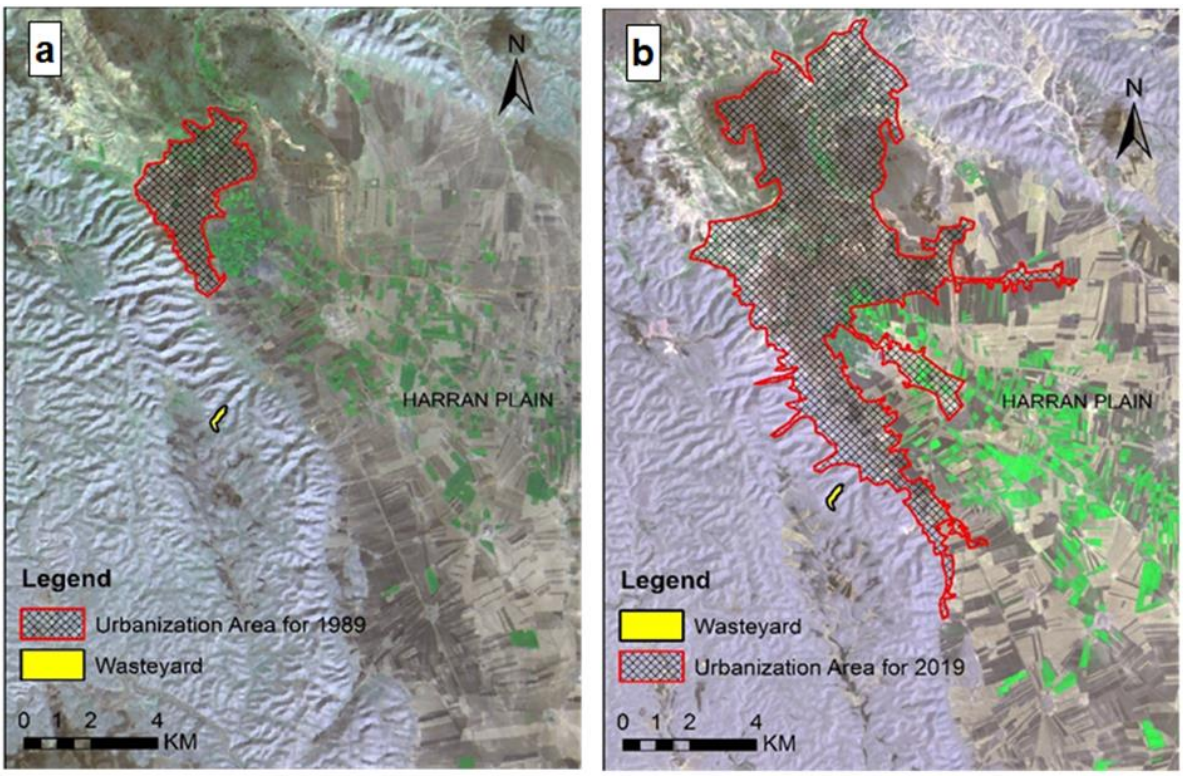

Fig 5. Classification results for (a) 1989 and (b) 2019

When Fig 5 is examined, it is understood that the construction works in the north, east, and southeast axes of the city have increased over 30 years. Especially in this process, it is seen that industry and construction areas interact. It is observed that the settlements also differed in these 30 years. In general, the population increases twice every 32 years, and the direction of the development area was determined by considering the land resources of the plain, the development direction of the city, and the areas suitable for the urban structure. Since its development towards the lands of the Harran plain is prevented by law no 5403 on soil protection and land use, the development is mostly towards Karaköprü, organized industry, and Fatik mountains (Fig 6).

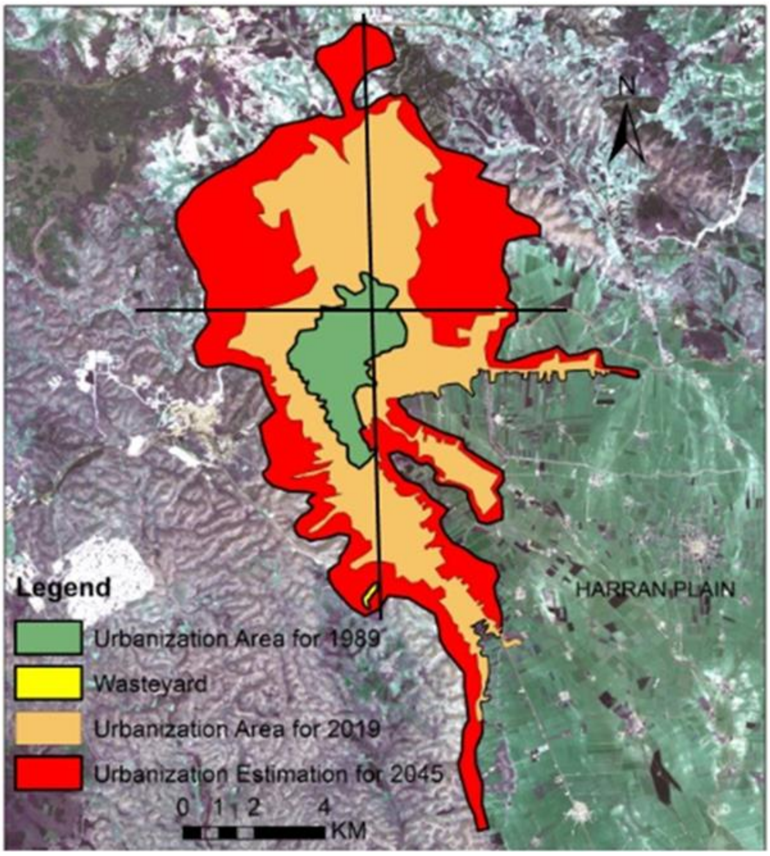

Fig 6. The development direction of the Sanliurfa city and areas suitable for the urban structure

The dynamics of established land-use models analyzed with remote sensing (RS) and GIS data revealed that it is useful to identify the type and development of urban growth, as well as the recent and future urban growth that helps local planning authorities manage growth and growth. Thanks to this study, the effects of urbanization on environmental and sustainable urban growth are seen and contribution is made to future planning to reduce its possible damages [30, 31].

Evaluation of a new sanitary landfill site is a difficult and complex process and requires consideration of many criteria such as distance from the settlement area, distance from main roads, investment costs, climate, availability [32]. Unregulated disposal has negative effects on all components of the environment and human health. Therefore, for the settlement of sanitary landfills, many effective criteria such as distance from residential areas, distance from main roads, investment costs, presence of solid wastes, geology, surface water, aquifer, land use, elevation, and land slope should be considered. There are various techniques for landfill selection, including GIS, mathematical models, heuristic algorithms and different multi-criteria decision-making methods, fuzzy analytical hierarchy process, and technique [33].

Methods based on traditional statistical data and old maps are mostly not possible in determining spatial growth areas and creating future predictions [17]. Another limitation of urban expansion modeling is that land change processes are not static. The instability of land change processes includes not only the rate of change but also the nature and spatial distribution of the changes [34]. Land cover and land use changes vary according to the physical, sociological, and administrative structure of the region. Since the end of the 20th century, both the development of remote sensing techniques and the efficiency of the GIS platforms enable us to make more efficient, faster, and more sensitive decisions at many points [35, 36].

4. CONCLUSIONS

Consequently, when the distance of the sanitary landfill site to the city periphery -at the site selection investigation stage- is 4 km in 1989 (this buffer distance complies with the Waste Management

Regulation); As of 2019, as a result of the increasing population and the related urbanization, the city and the landfill area are almost intertwined, and the distance has decreased to 800 meters. In the past 20 years, the failure to stop/limit or control this growth should lead to the self-criticism of central and local government actors' powers and responsibilities. Likewise, this situation has started to pose a serious problem in terms of environment and public health and has been recently caused the need for a new site selection for the sanitary landfill in Sanliurfa. This fact is not specific to the province of Sanliurfa. Unforeseen environmental threats have started to emerge as a result of socio-economic pressures such as industrialization, urbanization, migration, and population growth, especially in metropolitan settlements.

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RESEARCH ARTICLE

Waste management and zero waste practices in educational institutions

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ABSTRACT

In this study, the situation of waste management and zero waste applications in educational institutions was investigated in Turkey. For this purpose, the wastes collected and separated within the scope of zero waste and the wastes collected without separating them in trash cans were determined at certain periods and the total amount of waste generated per unit time and per person was calculated for an engineering faculty, vocational school, high school and primary school. A questionnaire study was conducted to determine the viewpoints of the students studying at the engineering faculty on zero waste management. According to the obtained data, the amount of waste collected in the faculty was calculated as 184 kg day^{-1} and only 27 kg day^{-1} of this amount is being recycled. Considering all types of waste in the whole schools, waste generation rates were found to be 17,6, 32,3, 93,7 and 113 g person^{-1} day^{-1} respectively for primary school, high school, vocational school, and engineering faculty. One of the important results obtained in the study is that the necessary training and awareness-raising activities in zero waste implementation are very important, and every stage from the reduction of the number of trash cans to the correct placement of zero waste sets requires detailed planning.

Keywords: Waste management, zero waste, educational institution

1. INTRODUCTION

According to the Waste Management Regulation of Turkey, waste refers to any substance that is or has to be disposed of or discarded to the environment by the manufacturer or the person who actually owns it [1]. Waste generation is a part of human existence. Differences in the quality, quantity and composition of the waste are associated with various factors such as cultural, economic, social and financial situation [2]. Waste management is carried out by using methods, such as collection, transport, storage, processing, recovery, disposal to minimize harmful environmental effects.

In developed countries, it is imperative to develop waste management strategies for each institution. In the USA, 80% of colleges and universities are using waste reduction and recycling strategies based on waste characterization studies. For example, at Brown University, a waste management program has been implemented since 1972 and currently 31% of waste is recycled. In the USA, it was stated that 53% and 30% of the total waste was recycled in Colorado State University and Florida University, respectively [3]. In the other hand, waste management is a basic public health service that is often neglected and faces a number of problems in developing countries [2, 4, 5]. Various researchers have stated that the most problematic functional element faced by waste management in developing countries is related to increased waste generation, high waste management costs, rapid population growth, insufficient infrastructure and insufficient expertise [6-9].

“Zero Waste”, an important component of waste management today, is a philosophy that expresses the goal of collecting and recycling separately at the source in case of occurrence of waste, and provides a holistic waste management from source to disposal. The zero waste philosophy is considered to be the one of the most holistic innovation for the twenty-first century to reach a true sustainable waste management system understanding. The term "zero waste", which was first introduced in 1973 to save natural resources from chemicals, has become a

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management approach that has become both an aim and a goal to overcome waste problems nowadays. Zero waste target has been adopted as part of waste management strategies in many cities around the world [10].

Although there are many studies in the literature on the management of domestic or municipal waste, the number of studies on the education sector is limited [11, 12]. Mainly, among institutions and organizations, especially educational units are the institutions that are obliged to act responsibly towards the environment due to their ethical and moral concerns and are expected to be leaders in the environmental protection actions [13]. Campus waste characterization studies are relatively low cost when carefully planned [14, 15]. Studies have indicated that the waste generated in educational institutions has a very high recycling potential and 55-90% of the waste stream in universities can be recycled [15-18].

In Turkey, "Zero Waste Regulation" came into force on 12.07.2019 [19]. The purpose of the regulation is to regulate the procedures and principles regarding the minimization and prevention of waste generation, establishment of an effective collection system for separate collection of waste at its source, and establishment of an effective zero waste management system in order to ensure the recycling/recovery of waste. In the calendar of "points to be implemented" specified in the annexes of the regulation, the transition year for "educational institutions with more than 250 students", which is the subject of this study, is stated as 31 December 2020. Looking at the practices in Turkey, in educational institutions, in this sense, it is seen that start realization of studies and awareness-raising activities.

In the study, the amount of waste collected and separated within the scope of zero waste and the amount of waste collected without separation was determined at certain periods in an engineering faculty, a vocational school, a high school and a primary school. With the data obtained, the total amount and type of waste generated per unit time and per person in each school was calculated. Studies were carried out in most densely populated districts of Tekirdağ, which is one of Turkey's big cities. A questionnaire study was also conducted to determine the viewpoints of the faculty students on zero waste management.

2. MATERIALS AND METHOD

2.1. Study area and educational institutions

The study was carried out in Tekirdağ province in the Marmara Region of Turkey. Tekirdağ is located at northwest of Turkey and north of the Sea of Marmara. The province, which has a developed transportation network, had an agriculture-based industry until 1970, but after 1970 it industrialized rapidly, especially some districts. According to 2020 data, the city has a population of 1.081,065 [20]. In Tekirdağ, domestic solid wastes have been disposed in the Solid Waste Regular Storage Facility of Tekirdağ Metropolitan Municipality since 2018.

There are 32 kindergartens, 149 primary schools, 137 secondary schools, 95 high schools and 44 private schools in Tekirdağ [21]. Tekirdağ Namık Kemal University (TNKU), which also plays an important role in population movements within the city boundaries, continues its educational activities with a total of 44 units.

Within the scope of the study, waste management was examined in 4 educational institutions with different student profiles: primary school (PS), high school (HS), vocational school (VS) and engineering faculty (EF) affiliated to TNKU. Detailed evaluations were made in the EF. General waste management information of these institutions is given in Table 1.

2.2. Waste weighing

Waste weighing was carried out 8 times in the EF, in weeks with different characteristics (including the weeks of exams). In the other 3 schools, one week weighing process was carried out. Weighing procedures were carried out at different periods in each school between January-March 2019.

The collected wastes were weighed at the end of the relevant week, and all the weeks of weighing were selected from the weeks when the student population was dense. Weighing operations were done with a 1,000 kg capacity, 200 g precision, 80x90 cm platform size Weighing Scale-7516. In the study, both wastes from zero waste sets and wastes from trash cans were evaluated under 4 categories. The categories considered in the classification are given in Table 2. Organic waste measurements were carried out only in EF. Separation and weighing operations were carried out at 15 points in EF, 6 points in VS and HS, and 7 points in PS.

Table 1. Information on waste management in studied educational institutions

Education Institution	Number of students	Number of Staff*	Zero Waste Set number	Number of Recycling Bins	Number of Trash Cans	Zero Waste Bins Emptying Frequency
Engineering Faculty (EF)	3911	149 (4)	7	13	243	One time per week
Vocational School (VS)	600	63 (3)	6	-	35	One time per ten days
High School (HS)	853	60 (11)	7	-	48	One time per week
Primary School (PS)	1178	52 (5)	-	4	60	One time per week

** The value in parentheses is the number of servants responsible for the collection and transportation of wastes at the school.*

Table 2. Waste categories

Category	Definition
Paper	Colored and colorless paper, notebooks, books, cardboard
Plastic	PET bottle, HDPE and other plastics
Glass	All glass materials
Metal	Aluminum cans, cans, iron and non-aluminum materials
E-waste	Electronic wastes
Other	Wastes remaining after all other wastes have been separated

The steps followed during weighing were: (i) Preparation of a suitable container and weighing instrument, (ii) determining the weight of the empty box, (iii) filling the box with segregated garbage and (iv) weighing the box with the garbage.

The formula used for determination of waste generation is:

$$WG=\frac{(W_{T-}W_b)}{p\ x\ t_s}\ \left(\text{kg per capita}^{-1}\ \text{day}^{-1}\right) \quad (1)$$

where W_b and W_t are the weights of the box when it is empty and full, respectively. p is the number of people at the time of waste collection; and ts is the period the waste is collected.

The following determinations were made for the obtained data within the scope of the study:

- The total amount of waste generated per unit time and the amount of waste per person
- Waste amount thrown into zero waste sets/recycling boxes
- Whether the wastes thrown into zero waste sets/recycling boxes are thrown into the right boxes
- Amount of waste thrown into trash cans
- Amount of recyclable wastes thrown into trash cans

2.3. Survey study

The survey has been conducted only in the engineering faculty. A total of 305 students, 103 women and 202 men, from 8 different engineering departments, participated in the 9-question survey. There were two groups of questions in the questionnaire. In the first group of questions, there were 7 questions and one of the "Yes/No/Partial" answers was expected from the students. The second group of questions, consisting of 2 questions, was formed in 5 options to understand general knowledge and tendency. The obtained information was evaluated according to the department and gender of the students.

3. RESULTS

According to the findings obtained from waste separating and weighing studies, the estimated daily waste amounts for each school, from zero waste sets, recycling bins and garbage bins are given in Table 3 on the basis of waste types.

3.1. Engineering faculty (EF)

Waste amounts in zero waste sets, recycling bins and trash cans on 8 different weeks were determined in the EF (Table 3). According to the results a total of approximately 184 kg of waste per day was collected and only 33 kg of it was separated. The total separation rate of the paper-cardboard wastes was only 26% in the faculty. Plastics were collected separately in the rate of 39% and metals by 42%. The separation rate of glass wastes was very high with 97%.

In the study, it was determined whether the wastes thrown into each zero waste box were in the correct boxes. In Fig 1, the matching of waste types detected in each zero waste box is given. In the figure, percentages painted in blue refer to waste thrown into the correct boxes, and percentages painted in red refer to waste thrown into the wrong boxes. Accordingly, 68-100% of the waste collected in the paper-box was paper or cardboard. The wastes in the paper-box were "Other" group and "Plastic" group, respectively, apart from paper. It has been determined that the waste collected in boxes for plastic is between 80-100% plastic. The most common type of wrong waste thrown into plastic boxes was paper. It was determined that 63-100% correct separation was achieved in boxes for glass and the highest amount of plastic and paper waste was disposed in these boxes after glass waste. Correct collection rates in boxes for metal have fallen down to 30% and the most plastic wastes has been thrown into these boxes.

The separation of waste types thrown into trash cans according to the weighing point is given in Figure 2. It was observed that there were recyclable wastes in trash cans, and especially paper and plastics in classrooms were thrown into trash cans. The paper wastes in the trash cans were generally lecture notes, and the plastic wastes were PET water bottles. As seen in Fig 2, 38% of the wastes thrown into trash cans in classrooms was paper waste, 49% was plastic waste and only 10% was non-recyclable wastes. In academic staff offices, 52% of the wastes were non-recyclable, 38% paper and approximately 10% plastic waste.

Table 3. Total daily waste amount and types in schools

School	Waste type	Trash Cans (g day^{-1})	Zero waste sets (g day^{-1})	Recycling boxes (g day^{-1})	Total (g day^{-1})
Engineering Faculty (EF)	Paper	21.612	5.975	1.494	29.080
	Plastic	10.819	5.401	1.350	17.570
	Glass	611	13.535	3.384	17.530
	Metal	1.837	1.054	264	3.154
	Other	115.300	763	191	116.255
	Total	150.180	26.727	6.682	183.590
Vocational School (VS)	Paper	5.325	1.209		6.534
	Plastic	2.500	694		3.194
	Glass	-	7.589		7.589
	Metal	-	23		23
	Electronic+Battery	-	200		200
	Other	18.358	1.591		19.950
	Total	26.183	11.306		37.489
High School (HS)	Paper	4.851	928		5.780
	Plastic	2.091	1.373		3.465
	Glass	-	3.735		3.735
	Metal	-	105		105
	Other	1.817	0		1.817
	Total	8.759	6.142		14.902
Primary School (PS)	Paper	1.743		4.654	6.398
	Plastic	697		2.211	2.908
	Glass	-		1.607	1.607
	Metal	1.260		579	1.839
	Other	237		0	237
	Total	3.937		9.051	12.988

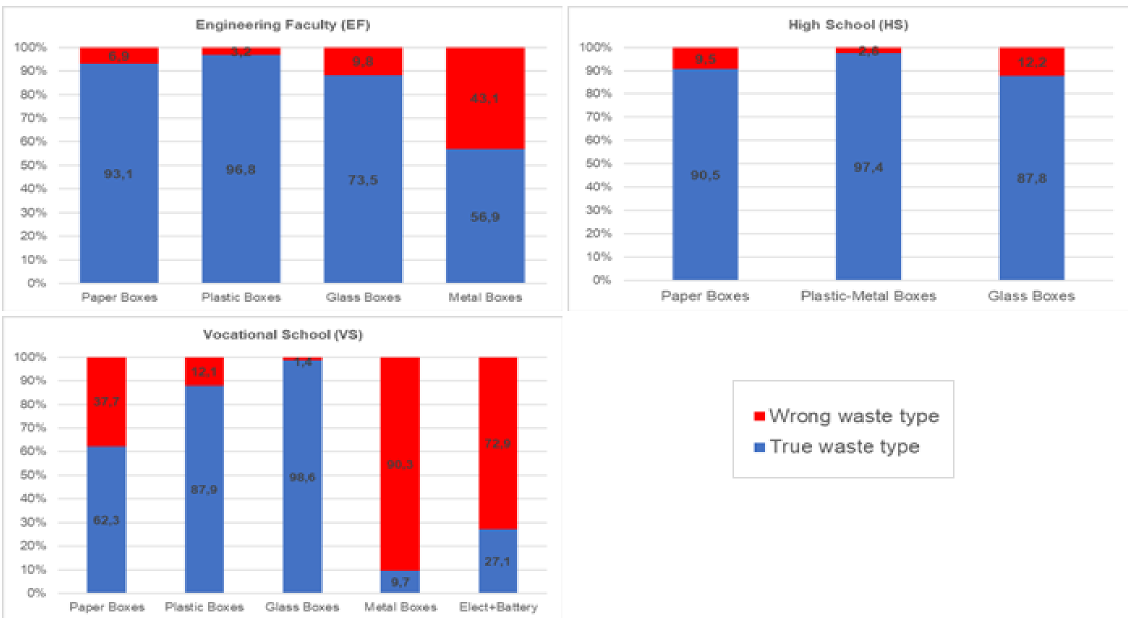

Fig 1. Average correct separation rates in zero waste sets

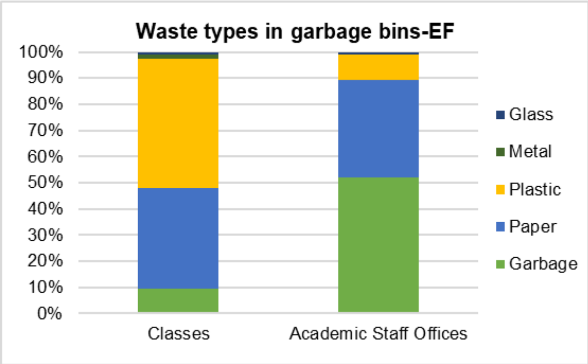

Fig 2. Separation rates in trash cans - Engineering Faculty (EF)

3.2. Vocational school (VS)

The daily total amounts of wastes in the VS are given in Table 3. As can be seen, "electronics+battery wastes" were also included in the zero waste sets in the school. Accordingly, approximately 38 kg of waste was collected in the school and 11 kg of this was separated. 60% of the collected waste was glass waste and 10% is paper waste in zero waste sets.

In Fig 1, the matching of waste types detected in zero waste bins in VS with the relevant waste bins is given. Accordingly, it was determined that 40% -90% of the waste collected in the box of paper was paper, and the highest amount of plastic waste was disposed in these boxes except paper. It was observed that the large amount of waste collected in plastic and glass boxes was generally collected in the correct box. Metal and electronics+battery boxes have often been the ones with the most unsuccessful separation. Waste with recyclable potential, other than garbage, has also been identified in trash cans in the school. According to the average values, 20% of the waste accumulated in the trash cans was paper and 10% was plastic waste.

3.3. High school (HS)

Total amounts of waste collected in zero waste and trash cans in the HS are given in Table 3. Accordingly, approximately 15 kg of waste was collected in the school and 6 kg of it was separated and recycled. Plastic and metals were collectively collected in zero waste bins at the school. 60% of the wastes collected in all zero waste bins were glass, 15% paper and 22% plastic waste. Wastes with recyclable potential, other than garbage, have also been identified in garbage cans. According to the average values, 55% of the waste accumulated in trash cans was paper and 24% was plastic waste.

The result of determining whether the wastes thrown into the zero waste sets were in the correct boxes is given in Fig 1. Accordingly, a correct distinction was made between 70-100% in the box for paper, and 98% in the box for plastic+metal. The correct separation rate for the glass was 80% and above.

3.4. Primary school (PS)

In PS, total amounts of waste are given in Table 3. Recyclable waste is collected in a single box throughout the school. Accordingly, a total of approximately 13 kg of waste was collected at the school and only 9 kg of it was recycled. 51% of the collected waste was paper, 24% plastic and 18% glass waste. Because of there was only one box, the correct waste separation study in the school could not be done.

3.5. Survey study

Two groups of questions were formed in the questionnaire. Yes/No/Partial answers were given to the 1st group question. Questions and answers, given by the whole population, are given in Fig 3. Accordingly, 99% of the participants stated that recycling is important, 53% of them discard their wastes in appropriate waste bins and 59% of them use the recycling bins during their time at school. 55% of the participants think that the zero waste application is not applied correctly at their school.

Looking at the answers given to the 2nd part of the questionnaire (Fig 3b), 90% of the participants stated that the waste that cannot be recycled is "Vegetable and fruit wastes"; 70% of them stated that the most important item to be recycled is "plastic bottle".

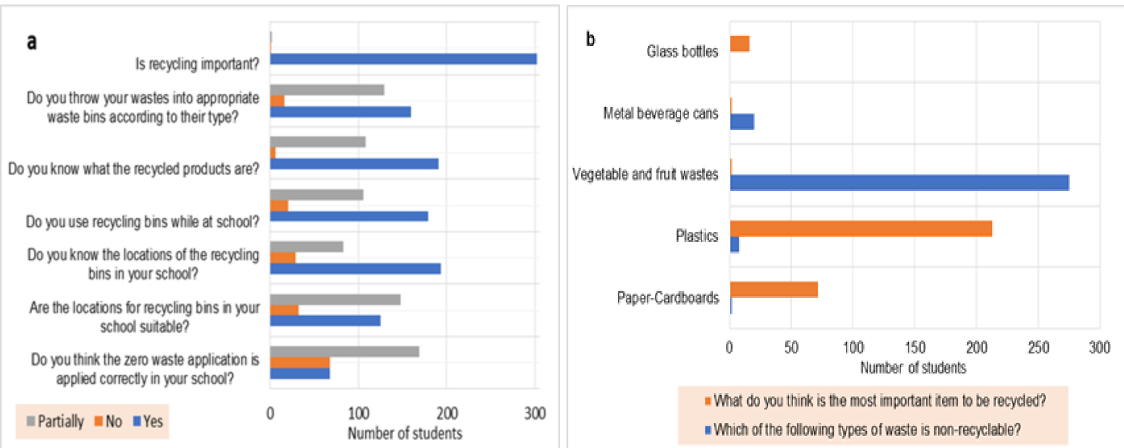

Fig 3. Some of the questions and answers given (a): Part 1 (b): Part 2

In the questionnaire answers, a comparison was made between the departments of students and the answers of women and men. In general, faculty students have a significant knowledge and desire on zero waste and recycling; it can be said that environmental engineering students gave more accurate answers, as expected, especially in some knowledge-based questions, and that environmental engineering and female participants were more sensitive about throwing waste into recycling bins.

4. DISCUSSION

The daily amount of wastes collected from 4 educational institutions and calculated/estimated daily values per person are given in Table 4. The daily total weighing data was divided by the school population to obtain the daily amount of waste generated per person. Since the number of people in the institutions at the time of weighing changed depending on the education period (weeks of exam, class, holiday, etc.), the occupancy rate was taken as 60-80% for all schools. Considering all types of waste in the whole school, the daily waste amount per person was found to be 113 g $person^{-1}$ day^{-1} for the EF. This value has been calculated as 93.7, 32.3 and 17.6 for VS, HS and PS respectively.

As can be seen from Table 4, the highest amount values of waste per person and daily waste collected per person is obtained for the EF. The values obtained for high school and especially primary school are very low. The reason for this was thought to be that students in primary school spend most of their time during the lesson hours due to their age groups, leave the school at the end of the lesson, have low socialization opportunities and therefore do not create individual waste in common areas.

Waste generation rates, obtained in this study, were compared with various studies in the literature, and general values of Turkey, Istanbul and Tekirdag (Table 5). As can be seen, there are various values in the literature. The faculty campus based on this study is a small, and socializing places are few. Therefore, the values obtained for faculties and vocational schools are generally low compared to other campus values. However, some campus values appear to be in line with the research [16, 22-24]. The values obtained for HS and PS remain at below these levels. On the country and provincial basis, waste generation rates remain at very high levels as expected. It can be said that approximately 10% of per capita waste generation for a university student is realized within the campus.

Considering the variability of the literature studies and the results of this study together, it was determined that the comparison of the amount of waste generated in educational institutions should be made together with the information about the size and population density of the campus.

Table 4. Total and per capita waste in schools

School	Collecting Type	Total Waste (kg day^{-1})	Waste generation rates (g per $capita^{-1}$ day^{-1})
Engineering Faculty (EF)	Zero waste sets	26,7	16,5
	Recycling boxes	6,7	4,1
	Trash Cans	150,2	92,5
	Total	183,6	113
Vocational School (VS)	Zero waste sets	11,3	28,3
	Trash Cans	26,2	65,5
	Total	37,5	93,7
High School (HS)	Zero waste sets	6,1	13,3
	Trash Cans	1,8	19
	Total	14,9	32,3
Primary School (PS)	Recycling boxes	9,1	12,3
	Trash Cans	3,9	5,3
	Total	12,9	17,6

Table 5. Waste generation rates in literature studies

University/Region		Waste generation Factor (g day^{-1} $capita^{-1}$)	Reference
University of Northern British Columbia		59	[22]
University of Berkeley		210	[24]
Universiti Teknologi Malaysia		830	[25]
University of Dar es Salaam, Tanzania		193	[16]
Water Resources Institute, Tanzania		83	[16]
METU Ankara Campus		400	[26]
Gazi University		309	[27]
Mersin University		80	[23]
Tekirdag/Corlu province		1150	[28]
Turkey		1170	[20]
Istanbul		1140	[29]
This study	Primary school	18	
	High School	32	
	Vocational school	94	
	Engineering Faculty	113	

5. CONCLUSIONS

Zero waste management is an integrated system that includes the process from the prevention of waste generation to the collection of all wastes generated separately at their source according to their characteristics and types and sending them to licensed waste processing facilities. In Turkey, in July 2019 the "Zero Waste Regulation" was established and has taken many steps starting from the relevant state institutions. According to the regulation, educational institutions are among the institutions that should primarily switch to zero waste practice. Waste management is more important and easier to implement, given the educational institutions, the types of waste that are generated, the availability of trained staff and students, and the institutions that should lead the society.

Within the scope of this study, a research has been carried out on the zero waste application in 4 educational institutions at different levels and the level of this application in terms of waste separation. According to the information obtained, waste generation per capita and success in correct waste separation increases as the education level increases. At this point, it was thought that the duration of students' staying at school and socializing was directly related to the time of waste generation. On the other hand, considering the primary, secondary and high schools studied, it is understood that there is a lower level of participation in the zero waste application at the administrative level, especially in public schools.

Another result obtained is that the strategies to be determined in the application of waste separation at the source are very important for the efficiency of the application. It is most important to carry out the necessary training and awareness studies in the institution where the zero waste application will start, and to reduce the number of garbage bins where all waste is disposed together. No garbage bins should be placed in areas where most of the waste types generated are recyclable, especially in classrooms. Correct location of zero waste bins is one of the most important issues. It is thought that providing an income for institutions by recycling the wastes and using the income to be obtained in activities that will increase the awareness of students will also increase the efficiency of zero waste practices.

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RESEARCH ARTICLE

Treatment of landfill leachate by anaerobic baffled reactor (ABR)

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ABSTRACT

Anaerobic baffled reactor (ABR) is one of the widely used wastewater treatment systems in industrial and domestic applications. In this study, the effect of dilution rates (5%, %10, 20%, 50%) on the landfill leachate (LFL) with regard to chemical oxygen demand (COD), color, nitrogen compounds, and organic matter was investigated. The maximum removals were observed when the dilution rate was 20% (v:v,1:5). COD, dissolved organic carbon (DOC), total nitrogen (TN), color, nitrate (NO_3^-) and ammonium (NH_4^+) removal efficiency was approximately 81%, 61%, 15%, 17%, 1% and 5%, respectively. The results indicated that the adverse effects of the dilution rate on the removal of contaminants are high when it is higher than 1:5 (v:v). The study suggests that the dilution of leachate presents a significant effect on the treatment performance.

Keywords: Anaerobic baffled reactor, landfill leachate, dilution rate

1. INTRODUCTION

The sanitary landfill method has been commonly used for garbage treatment and disposal as it is cheaper and has easy maintenance when compared to other technologies [1, 2]. However, the major environmental concern of this method is the generation of large amounts of landfill leachate (LFL), which may cause serious pollution to groundwater and surface waters. Landfill leachate is highly toxic wastewater that is formed as a result of the decomposition of wastes in wild or landfill sites and has a highly toxic effect on the environment and aquatic life [3, 4]. The components of landfill leachate vary from region to region depending on the solid waste composition, storage method, hydrology of the landfills, climate, and storage age [5]. The age of solid waste has important impacts on the compounds of LFL. Age of LFL; depending on factors the characteristics of solid waste, components of waste, moisture content, rainwater, temperature, etc. [6]. Therefore, the accumulation and treatment of LFL are known as major problems. Many treatment technologies are used for LFL treatment. Biological treatment methods are preferred due to the high organic compounds of LFL [7]. Anaerobic treatment processes are widely used for LFL treatment. The anaerobic baffled reactor (ABR) first developed by Bachmann et al. [8] can be described as a series of up-flow anaerobic sludge blanket reactors (UASB). The ABR can provide favorable environmental conditions for the development of different microbial populations in each a compartment due to baffles in their structure. This property of ABR indicates that it can occur in the single reactor of sequential anaerobic and anoxic steps [9]. Compared with the high-rate anaerobic reactors, the ABR is one of the most favorable anaerobic treatment systems. ABRs were commonly applied to treat various wastewater such as domestic wastewater, palm oil mill effluent, swine wastes, pulp, and paper mill black liquors, azo dyes containing wastewater, landfill leachate, synthetic tannery wastewater containing sulfate and chromium (III), whisky distillery wastewater, nitrogen-containing wastewaters, textile dye wastewater, and brewery wastewater [10]. Compared with other anaerobic reactors, ABR has many advantages such as a low energy consumption, low sludge production, longer sludge retention time, high strength to organic

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and hydraulic shock loading, efficient removal of soluble microbial products [11]. The ABR has several advantages due to its circulation pattern that approaches up-flow sludge blanket reactor. The difference from other studies, its design simplicity, use of easy equipment, low sludge production, high treatment efficiency, and low capital and operating costs are among its attractive features.

This study aims to investigate the treatability of LFL using an anaerobic baffled reactor. The influence of several dilution rates on the efficiency of LFL treatment performance was determined with regard to COD, color, nitrogen compounds, and organic matter.

2. MATERIALS AND METHOD

2.1. Anaerobic baffled reactor (ABR) operation

A schematic of the laboratory-scale ABR is demonstrated in Fig 1. ABR used ın this study has a working volume of 19 L (wide: 20 cm, long: 80 cm, deep: 20 cm), and a continuous flow four-compartment system. The working temperature of ABR was kept at 30^{o}C by a heater. A peristaltic pump was used for feeding LFL to the ABR reactor. The anaerobic baffled reactor (ABR) was seeded with sludge collected from the anaerobic reactor at the wastewater treatment plant (WWTP) (Kahramanmaraş, Turkey). The four-compartments of the ABR were filled with anaerobic sludge (1:4,v:v) from anaerobic sewage sludge. Initially, the mixed liquor suspended solids (MLSS) concentration of ABR was adjusted to 17000 mg L^{-1}. The ABR system was operated at a 24-h hydraulic retention time (HRT). The experimental plan used in this study is given in Table 1 below. This landfill leachate was diluted rate in proportions 1:2, 1:5, 1:10, and 1:50 with tap water to increase the biodegradability of landfill leachate. A four-compartment ABR was adopted in the experiment plan (Table 1) and the system performance of the ABR was determined for 105 days over 4 different dilution rates.

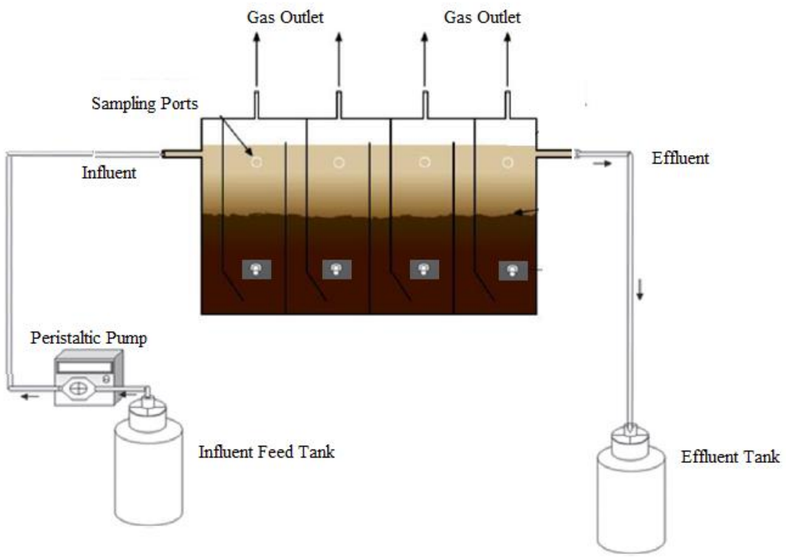

Fig 1. Anaerobic baffled reactor (ABR)

Table 1. Experimental Plan

PARTS	Dilution Rate % (v:v)
Part I	5% (1:20)
Part II	10% (1:10)
Part III	20% (1:5)
Part IV	50% (1:2)

2.2. Landfill leachate characterizations

LFL was gathered from Kahramanmaraş (Turkey) sanitary landfill on-site. LFL generated in this landfill site was about 815-830 tons day^{-1}. The LFL is collected in pools before it is discharged and treated. LFL was regularly taken from the pools and stored under laboratory conditions (4°C). These leachate samples were collected four times per month. The characteristic of LFL was given in Table 2.

2.3. Analyses

The ABR influent, the four compartment effluent, and the ABR effluents were sampled once every two days. All samples were centrifuged at 4000 rpm for 5 min (Eppendorf Centrifuge 5415R, Hamburg, Germany) and then, were filtered using a sterile syringe 0.45µm filter (Sartorius AG, Gottingen, Germany). The influent, each-compartment, and effluent DOC, TN concentrations were analyzed using a TOC instrument coupled with TN (Shimadzu TOC-VCPN, Kyoto, Japan).The pH was measured by a pH meter (Thermo, Orion 4 Star, Indonesia). The color was analyzed as Pt-Co units. Pt-Co color measurements were performed spectrophotometrically at 465 nm during lab-scale studies. Ionic composition of influent, each-compartment and effluent samples (ammonium, nitrate) was measured by ion chromatography (Dionex ICS-3000, Sunnyvale, CA, USA). The COD measurements were carried out according to the dichromate-closed reflux Colorimetric Method described in Standard Methods (Standard Methods, 5220 D).

Table 2. LFL Characterization

Parameters	Concentration (mg L^{-1})	Parameters	Concentration (mg L^{-1})
Dissolved Organic Carbon (DOC)	7058±400	NO_2^-	320±20
COD	16000±1500	NO_3^-	670±40
Biochemical oxygen demand (BOD)	1500±300	Color	6380±300 Pt-Co (Color unit)
NH_4^+-N	2120±200	PO_4^{-3}-P	78±10

3. RESULTS & DISCUSSION

3.1. COD removal performance

ABR performance with LFL addition with a ratio of 5, 10, 20, and 50% (v/v) was studied to determine the biodegradability of LFL (Table 1). Initially (part I, Table 1.) the minimum dilution rate of LFL in the influent was determined. COD removal performance was shown in Fig 2. COD removal efficiency was 26, 57, 80, and 70% at dilution rates of 5, 10, 20, and 50%, respectively. A gradual increase in COD removal was observed in the first three dilutions in the ABR. Then, a decrease in COD removal efficiency was observed at 50% dilution rate. It has been determined that COD removal efficiency was above 80% and 70% at dilution rates of 20% and 50%, respectively. According to COD removal efficiency, the optimum dilution rate was determined as 20%. A gradual increase in COD removal efficiency was investigated in the first three compartments of the ABR process. Therefore, anaerobic biological degradation has occurred at this stage. In a study performed by Krishna et al. [12] the ABR process was evaluated different HRTs for the treatment of complex wastewater. They obtained the COD removal efficiency above 88% for 0.6 to 2 kg COD $m^{-3}d^{-1}$ of organic loading rate (OLR). Mohtashami et al. [13] investigated that treatment of the landfill leachate using an ABR system of four compartments (total rector volume of 64L and HRT of 4 days). COD removal efficiencies over 80% were achieved in different OLR (1.2-7.75 kg COD $m^{-3}d^{-1}$).

In another study, the performance of ABR was evaluated with diluted wastewater (500 mg COD L^{-1}). The ABR was operated with an HRT of 80 h at 35°C, resulted in more than 80% COD removal [14]. Arvin et al. [15] the performance of an ABR treating LFL was evaluated in their study. They observed that the change in HRT and the concentration of LFL increased the COD removal efficiency (>86%). Similarly, in our study COD removal efficiency was approximately 80%, the corresponding dilution rate was 20%. Wang and Shen [16] used an ABR unit for co-treatment of landfill leachate and municipal sewage. They investigated the effect on ABR performance of different mixed rates of landfill leachate and municipal sewage. The results showed that the biological treatment performance in ABR increased when BOD_5/COD ratio was increased from 0.15–0.3 to 0.4–0.6. To investigate the effect of OLR and sulfate loading rate (SLR) on landfill leachate treatment, Burbano-Figueroa et al. [17] was used an ABR.

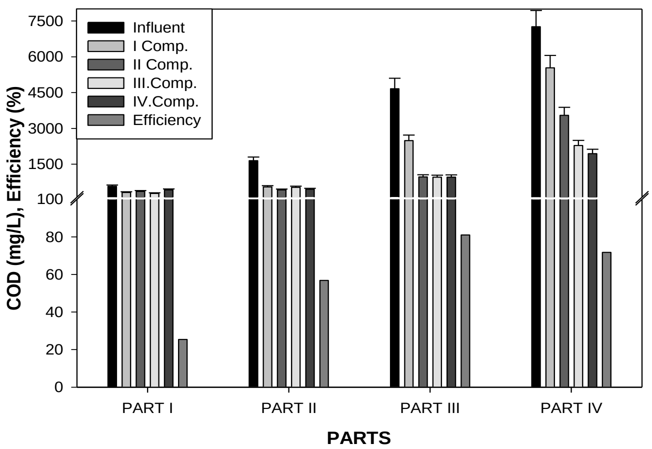

Fig 2. COD removal performance

3.2. Color removal performance

Biological treatment of LFL is very difficult due to the high amount of pollutant parameters [18,19]. In our study, color removal efficiency was observed using the ABR system. In recent years, color removal from LFL has been much attention. In this context, the color removal performance of ABR during LFL treatment was shown in Fig 3. In the ABR, the color removal efficiency was 16, 31, 16, and 36% at dilution rates of 5, 10, 20, and 50%, respectively. The highest color removal efficiency was observed at a dilution rate of 50% and the corresponding removal efficiency was 36%. According to color removal efficiency, the optimum dilution rate was determined to be 50% (Fig 3).

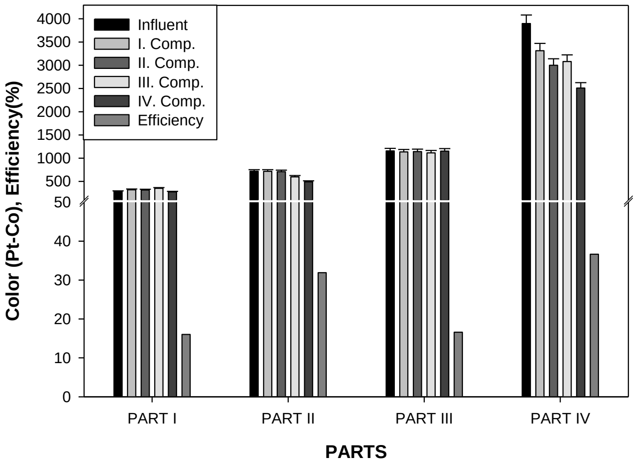

Fig 3. Color (Pt-Co) removal performance

3.3. OC and TN removal performance

DOC removal efficiency was 12%, 45%, 61%, and 30% at dilution rates of 5, 10, 20, and 50%, respectively (Fig 4A). The DOC removal efficiency reached over 60% when increasing the dilution rate from 5% to 20%. Also, DOC removal efficiency was reached 30% when the dilution rate was increased to 50%. In the lowest dilution rate (5%), the TN removal efficiency was 1% as a result of the removed TN concentration to 54mg L^{-1} (Fig 4B). At an increasing dilution rate from 5% to 50% the TN removal efficiency was increased from 1% to %28. The highest DOC removal efficiency was observed at a dilution rate of 20% and the corresponding removal efficiency was 61% (Fig 4A). The highest TN removal efficiency was observed at a dilution rate of 20% and the corresponding removal efficiency was 28%. According to TN removal efficiency, the optimum dilution rate was determined to be 20% (Fig 4B). To treat palm oil mill wastewater, Faisal and Unno [20] used A modified anaerobic baffled bioreactor (MABR) under steady-state conditions. They showed that the organic matter removal efficiency in terms of COD and total organic carbon was achieved as 72.1–95.9% and 44.2–91.3% under steady-state conditions (HRT from 3 to 10 days), respectively.

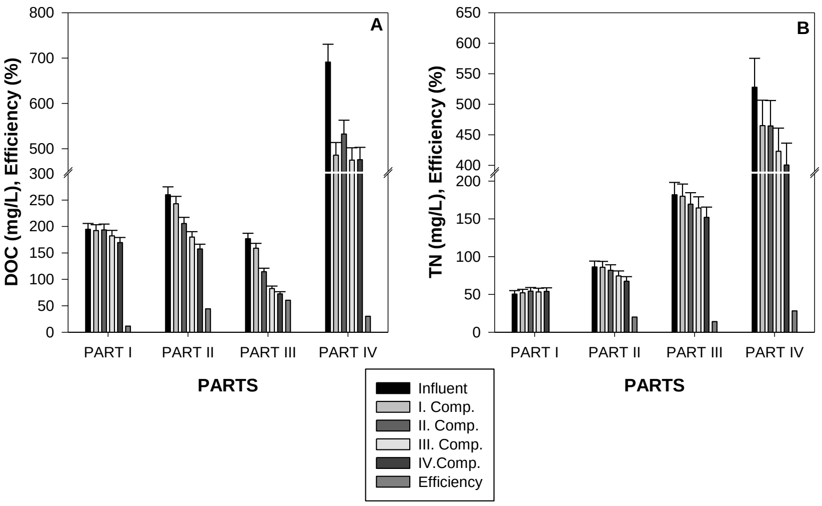

Fig 4. DOC removal performance (A); TN removal performance (B)

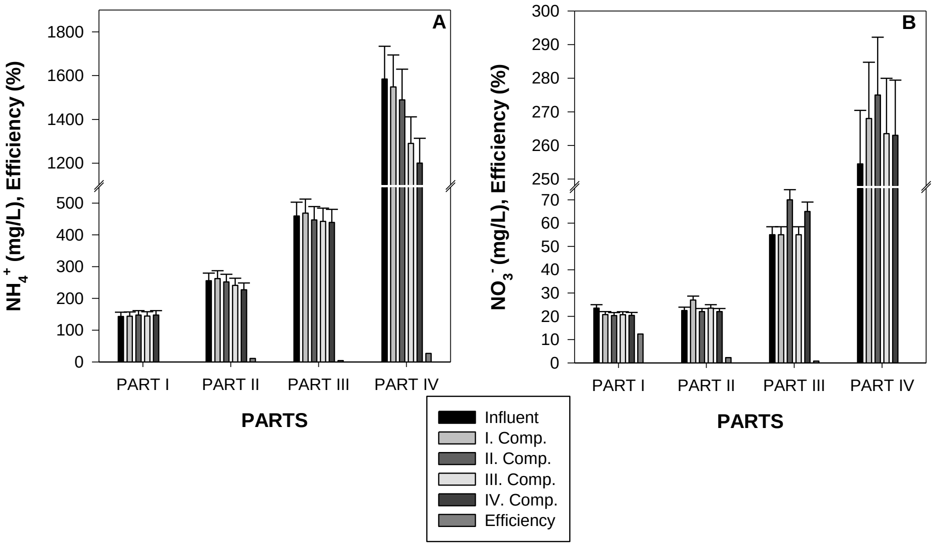

Fig 5. NH_4^+ removal performance (A); NO_3^- removal performance (B)

3.4. NO_3^- and NH_4^+ removal performance

Biological treatment of LFL is very difficult due to high ammonium and other pollutant parameters [21]. Increase in dilution rate to 5% and 50% increased NH_4^+ removal from 1% to 27% and decreased NO_3^- removal efficiency from 12% to 1% (Fig 5A-B). However, a further increase in dilution rate to 50%, positively affected the NH_4^+ removal, which was slightly increased to 1% and 26% at 5% and 20% dilution rate, respectively (Fig 5A). The maximum NH_4^+ removal efficiency of 26% was obtained at a 50% dilution rate. An increase in dilution rate to 50%, negatively affected the NO_3^- removal, which was significantly decreased to 12% and 1% at 5% and 50% dilution rate, respectively (Fig 5B).

4. CONCLUSIONS

In this paper, dilution rates of landfill leachate were investigated to evaluate the ABR performance. The effects of different dilution rates on LFL treatment using ABR was evaluated with regard to the removal performance of COD, color, NO_3^-, NH_4^+, and organic matter.

The most important results obtained in this study are as follows:

- High COD removal efficiency was observed in the ABR process, optimum conditions were determined as a dilution rate of 20% (v:v,1:5), corresponding to removal efficiency above 80%.
- The efficiency of organic and inorganic material removal increased significantly with the increase in the dilution rate of the landfill leachate.
- COD, DOC, TN, Color, NO_3^- and NH_4^+ removal efficiencies were approximately 81, 61,15, 17, 1, and 5%, at dilution rate of 20%.

This study showed that the ABR could offer an attractive alternative for COD removal from LFL. However, air stripping as pre-treatment or aerobic reactor as post-treatment may be used added in order to

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RESEARCH ARTICLE

Investigation of microalgal treatment for poultry slaughterhouse wastewater after the dissolved air flotation unit

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ABSTRACT

Meat and meat products are some of the primary consumption products required for the continuation of life. The world population accessed over 7.5 billion that means the demand for food is increasing every day. Slaughterhouses and integrated meat facilities are being rapidly developed and established to satisfy meat and meat product requirements. In slaughterhouse poultry plants, high amounts of water are utilized for the meatpacking process. The poultry slaughterhouse wastewaters contain high levels of organic solids such as fat, blood, suspended matter, and dissolved protein, which can be treated using physical, chemical, and biological treatment methods. In this study, the treatment of poultry slaughterhouse wastewater preliminarily treated by dissolved air flotation, with microalgae culture (Chlorella Vulgaris) development, unlike traditional treatments, was investigated. Chemical oxygen demand and total suspended solids parameters for wastewater treatment have been monitored for 15 days of incubation. 0.8, 4, 8, 12, and 20% by volume algae were applied for slaughterhouse wastewater, and the optimum amount of algal inoculation was determined after 15 days. When the removal efficiencies were examined, the most appropriate amount of inoculation rate with 76 % chemical oxygen demand removal and 87% algal growth (as total suspended solids) was selected as 12%.

Keywords: Chlorella Vulgaris, microalgae, poultry slaughterhouse wastewater

1. INTRODUCTION

Industry and technology have been developing day by day in our country. As a result, the population increases and the need for meat and meat products arises. According to OECD-FAQ, while meat consumption is 34.4 kg person^{-1} in the World, 32.4 kg person^{-1} is in Turkiye in 2019 [1]. As of 2019, 2335 thousand tons of poultry meat are produced in Turkey [2]. Therefore, slaughterhouse and meat integrated facilities numbers increasing day by day. However, meat processing in slaughterhouse and meat integrated facilities requires high amounts of water. When the wastewater of the integrated meat and slaughterhouse industry is discharged to the receiving medium without any treatment, it causes a decrease in the dissolved oxygen value of the receiving medium and the deterioration in the quality of the water environment [3]

The poultry slaughterhouse industry is also one of the rapidly developing industries. The poultry slaughterhouse industry wastewater contains high organic solids such as fat, blood, suspended matter, and dissolved proteins [4,5]. The organic substance content of the poultry slaughterhouse industry wastewater is high, and its temperature varies between 20-35 °C, and that can be treated in treatment plants where physical, chemical, and biological methods are used [5–11].

Microalgae's are heterotrophic and/or autotrophic, unicellular or multicellular organisms that grown in aquatic environments. Microalgae's are photosynthetic organisms and, CO_2, water, and nutrients (e.g., nitrogen, phosphorus, and potassium) are necessary for their growth [12–14]. They can continue to live by adapting to adverse environmental conditions because they can overgrow. According to the types of algae and the culture conditions, the

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structure of algae (mainly lipids, carbohydrates, proteins) can alternate [14–17].

Advanced treatment systems, in which ammonia, nitrate, and phosphate can be removed, are high-cost systems compared to the traditional treatment systems. Microalgal treatment systems are favourable advanced treatment systems due to inorganic nitrogen and phosphorus degradation [18]. This study is an example to prove the feasibility of microalgae treatment to the slaughterhouse wastewater after the air flotation unit. Slaughterhouse wastewater contains a high amount of oil-grease and suspended solids that prevent light transmission and air transfer in water. Microalgae require light and optimum air transfer to develop, and slaughterhouse wastewater includes excessive level suspended solids for algal growth before air flotation. After the dissolved air flotation unit, the inhibitory organisms, oil-grease, total suspended solids are eliminated roughly %99 in slaughterhouse wastewater which makes a suitable environment for microalgae existence.

This study aims to investigate the treatment of poultry slaughterhouse wastewater coming from the pre-treatment and dissolved air flotation units by microalgae's (*Chlorella Vulgaris*) at a laboratory scale. These wastewaters have a suitable medium for the growth of microalgae. Air floated poultry wastewater different inoculum rates of total wastewater volume 0.8, 4, 8, 12 and 20 % were investigated for 15 days. Chemical Oxygen Demand (COD) and Total Suspended Solid parameters were measured to determine the treatment of wastewater. While the studied optimum inoculum rate was specified as 12 %, in the same ratio, COD removal 76% and 87% algae growth as mass was observed

2. MATERIALS AND METHOD

2.1. Reagents and chemicals

All chemicals and reagents have been supplied by Merck Millipore Company.

2.2. Microalgae cultivation

Chlorella Vulgaris has been preferred as a convenient algae culture to realize the objectives of the current research. The algae culture cultivated in Sakarya University, Department of Engineering, Sakarya, TURKEY. Chlorella Vulgaris were cultured before for this study at BG-11 medium ($NaNO_3$, 1.5 g L^{-1}; K_2HPO_4, 0.04 g L^{-1}; $MgSO_4{\cdot}7H_2O$, 0.075 g L^{-1}; $CaCl_2{\cdot}2H_2O$, 0.036 g L^{-1}; citric acid, 0.006 g L^{-1}; ferric ammonium citrate, 0.006 g L^{-1}; EDTA (disodium salt), 0.001 g L^{-1}; Na_2CO_3, 0.02 g L^{-1}; 1 mL trace elements solution (in g L^{-1}:H_3BO_3, 2.86; $MnCl_2{\cdot}4H_2O$, 1.81; $ZnSO_4{\cdot}7H_2O$, 0.222; $NaMoO_4{\cdot}2H_2O$ 0.39; $CuSO_4{\cdot}5H_2O$, 0.079; $Co(NO_3)2{\cdot}6H_2O$, 0.0494 at pH 7±2). The BG-11 media and all glassware were autoclaved at 15 Psi and 120 °C for 20 minutes for sterilization.

2.3. Wastewater samples

Air floated poultry slaughterhouse wastewater (AFPSWW) has rich content; it provides a suitable environment for algal culture development [6]. The PSWW samples were obtained from a local poultry slaughterhouse in Sakarya, Turkey. PSWW was pre-treated with a dissolved air flotation unit.

The characterization of the Air Floated PSWW was made by using the wastewater sample taken from the air flotation unit before starting the study. The results are as shown in Table 1.

Tablo 1 Air floated PSWW characterization

Parameters (mg L^{-1})	COD	S.Solid	PO_4	TOC	TN
Initial Values	717.6	22	1.52	320	144

2.4. Experimental set-up

Chlorella Vulgaris has cultivated in 300 ml Erlenmeyer flasks containing a total of 250 mL poultry wastewater (after flotation) at a shaker (Biosan, Multi shaker PSU 20) at room temperature with 160 rpm shaking and a continuous illumination, fluorescent light (intensity is 3600 lux). Microalgae mixtures were added to the total volume of 250 mL with 0.8, 4, 8, 12 and 20 % different ratios. In the studies conducted with *Chlorella Vulgaris* in the literature, different cultivation times such as 7,8,12 and 14 days were selected [1–4]. Based on these studies, cultivation time was determined as 15. *Chlorella Vulgaris,* the initial pH of solutions was adjusted to be 7.0 ± 0.1 with pH meter (Hanna Ins. 301) by using 1.0 M HCl and 1.0 M NaOH solutions. No external CO_2 source was used for the algal cultivation other than the atmosphere. Fig 1 shows the first day of cultivation flasks after microalgae addition with the different ratios. All studies were repeated three times.

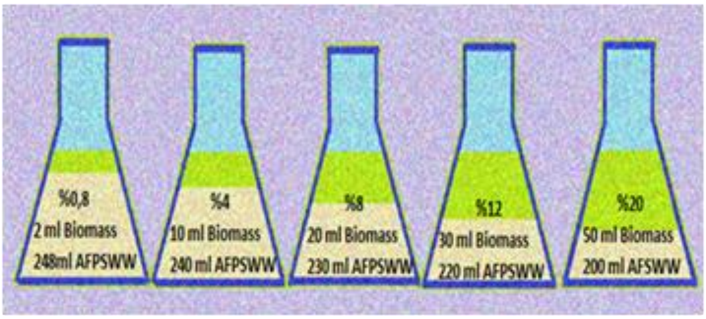

Fig 1. Poultry wastewater (after dissolved air flotation) samples with different ratio microalgae addition (0.8, 4, 8, 12 and 20%)

2.5. Parameters analysis

Water samples COD analyzes were carried out according to Standard Methods 5220-D-COD by using MERCK Spectroquant Pharo-300. Suspended organic matter analyses were carried out to obtain algal growth [6]. Suspended Solids filtered by using millipore 47 mm 0.22 µm glass fibre filters [23].

3. RESULTS AND DISCUSSION

3.1. Optimum concentration of microalgae

Biomass growth can be characterized as total suspended solids in algal systems [6, 24]. Glass fibre filter papers filtered the algal solutions, and after drying, the residual solid mass refers to algal growth. The growth of the algae culture in different algal additions of AFPSWW throughout the cultivation period is illustrated in Fig 1. During 15 days, under the same experimental conditions, biomass growth has been examined in different algal addition rates.

As can be seen in Table 1, raw AFPS wastewater included only 22 mg L^{-1} total suspended solids. The initial suspended solids amount was determined after algal addition for all ratios separately. Algal growth calculated with the formula of

$$\text{Algal Growth (\%)} = \frac{S - So}{S} x100 \qquad (1)$$

S; Total suspended solid matter (mg L^{-1}) after incubation, S_0; Initial total suspended solid matter (different for all algal addition ratios) (mg L^{-1})

After five days of incubation, the amount of TSS was started to increase rapidly for all algal addition levels except 20%. Although TSS rise was observed for all inoculum rates, the maximum biomass growth was investigated at 12%. Fig 2 shows the algal growth levels as TSS percentages.

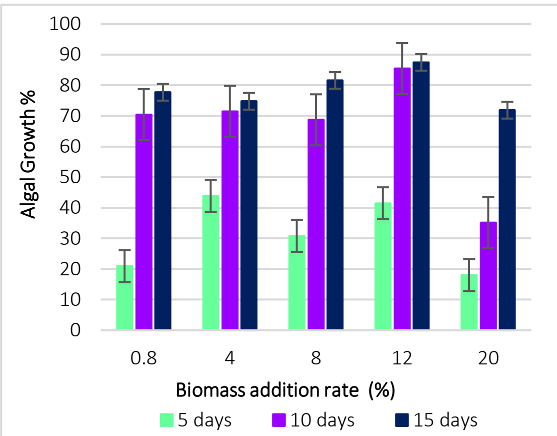

Fig 2. Algal growth (%)

Except for 20%, all other four algal concentrations algal growth trends were observed as similar in the log and lag phase. The further biomass content of 20% addition caused a lack of organic matter and nutrients. According to the experiment's results, biomass growth was directly affected by the nutrient and organic substances levels. C, N or P ingredients in wastewater can be a limiting factor for algal growth [18,25-26]. Similar research was conducted for raw slaughterhouse wastewaters diluted with distilled water by Azam et al., (2020) [27], Taşgan, E. (2016) [28], and with tap water Hernández et al., (2016) [29].

3.2. COD removal

CO_2 is the first inorganic carbon source for microalgae. The Absence of CO_2, bicarbonate (HCO_3^-) is the second source [30]. Microalgae are autotrophic organisms that can synthesize organic matter from inorganic substances. The well-known algal cell stoichiometric formula is $C_{106}H_{181}O_{45}N_{16}P$. That means the optimal reproduction media should be includes with these proportions [31]. In the other research, these proportions specified as 53:15:1 (C/N/P) [32].

Considering Table 1, AFPSWW provides a suitable environment for algae nutrition under the rates specified in the literature [14, 31–34].

It should be noted that *Chlorella Vulgaris* can function under heterotrophic conditions depending on the nature of carbon availability [35]. COD concentrations were observed during microalgae treatment for 15 days. All removal efficiencies values calculated with the formula;

$$\text{Removal Efficiency (\%)} = \frac{Co - C}{Co} x100 \qquad (2)$$

C_0; İnitial COD value after algal solution addition(mg L^{-1}), C; COD value after incubation (mg L^{-1})

Fig 3 shows COD removal rates trends for AFPSWW for all different inoculum rates.

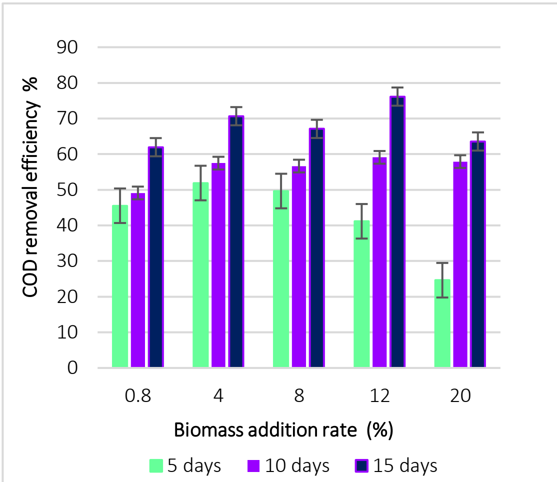

Fig 3. Removal of COD (%)

The more efficient inoculum rate was observed from the inoculum rates perspective as 12% with 76% COD removal efficiency. Within 15 days, COD values were decreased from 717 to 171 mg L^{-1} by microalgae. Therefore, the poultry wastewater treatment depends on the appropriate nutrient ratio to algae cells grow up rather than the algae density in the water.

As shown in Fig 2, the increase in algae quantity is not proportional to the removal efficiency. Hongyang et al. (2011) reported 70.3% COD removal using *Chlorella Pyrenoidosa* from soybean processing wastewater [36]. Hernández et al. (2016) observed 92 % COD removal for slaughterhouse wastewater in the high rate algal ponds with *Chlamydomonas Subcaudata*, Anabaena sp. and Nitzschia sp. [29]

4. CONCLUSION

According to Turkey water quality and control directive table 5.8 [5], discharge standards of slaughterhouse wastewater to the receiving environment are determined as the maximum COD values 200 mg L^{-1} for 2 hours of composite samples. Within this scope, the treatment with microalgae is proper for discharge to the receiving environment. On the other hand, if the produced algal biomass is considered an energy source, it is an acceptable wastewater treatment method that can bring considerable gains.

This study observed that 3.58 mg biomass could be produced per 1 mg COD removal for one litre of wastewater in the 12% algae addition ratio. In other words, a slaughterhouse facility producing 1000 m^3 wastewater can be grown theoretically 35.8 kg biomass per day.

Nowadays, microalgae biomass is used for many applications such as human consumption (food, cosmetics and pharmaceuticals), agricultural aims, etc. [38]. From this perspective, an economically valuable raw material will be produced from the biomass obtained from the wastewater treatment. In this study, even if it is not sufficient for energy production in the facility where it can purchase to a suitable market. Thus, both a very harmful wastewater to nature will be treated, and the biomass sale could reduce the treatment costs.

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REVIEW ARTICLE

The effects of endocrine disruptors on fish

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ABSTRACT

Nowadays, there are a lot of researches about the effects of endocrine disruptors on human and wildlife organisms. Endocrine disruptors are exogenous substances or substance mixtures that cause undesired effects in the organism or in future generations by altering the endocrine system of the exposed organism. Fish are exposed to endocrine disruptors in several ways including water, sediment, and diet. The toxic effects of endocrine disruptors on fish vary according to the exposure period, duration of exposure, chemical properties of the substances, and whether the exposed substance is single or mixed with other substances. Within the scope of this review, the classification of endocrine disruptors, their usage areas, their way of mixing into the aquatic ecosystem, and their toxic effects on fish will be explained.

Keywords: Endocrine disruptors, aquatic ecosystem, fish

1. INTRODUCTION

Endocrine disruptors (EDCs) can be produced either in nature or in industrial and have a wide range of usage areas including pesticides, personal care products, food contact materials, textiles, clothing, medical tubing, electronic and building materials. Rachel Carson mentioned about undesired effects of the manufactured chemicals on the birds population, in other words wild life, in her book, Silent Spring. Since then, it is understood that even though EDCs have been used and preferred various areas and made easier life for people, they tend to persistent in the environment and bioaccumulate in the organisms tissues. Therefore, their effects on human and wildlife have been very interesting research areas. Wild life and human populations are exposed to EDCs via food, water, air, through the skin, by transfer from mother to fetus (through placenta) or infant (through breast-feeding). Even though their first target mechanisms are endocrine systems of organisms, they also affect the other systems of the organisms such as neurological system [1]. In this review, the classification of EDCs, EDC contamination of aquatic ecosystems, exposure factors that can change the effects of EDCs on fish and the effects of EDCs on fish will be examined.

2. ENDOCRINE DISTRUPTORS

The endocrine system is a complex system that contained the thyroid, testis, ovary, pancreas, adrenal glands, and brain in mammals. However, the endocrine system organs in vertebrates vary according to the groups in which the organism is classified [2] (Fig 1).

Fish have pituitary, urohypophysis, thyroid, thymus, islets of Langerhans, chromaffin tissue, interrenal tissue, intestinal tissue in the gonads, ultimobranchial body, intestines, kidney, pineal gland, and Stannius bodies [2]. Like the other vertebrates, the pituitary secretes hormones which are responsible for the melanin pigment distribution in the cells, thyroid, and sex hormones secretion. The permeability of the gills is controlled by these hormones [3]. Thyroid gland hormones control all body systems including brain development, heart rate, blood flow, steroid hormone production, metamorphosis, migration of eyes, development of the dorsal ray. Thyroid hormones are

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secreted at high levels in freshwater migration and low levels in saltwater migration. The most common thyroid hormones in fish are triodotrione (T3) and thyroxine (T4) [3]-[4]. The androgen hormones secreted from the gonads are responsible for sexual development, reproduction, nest building, and swimming speed. The estrogen hormones decrease the belligerent behavior, and are responsible for fertilization and sexual activity. Prolactin hormone is involved in osmoregulation [4]. The regulation of calcium metabolism is controlled by the ultimobranchial body. The carbohydrate metabolism is controlled by the islets of Langerhans [3]. The melatonin hormone secreted by the pineal glands is involved in gonad development and adaptation to light / dark environments and seasonal adaptation [4].

Endocrine disruptors (EDCs) are exogenous substances or substance mixtures that cause undesired effects on the endocrine system of the organism [5]. These substances, acting on the receptors, bind to the receptor by mimicking the natural hormone, activate the receptor and produce a response (agonistic effect) or prevent the natural hormone from being activated by binding to the receptor (antagonistic effect) [6]-[7].

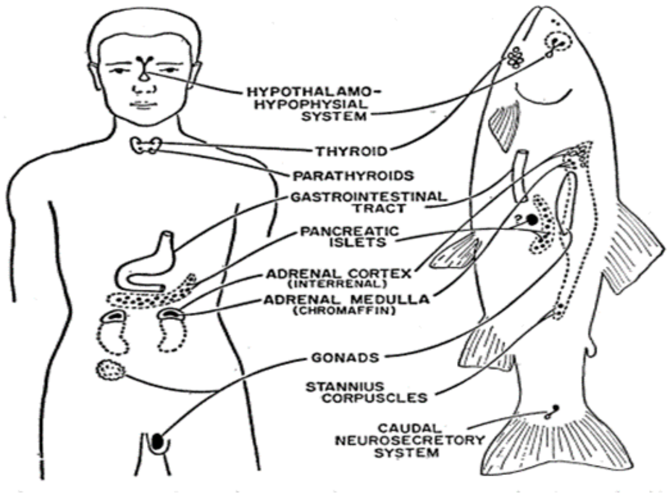

Fig 1. The endocrine system organs in human and fish [2]

Scientific Global Identification/Assessment of Endocrine Disruptors held by International Chemical Safety Program (IPCS), World Health Organization (WHO), United Nations Environment Program (UNEP), and the International Labor Organization (UNEP) made a definition of EDCs. According to this definition, EDCs are “exogenous substance/substance mixtures which affect the synthesis/production, release, transport, attachment, activity, and excretion of natural hormones responsible for homeostasis, reproduction, development and behavior” [5]. Another description of EDCs by the European Union is "secondary changes in the endocrine system affected by exogenous substances create an adverse effect in a healthy organism or its later generations” [8].

Human and wildlife organisms are exposed to many exogenous substances which have negative effects on their biological systems. Most of these substances have detected various environmental matrix including water, sediment, soil, lipid tissues of animals [6]-[9]-[10]. Laboratory experiments showed that the exogenous substances effect on the endocrine system, behavior, reproduction, growth, survival rate of the organisms [6].

2.1. The classification of EDCs

EDCs contain many chemical substances and can be classified into three ways that are natural, synthetic, and environmental [11]. Natural EDCs are phytoestrogens and mycoestrogens. Phytoestrogens are produced by plants such as isoflavone. Mycoestrogens are estrogen-like structures found in mushrooms. The effect of these compounds can be antiestrogenic or generally estrogenic [4]. Due to having natural hormones structure, they can easily collapse and they don’t accumulate in the tissues of the organism [11]-[12]. Synthetic EDCs contain construction pills, hormonal treatment ingredients, and some animal additive substances [12]. Environmental EDCs include chemicals that are used in industrial activities. This group includes plastics and plasticizers (such as bisphenol A and phthalates), pesticides, industrial chemicals, organohalogen chemicals (including polychlorinated biphenyls, polybrominateddiphenyl ethers), organic tin compounds, polyaromatic hydrocarbons, drugs and metals [4].

2.2. Contamination of aquatic ecosystems with EDCs

EDCs have an important place in environmental toxicology studies due to adverse effects on humans and wildlife. These substances are contaminated into aquatic ecosystems in various ways such as domestic, municipal wastes, industrial wastes, forest fires, and mine wastes. They accumulate in the water, sediment, and aquatic organisms and therefore,they tend to biaccumalation and biomagnification in the tissues of organisms via aquatic food web [1]-[13]. Fish, one of these aquatic organisms, are exposed to EDCs through water (skin and respiration) and diet (consumption of aquatic organisms affected by EDC) [14].

2.3. Factors that can change the effect of EDCs on the organism

Age of the exposure: It is thought that exposure to a developing organism and an adult individual to EDCs may produce different results [15]. It has been observed that exposure in the early stages of development causes more permanent damage [8].
The time after exposure: The effects may not be observed immediately after exposure to EDCs. These effects may occur the following years [8].

Mixture effects: In the environment, EDCs are not usually found alone. They are mixed with other EDCs. For this reason, organisms are under the influence of not just one substance but many substances at the same time. Thus, these substances can create an antagonistic or synergistic effect with each other [16].
Unusual dose-response relationship: EDCs act on organisms even at very low concentrations. It is important to know the critical window which occured in the developmental period of organisms [16].

Epigenetic and genotoxic effects: Due to epigenetic and genotoxic effects, EDCs can show their effects on the individual, on future generations, and subpopulations [17].

3. EDCS EFFECT ON FISH

3.1. Reproductive health and EDCs

Except for some special conditions, reproduction in fish is an event that takes place in the form of external fertilization. Fertilization takes place by the combination of the egg and sperm released by the female and male individuals in the water environment. Therefore, the chemical properties of the water environment are important for the healthy fertilization of the egg and sperm [18]. Therefore, many studies have been conducted to understand the effects of EDCs on reproductive health. Studies have reported that the amount of vitellogenin, which is an important hormone in reproduction, decreases after plasticizers (bisphenol A) exposure of goldfish [19], Japanese medaka [20], zebrafish [21], and fathead minnow [22]. However, it was reported that exposure to polychlorinated biphenyls (PCB 126 and PCB 153) caused the increase of the vitellogeninof Gilthead seabeam [23]. The production of egg and sperm also decreased after the exposure of the phthalates (di(2-ethylhexyl) phthalate and mono-(2-ethylhexyl)-phthalate)[24]-[25]. It was observed that pesticide (DDT, malathione and atrazine) exposure has effects on the female reproductive system such as narrowing of fish ovaries and a decrease in egg diameter [26]-[27]-[28]. Exposing to polybrominated biphenyls (PBDE 47 and PBDE 71) resulted in the decrease of cumulative egg production [29]-[30] and sperm counts [29]-[31]. It has been observed that the ratio of males and females in thezebrafish population changes as a result of exposure to EDCs [32].

3.2. Development effects and EDCs

The growth stages in fish progress as fertilization, the formation of the blastopore, egg sac and exit from egg sac, the flexibility of notochord, metamorphosis, juvenile and mature individuals. In these developmental stages, embryonic deformation and disorders in tail development occur in organisms exposed to EDCs [33]. Studies have been reported that exposure to bisphenol A caused pericardial edema, bleeding, congestion in embryos, and the development of the round tale of the larvasof Japanese medaka [34] and zebrafish[35]. Exposure to organic tin compounds (zinc pyrithioneand copper pyrithione) made disorders in tail development of Japanese medaka [36], notochord bending, cardiac and ovarian edema, and anomalies in swimming sacs of zebrafish [37] It was observed that polybrominated biphenyls (PBDE 47) caused pericardial edema, tail deformation, and notochord twisting in embryos and larvas of zebrafish[38]. It was reported that after male zebrafish exposed to dibutyl phthalate and mated with healthy female zebrafish, such malformations like edema, bent trunk were occurred in their embryos [39].

3.3. Growth effects and EDCs

There are many studies that have been obtained population growth rate and survival rate effects of EDCs on fish. Studies are noted that bisphenol A caused the decreasing of somatic growth rate, gonadosomatic index and survival rate [22]-[40]-[41]. Although exposure to pesticides (hexazinone and atrazine) decreased the somatic growth rate of red drum larvae [42] and Atlantic salmon[43], exposure to sodium perchlorate salts at very low concentration increased the growth of mosquitofish [44]. Besides, some EDCs like nonylphenol and arsenic don't affect the growth [45]-[46].

3.4. Histopathological changes and EDCs

EDCs alter the normal pathologies of the tissues and organs. It was observed that atrazine, one of the pesticides, caused autolysosome, emphysome, and vacuolization of mitochondria in kidney and spleen organs [47]. Exposure to sodium perchlorate salt made hypertrophy in thyroid gland tissue of stickleback [48]. In a study investigating arsenic exposure of tilapia, histopathological findings were detected as epithelial hyperplasma, edema, lamellar fusion, aneurysm, and necrosis in gill tissue; focal lymphotic and macrophage infiltration in liver tissue; a hollow appearance and elongation in liver cells (hepatocytes), vacuole degeneration, focal necrosis and nucleus hypertrophy [49]. It has been determined that cell height in thyroid gland epithelial cells and deterioration in colloidal matter occurred in polybrominateddiphenyl ether exposure of fathead minnow [50]. Hyperaemia, epithelial lifting, fusion of secondary lamellae, telangiectasia in gill tissues and hyperaemia, mononuclear cell infiltration vacuolization of hepatocytes, hydropic degeneration in liver tissues were observed in the imidacloprid pesticide exposure of Nile Tilapia[51]. Exposure to propoxur made hyperemia, branchitis in primary lamella, and telangiectasis, hyperplasia, fusion, epithelial lifting, and epithelial desquamation in secondary lamella of gill tissues; hemorrhage, destruction, prenephritis, and inflammation and desquamation in the tubules; edema in the kidney; passive hyperemia, albumin, and hydropic degeneration in the liver; and hyperemia, chromatolysis, and glial proliferation in the brain tissues of common carp [52].

3.5. Thyroid hormone and EDCs

Triodotrione (T3) and thyroxine (T4) hormones secreted from the thyroid gland in fishes are responsible for the brain, skeletal and organ development, migration of eyes and the formation of dorsal fin rays at the embryonic stage, physical, and morphological changes (smoltification), sexual maturation, and adjusting the metabolic rate [4]-[5]. For this reason, changes in plasma levels of T3 and T4 hormones in fish exposed to EDCs may cause many effects. It has been determined that fish exposed to arsenic have a decrease in T4 hormone levels and a decrease in migration movements from sea to freshwater [53]. It was observed bisphenol A and bisphenol S caused the increasing level of T3 hormone of juvenile brown trout [54].

3.6. Biochemical parameters and EDCs

EDCs change the biochemical parameters of fish including lipid, protein, and enzyme. In fish exposed to arsenic, apoptosis and necrosis events were observed in the cell division cycle. An increase in catalase enzyme activity was detected with a decrease in superoxide dismutase and glutathione peroxidase enzyme activity [55]-[56]. Common carp were exposed to esbiothrin(pesticide), total antioxidant status was decreased at first and then increased in time [57]. It was observed that malondialdehyde levels increased while glutathione-s-transferase levels decreased exposure to pesticides [51]. Bisphenol A exposure of bighead carp increased thiobarbituric acid reactive substance (TBARS), reduced glutathione (GSH) whereas catalase, superoxide dismutase, peroxidase, and total proteins were decreased [58]. It was observed to bisphenolA exposure disrupted lipid metabolism and decreased the oxidative stress response in the liver of common carp [59]. In another study with Bisphenol A, it was concluded that the ratio of protein and nucleic acid (RNA: DNA) decreased with the observation of histopathological changes in fish gonad tissues [40].

3.7. Genotoxic effects and EDCs

There are many studies that have been obtained genotoxic effects of EDCs on fish. Increases in micronucleus frequencies and DNA strand breakage levels were observed in fish exposed to pesticides (esbiothrin and fenitrothion) [57]-[60]. It was recorded that exposure to dialkyl phthalate,bisphenol A and tetrabromodiphenylether caused increasing micronucleus level and nuclear anomalies were recorded as blebbed, notched, and lobed nuclei [61]. In the long term exposure to bisphenol A, it was observed morphological abnormalities of erythrocytes (such as broken nucleus, lobed nucleus, micronucleus, and blabbed nucleus) of bighead carp [58]. Bisphenol A and bisphenol S caused increasing micronucleated cells of juvenile brown trout [54].

4. CONCLUSION

As a result of the contamination of EDCs in aquatic ecosystems, changes in antioxidant mechanisms, histopathological differences, disease formation and related deaths, physiological dysfunctions, teratogenic effects, changes in reproductive behaviors, and a decrease in the reproduction rate have been observed as a result of studies on fish from aquatic organisms. The presence of EDCs in very low amounts and in the mixture increases the effect on non-target organisms even more. Although there are many studies about these substances, their mechanism of action has not been fully understood yet. For these reasons, various national and international regulations regulated within the framework of the production, distribution, and use of EDCs should be followed, and the people who use these substances should be trained. In addition, the ways these substances enter aquatic ecosystems should be examined and these routes should be reduced as much as possible.

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RESEARCH ARTICLE

Lead removal from soil by phytoremediation method

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ABSTRACT

Many control approaches are used today to prevent the contamination of soils with heavy metals and to remove pollution. One of these approaches is phytoremediation for the on-site treatment of pollutants. In phytoremediation, hyperaccumulator plants are used, which absorb heavy metals, accumulate at high levels in their tissues, and neutralize them after various processes. It was aimed to determine the effects of heavy metals on plant growth and the heavy metal accumulation capacity of plants in this study. Using the phytoremediation method, the growth process of the canola plant and its lead removal capacity from the soil were investigated. The study was carried out in 3 replicates by watering the plants only with tap water and tap water containing different concentrations of lead in greenhouse conditions. The prepared soil mixture was placed in pots as 2000 g pot^{-1}. The sown seeds were germinated using tap water in the plant growing room and the water requirement of the plants was met with tap water containing a certain concentration of lead during the next growing period. Plants were harvested at the end of the 3 month growth period. The plants irrigated with the lead solution were compared with the plants irrigated with only tap water, and the elongation amounts of root and stem lengths were determined. Plant samples with dry weights determined were burned with certain chemicals using the microwave method, and then the amount of lead in the plants was measured with the ICP-MS device.

Keywords: Canola plant, heavy metal, lead, phytoremediation, soil pollution

1. INTRODUCTION

As a result of the increase in living standards in the world and in our country, the expansion of the industrial areas, the burning of coal containing heavy metals and the increasing traffic density have caused the amount of heavy metals in the environment to reach high amount such as many pollutants. These substances can not only accumulate in organisms, but also can travel through food chains and stay in ecosystems at dangerous concentrations for a long time. As a result of this intensity, living things in nature are negatively affected and the products obtained are extremely dangerous in terms of health. The environment is an inseparable whole with soil, air and water components that are in constant interaction with each other. Soil pollution is one of the major environmental problems in this cycle, where any degradation affects the others. Humans, animals and plants need quality soils in order to maintain their life. Heavy metals such as Cu, Zn, Mn, Fe and Mo are essential nutrients for plants and naturally occur in the soil. However, the increase in the production or need of some elements in constructed and developing countries, the accumulation areas developed for the regular storage of agricultural wastes and other solid wastes can increase the metal load of the soil. Heavy metals such as Hg, Cd, Ni entering the soil in various ways are held by the soil and affect soil microorganisms. As a result of the loss of the vitality of the soil, both plants and other living things are negatively affected by this situation.

Some of the heavy metals that mix into the soil in unnatural ways and their sources can be listed as follows [1].

- Primary sources
    - Fertilizers (Cd, Pb, As, Se)

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- Lime (As, Pb)
- Pesticides (Pb, As, Hg)
- Waste sludge (Cd, Pb, As)
- Irrigation (Cd, Pb, Se)

- Secondary sources
    - Automobile aerosols (Pb)
    - Mine melting areas (Pb, Cd, Sb, As, Se, Hg)
    - Waste incineration plants (Pb, Cd)
    - Mine areas (Pb, Cd, As, Hg)
    - Outer tire (Cd)
    - Paint (Pb, Cd)
    - Sea (Se)
    - Garbage dump areas (Pb, Cd, Se)
    - Aerosols with long spreading areas (Pb, Cd, As, Se)
    - Coal burning (Pb, Cd, As, Se)
    - Alkaline batteries (Hg)

Heavy metals such as Hg, Cd and Ni usually collect in the topsoil and humus. Metals holding in the topsoil at the beginning of heavy metal pollution can penetrate deeper with the acidification of the soil in the future and mix into underground waters. For this reason, heavy metals pass into the human body both through drinking water and some plants. Besides the effects of heavy metals as ions, it is known that the toxic effects of organometal compounds are higher [2].

Until now, various remediation methods have been used to improve soil contaminated with heavy metals [3, 4]. However, these methods, besides being expensive and requiring a lot of effort, did not give definitive results in the complete removal of soil pollution. For this reason, green breeding (phytoremediation) techniques, with lower costs have been developed in recent years [5].

In phytoremediation technique, hyperaccumulator plants are used that can absorb heavy metals and accumulate them at high levels in their tissues and neutralize them after various processes [6]. Compared to different breeding methods, its most important advantages are its low cost, easy application and aesthetically beautiful appearance [7].

Phytoremediation is classified according to pollutant types. If these pollutants contain metal; phytoextraction, phytostabilization and rhizofiltration, if they contain organic matters, as phytodegradation, rhizodegradation and phytovolatization is divided into six different classes.

Phytoextraction; it is the name given to the method of taking by the root of the plants the metal compounds that cause pollution in the soil. Plants display different characteristics in absorbing harmful substances in the soil. Therefore, high amounts of contaminant resistant plants should be used.

Phytostabilization; it is generally used to prevent erosion in areas with erosion, to prevent leakage of pollutants into groundwater and their direct contact with soil. In this method, the soil surface is covered with hyperaccumulative plants suitable for the area [8]. In this method, plants fix pollutants physically and chemically by means of roots [9]. For this method, plants that can grow and develop in soils contaminated with heavy metals and that can change the physical, chemical and biological properties of the soil in order to convert toxic substances into less toxic forms are needed.

Rhizofiltration; it aims to remove heavy metals in contaminated waters rather than reclamation of the soil. In the plants to be used in this method, a well-developed root system that can act as a filter is required. Pollutants are either absorbed on the root surface of the plants or transported to the other organs of the plant by being absorbed through the roots.

The advantages and disadvantages of phytoremediation are listed below [10].

- Advantages of phytoremediation
    - It is more economical than other improvement types
    - No new plant is needed to invade the field again
    - No extra field is required for waste dumping
    - It has an aesthetic appearance and is pleasing
    - Due to on-site improvement, the pollutant is prevented from moving to another area and spreading
    - Just not a single pollutant, but many pollutants can be tackled at the same time
- Disadvantages of phytoremediation
    - Pollutants accumulated on the leaves can be mixed with the soil again in autumn
    - Pollutants may have accumulated in the plants used as firewood
    - The improvement period may take a long time
    - Pollutants can be mixed back into the soil by washing and dissolving

2. MATERIAL AND METHODS

In the study, it was used canola (*Brassica napus*) as hyperaccumulator plant and lead as a soil pollutant. The studies were carried out in the plant growth cabin and the pots and soils used were obtained from the florist.

Soils were prepared by mixing 1/3 fine-grained sand, 1/3 field soil and 1/3 fertilizer. The prepared mixture was placed weight of 2000 g pot^{-1} in 12 pots with a diameter of 20 cm and each seed was planted at 5 cm intervals. The sowing of canola seeds is shown in Fig 1.

Fig 1. Sowing of canola seeds

The experiments were carried out by giving water in different lead concentrations of 25 ppm, 50 ppm and 75 ppm to the plants under greenhouse conditions. 9 pots were used by working in 3 repetitions for each determined lead concentration. In addition, 3 different pots irrigated with tap water were used as control plants in the study. Lead solutions were added to the pots in the indicated repetitions and concentrations as use all the soil capacity. Lead solutions were obtained by dissolving $Pb(NO_3)_2$ in tap water, and the water requirement of the plants was met with prepared lead solutions. Irrigation with lead solutions was carried out after germination to prevent the plant from dying. The study was carried out for the absorption of heavy metals added to the pots by the soil in a growing cabinet with 10-12°C of night temperature, 25-30 °C of daytime temperature and 30-40% of humidity for 12 hours of illumination and 12 hours of darkness for 3 months. The germination of canola seeds is shown in Fig 2.

Fig 2. Germination of canola seeds

Plants were harvested at the end of the 3 month growing period, root and stem parts were washed with pure water, their wet weight was weighed and left to dry for 24 hours at 68°C. 3 ml H_2O_2 (hydrogen peroxide) and 2 ml HNO_3 (nitric acid) were added to the plant samples whose dry weights were determined, and they were ground by wet burning method in a microwave oven. The caps of the microwave tubes containing the samples were closed tightly and the burning process was completed and then lead analysis was performed with the Agilent 7800 ICP-MS device. The irrigation process, the harvesting process and the drying process are given respectively in Fig 3, Fig 4, and Fig 5.

Fig 3. Performing the irrigation process

Fig 4. Performing the harvesting process

Fig 5. Performing the drying process

3. RESEARCH FINDINGS AND DISCUSSION

Root and stem lengths of plants irrigated only with tap water are given in Table 1, and root and stem sizes of plants given tap water containing lead in different concentrations are given in Table 2, Table 3, and Table 4.

The results in Table 1, Table 2, Table 3, and Table 4 show that the increase in the amount of lead causes a shortening in the plant stem. On the contrary, it is seen that there is elongation in the roots. This situation has been interpreted as the above-ground part of the plant is more sensitive to lead, and lead disrupts the nutrient intake and transmission balance of the plant. As a result, plant roots react to growth and create more contact areas to increase nutrient intake. These results are shown schematically in Fig 6. The amounts of lead accumulated in the plants according to the lead analysis performed by harvesting the plants and then subjecting them to heat treatment are given in Table 5.

Table 1. Elongation in tap water plants

Pots	Root (cm)	Stem (cm)
1. Pot	13.3	5.10
2. Pot	14.4	6.05
3. Pot	12.68	5.41
Average length	13.46	5.52

Table 2. Elongation in plants fed tap water containing 25 ppm lead

Pots	Root (cm)	Stem (cm)
1. Pot	13	4.5
2. Pot	16.33	4.85
3. Pot	13.89	5.52
Average length	14.41	4.96

Table 3. Elongation in plants fed tap water containing 50 ppm lead

Pots	Root (cm)	Stem (cm)
1. Pot	15.18	3.5
2. Pot	14.44	4.2
3. Pot	20.83	5.25
Average length	16.82	4.32

Table 4. Elongation in plants fed tap water containing 75 ppm lead

Pots	Root (cm)	Stem (cm)
1. Pot	20.625	4.125
2. Pot	17.5	3.875
3. Pot	14.56	3.16
Average length	17.56	3.72

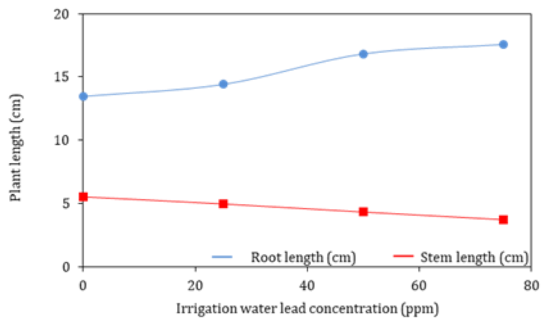

Fig 6. Schematic representation of plant root and stem sizes

Table 5 The amounts of lead found in the roots and stems of the plants according to the analysis results (mg kg^{-1})

	Without lead	25 ppm lead	50 ppm lead	75 ppm lead
1. Pot	1.05	11.01	14.45	18.32
2. Pot	1.1	14.83	16.22	20.89
3. Pot	0.95	12.02	15.50	18.35
Average	1.033	12.63	15.39	19.18

When the results are examined, the plants took an average of 12.63 ppm from 25 ppm lead. This equates to approximately 50.52% of the total lead. Likewise, an average of 15.39 ppm lead was found in the structure of plants irrigated with 50 ppm lead solution. This equals to 30.78% of the given lead. The average amount of lead in plants irrigated with tap water containing 75 ppm of lead is 19.18 ppm. In other words, 25.6% of it has passed into the plant. These values are expected to be higher in longer study time.

4. CONCLUSIONS

The data obtained as a result of this study have shown that lead removal from soil and wastewater can be done by phytoremediation in natural environments using canola plants. In the study, it was observed that the roots of canola plants irrigated with tap water containing lead lengthen as the lead concentration increased, but the stem length decreased. This situation can be explained as the mechanism by which heavy metals (lead) taken into plant tissues disrupt the nutrient absorption and mineral transmission balance in plant tissues and the plant roots respond by growing to increase the absorption of nutrient water. In addition, it turns out that canola plant roots are more resistant to lead, but the parts remaining above the soil and making photosynthesis are more sensitive. The removal of heavy metal-containing waters by phytoremediation method can be preferred because it reduces soil pollution and provides an aesthetic appearance to the environment by covering the soil surface with green tissue.

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RESEARCH ARTICLE

Comparison of incineration and autoclave methods in the treatment of medical wastes through life cycle assessment: A case study for Istanbul

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ABSTRACT

Medical waste management has always been an important topic due to its infectious status. Recently, more care has been given to it due to the COVID-19 pandemic throughout the world. Several methods are applied to handle medical wastes. Incineration and sterilization with autoclave are among the most common medical waste treatment methods. Among all methods, incineration serves the ultimate method of waste destruction since the waste is exposed to high temperatures (~800 °C) for about 2 hours. Because of the pandemic or some other reasons, administrations may want to shift their technology to incineration from autoclave. Therefore, in this study, we aimed to prepare a comparison of both technologies in terms of life cycle perspective. We used OpenLCA for calculations. Two different calculations were conducted. In the first one, the actual treatment methods and the waste amount were used. In the second one, a scenario was formed that included the treatment of the whole medical waste of Istanbul by only incineration process. The results indicated a higher mid-category life cycle impact for the combustion method. The highest contribution was for human toxicity with 3.8e4 kg 1,4-DB eq and 1.7e5 kg 1,4-DB eq for the current operation and scenario, respectively. The environmental impact of the sterilization process remained negligible relative to the combustion process.

Keywords: Medical waste, life cycle assessment, incineration, autoclave, OpenLCA

1. INTRODUCTION

Health services generate various types of waste. The World Health Organization (WHO) reported that approximately 10-25% of the waste produced in healthcare facilities can be considered hazardous [1]. Various treatment methods are available for medical wastes and they can be used for their disposal wastes [2]. Life Cycle Assessment (LCA) can be used to monitor the environmental impacts of similar activities [3].

In a study, the optimum municipal solid waste management strategy was investigated through an LCA study in Eskişehir in 2008 [4]. It was reported that 750 tons of waste per day was produced in Eskişehir and the city is among one of Turkey's developing cities. Five alternative scenarios were developed apart from the actual waste management system. These scenarios considered waste collection, transportation, handling, and disposal. According to scenario comparisons and sensitivity analysis in SimaPro7, the composting scenario was found to be more environmentally friendly among the alternative scenarios.

LCA was applied in Aksaray, Turkey, to determine the best strategy for municipal solid waste management for the year 2017 [5]. As an alternative to the available waste management system, four different scenarios were generated and evaluated for the best environmental solution. The scenario with 75% landfilling and 25% composting had the least impact on the environment and human health. Carbon dioxide and methane emissions were estimated from the existing municipal solid waste facility. Annual emissions were 8674 and 3161 tons for CO_2 and CH_4, respectively.

Another study was conducted in Pakistan to determine the environmental impacts of different medical waste management scenarios using the LCA approach [1]. The scenarios included the

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transportation of the wastes and their disposal through material recycling, landfilling, composting, and incineration methods. These methods were evaluated according to greenhouse gas (GHG) emissions. Landfilling and incineration were the worst final disposal alternatives. An integrated system, including composting, incineration, and material recycling methods, was reported to be the best solution among all scenarios.

A preliminary LCA study was conducted in Bangladesh based on existing waste management scenarios [6]. The study was conducted in the city of Chittagong on the management of medical waste. For the available medical waste management system, three scenarios were generated based on previous data together with the previous scenario. Previously calculated scenario values were used as input to the LCA database. The collected data were analyzed using SimaProv7 to calculate terrestrial ecotoxicity potential, freshwater aquatic ecotoxicity, human toxicity, and global warming. It was incicated that incineration and open burning of the medical waste significantly contributed to human toxicity potential and global warming. The landfilling disposal method mainly contributed to terrestrial ecotoxicity potential and freshwater aquatic ecotoxicity categories. The suggested scenario had lower impacts on each category, compared to existing public and private medical waste management systems. The incineration of medical waste with 30% energy recovery had the lowest environmental impact for all impact categories.

Medical wastes are regularly collected and disposed of in sterilization (infectious and cutting wastes) and incineration (infectious and pathological wastes) facilities with an average of 77 tons of medical wastes per day from health institutions in Istanbul [7]. Annually 29,065 tons of medical waste were produced in Istanbul in 2019 [8]. In Istanbul, 22% of medical waste (pathological and infectious wastes) is sent to the incineration facility, and 78% of medical waste (infectious and cutting wastes)is sent to the sterilization facility [9].

In this study, two cases are calculated through OpenLCA and discussed. In the first case, it is aimed to evaluate the existing medical waste disposal methods for Istanbul with LCA and in the second case, it is aimed to evaluate the disposal of Istanbul medical wastes only by incineration with LCA. The boundaries of the study is the disposal of Istanbul medical wastes collected in 2019 at the medical waste sterilization facility and medical waste incineration facilities. In the study, the transportation to the disposal facilities and the process after disposal were not considered. Because these parts are fixed regardless of disposal.

2. MATERIALS AND METHOD

The LCA methodology provides a "cradle to grave" perspective, keeping in mind that all stages involved in the life cycle of a product or activity have responsibility for its environmental consequences [10]. LCA application consists of four separate parts; target and scope definition, inventory analysis, impact assessment, and interpretation [3]. Fig 1 shows the LCA stages.

An important perspective of a waste management strategy is to identify areas where specific measures have to be taken to reduce the environmental impacts of waste management. LCA was used in several studies as an environmental tool to benchmark waste disposal options or management scenarios [12].

Medical wastes characterization is required for LCA, but no such study is available for Istanbul. According to a study, which reported the characterization of medical waste in Tabriz, Iran[13],is used in this study to represent the shares of waste type. The distribution of medical waste characterization calculated according to the percentages in Fig 2.

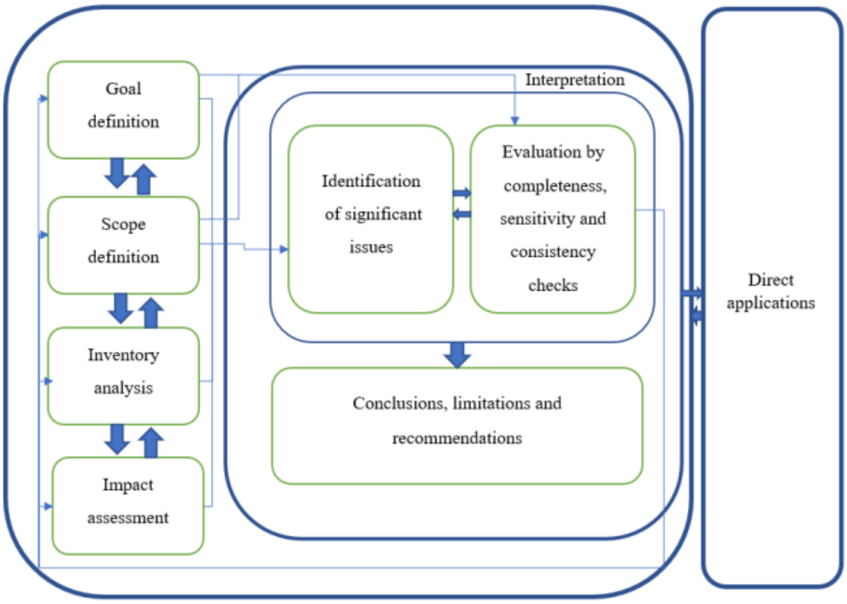

Fig 1. The elements of the interpretation phase and their relations to each other and to the other phases of the LCA [11]

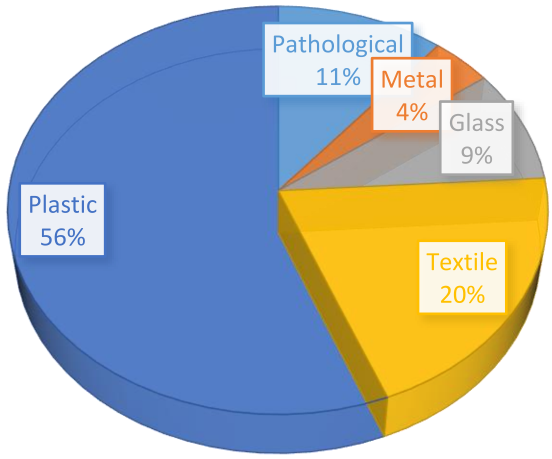

Fig 2. The medical waste share used in this study

The highest waste type was plastic with 56%. The remaining were textile, pathological, glass, and metal in the descending share order. These data were given an input to the software. In this study, the 1.10 version of the openLCA program and ELCD 3.2 database was used. OpenLCA is an open-source software used for life cycle analysis and sustainability assessment[14]. In openLCA; flows, processes, product systems were created for the current disposal method and scenario. CML-IA method was used to perform the impact analysis. The impact categories in CML-IA is given in Table 1.

Table1. Impact categories and units of CML-IA impact analysis method

Name	Reference unit
Abiotic depletion	kg Sb eq
Abiotic depletion (fossil fuel)	MJ
Acidification	kg SO_2 eq
Eutrophication	kg PO_4 eq
Freshwater ecotoxicity	kg 1,4-DB eq
Global warming potential (GWP100a)	kg CO_2 eq
Human toxicity	kg 1,4-DB eq
Marine aquatic ecotoxicity	kg 1,4-DB eq
Ozone depletion potential (ODP)	kg CFC-11 eq
Photochemical oxidation	kg C_2H_4 eq
Terrestrial ecotoxicity	kg 1,4-DB eq

In the availability of different methods for the mandatory impact categories, a key indicator is selected based on the existing principle of best practice. These key indicators are category indicators at the "midpoint level" (approach to the problem)[15]. Depletion of abiotic resources includes depletion for elements, ultimate reserves, and abiotic depletion for fossil fuels as impact categories. The abiotic depletion of elements, ultimate reserves are related to the extraction of minerals due to inputs in the system. The abiotic Depletion Factor (ADF) is determined based on the concentration reserves and decrease rate for each mineral extraction (kg antimony equivalent/kg extraction). Abiotic depletion of fossil fuels is related to the Lower Heating Value (LHV), which has the unit of MJ per kg m^3 of fossil fuel. Global Warming Potential (GWP100) is calculated according to the characterization model generated by the Intergovernmental Panel on Climate Change (IPCC), which has the unit of kg carbon dioxide equivalent/kg emissions for a time horizon of 100 years. The characterization model for ozone depletion (steady state) was developed by the World Meteorological Organization (WMO) and describes the ozone depletion potential of different substances (in kg CFC-11 equivalent kg^{-1} emission). The photochemical oxidation model was developed by Jenkin & Hayman and Derwent. It defines photochemical oxidation in kg ethylene equivalents per kg emission. Acidification potential model was developed by Huijbregts and it is expressed in kg SO_2 equivalents per kg. Eutrophication (fate not included) midpoint category is expressed in kg PO_4 equivalents per kg emission. Characterization factors for human toxicity, freshwater aquatic ecotoxicity, marine aquatic ecotoxicology, and terrestrial ecotoxicity are expressed in terms of Human Toxicity Potentials (HTP), describing fate, exposure, and effects of toxic materials for an infinite time horizon. The unit of each toxic substance HTP's are expressed in 1,4-dichlorobenzene equivalents per kg emission.

3. RESULTS & DISCUSSION

3.1. Life cycle assessment of current operation conditions

For the existing medical waste sterilization and incineration facility in Istanbul province, the results were obtained by using the CML-IA impact analysis method after entering the flows as input and output to the processes. The results of the impact analysis of the medical waste sterilization facility are given in Table 2.

According to Table 2, the highest impact of the medical waste sterilization facility occurs due to marine aquatic ecotoxicity, global warming, and human ecotoxicity, in descending order, respectively. It is the electricity use at the facility that contributes the most to the impact analysis results. Electricity consumption was the primary contributor to impact assessment results with 552.8 kg 1,4 DB eq. The results of the impact analysis of the medical waste incineration facility are given in Table 3.

Table2. Medical waste sterilization plant impact analysis results

Name	Impact result of sterilization
Marine aquatic ecotoxicity	552.8 kg 1,4-DB eq
Global warming potential (GWP100a)	3.3 kg CO_2 eq
Human toxicity	0.1 kg 1,4-DB eq
Acidification	7.7e-3 kg SO_2 eq
Freshwater ecotoxicity	2.6e-3 kg 1,4-DB eq
Terrestrial ecotoxicity	1.8e-3 kg 1,4-DB eq
Europhication	6.2e-3 kg PO_4 eq
Photochemical oxidation	5.4e-4 kg C_2H_4 eq
Abiotic depletion	1.4e-6 kg Sb eq
Ozone depletion potential (ODP)	5.2e-9 kg CFC-11 eq
Abiotic depletion (fossil fuel)	0 MJ

Table3. Medical waste incineration plant impact analysis results

Name	Impact result of incineration
Human toxicity	3.8e4 kg 1,4-DB eq
Marine aquatic ecotoxicity	2.1e4 kg 1,4-DB eq
Acidification	1.6e4 kg SO_2 eq
Europhication	4.1e3 kg PO_4 eq
Photochemical oxidation	438.7 kg C_2H_4 eq
Global warming potential (GWP100a)	215.5 kg CO_2 eq
Freshwater ecotoxicity	0.4 kg 1,4-DB eq
Terrestrial ecotoxicity	0.1 kg 1,4-DB eq
Abiotic depletion	9.2e-5 kg Sb eq
Ozone depletion potential (ODP)	2.0e-5 kg CFC-11 eq
Abiotic depletion (fossil fuel)	0 MJ

The highest three impacts of medical waste incineration facility are from human toxicity, marine aquatic ecotoxicity, and acidification in descending order, respectively. The mass values of each impact analysis of incineration remained much higher than the sterilization. The human toxicity contributions were 1.95e4, 1.80e4, 6.04, and 0.57 kg 1,4-DB eq from secondary incineration, rotary kiln, process water, and electricity grid, respectively. Secondary combustion in waste incineration is a vital part of the system since the generated persistent organic pollutants are removed from the stack gas via this unit [16]. The contributors for marine aquatic ecotoxicity were 1.82e4 and 3.22e3 kg 1,4-DB eq for process water and electricity grid, respectively. As acidification and eutrophication have major mass impacts, their contributions were also evaluated according to the operation unit. Secondary combustion chamber and rotary kiln were the highest contributors. The study results showed that the highest contribution for acidification and eutrophication was caused by the secondary combustion chamber and the rotary kiln. Contributions for photochemical oxidation originated from the secondary combustion chamber, process water use, electricity use, and rotary kiln, respectively.

The relative results of combustion and sterilization is provided in Fig 3.

Combustion process was the dominant process for all environmental impacts relative to sterilization process. Only sterilization has 3% contribution for marine aquatic toxicity.

3.2. Life cycle assessment of combustion scenario

As an alternative to current operation conditions, we considered only combustion treatment. In this scenario, all medical waste is assumed to be treated in a rotary kiln process. The results of the impact analysis of the medical waste incineration facility in the new scenario are given in Table 4.

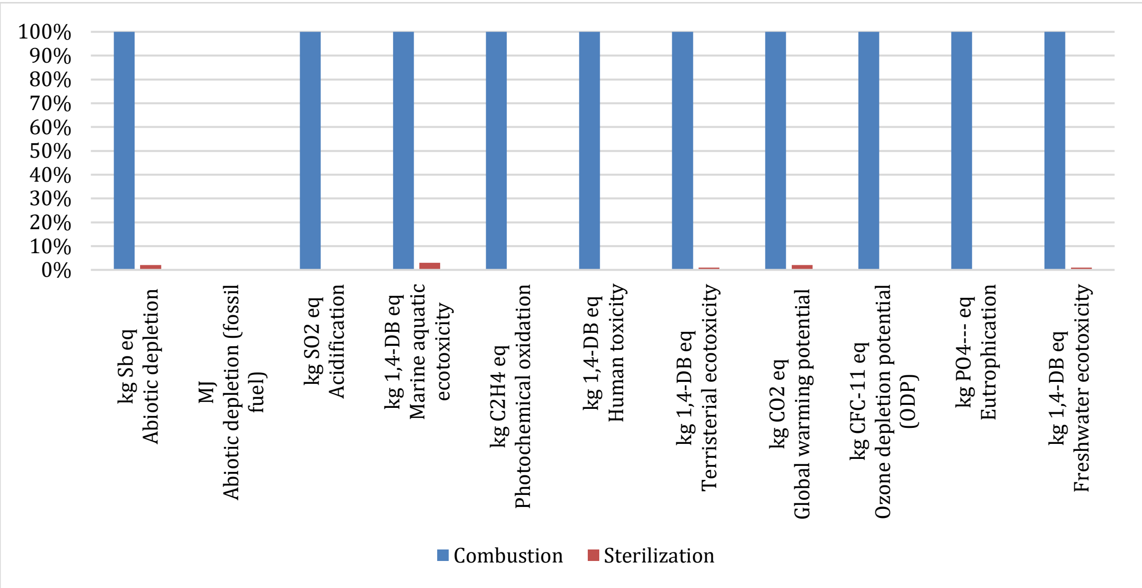

Fig 3. Relative impact assessment results of combustion and sterilization

Table 4. Impact analysis results of the scenario of only combustion

Name	Impact result of the scenario
Human toxicity	1.7e5 kg 1,4-DB eq
Acidification	7.1e4 kg SO_2 eq
Marine aquatic ecotoxicity	2.1e4 kg 1,4-DB eq
Eutrophication	1.8e4 kg PO_4 eq
Photochemical oxidation	1.9e3 kg C_2H_4 eq
Global warming potential (GWP100a)	215.5 kg CO_2 eq
Freshwater ecotoxicity	0.4 kg 1,4-DB eq
Terrestrial ecotoxicity	0.1 kg 1,4-DB eq
Abiotic depletion	9.2e-5 kg Sb eq
Ozone depletion potential (ODP)	2.0e-5 kg CFC-11 eq
Abiotic depletion (fossil fuel)	0 MJ

The highest impact is calculated for human toxicity. Since it is mostly due to combustion process, its value increased significantly with the only combustion treatment scenario. Other considerable changes were observed for acidification, human toxicity, eutrophication, and photochemical oxidation. The results remained the same for global warming potential, freshwater ecotoxicity, terrestrial ecotoxicity, abiotic depletion, and ozone depletion potential. The relative results of current operating conditions and scenario are provided in Fig 4.

The scenario had the highest impact for all categories. In the current operation conditions, acidification, eutrophication, human toxicity, and photochemical oxidation impacts were 22% on a quantity basis relative to scenario operation. This is due to lower mid-category impact of the sterilization process.

According to a study conducted in Pakistan, two scenarios were used to calculate the current medical waste disposal method, that is, incineration and the storage of medical wastes without classification (Scenario A and Scenario B) with LCA [17]. Scenario C, which included disposal by pyrolysis and chemical disinfection, was considered as an alternative. Existing applications (Scenario A and Scenario B) were the worst for all categories. Especially, the greatest impact from existing methods were for human toxicity produced from incineration. Human toxicity and marine aquatic ecotoxicity were found to be the categories with the highest impact for all selected treatment processes. It was observed that Scenario C would have lower effects. More specifically, in the case of incineration, the highest impact was on human toxicity. In the storage state, seawater ecotoxicity had the highest impact. Regarding sterilization, autoclaving of medical wastes was considered to be the most suitable technology according to the assessment criteria. However, it seems that their costs will be higher than incineration. Therefore, large amounts of infectious waste cannot be disposed of by sterilization technology. In addition, some chemicals and infectious substances cannot be treated by autoclaving, such as mercury, chemotherapy-derived compounds and materials, volatile and semi-volatile organic compounds, and radioactive waste. When we compare our study with the Pakistan example, the highest environmental impact for either incineration processes was for human toxicity and seawater ecotoxicity. In the Pakistan case, 7.5e-5 kg 1,4-DB eq human toxicity and 1.53e-3 kg 1,4-DB eq marine aquatic ecotoxicity were calculated. In our study, human toxicity of the existing incinerator plant was calculated as 3.8e4 kg 1,4-DB eq and marine aquatic ecotoxicity was 2.1e4 kg 1,4-DB eq. When the populations of both cities are considered, the results are in agreement.

In a study in China, environmental impacts and LCA of three mobile disposal scenarios (incinerator, mobile steam, and microwave sterilization equipment, followed by incineration with urban solid waste) were studied in the post-COVID-19 outbreak [18].The results showed that incineration along with municipal solid waste had the lowest environmental impact due to the environmental benefits generated by energy recovery, and that incineration with hazardous waste has the highest environmental impact due to high energy consumption. Energy consumption (ie kerosene, electricity and diesel) were key factors for the three mobile disposal scenarios. In Scenario 1, the combustion process, direct emissions, electricity, and kerosene were the primary contributors to most categories. Direct emissions during incineration of medical waste included acidic gases (e.g. SO_2) and particulate matter, which contributed greatly to acidification potential and respiratory inorganics. In Scenario 2, in the sterilization process, the highest energy consumption was through the boiler in the steam generation system, which consumed diesel to generate steam at high temperatures for sterilization. Electricity consumption also had a significant adverse impact on global warming, acidification potential, respiratory inorganics, ionizing radiation-human health effects, CO_2, and SO_2. According to the results of the study, energy recovery was regarded an option to reduce the environmental impact for the waste disposal vehicle. The results showed that incineration with municipal solid waste had the lowest environmental impact due to electricity generation, and incineration with hazardous waste had the highest environmental impact. Co-incineration plants were not recommended to dispose of infectious medical waste due to the risk of infection from disposal. Compared to our study, both exhibited a significant negative effect of acidification potential due to incineration process. When sterilization processes are examined, the electricity used, contributed to the impact categories in both studies. It was observed that electricity consumption in the sterilization facility had a significant effect on global warming in both studies.

In a study conducted in China, the environmental and economic impacts of three medical waste disposal scenarios (pyrolysis, steam sterilization, and chemical disinfection) were measured through a cost-related LCA to determine the effective technique for medical waste disposal [19]. The results showed that, the steam sterilization and chemical disinfection scenarios had the highest overall environmental and lowest economic impacts, respectively, due to differences in energy consumption. Energy (e.g. electricity and diesel) contributed the highest contributor to each impact category for steam sterilization scenario. This outcome was the same for also our study. Global warming was the highest calculated impact category for the Chinese sterilization scenario. However, in our study, the highest value for sterilization was calculated for seawater ecotoxicity, followed by global warming.

A study was conducted in Northern Italy (Emilia Romagna Region) to evaluate the effects of waste incineration plants by applying the LCA methodology and highlight the most effective steps in the incineration process [20].The management of solid residues and heavy metal emissions were the most important environmental concerns. In addition, a temporary comparison with the environmental impact of landfills for the same amount of waste indicated that incineration should be considered environmentally preferable. The most important effects were identified for carcinogenic and inorganic pollutants that produce respiratory diseases. In comparison, disposal with landfills has resulted in worse human health or ecosystem quality in terms of resource utilization.

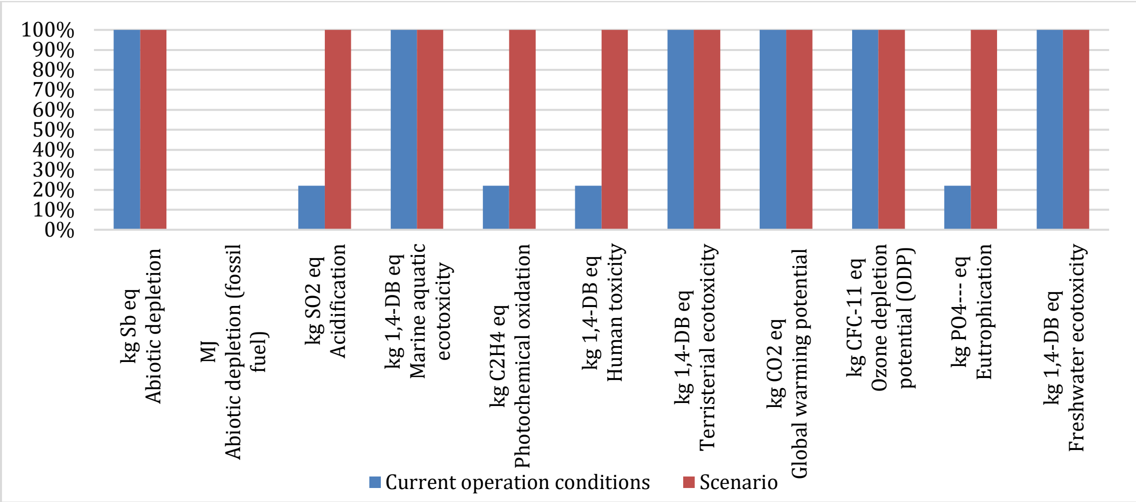

Fig 4. Relative impact assessment results of considered operation options

There has been a large increase in Personal Protective Equipment (PPE) kit use to reduce the likelihood of infection during the COVID-19 outbreak [21]. The used PPE kits, which are potentially infectious, pose a threat to human health, terrestrial and marine ecosystems unless scientifically addressed and destroyed. In a study conducted in China, LCA of PPE kits was performed using GaBi version 8.7 for two disposal scenarios for six environmental impact categories covering general impacts on both terrestrial and marine ecosystems. Three situations with different disposal options were considered. Two of these are centralized and decentralized incineration and the other is landfilling. The combustion process (central - 3816 kg CO_2 equivalent and decentralized - 3813 kg CO_2 equivalent) showed high global warming potential. Human toxicity potential of decentralized combustion was calculated as 250.3 kg DB eq and central combustion as 250.2 kg DB eq. Decentralized incineration was found to be a suitable option for the destruction of PPE both in terms of environment and health. The least viable option was identified as landfilling. Considering the above, it is important to point out that LCA impact categories also produce high footprint values for the decentralized system, so there is always a need to improve systems at hand to reduce overall impacts.

4. CONCLUSIONS

The COVID-19 pandemic is causing global concern and an increase in medical waste production. The disposal of medical waste is an urgent need to prevent the spread of the epidemic. Emergency disposal scenarios of medical waste generated during the COVID-19 pandemic require a systematic assessment to measure potential environmental impacts. Several medical waste treatment methods are employed all around the world. Among these methods, incineration and sterilization are the most common medical waste treatment techniques. In order to determine the environmental impact in different mid-categories LCA is employed in this study. Our aim was to perform a scenario which is alternative to current operation conditions in Istanbul for medical waste treatment. The environmental impact of incineration remained higher relative to sterilization process. Significant differences were calculated for acidification, eutrophication, human toxicity, and photochemical oxidation. Effective measures can be taken to reduce environmental impact include improving the efficiency of electricity consumption, reducing the use of chemicals (eg sodium hydroxide, lime and chlorine oxide), selecting clean energy and providing energy recovery and incineration of medical waste. Extensive studies have shown that energy recovery is a key factor in reducing the overall environmental burden for solid waste incineration. The results herein can be exploited as a quick reference guide for those who want to apply medical waste treatment method for different purposes. The LCA method compares only treatment stage of incineration and sterilization. Firms and municipalities may decide the best available method for their ultimate purpose according to the results presented herein.

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RESEARCH ARTICLE

Single-step pyrolysis for producing activated carbon from sucrose and its properties for methylene blue removal in aqueous solution

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ABSTRACT

Herein, activated carbon was prepared from sucrose, renewable carbon precursor by chemical activation method. Chemical activation process was carried out with KOH at 750 °C. The effects of chemical activation on the structure and morphology of activated carbon products were evaluated using TGA, BET, SEM, FT-IR, and zeta potential techniques. As a result of the activation process, the activated carbon having microporous (1.138 $cm^3\ g^{-1}$) with high specific surface area (2116.42 $m^2\ g^{-1}$) was obtained. The potential of using activated carbon as an adsorbent for removal of methylene blue in water was investigated under several experimental conditions. Langmuir adsorption capacity for methylene blue is 1666.66 mg g^{-1} and its higher adsorption capacity than other adsorbents. Regeneration studies have shown that the activated carbon can also be used at least ten times for the removal of methylene blue with no change in its adsorption capacity. The performance was tested on real textile wastewater.

Keywords: Activated carbon, sucrose, adsorption, reusability, real textile wastewater

1. INTRODUCTION

Dyes can be used on textiles, paper, rubber, leather, food, etc. it is widely used in various industries and the waste water from these industries is one of the main pollutants. Industrial wastewater containing dyes has high chemical oxygen demand (COD), strong coloring effect, high pH and biologically toxic properties [1]. Discharge of industrial wastewater containing dyes to streams, lakes, marine and other receiving environments constitutes an important environmental problem and and many of the dyes have carcinogenic and mutagenic properties for humans as well as aquatic life [2]. Therefore, industrial wastewater containing dyestuffs should be treated before discharging to the receiving environment.

In recent years, many techniques are used for the treatment of industrial wastewater containing dyes, including coagulation [3], photocatalytic degradation [4], membrane separation [5], biodegradation [6], advanced oxidation [7] and adsorption [8,9].Among these methods, due to the ease of application and high removal efficiency of the adsorption method, it is accepted as an effective method for removing dyes from wastewater [10]. Recent studies for the treatment of wastewater containing dyes by adsorption method have focused on the preparation of efficient, cheap and renewable adsorbent materials. One of the most commonly used adsorbents for the treatment of wastewater containing dyes is activated carbon. Activated carbon is known as carbon based materials with its highly porous structure and wide surface area [11]. In particular, the large surface area and chemical structure of activated carbon provide high removal of dyes from wastewater. In recent years, there has been an increasing interest in studies for the production of activated carbon from renewable and inexpensive starting materials [12]. Low-cost many biomass wheat bran [13], popcorn [14], waste vinasse [8], *thuja orientalis* cone [15], starch [16]were used as starting materials to prepared activated carbon. Although the reported activated carbon products are used in dyes adsorption, it is observed that the adsorption removal capacities are insufficient and have low regeneration efficiency. Also, few studies on the performance of activated carbon products were tested with real textile wastewater.

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Compared to different starting materials, sucrose is considered a very attractive precursor material for obtaining activated carbon due to its low-cost, recyclable and rich carbon content [17]. With its simple molecular structure, sucrose can be obtained with high surface area with practical processes and provides less dangerous emission release during the pyrolysis process. This study, activated carbon production was carried out by simple chemical activation with KOH from sucrose. The structural and morphological properties of the products are characterized by Thermal Gravimetric Analysis (TGA), Brunauer Emmet and Teller (BET) (specific surface area, pore volume and pore size distribution), Scanning Electron Microscopy (SEM), Fourier Transform İnfrared Spectroscopy (FT-IR), techniques and zeta potential analysis. The removal of activated carbon with the highest surface area, pore volume and size distribution were evaluated using model contaminant methylene blue in the aqueous solution. The effect of different pHs and contact time on activated carbon efficiency was investigated. Isotherm analysis and regenerability of activated carbon was presented. The adsorption capacity of activated carbon was compared with the literature. Finally, the adsorption mechanism was explained and activated carbon tested with real textile wastewater.

2. MATERIALS AND METHOD

2.1. *Materials*

Sodium hydroxide, Hydrochloric acid (30%), Sulfuric acid (98%) Sodium chloride, Potassium hydroxide, Methylene blue, Sucrose, Ethanol, were purchased from Merck Co. (Darmstadt, Germany).

2.2. *Activated carbon preparation from sucrose*

Firstly, starting carbon-based material was obtained from sucrose. To obtain the carbon-based starting material, 50 g of sucrose and 50 mL of 98% H_2SO_4 were added to the glass beaker in a controlled manner and mixed quickly with a glass stick for 30 seconds. With this method, according to the reaction given in Eq. (1), sucrose sulfuric acid was dehydrated and carbon-based starting material (CBM) was obtained.

$$C_{12}H_{22}O_{11(s)} + H_2SO_{4(aq)} \rightarrow CBM + SO_2 + H_2O \quad (1)$$

CBM was washed with pure water until the pH of the wash water was 6.5-7. The washed material was dried at 105 °C and ground in agate mortar. KOH was used to activate of CBM. The CBM was homogeneously mixed with KOH in 1:1, 1:2, 1:3, 1:4, and 1:5 (w/w) ratios by mass. The mixture prepared in the stainless-steel reactor oven (Ptf Protherm 12/75/800) under a nitrogen atmosphere (200 mL/min) activation by heat treatment at 750 °C for 1 hour was performed. The activated carbons obtained were washed with pure water until the wash water is about 6-7, and dried in an oven at 105 °C. The activated carbons obtained are named as AC-*x* (*x* = 1, 2, 3, 4 and 5 KOH mixture ratio).

2.3. *Characterzation studies*

The thermal behavior of CBM was analyzed with thermal gravimetric analyzer (Setaram, Setsys Evolution, France) under argon atmosphere at 25 mL/min flow rate, in the range of 40-800 °C with a temperature increase of 5 °C min^{-1}. FT-IR spectra of the products were recorded by FT-IR spectrophotometer (Perkin Elmer 1600, USA) in the range of 500-4000 cm^{-1} wavelength. The surface morphologies of the products were obtained using FESEM (Zeiss, Geminisem 500, GERMANY). Using the BET analyzer (Quantachrome Quadrasorb evo, USA), the BET surface area and pore size distribution from N_2 adsorption isotherms were determined at 77K. Total pore volume (V_{total}) was obtained from the amount of N_2 adsorbed at P/P_o=0.95 according to the NLDFT (Non Local Density Functional Theory) method. The zeta potential of the product used in the adsorption studies was determined by using a Nanoplus 3 (Japan).

2.4. *Adsorption studies*

The most suitable product was used as a result of structural characterization (specific surface area, total pore volume and others) processes in adsorption studies. To study the adsorption performance of the product, the batch adsorption experiments were carried out using aqueous solution of methylene blue (λ_{max}= 660 nm).

Adsorption experiments, 0.01 g of product was put into the 20 mL of methylene blue solutions at various concentrations in the range of 250-1500 mg L^{-1}, the mixtures were shaken at 210 rpm over a period of time at 25 °C. After separation of each solution by simple filtration, the initial and remaining dye concentrations of each solution were determined by using a UV–visible spectrophotometer (Hach Lange, DR 5000, Germany) at each corresponding λ_{max} mentioned above. The pH of the solutions was adjusted with 0.01 M HCl and/or 0.1 M NaOH. Ionic strength of the mixtures was kept down as 0.01 M with NaCl. The amount of methylene blue adsorbent by product was determined using Eq. (2).

$$q = \frac{(C_o - C_e) * V}{m} \quad (2)$$

where q is sorbed amount of methylene blue by product (mg g^{-1}); C_o and C_e are the initial and equilibrium concentrations of methylene blue (mg L^{-1}); V is the solution volume (L); m is the mass of product (g). The effects of experimental parameters studied are pH (3-11), contact time (5-180 minutes), initial methylene blue concentration (250-1500 mg L^{-1}) and its reusability by using washing with 20 mL ethanol for 10 minutes was performed.

2.5. *Real textile wastewater application*

Real textile wastewater without any treatment was used in experimental studies. Physico-chemical characteristics of the the real textile wastewater used for study were pH: 9.80- 10.87, COD: 487 mg L^{-1}, Conductivity: 1987 µS cm^{-1}. Real textile wastewater was supplied from a textile factory in Konya (Turkey). The color and chemical oxygen demand (COD) change of the real textile water at different pH (3, 7, 11) was observed.

3. RESULTS AND DISCUSSION

3.1. Determination of activation temperature

The effectiveness of the activation process depends on the interaction of the oxidizing agents used in the process with the carbon-based materials and the activation temperature. The activation process is generally carried out at temperatures where the mass loss of the starting material stabilizes [18]. Therefore, firstly, thermal behavior of CBM in argon atmosphere was evaluated and activation temperature was determined. The thermogram of the CBM obtained as a result of TGA is shown in Fig 1.

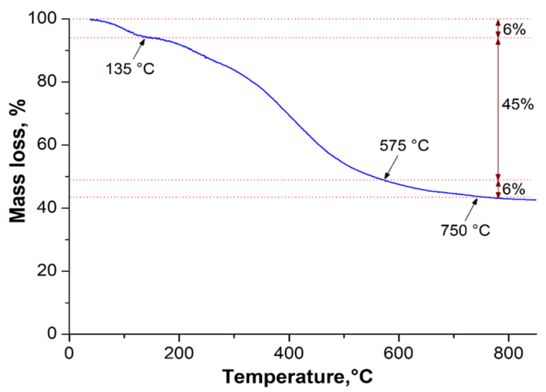

Fig 1. Thermal behavior of the carbon-based material (CBM)

With the increase in temperature, mass loss in CBM was determined to occur in three stage. The first stage, the 6% mass loss in which the temperature reaches 135°C is caused by the loss of moisture in the CBM [12]. The mass loss (45%) between 135-575 °C in the second stage may be due to the loss of oxygen-containing functional groups within the CBM as CO and CO_2 [19]. In the third stage, the mass loss (6%) at the temperature increase after 600 °C slowed down considerably and became stable. As a result of the TGA of the CBM, it was observed that there was no significant mass loss in the mass above 600 °C. Therefore, the temperature of 750 °C was chosen for activation of CMB with KOH.

3.2. Characterization of ACs

The nitrogen adsorption desorption isotherms and pore size distribution of the activated carbon products obtained with different amount of KOH (CBM: KOH, w/w) were compared, shown in Fig 2a-b. According to Fig 2a, AC-1, AC-2 and AC-3 show an isotherm with low porosity material properties, while AC-4 and AC-5 show an isotherms classified as type 1 according to the IUPAC classification and have microporosity [20,21]. It is seen that AC-4 and AC-5 have DFT pore size distributions (Fig 2b) less than 20 Å and microporous structure.

Surface areas, total pore volumes and micropore volumes of activated carbon products were examined and the results are presented in Table 1. As can be seen in Table 1, while the amount of KOH is increased from 1 to 4, the surface areas, total pore volumes and micropore volumes of activated carbon products increased from 756.24 to 2116.42 m^2 g^{-1}, from 0.412 to 1.199 cm^3 g^{-1}, from 0.404 to 1.138 cm^3 g^{-1}, respectively, above 1:4 these values decreased. KOH amount above 1:4, excessive metallic potassium on the carbon surface might cause blocking and collapsing in the pores which leads to a reduction in the surface area and pore volume [22]. According to these results, the amount of KOH appears to significantly affect the change in the surface area and pore structure. The fact that activated carbon has a large surface area and high pore volume means that higher adsorption efficiency will occur [23]. Consequently, the activated carbon product (AC-4), which is most suitable for adsorption, has been tried to be determined with the highest surface area (2116.42 m^2 g^{-1}) and total pore volume (1.199 cm^3 g^{-1}).

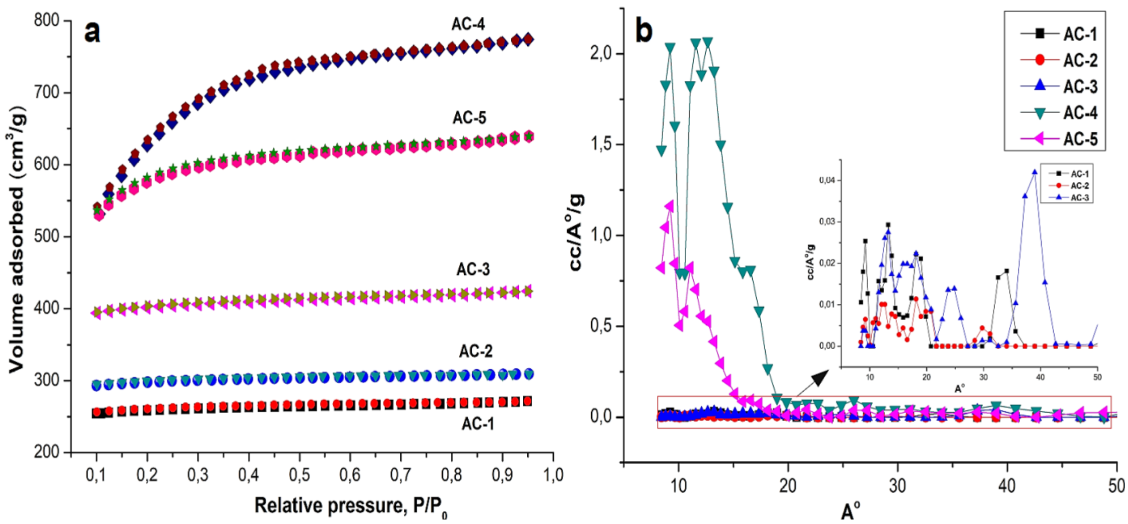

Fig 2. N_2 adsorption-desorption isotherms (a) and the DFT pore size distribution (b) of activated carbon products

Surface morphology of products obtained were examined by SEM technique and the images obtained are shown in Fig 3. It can be observed that the surface of the CBM is quite smooth and there are no pores. The porous structure of the products obtained as a result of activation of CBM with KOH appears to improve. When Fig 3 is examined, it is seen that increasing the amount of KOH causes the development of porous structure on the surface of activated carbon products. The development of the products in the pore structure is due to the reaction between the carbon atoms and KOH, and the effect of the activation temperature [24].

Table 1. Surface area ($m^2\ g^{-1}$) and pore volumes ($cm^3\ g^{-1}$) of the products

Carbonaceous product	Specific suface area, $m^2\ g^{-1}$	Vtotal, $cm^3\ g^{-1}$	Vmicroa, $cm^3\ g^{-1}$	Vmeso, $cm^3\ g^{-1}$
CBM	5.54	0.012	nd*	nd*
AC-1	756.24	0.421	0.406	0.015
AC-2	894.72	0.479	0.468	0.011
AC-3	1216.22	0.657	0.632	0.025
AC-4	2116.42	1.199	1.138	0.061
AC-5	1756.25	1.014	0.940	0.074

[a]V_{meso} was determined by subtracting V_{micro} from V_{total} *nd: could not be determined

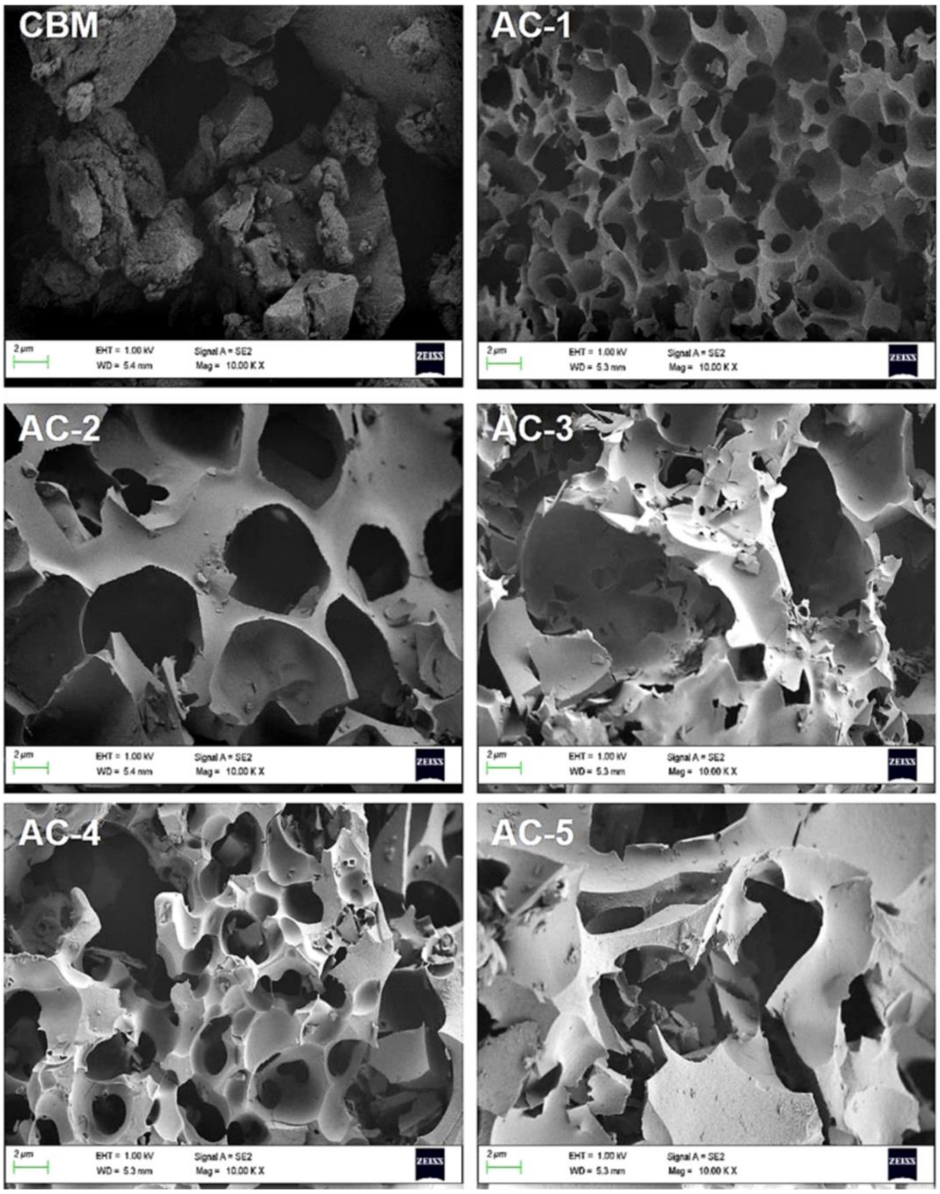

Fig 3. Surface morphologies of CBM and activated carbon products

Changes in the chemical structure of the activated carbon (AC-4) obtained by activation of the CBM product with KOH were examined by FT-IR analysis and the results are shown in Fig 4. In the FTIR spectrum of CBM, it originates from the band -OH group at 3375 cm^{-1}[25]. The bands seen in 1697 and 1242 cm^{-1} can be linked to the stretching the C=O and C-O-C groups, respectively [26]. The band seen at 1600 cm^{-1} comes from C=C vibrations [27]. As a result of the activation process applied, there is a decrease in the intensity of the bands in the FT-IR (Fig 4) spectrum of CBM.

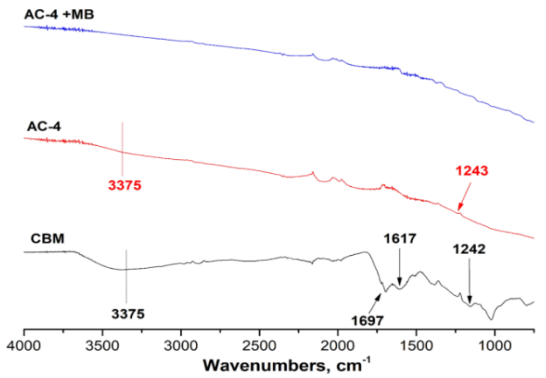

Fig 4. FT-IR spectra of the CBM and AC-4 before and after adsorption

3.3. Adsorption Studies

In the first studies conducted with methylene blue, the performance of the activated carbons (AC-x) obtained with different KOH ratioswas tested with 500 mg/L methylene blue solution. The results obtained are shown in Fig 5. As shown in Fig 5, AC-4 product has been determined to have the highest methylene blue removal efficiency. This result is due to the higher surface area and total pore volume of the AC-4 product than the surface area and total pore volumes of other products. The results obtained from this preliminary experiment with methylene blue and the characterization studies, it was confirmed that it would be more appropriate to use the AC-4 product in adsorption studies.

3.4. Effect of pH

The pH of the solution, are important parameters that can affect the adsorption of substances from solution media. The adsorption of methylene blue (500 mg L^{-1}) from the aqueous solution with the AC-4 product was carried out at a different pH in the range of 3-13, and the results obtained are shown in Fig 6. As seen in Fig 6, the highest methylene blue removal capacity was obtained at pH 7. The zeta potential values of the AC-4 product in the range of pH 3-13 range between (24.86 and -34.08 mV respectively). According to these results, the increase in the pH of the solution increased the negative surface loads of the adsorbent. Adsorbent has a negative surface charge in the pH>5. As expected, the adsorption performance of the MB solution at pH>5 was significantly increased due to the electrostatic interaction between the positively charged methylene blue molecules and the negatively charged adsorbent surface [28]. Then the adsorption performance increased insignificantly with further increase of pH>7, probably because the adsorption has reached saturation. It can be stated that due to the lower removal capacities determined for pH<7, the adsorption zones are partially covered with hydronium ions, the regions to absorb the methylene blue molecules are reduced and the removal capacity decreases accordingly [9]. The ability to be used as an adsorbent with high adsorption efficiency without the need for pH adjustment can be considered as an advantage for environmental and practical applications. Therefore, no adjustment of the solution pH was made in the next stages of the adsorption.

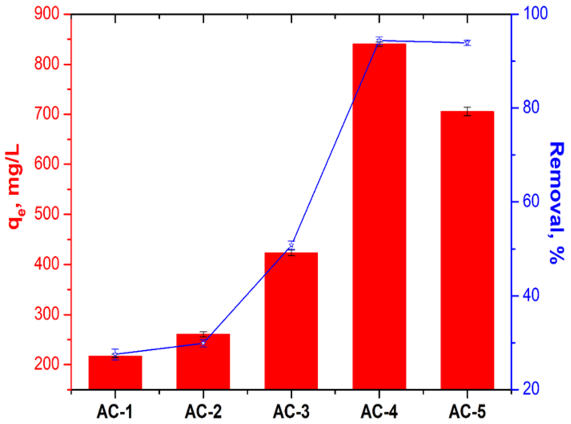

Fig 5. The removal of methylene blue from aqueous solutions with concentrations of 500 mg L^{-1} by using AC-1, AC-2, AC-3, AC-4 and AC-5 (pH of solutions: 7.03, amount of adsorbent: 0.5 g L^{-1}, contact time: 2 h, ionic strength: 0.01 M, shaking speed: 210 rpm, temperature: 25 °C)

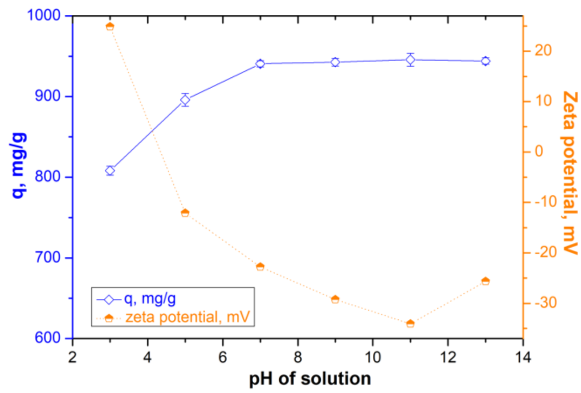

Fig 6. Effect of solution pH on the adsorption of methylene blue by AC-4 (Concentration of methylene blue: 500 mg L^{-1}, amount of adsorbent: 0.5 g L^{-1}, contact time: 2 h, ionic strength: 0.01 M, shaking speed: 210 rpm, temperature: 25 °C)

3.5. Effect of contact time

The effect of contact time on methylene blue (250 and 500 mg L^{-1}) adsorption with the AC-4 product is shown in Fig 7(a). It was found that the adsorbent adsorbed a significant amount of methylene blue in the first 5 min for two different concentrations (250 and 500 mg L^{-1}). In this short time, high removal of methylene blue can be attributed to the large surface area of the adsorbent and thus to a large amount of areas where adsorption will occur. The methylene blue removal rate decreased after 5 min and reached equilibrium in 90 min. It has been observed that the required contact time (90 min) is comparable with the studies in the literature on the subject [10]. The decrease in removal rate for the adsorbent after the first 5 min may be caused by the intra-particle diffusion effect [29]. The role of diffusion in adsorption was examined according to the intraparticle diffusion model expressed by Eq. (3) [30].

$$q_t = k_i \times t^{1/2} + C \quad (3)$$

where, k_i is a constant of the intra-particle diffusion rate [mg (g^{-1} min$^{-(1/2)}$)], C is a constant about the boundary layer (mg g^{-1}).

Fig 7 (b) showing the plots of q_t vs $t^{1/2}$ for the concentrations of 250 and 500 mg L^{-1} have three stages. The first stage is due to the diffusion (film diffusion) of methylene blue molecules to the adsorbent surface. The second stage consists of intra-particle diffusion of methylene blue molecules. The final stage, it is possible to mention that the adsorption has reached equilibrium. From the results obtained in this study, it can be concluded that intra-particle diffusion is effective in adsorption, but it is not the only mechanism controlling adsorption [10]. The change in the color of the 500 mg L^{-1} methylene blue solution is shown in Fig. 7(c) and the consistency of the obtained result was checked.

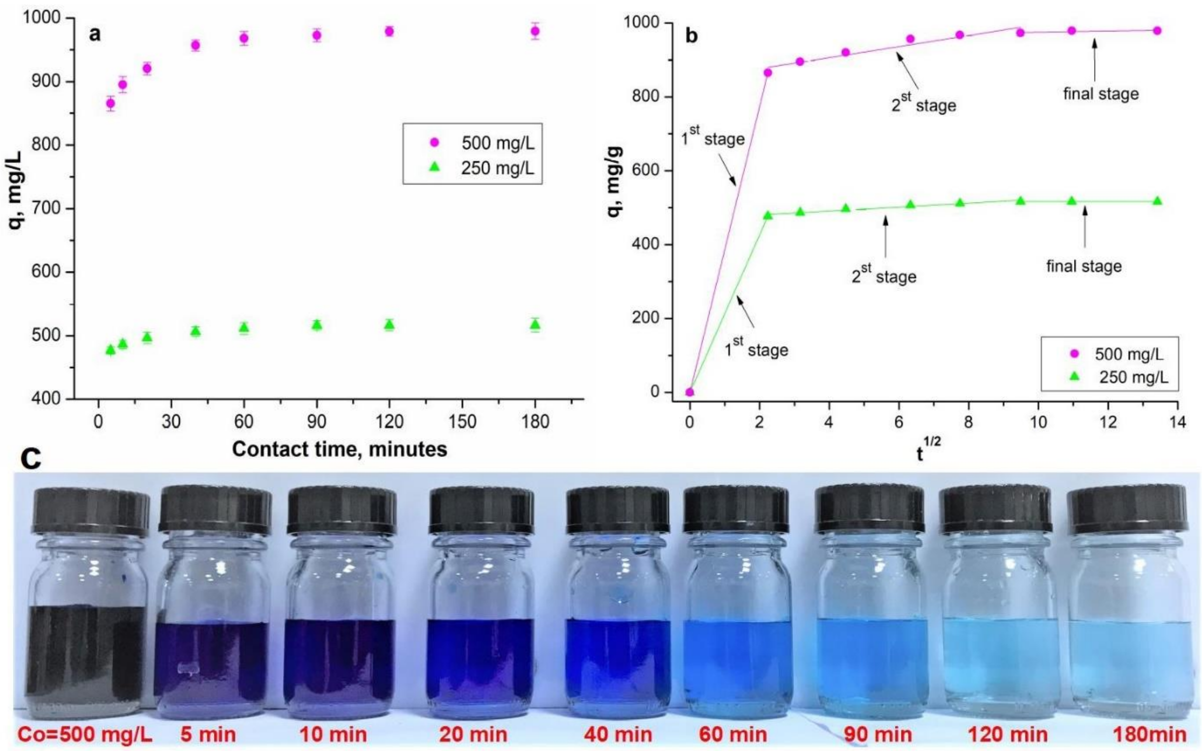

Fig 7. Effect of contact time on the adsorption of methylene blue by AC-4 (a), the plots of intra-particle difussion model (b) and the change in the color of 500 mg L^{-1} of methylene blue solution as a function of contact time (c)

3.6. Isotherm analysis

The change of concentration (C_e, mg L^{-1}) remaining in the solution after the adsorption of methylene blue with AC-4 product with the amount of methylene blue (q_e, mg g^{-1}) per unit adsorbent mass is shown in Fig 8(a). Langmuir, Freundlich and Dubinin-Radushkevich (D-R) isotherm models, which are widely used to perform isotherm analysis for adsorption data. Isotherm graphs formed by applying the adsorption data obtained for the AC-4 product to the isotherm equations given between Eq. (4-6), respectiveliy.

$$q_e = \frac{Q_o * b * C_e}{(1 + b * C_e)} \quad (4)\ [31]$$

$$q_e = k * C_e^{1/n} \quad (5)\ [32]$$

$$\ln q_e = \ln X_m - K * \varepsilon^2 \quad (6)\ [33]$$

where q_e is the amount of methylene blue adsorbed by AC-4 (mg g^{-1}) at equilibrium, C_e is the equilibrium concentration of methylene blue (mg L^{-1}), Q_o is the Langmuiradsorption capacity of the AC-4 (mg g^{-1}) and b is the adsorption constant of Langmuir isotherm (L mg^{-1}), k is an indicator of the Freundlich adsorption capacity [(mg g^{-1}).(mg L^{-1})$^{-1/n}$], n is an empirical parameter.

For the D-R isotherm, Xm, adsorption capacity (mmol g^{-1}), K, constant the adsorption energy (mol^2 kJ^{-2}), ε, Polanyi Potential, which iscalculated from the Eq. (6). Average energy of adsorption (E) was determined on the basis of Eq. (7) [34].

$$R * T * \ln(\frac{C_e + 1}{C_e}) \quad (7)$$

$$E = (-2 * K)^{-0.5} \quad (8)$$

where R is ideal gas constant [8.314 J (mol.K)$^{-1}$] and T is temperature (K). The constants of each parameters and R^2 values were obtained from linear graphs of isotherm models (Fig 8 (b-d)) and listed in Table 2.

Langmuir adsorption capacity (Q_o) and isotherm constant (b) for AC-4 methylene blue adsorption were calculated as 1666.66 mg g^{-1} and 0.060, respectively. From the Freundlich isotherm model, adsorption capacity (k) and isotherm constant (n) were found as (822.24 (mg g^{-1}). (mg L^{-1}) $^{-1/n}$) and (9.680), respectively. According to the D-R isotherm model, the adsorption energy (E) was determined to be 7.332 kJ mol^{-1}. In the adsorption process, it is possible to state that E value is between 8-16 kJ mol^{-1}, ion exchange is effective in removal, and if it is less than 8 kJ mol^{-1}, physical adsorption is effective in removal. According to this information, it is possible to say that physical adsorption has a role in methylene blue adsorption with AC-4 product. As shown in Table 2, the R^2 values of these isotherm models indicate that the adsorption data fit more with the Langmuir isotherm model. This result shows that the AC-4 surface is homogeneous and the methylene blue molecules are adsorbed in a singel layer on the adsorbent surface. Langmuir adsorption capacity of AC-4 product for methylene blue was compared with Table 3 in methylene blue removal capacities of activated carbons obtained from different starting materials in the literature. It has been determined that AC-4 product has higher adsorption capacity than others.

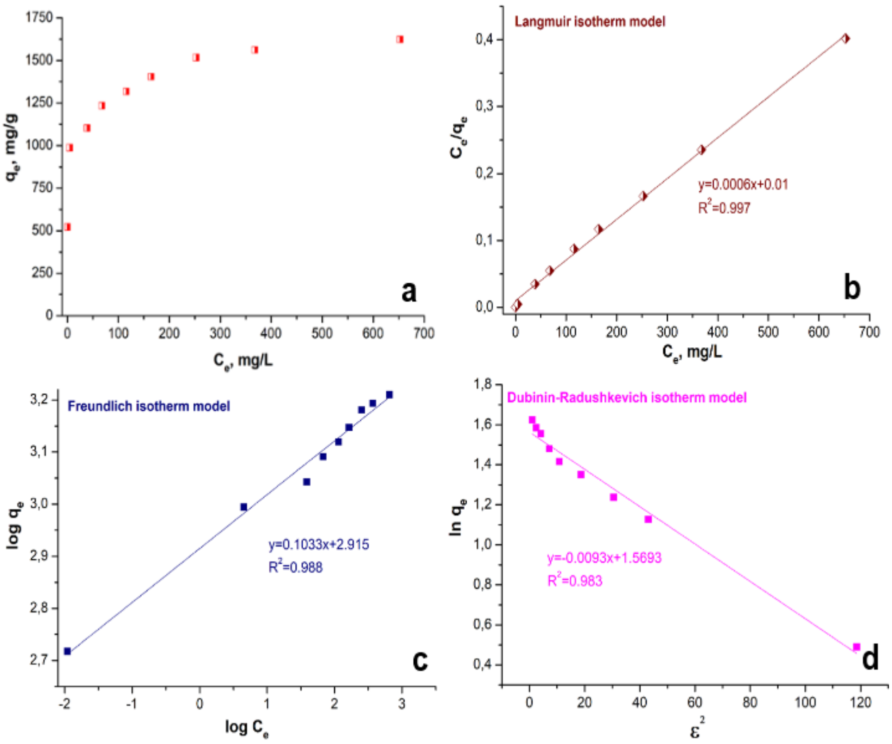

Fig 8. Variation of q_e (mg g^{-1}) as a function of equilibrium concentration (C_e) of methylene blue (mg L^{-1}) (a) Langmuir (b), Freundlich (c) and Dubinin-Radushkevich (d) isotherm model for the adsorption of methylene blue by AC-4 (pH of solution: 7.05, amount of adsorbent: 0.5 g L^{-1}, contact time: 2 h, ionic strength: 0.01 M, shaking speed: 210 rpm, temperature: 25 °C)

Table 2. Parameters of Langmuir, Freundlich and D-R isotherm models for removal of methylene blue by AC-4

Langmuir isotherm model	Q_o, mg g^{-1}	b, L mg^{-1}	R^2	
	1666.66	0.060	0.997	
Freundlich isotherm model	k, (mg g^{-1}).(mg L^{-1})$^{-1/n}$	n	R^2	
	822.24	9.680	0.988	
D-R isotherm model	X_m, mol g^{-1}	K, mol^2 kj^{-2}	R^2	E, kj mol^{-1}
	4.803	0.0093	0.983	7.332

Table 3. Comparison of adsorption capacity of AC-4 from Langmuir isotherm model (Q_o) with activated carbons obtained from different starting materials for methylene blue

Adsorbent	BET suface area, $m^2\ g^{-1}$	Q_o, $mg\ g^{-1}$	Reference
Sucrose	2116	1666.66	This study
Mangosteen peel	1621	1193	[9]
Pecan nutshell	2342	1190.62	[28]
Fox nutshell	2869	968.74	[35]
Coconut shell	2825	916	[36]
Vinasse	832	909.09	[8]
Wheat straw	2263.10	883	[37]
Waste coffee grounds	2407	678	[38]

3.7. Reusability of adsorbent

Desorption processes have been used pH shift and solid-liquid extraction methods for regeneration of adsorbent materials [39]. In this study, solid-liquid extraction method was used for the desorption process. Ethanol was used as solvent in desorption process by solid-liquid extraction method. The advantage of using ethanol is that it can be easily evaporated at room temperature and that desorbed dyes can also be reused.

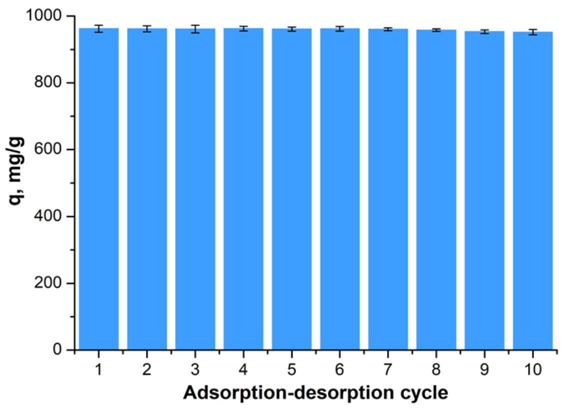

Fig 9. Adsorption performance of AC-4 after each adsorption-desorption cycle (methylene blue concentration: 500 mg L^{-1}, pH 11.09, amount of adsorbent: 0.5 g L^{-1}, contact time: 2 h, ionic strength: 0.01 M, shaking speed: 210 rpm, temperature: 25 °C)

Desorption of 0.5 g L^{-1} amount of AC-4 product used in adsorption of 500 mg L^{-1} methylene blue was performed by washing with 20 mL ethanol for 10 minutes. Adsorbents separated from the desorption solution and dried at room temperature were tested in the adsorption-desorption cycles and the results are shown in Fig 9. It has been determined that AC-4 can be used at least ten times in the adsorption-desorption cycle without any change in removal efficiency.

3.8. Adsorption mechanism

Physical and chemical adsorption types can be effective in removing methylene blue from water environment with carbon-based adsorbents. Results of characterization and adsorption studies of AC-4 product, adsorption mechanism of methylene blue was analyzed. The fact that the adsorbent has a large surface area and large pore volume means that the areas where methylene blue adsorption will occur are quite high [40]. In addition, depending on the pH effect, electrostatic interaction between negative surface charge and positive methylene blue molecules can also be important in removal. It showed that the AC-4 product has the highest removal efficiencies. This result is due to the surface area and total pore volume of the AC-4 product being higher than the surface areas and the total pore volumes of other products. In addition, the pore size distribution of AC-4 was compatible with the size of the methylene blue (14.3 Å x 6.1 Å x4.0 Å), probably resulting in very high removal efficiency [41]. The density of functional groups did not change after adsorption (Fig 3). The characteristic peaks, which were reported to contribute to the methylene blue removal process, were not observed. There was no chemical change in this case. The highest negative surface charge of AC-4 is pH 7. Accordingly, a large amount of adsorption occurs due to the electrostatic interaction between the positively charged methylene blue molecules and the negatively charged adsorbent surface. Thanks to the effects of these factors, AC-4 has been found to be dominant in physical adsorption. Considering all these results, it has been determined that AC-4 product has a very high methylene blue removal capacity.

3.9. Real textile wastewater application

AC-4 adsorption performance was tested using real textile wastewater chemical composition given in section *real textile wastewater application*. In experiments with real textile wastewater, the removal performance of the adsorbent was evaluated by taking into account the decrease in the COD value of the real textile wastewater. The change in the color, UV absorbance value and COD of textile wastewater at different pHs (3, 7 and 11) are shown in Fig 10.textile wastewater COD value was determined at the end of 120 minutes contact time decreases by 64%. When this result is compared with the previous reported results, it is determined that it has adsorbent with high removal efficiency [42–44].According to these results obtained from real textile wastewater applications, it has been determined that AC-4 can be used effectively in the treatment of these wastewater.

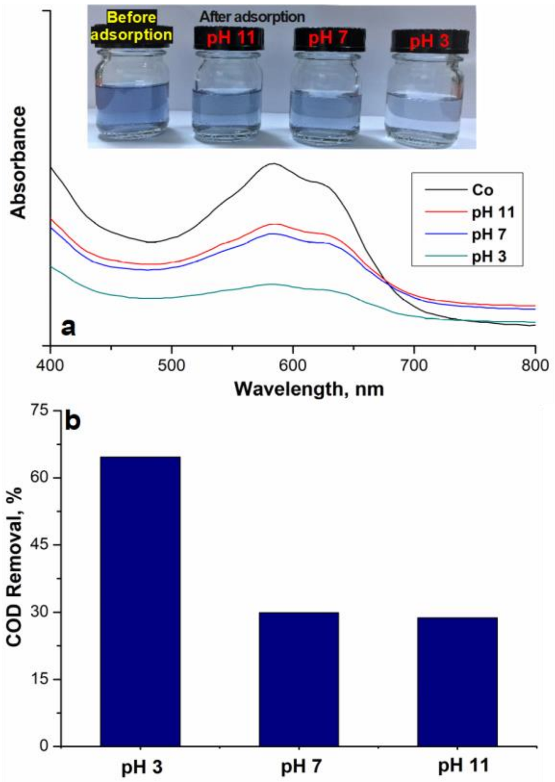

Fig 10. The change in the color and absorbance at wavelenght between 400 and 800 nm as different pHs (3, 7 and 11) for adsorption of real textile wastewater by AC-4 (a) and adsorption performance of AC-4 towards of real textile wastewater (COD of real textile wastewater: 368 mg L^{-1}, pH: 3, 7 and 11, amount of adsorbent: 0.5 g L^{-1}, contact time: 2 h, shaking speed: 210 rpm, temperature: 25 °C) (b)

4. CONCLUSION

In the presented study, activated carbon with a high surface area from sucrose was successfully obtained. Activated carbon with the highest surface area (2116.42 m^2 g^{-1}) and microporous (1.138 g cm^{-3}) was obtained at a rate of 1:4 (w/w) KOH at 750 °C. Langmuir adsorption capacity of the activated carbon obtained is higher than many other activated carbon for methylene blue (1666.66 mg g^{-1}). Activated carbon can be used at least ten times in the adsorption-desorption cycle without change in its adsorption performance. Also, it has been determined that the activated carbon obtained can be used successfully in real textile wastewater treatment.

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RESEARCH ARTICLE

Application of IWA standard water balance in strategic water loss analysis: Benefits and problems

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ABSTRACT

Water losses occurring in distribution systems have effect on the operating cost, water and energy efficiency, service quality, customer satisfaction, maintenance and new resource demand. The standard water balance recommended by International Water Association (IWA) were used for defining, analyzing, regularly monitoring the water balance and sub-components, and determining the weakness and strengths of system. Water Utilities in Turkey are required to fill the water balance annually in order to analyze and monitor the performance with the regulation published in year 2014. However, in the use of this table, important problems are experienced due to the lack of technical, technological, personnel and economic conditions, data representing the field are not used and in many cases the real performance of the system is not revealed. In this study, the importance of IWA water balance in water loss management and monitoring system performance is emphasized, and the benefits and advantages are detailed by analyzing the pilot regions. In addition, problems encountered during filling the water balance, mistakes made, incomplete or incorrectly filled data and other problems were discussed. It is thought that this study will constitute a reference for the technical personnel in Utilities for measuring the data, analyzing the components and interpreting the results.

Keywords: Water losses, water balance, water loss management, performance monitoring

1. INTRODUCTION

Non-revenue water (NRW) is defined as water that is supplied to the system but cannot generate revenue and consists of three basic components: ApparentLosses and Real Losses and unbilled authorized consumptions [1-2]. The most basic approach for NRW rate is the ratio of NRW volume to system net input volume. In order to put forward a sustainable strategy in water loss management and to reduce this rate, sub-components of NRW should be analyzed and monitored. In the literature, the most common method used to calculate NRW and its sub-components in a certain standard and to reveal the weaknesses of the system according to the sub-components is the "standard water balance" recommended by International Water Association (IWA)[1-2]. In the IWA water balance, it is possible to monitor the real and apparent loss rates and their sub-components, as well as the NRW rate. However, while filling this table, detailed data are needed and in many cases, data are estimated in developing countries. In Turkey, water loss rates for local administrations were first determined by the "Regulation on Control of Water Losses in Drinking Water Supply and Distribution Systems" (8 May 2014). In this context, Water Administrations have become obliged to reduce their water losses to a maximum of 30% within 5 years and to a maximum of 25% within the following 4 years. Later, due to the fact that the targets were not realistic for the administrations and the difficulties in achieving the determined targets, the values were updated with the regulation on 31 August 2019. In this context, Water Administrations have become obliged to reduce their water losses to 30% at most by 2023 and to 25% by 2028. With this regulation, administrations are required to fill the standard water balance table annually. Thus, it was aimed to regularly monitor the performance of the administrations in water management.

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Liemberger et al. [3] emphasized that the amount of leakage in developing countries is approximately 45 million m³ per day. It was revealed that if the average consumption per capita is accepted as 100 liters/day/person, half of the population who cannot reach quality water can be served. Limberger and Farley [4] stated that understanding and realizing water losses and creating a roadmap is the first step in developing a strategy and for this, the standard water balance should be filled. It was emphasized that in the water balance, the components should be filled according to the field data, the calculation of the uncertain leaks in the performance monitoring and the network length and the number of service connections in active leakage control (ALC) should be taken into account. Farah et al. [5] applied the minimum night flow (MNF) method to a large-scale pilot project to predict leaks and monitored the area with a real-time system. It was expressed that with the strategy developed, the rate of water loss has decreased from 43% (2015) to 7% (2016). Mutikanga et al. [6] presented a methodology that determines the administrative loss components for the water distribution system using field audit and operational data. The results showed that measurement errors and illegal use were the most important components of administrative losses. Xin et al. [7] pointed out that most of the apparent losses are present in the distribution system and stated that these losses are often not included in the evaluations due to their complexity and difficulty to control. Lipiwattanakarn et al. [8] reported that after the leakage was repaired in the isolated zone, the isolated zone input flow rate decreased by 9%, and accordingly, the system input energy decreased by 8%, and system efficiency improved with the implementation of active leakage control. Creaco et al. [9] indicated that real-time control and automation systems provide significant benefits in monitoring and controlling water distribution systems and components. Boztaş et al. [10] investigated the effect of breakdowns in service connections in distribution systems on leaks and water losses, and emphasized that according to field data, the quality of workmanship and material can be improved in service connections and the rate of breakdowns and leakage can be reduced. Yazdekhasti et al. [11] stated that in order to ensure water and economic efficiency and to ensure sustainable urban water management, leaks should be detected and the most appropriate detection methods and equipment should be used. Jafari-Asl et al. [12] aimed to reduce and manage pressure with an optimization-based model to reduce the impact of pressure on leakage in distribution systems and showed that leaks can be significantly reduced by monitoring pressure.

The purpose of this study is to analyze the losses and subcomponents in water distribution systems by using the standard water balance, to discuss the problems encountered during filling the IWA water balance table, the advantages and benefits of this method. For this purpose, analysis was carried out for the pilot regions, the water balance was filled, and the evaluation was made on the basis of sub-components.

2. MATERIALS AND METHOD

2.1. Standard water balance

The most basic approach for NRW rate is the ratio of NRW volume to system net input volume. In order to put forward a sustainable strategy in water loss management and to reduce this rate, sub-components of NRW should be analyzed and monitored. In the literature, the most common method used to calculate NRW and its sub-components in a certain standard and to reveal the weaknesses of the system according to the sub-components is the "standard water balance" recommended by IWA(Table 1)[1-2, 13].

The "top-down approach" has been proposed as the simplest way followed in filling the standard water balance table used in establishing the water balance [2,14]. In this approach, the NRW volume is calculated by subtracting the billed authorized consumption volume received from the customer management system from the system input volume measured by the flow meter [1-2,15]. In this method, in the next stage, apparent and real losses and their sub-components are calculated or estimated based on authorized billed consumption and input volumes. The most important disadvantage in this approach is that the physical losses, which constitute the most important part of water losses, are calculated after determining the other components. Therefore, the accuracy of the data of the components (apparent losses, unbilled authorized uses) calculated in the previous stage directly affects the real loss calculation results.

Table 1. IWA Standard water balance [1-2]

<table>
<tr><td rowspan="10">(1) System Input Volume</td><td rowspan="4">(10) Authorized consumption</td><td rowspan="2">(4)Billed authorized consumption</td><td>(2) Billed metered consumption</td><td rowspan="2">(5) Non-revenue water</td></tr>
<tr><td>(3) Billed unmetered consumption</td></tr>
<tr><td rowspan="2">(9) Unbilled authorized consumption</td><td>(7) Unbilled metered consumption</td><td rowspan="8">(6)Revenue water</td></tr>
<tr><td>(8) Unbilled unmetered consumption</td></tr>
<tr><td rowspan="6">(11)Water losses</td><td rowspan="3">(15)Apparent losses</td><td>(12)Illegal consumption</td></tr>
<tr><td>(13) Losses due to meter inaccuracies</td></tr>
<tr><td>(14) Losses due to reading errors</td></tr>
<tr><td rowspan="3">(16)Real losses</td><td>(17) Leakages in transmission and distribution systems</td></tr>
<tr><td>(18) Leakages in reservoirs</td></tr>
<tr><td>(19) Leakages in service connections</td></tr>
</table>

On the other hand, during the filling of the standard water balance table with the "top-down approach", the bottom-up approach by using minimum night flow analysis makes significant contributions in the more precise monitoring and determination of the sub-components that have been estimated in many cases, and especially in the detection and calculation of leaks in the WDSs. In the bottom-up method, leaks are determined directly according to field data based on the minimum night flow analysis. To achieve this, it is necessary to create isolated zones in the system, to establish a SCADA monitoring system and to perform minimum night flow analysis. Although the application of this method makes a significant contribution to the correct detection of leaks, field studies and infrastructure requirements create costs for the administration.

Another approach to filling the water balance is the component analysis, which allows to calculate leaks based on field data. In this method, data such as the numbers of the reported and unreported failures recorded in the system, failure intervention time and unit leakage rate in a failure are required. In order to provide these data in an accurate and sustainable manner, a systematic call center should be established. As can be seen, leaks are determined more accurately in bottom-up and component analysis approaches compared to direct field data. However, in the implementation of these approaches, significant investments must be made and the technical and equipment infrastructure must be sufficient.

The standard water balance table, which is filled using real data to represent the system, provides the opportunity to reach information about the sub-components of water losses as well as the NRW ratio. Thus, the loss rates on the basis of subcomponents in the system can be monitored, the component that creates the biggest problem in terms of water and economy for the administration can be determined, and it is possible to have information about the component that needs to be reduced and focused primarily.

2.2. Advantages and problems of the water balance

Measuring or estimating the components in the water balance table directly affects the precision of the water budget. Therefore, in order to fill in the rates of the sub-components in this table correctly, (i) determining and monitoring the meter error rates regularly with the samples to be taken in the field, (ii) making field inspections and inspections similarly for illegal use and illegal consumption rates, (iii) regular monitoring of inflow and outflow rates and level changes in order to detect leaks in the warehouse, (iv) regular inspections to identify and monitor leaks belonging to subcomponents in the distribution system, as well as devices and equipment should be placed and monitored. However, it is very difficult to fill and monitor the sub-components of the water balance in an accurate, continuous and sustainable manner according to the actual field data in the administrations where the existing technical, technological, economic and personnel background is not sufficient. In cases where the infrastructure of the administration is weak, the ratios of sub-components are entered as estimates in many cases, and this gives results that are far from reflecting the truth in most cases. In such cases, since the standard water balance is not filled according to the actual data, it is not possible to reach the correct conclusion about the components that need to be improved in the system, and to determine the components that should be monitored and focused in inspections.

2.3. Required data and evaluation

The water balance table (Table 1) is filled according to a certain systematic based on the top-down method proposed by IWA. For this, accurate and regular measurement of basic data in the field will provide a more precise assessment of water loss management components. In this section, the data required to fill the water balance according to the top-down approach and their evaluations are presented. The system input volume is obtained by regularly measuring the water from all sources feeding an isolated zone or distribution system. Since this data is the most basic data used in the analysis of water balance and performance indicators, it is very important that the flow meter is calibrated, the data is measured and monitored regularly, and most importantly, and all resources are measured. The main problems encountered in obtaining this data are the lack of calibration of the flow meter, the absence of a Supervisory control and data acquisition (SCADA) system to monitor the data, the lack of measurement in the resources used in the summer when needed and not being included in the water budget. The sum of the billed metered and unmetered usages include consumptions of legal customer registered in the customer management system. Since this component equals the revenue water, it is very important to make regular customer readings, to have high reading efficiency (generally 90-95%), and that customers registered in the system coincide with the field. The unmetered authorized consumption component mainly includes estimated readings or water allocated according to annual agreements with particularly large consumption customers. It is a desired option for the subscriber and the Administration to have the minimum of this component that is to read the consumption regularly as much as possible. The sum of billed metered and unmetered components gives the billed authorized consumption, which is equal to the revenue generating water, the component from which the Administration generates revenue. Therefore, making this component the largest in the water budget should be essential. The NRW volume is obtained by subtracting the revenue water volume from the total inlet volume. The unbilled metered and unmetered authorized uses that are non-revenue water for the administration and include mosque, park-garden irrigation and fire hydrant uses. It is essential to install meters and regularly monitor the water used in mosque and park irrigation in order to evaluate the water budget correctly. Since these two components are non-revenue water, minimizing consumption by raising awareness is very important in terms of decreasing income loss. The sum of unbilled metered and unmetered components gives the unbilled authorized consumptions. In top-down approach, the total water losses are obtained by subtracting the billed authorized consumptions from the system input volume. Losses due to the inaccuracies in water meters include the losses arising from reasons such as incomplete or no reading in legally registered customer meters. Since this component contains water that is consumed by the subscriber but cannot be charged, it means a direct loss of revenue for the administration. In order for the water budget to be made correctly, it is necessary to determine the weighted error rate by testing the meters purchased in the field annually. Illegal uses include illegal water consumed by unregistered users, resulting in direct loss of revenue for the administration. The sum of the losses due to meter inaccuracies, illegal consumption and losses due to reading errors gives the apparent losses. In order to determine this component, there must be a field-updated subscriber system, audits according to a specific schedule, and legal regulations. In water balance, after the apparent losses are determined, real losses are obtained by deducting the apparent losses from the total water losses. After the total real loss volume has been determined, its sub-components must be defined. For this purpose, leaks in water reservoirs are determined or predicted based on field data. Leaks in distribution systems (main line and service connections) are determined by subtracting this component from the total physical loss volume.

2.4. Establishing water balance and evaluation

Basically, top-down, bottom-up and component analysis approaches are used separately or together in establishing the water balance. However, overall, the top-down approach is preferred because it is easy and less measurement and monitoring activities are needed. In the top-down approach, the system input volume and invoiced legally measured uses are provided from the field and the other components are calculated according to the order given in Table 1. The most important problem in this approach can be shown to determine the physical losses that constitute the highest rate of total losses. In other words, mistakes made in determining the previous components or incorrect or incomplete measurement of data or using estimated data may cause the physical loss volume to be determined incorrectly or incompletely. If the components given in the previous section are determined according to field measurements, a more accurate evaluation can be made about the system and the weaknesses and strengths of the system can be identified. In our country, the water balance table is filled by Water Administrations according to the top-down approach. Considering that the input volume is not measured clearly in some administrations, it is not possible in many cases to fill in such detailed data regularly and systematically. In order to regularly monitor the data of the components, there must be sufficient equipment, an up-to-date subscriber management system, geographic information systems and SCADA system. As a result, predictions are usually filled with data and unfortunately the system performance is shown well. As a result, it is not possible to regularly measure the event data due to technical, equipment, personnel, knowledge and awareness and economic factors in institutions and the table is filled in a way that does not represent the field. Bottom-up and component analysis approaches, which allow more precise determination of physical losses, are generally applied in isolated areas. Since these methods require detailed data measurement and monitoring, monitoring detailed data at the same time in large systems is costly and time consuming. In these methods, detailed analyzes such as the number of failures (reported and unreported), minimum night flow and pressure changes, determination of the location of leaks by acoustic methods are performed. In this way, the leakage volumes occurring in the system are determined directly according to the field data. It is possible to obtain more precise data without the problems in the top-down method.

3. STUDY AREA AND DATA

In Malatya province, selected as the application area, the water distribution system with the length of approximately 2,000 km network and number of customers 350000 is generally very old and the level of pipe failure is quite high. In order to use the standard water balance, 10 isolated measurement zones (DMA) in the water distribution system (WDS) of Malatya province were determined as pilot areas (Fig 1, Table 1). In the application area, DMA studies were carried out by the Malatya Water and Sewerage Administration (MASKI) between years 2016-2018 to ensure sustainable water loss management. The pipes in the WDS currently serving in the application area were laid at different times and DMA was planned in areas where the failure rate is generally high. Within the scope of this study, leakage rates are at high levels in the selected pilot areas, and mitigation and prevention activities have been carried out by the administration by applying an active leakage control strategy. All of the components of the system are clearly controlled in these areas, which are defined in this way and whose entrance to the system is regularly measured and located within the system. Inlet flow rates are regularly measured and monitored instantly with the SCADA system in DMAs. Network length, number of customers, service connection length and total consumption were determined for each region by using customer management and GIS databases. As a result of these efforts, the rate of non-income water, which was 65-70% in 2015, was reduced to 45-50% in 2018 [16].

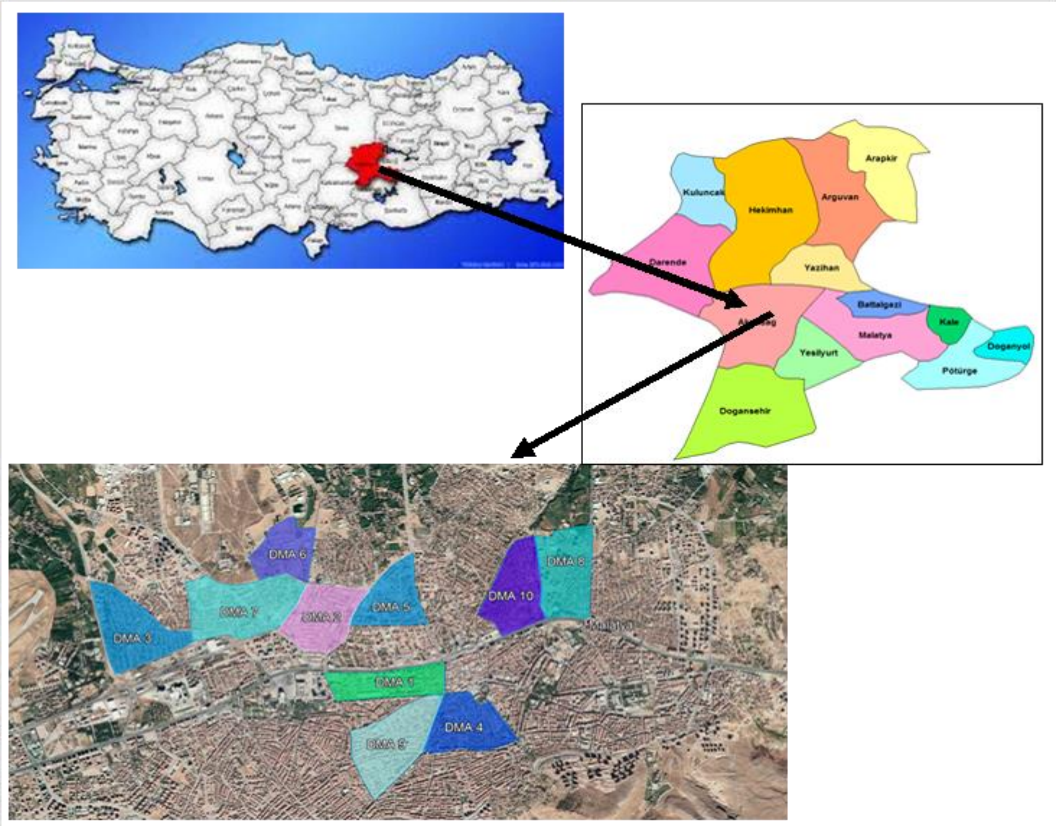

Fig 1. Study area

4. ANALYSIS AND DISCUSSION

In order to use the standard water balance in water loss management, to discuss its advantages and the problems encountered in the calculation of this indicator, an application was carried out for 10 pilot regions in the application area (Table 2). In isolated regions, the water budget was created based on monthly data. While creating the water balance for the pilot regions, the input volumes, billed metered and unbilled metered consumptions were obtained by field measurements. Since there is usually only one entrance in isolated areas, flow meter flows are monitored regularly. As mentioned before, it is very important to calibrate the input flow meters to minimize measurement errors in the flow meter. As a result of the tests performed by the Administration in the application area, weighted error rates were determined as 3.92% meter error rates in the pilot areas. Therefore, this error rate has been taken into account in all pilot regions. This rate is multiplied by the metered usage that are invoiced and not invoiced, to obtain the volumes of lost due to meters. On the other hand, since illegal use rates could not be obtained for the regions, it was taken as zero (0). Using these data, the steps given in the previous section were followed and the water budget was calculated.

When the table is examined, water loss and non-revenue water rates and volumes are given and evaluated separately. The difference between these two components can be expressed as unbilled uses. While the rate and volume of water loss includes real and apparent losses, NRW volume also includes unbilled uses. When these ratios are considered, it is seen that DMA is at a very high level for 1-2-3 and 7, and it is calculated very close to the 10% limit value recommended in the literature for DMA 6. Considering that the Ministry takes the water loss rates into account in our country and it is considered that the rates are expected to be around 25%, it is seen that some regions are far from this target. In addition, physical and apparent loss rates are given separately in the table and their effects in the total loss are evaluated. Considering that the error rate is taken as the same in the regions, illegal use is not taken into account and the entrance volumes are also close to each other, it is seen that the apparent loss rates are very close to each other in all regions. Calculating these components separately is particularly important in terms of identifying weaknesses, calculating the costs incurred, and monitoring the volumetric and monetary gains achieved through reduction. The table also calculates the unavoidable annual real losses (UARL) parameter, which represents the technically lowest value the leak will get in a network (Equation 1) [1, 14]. UARL is sensitive to system operating pressure and network characteristics and is directly affected by changes in pressure. With this parameter, the physical loss volume is compared and it is analyzed how much the current physical loss volume is technically higher than the lowest value. This UARL value may not always equal the economic leakage level, or it is not always economical to reduce the leak to this level in all systems.

Table 2. IWA water balance for pilot DMAs

Parameters	Unit	DMA1	DMA2	DMA3	DMA4	DMA5	DMA6	DMA7	DMA8	DMA9	DMA10
Number of customers	#	3391	3384	1046	2337	1208	2717	4208	1514	2895	7032
Main length	km	5.8	6.2	4.78	11.01	3.16	3.68	15.62	13.12	6.9	13.48
Number of service connections	#	500	522	315	517	300	384	526	689	427	1386
Pressure	m	38	41	45	55	52	45	51	50	60	55
Inaccuracy rate in water meters	%	3.92	3.92	3.92	3.92	3.92	3.92	3.92	3.92	3.92	3.92
Illegal usage rate	%	0	0	0	0	0	0	0	0	0	0
System input volume	m^3 $month^{-1}$	79762	128720	33531	39908	26540	32984	35050	25225	46220	109340
Billed metered consumption	m^3 $month^{-1}$	39439	63890	11446	29123	16700	28911	9900	18022	34080	84144
Unbilled metered consumption	m^3 $month^{-1}$	1500	1900	500	600	400	500	600	380	690	1650
Losses due to meter inaccuracies	m^3 $month^{-1}$	4000	5600	1450	1740	1160	1400	1400	1100	2020	4300
Authorized consumption	m^3 $month^{-1}$	40939	65790	11946	29723	17100	29411	10500	18402	34770	85794
Apparent losses	m^3 $month^{-1}$	4000	5600	1450	1740	1160	1400	1400	1100	2020	4300
Real losses	m^3 $month^{-1}$	34823	57330	20135	8445	8280	2173	23150	5723	9430	19246
Water losses	m^3 $month^{-1}$	38823	62930	21585	10185	9440	3573	24550	6823	11450	23546
Non-revenue water	m^3 $month^{-1}$	40323	64830	22085	10785	9840	4073	25150	7203	12140	25196
UARL volume	m^3 $month^{-1}$	686	780	541	1098	557	608	1235	1388	992	2632
Non-revenue water rate	%	51.0	50.0	66.0	27.0	37.0	12.0	72.0	29.0	26.0	23.0
Water loss rate	%	48.7	48.9	64.4	25.5	35.6	10.8	70.0	27.0	24.8	21.5
Real loss rate	%	44.0	45.0	60.0	21.0	31.0	7.0	66.0	23.0	20.0	18.0
Apparent loss rate	%	5.0	4.4	4.3	4.4	4.4	4.2	4.0	4.4	4.4	3.9
Cost of Apparent losses	TL $month^{-1}$	14000	19600	5075	6090	4060	4900	4900	3850	7070	15050
Cost of Real losses	TL $month^{-1}$	62681	103194	36243	15201	14904	3911	41670	10301	16974	34643
Cost of Total water losses	TL $month^{-1}$	76681	122794	41318	21291	18964	8811	46570	14151	24044	49693
Cost of UARL	TL $month^{-1}$	1235	1404	975	1976	1002	1094	2223	2498	1785	4738

$$\text{UARL} = \left(18 * L_m + 0.8 * N_c + 25 * L_p\right) * P \qquad (1)$$

P: the average pressure (m), Lm: the main length (km), Nc: the number of the service connection, Lp: the length of service connection on private property (km). As a result, if the water balance table is filled in according to the actual field data, it is possible to; (i) monitor the performance according to the NRW and its sub-components, determine the strengths and weaknesses on the basis of the component, (ii) monitor the improvements on the basis of the component depending on the implementation of the reduction methods, (iii) demonstrate the economic cost of each component.

5. CONCLUSIONS

In this study, it was aimed to apply the water balance in order to analyze water losses and sub-components, determine their rates and monitor the performance of the system. For this, the water budget was prepared by collecting data for 10 isolated regions, and component-based evaluations were made. Basically, top-down, bottom-up and component analysis approaches are used separately or together to establish the water balance. However, overall, the top-down approach is preferred because it is easy and less measurement and monitoring activities are needed. For this, accurate and regular measurement of basic data in the field provides a more precise assessment of water loss management components. While creating the water balance for the pilot regions, the input volume, billed metered and unbilled metered consumptions were obtained by field measurements. When the table is examined, water loss and NRW rates and volumes are given and evaluated separately. The difference between these two components can be expressed as unbilled uses. While the rate and volume of water loss includes physical and administrative losses, NRW volume also includes unbilled uses. When these ratios are considered, it is seen that DMA is at a very high level for 1-2-3 and 7, and it is calculated very close to the 10% limit value recommended in the literature for DMA 6. Considering the water loss rate target (25%) defined in the regulation published in 2014 in our country, it is seen that some regions are far from this target.As a result, if the water balance table is filled in according to the actual field data, it is possible to (i) monitor the performance according to the GGS and its sub-components, determine the strengths and weaknesses on the basis of the component, (ii) monitor the improvements on the basis of the component depending on the implementation of the reduction methods, (iii) demonstrate the cost of each component economically. Measuring or estimating the components in the water balance table directly affects the precision of the water budget. Therefore, in order to fill in the ratios of the sub-components in this table correctly, it is very important to determine and monitor the meter error rates regularly with the samples to be taken in the field, and to make field inspections and inspections similarly for illegal use and illegal consumption rates. In addition, it is necessary to regularly monitor the inflow and outflow flows and level changes in order to detect leaks in the warehouse, to identify and monitor the leaks belonging to the sub-components in the distribution system, as well as regular inspections and monitoring by placing devices and equipment.

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RESEARCH ARTICLE

Performance evaluation of a non-odorous compost barrel for household purposes

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ABSTRACT

Composting is one of the simplest and oldest methods for reducing biowaste at source before it goes to the main waste stream. However, odor from the degradation procedure can be a significant problem, which can hinder household to pursue this kind of endeavor. This study aimed to evaluate the composting barrel using a covering device to mitigate the emission of foul odor during composting of typical household biowaste. Turning the substrates inside the barrel is recommended, but the effect of turning frequency needs additional discussion. Hence, two barrels with the same capacity were used in the study for comparison. Barrel A was turned daily while Barrel B was turned once a week, both with five complete rotations. Results showed that compost from Barrel A could be harvested earlier than Barrel B, as a result of the higher turning rate. Composting parameters such as temperature, pH, moisture content, and mass variations were carefully monitored and exhibited acceptable operating conditions.

In terms of the quality of the final compost, the former had a total Nitrogen, Phosphorous, and Potassium (NPK) of 4.67 %, while the latter has a total NPK of 4.86 %, which are both classified as soil conditioners based on the standard for organic soil amendments. Moreover, the activated carbon (AC) mat cover was found to be effective ($p<0.05$) in deterring odor in the course of the decomposition process. Hence, this study demonstrates that the composting can be a non-odorous and eco-friendly solution for household's biodegradable waste management.

Keywords: Compost barrel, turning, non-odorous, soil conditioner, household composting

1. INTRODUCTION

In the Philippines, biodegradable or organic waste contributes the largest percentage (52.31%) of its total municipal solid waste, which produces leachates that can be odorous and harmful to the environment [1]. Improper disposal of these wastes to open dump sites results in the contamination of groundwater resources and soil [2]. To avoid this problem, the community must focus on treating biodegradable solid waste at the source [3]. The method of household composting is not new in the management of solid waste. It is one of the cheapest techniques in the reduction of biowaste at source. Composting at home also encourages family members to segregate their waste as biodegradable and non-biodegradable. Moreover, it has the potential to enhance rural/urban people's economic conditions through backyard gardening, marketing of their compost and recyclables [4].

Nowadays, there are various types of composting methods for biodegradable waste: from the traditional compost pit, which has been a common method in rural areas, to simple tire composters, and more complex designs like rotating barrels [5]. However, in urban areas, there is a strong preference for compost barrels because of the less space they occupy. Rotating barrels is an efficient and promising decentralized composting approach, which involves aeration and mixing of compost materials to produce a quality byproduct [6]. Either way, odor is recognized as a contentious issue in composting, which has been labeled as composting's "achilles heel" [7]. Compounds causing foul odors present at low concentrations do not cause much illness, but excessive odor can result in symptoms such as nausea [8]. Odor, which is caused by the breakdown

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process of biodegradables that can be minimized using methods such as absorption, adsorption, and bio filtration [9]. Fresh compost products and activated carbon (AC) are examples of biofiltering medium, which can be used as an odor controller during the composting process [10, 11]. However, limited literature is available on the investigation of activated carbon used as in-situ biofiltration during composting. Dyer [11] mentioned that activated carbon or charcoal can be mixed with the compost substrates to neutralize odor, but no literature has been found to use activated carbon (AC) as a cover mat to prevent odor emission in compost barrels.

Aeration is also one of the methods to control odorous compounds and an integral part of the over-all compost procedure because it stimulates microbial degradation of organic matter [12]. The turning of compost materials inside an enclosed reactor, which involves rotating the compost barrel, is the most common aeration technique [6]. However, excessive or lack of aeration has a major effect on the compost parameters and the quality of the final compost [13]. Thus, several studies were conducted to determine the effect of turning frequencies on biowaste composting but few literatures were seen regarding the number of turnings for rotating barrels. Most researchers agreed that turning the compost yielded better result compared to without or no turning treatment [14, 15]. Kalamdhad and Kazmi [6] recommended once a day turning of compost barrel to produce stable compost output. Another experiment conducted by Boyle[16], states that there is little to no effect on the quality of the compost between every 3 days and every week turning. To fill this gap, a comparison between daily turning and weekly turning needs further analysis. This study therefore aims to evaluate the composting process inside the composting barrel with the application of AC used as cover mat to mitigate the smelly odor that comes out from the barrel's aeration holes. Moreover, it seeks to determine whether the frequency of turnings will have a significant effect on the compost parameters and physio-chemical quality of the end product.

2. MATERIALS AND METHOD

2.1. Compost barrel with AC mat cover

A 114-liter recycled HDPE plastic drum is selected as the compost barrel that can accommodate an estimated 30-40 kg of biodegradable household wastes. For aeration, 5.08-cm holes are drilled at the top and 0.79-cm diameter holes at the bottom to serve as an outlet for the leachates, which is collected in a basin. Fine screens were attached to the surface of the holes in order to prevent flies, insects, and rodents from entering the bin. The odor control cover mat (60 x 50 cm) was a fabric material sewn into four equal portion and was filled with a total of two kilograms activated carbon (AC), as seen in Fig.1. The AC cover mat was placed over the top of the barrel, covering the aeration holes. Inside the barrel are four baffles installed to enhance mixing. A steel frame with four rollers is fabricated to support the barrel's full weight and to ensure proper turning. The completed compost barrel is seen in Fig. 2 is placed in an open area occupying approximately one square meter of space where it is protected from rainwater.

Fig 1. The mat cover filled with activated carbon

Fig 2. Barrel A with odor control cover (left) and Barrel B without cover (right)

2.2. Preparation of compost materials

Good compost usually contains carbon (brown) and nitrogen (green) materials. Green substrates come from vegetable peelings, fruit rinds, and small discarded pieces of meat, fish, and poultry, while brown material used was sawdust from Saint Louis University's carpentry shop. The green materials for the composting procedure are chopped into pieces that were collected from seven households in an apartment complex. The compost materials were mixed with an initial carbon to nitrogen ratio of 22:1. The mixed organic substrates were loaded in the two barrels with 40 kgs for each unit, filling up to 50% of each barrel's total capacity for aeration purposes.

2.3. Experimental analysis

The experimental procedure was conducted by fixing the frequency of turning the compost unit. Barrel A was set to rotate (5 rotations) daily while the same five rotations also turn barrel B but only during the weekend (once a week). Five rotations were made to ensure proper mixing and aeration of biomaterials inside the composting unit. The temperature parameter was monitored daily using a standard glass thermometer inserted 3 to 5 inches in three different points inside the compost, wherein the reading is equilibrated for 5 minutes [17]. Ten grams of each sample were grabbed from three different points without disturbing the adjacent materials. A triplicate sample was collected and analyzed for pH and moisture content. The daily pH variation of compost was determined by H18733 pH meter, while the weekly moisture content of the sample was determined after drying 24 h at 105 °C. The mass variation of each compost was determined using gravimetric weighing scales. The final composts samples from both barrels were brought in standard soil laboratory for analysis. Total nitrogen was determined using the Kjeldahl method; total phosphorous, vanadomolybdate method; total organic carbon, based on ash content using standard equation; total potassium, flame atomic emission spectroscopy method.

2.4. Odor evaluation and statistical analysis

The AC cover mat was placed over the top of the barrel every after turning, where it covers the aeration holes, as shown in Fig. 2. The compost barrel's level of the odor was evaluated weekly by the representative of the seven households using a 7-point odor intensity Likert scale throughout the composting process. The respondents standing within 1 meter distance were asked to rate the odor intensity from both barrels with and without the odor control cover, with 0-no odor, 1-very weak (odor threshold), 2-weak, 3-distinct, 4-strong, 5-very strong, and 6-intolerable [18]. To determine the effectiveness of the odor control cover mat and the effect of frequency of turning on compost parameters, a paired t-test ($p<0.05$) was performed using the real-stat add-ins in Microsoft excel.

3. RESULTS AND DISCUSSION

3.1. The compost parameters

Temperature is an important parameter which reflects the breakdown of compost materials, metabolism microorganisms, and the efficiency of the composting process [19]. The temperature profile of the two compost barrels as a function of time is shown in Fig. 3, with an ambient temperature of 23°C. The two composting barrels showed an increase in temperature that depicts the stages of the composting process which is the mesophilic phase (ambient temperature to 40°C), thermophilic phase (above 40°C) and cooling stage (below 40 °C to ambient temperature) [20, 21]. The rapid rise in temperature at the initial stage was due to the biodegradation of an adequate amount of substrate, which causes the activation of microorganisms. The optimum range of temperatures for the composting process is 40-65°C, with 55-60 °C as the most favorable for the pasteurization of pathogens [22, 23]. Results showed that both composts have reached the thermophilic stage of composting with barrel A peak temperature of 48 °C and barrel B rise to a maximum temperature of 45°C. Barrel A's higher peak temperature compared to barrel B is attributed to the frequency of turning. Higher temperature corresponds to a greater rate of turning as supported by Zhou [14]. In contrast, the lower temperature was linked to a lesser number of turning yielding to an insufficient supply of oxygen. An observation on compost barrel B showed an increase in temperature caused by the activation of microorganisms after it was turned [24]. After the thermophilic stage, all barrels manifested a gradual decrease in temperature until they return to the normal ambient condition, due to lesser microbial activity [25]. Barrel A returns to ambient temperature after 18 days, in which, the decrease of temperature towards ambient condition can be an initial sign to harvest the compost, ready for maturation. The compost from barrel B has conformed to its surrounding temperature on the 21st day until the end of composting. Although, both barrels did not reach the ideal temperature at 55°C, still, they fall into the acceptable range of composting process. Moreover, the effect of frequency of turning showed a significant difference (p-value <0.05) in the temperature profile of the compost barrels (Table 1). Previous literature also reported similar significance about the turning frequencies on temperature during composting [6, 26].

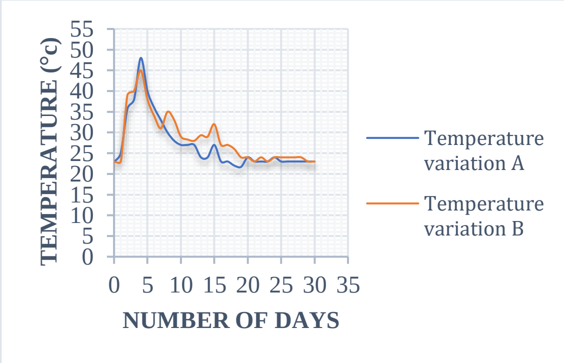

Fig 3. The temperature profile in Barrels A and B throughout the composting process

pH is a factor that is associated with the odor emission during composting [27]. The normal range of pH during the composting process should be around 5.5 to 8.5, with pH seven as the most ideal [22]. The variations of pH on the compost barrels are shown in Fig. 4. Results showed a rapid decline of pH during the initial composting procedure in both barrels. This was due to the fermentation of organic matter that turns the compost to be acidic, which causes an odor problem and even inhibit the process of degradation [27, 28]. Nonetheless, the pH progresses towards the ideal pH range until the end of the composting process. The increase in the compost pH after the sudden decrease was due to the biodegraded lactic and acetic acids caused by the transition from mesophilic to the thermophilic stage [28, 29]. Moreover, the study showed a significant difference in pH variation (p-value <0.05) with the turning frequency of compost barrel (Table 1).

Fig 4. Variation in pH values as composting progress

Moisture Content is an essential parameter in aerobic composting, influencing microorganisms' activity during the process [30]. The amount of compost moisture in each barrel is shown in Fig.5. During composting, the initial moisture content is higher than the recommended moisture of 40-60% [30]. This leads to anaerobic conditions (humidity higher than 65%) during the initial composting phase, contributing to a lower pH and the generation of leachate and foul odor [21]. But as the degradation process continues, the moisture content of compost from each barrel gradually decreases towards the recommended ideal moisture level (50%) [31]. This moisture loss was associated with the increase in compost temperature [32]. In this study, it was found that there is no significant effect of the frequency of turning in the moisture profile. Nevertheless, the moisture falls under the optimum humidity during the second week of composting up to the latter part of the process.

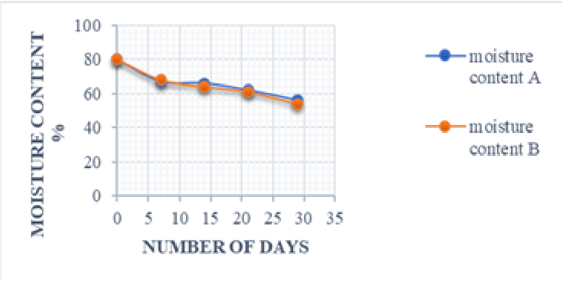

Fig 5. Moisture content variation during decomposition

The mass reduction during the composting process is shown in Figure 6. The mass of the compost is also a significant parameter of composting since it depicts the weight reduction of biomaterials used. Both barrels performed well in the reduction of weight of the biomass, which resulted in about 65 – 70% mass reduction. Results showed that both barrels exceeded the expected mass loss (between 30% to 60%) of Diaz et al. [33] However, no significant change was observed between the gravimetric weight of both composts (Table 1).

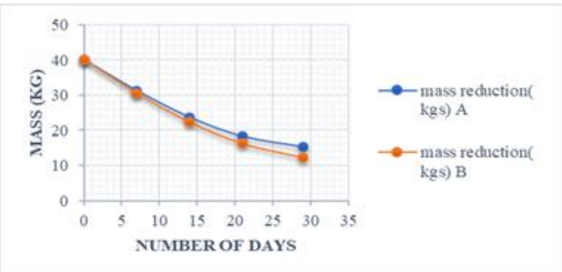

Fig 6. Mass reduction during decomposition

Table 1. Mean and p-value with significant difference

Properties	Barrel A	Barrel B	P-value	Significance at P<0.05
Temperature	27.0097	28.4074	0.0029*	Yes
pH	6.6290	7	0.0005*	Yes
Moisture Content	66.2	65.4	0.2420	No
Mass	25.7	24.26	0.0515	No
Odor emission	2.85714	2.5714	0.1723	No

3.2. Odor

In terms of odor evaluation, Fig. 7 and 8 below showed a significant effect (p-value,0.0007 <0.05) in the reduction of foul odor during the decomposition process because of the usage of activated carbon cover mat. The substantial decrease of the odor was mainly due to the adsorptive property of the activated carbon. Nevertheless, the high odor emission during the first week does not significantly change concerning the frequency of turning, as shown in Table 1. The odor is associated with the pH level of the compost materials. According to Sundberg et al. [27], high odor emissions shown in the figures below were due to low pH, especially during the initial composting stage. To reduce odor emission, Sundberg et al. proposed that the pH should be increased via aeration and usage of additives. At any rate, during the third and fourth weeks of composting, the odor level detected by the respondents decreases even without AC probably because of less microbial activity as observed in the curing stage and due to the increase of their pH. Nonetheless, the AC cover mat's application resulted in an almost zero odor intensity up to the end of the composting process.

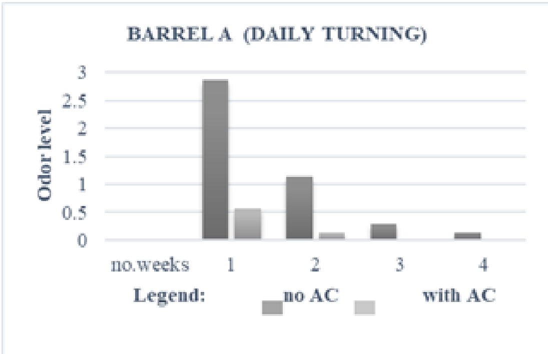

Fig 7. Odor level of Barrel A with and without AC covers

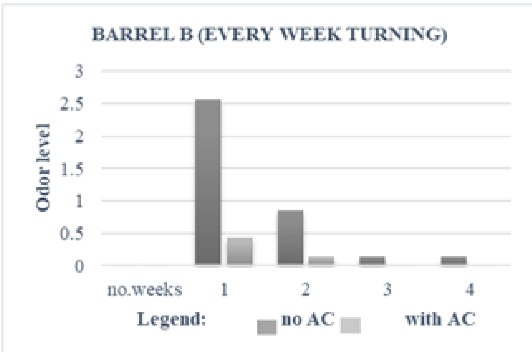

Fig 8. Odor levels of Barrel B with and without AC

3.3. Quality of the compost output

The table below shows the summary regarding the quality of compost output, based on the Philippine National Standard for organic soil amendments [34]. The study showed that both composts from barrel A and B fall under the category of soil conditioner in terms of total NPK. It revealed that over-all, there is no significant effect of turning frequency to the quality of compost, which is similar also in the study of Page [16]. The only noteworthy observation was that compost from barrel A has lower carbon to nitrogen (C/N) ratio compares barrel B. The lower C/N ratio was associated to a higher frequency of turning in barrel A as a result of the volatilization of N as NH3 and C as CO2 [26]. Nevertheless, the carbon to nitrogen (C/N) ratio decreasing pattern from 22:1 to 12:1 (barrel A) and 18:1 (barrel B) indicates the formation of a stable and matured compost, as can also be seen in the previous literatures [14, 26]. With regards to the moisture content (MC), color, consistency, and odor, the finished compost fall under organic fertilizer or soil conditioner.

Table 2. Summary of compost output parameters

Properties	Organic Fertilizer	Soil Conditioner	Compost A	Compost B
Total $N\text{-}P_2O_5\text{-}K_2O$	5-10%	2.5-5%	4.67%	4.86%
C/N	10:1-20:1	10:1-20:1	12:1	18:1
MC	10-35%	10-35%	16.91 %	15.11%
Color	Brown to black	Brown to black	Brown to black	Brown to black
Consistency	Friable	Friable	Friable	Friable
Odor	No foul odor	No foul odor	No foul odor	No foul odor

4. CONCLUSIONS AND RECOMMENDATIONS

The amalgamation of this study's findings establishes that composting can significantly reduce biodegradable waste at source and convert it to a quality compost product. The physio-chemical analysis of the mature compost from both barrels is in the range for soil conditioners that can improve soil conditions for an effective plant nutrient uptake. The frequency of turnings did not significantly affect the quality of the end-compost as long as adequate aeration (5 rotations) is provided. However, the turning rate significantly affects temperature and pH during the decomposition process. Daily turning makes oxygen more available, resulting in a faster-composting process, which is why compost from barrel A can be harvested earlier than barrel B. The odor-controlling media contributes to the reduction of odor and found to be effective in mitigating foul smell during the composting process. The other source of the offensive odor was leachates produced; therefore, it is necessary to discard it regularly. The barrel designed in this study can be an alternative composting method suitable for urban areas with limited space (at least 1 square meter is required), without affecting the adjacent household due to its odor absorbent feature. This research endeavor showed a humble attempt to evaluate a composting barrel, which can be a practical, non-odorous, and eco-friendly solution in biodegradable solid waste management for household purposes.

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