Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Estimation of COVID-19 generated medical waste in the Kingdom of Bahrain

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HIGHLIGHTS

- COVID-19 medical waste is a serious threat to the environment.
- Bahrain faces solid waste in the form of Face masks, PPEs, vaccination, and tests.
- Plastic is among the major portion of the waste requiring urgent attention.
- Basic and environmental research for efficient waste conversion can addressing these challenges.

GRAPHICAL ABSTRACT

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ABSTRACT

Coronavirus disease 2019 (COVID-19) is not only a great matter of concern from a medical and health perspective, but it is a serious threat to the environment in terms of waste generated during the prevention and cure of COVID-19. The world has so far compromised more than 3 million human lives, and millions are being infected. Environmental threat is most serious because it can cause secondary complications. As per our knowledge, the amount of waste generated during the pandemic and its estimated quantity has not been assessed, thereby keeping the scientific community, Government authorities and public ignorant of its adverse effects. In this context, we have evaluated the waste generated by the Kingdom of Bahrain, estimated to be 35.480 kg/day (face masks), 1894 kg/day (PPEs) by the selected health facilities, 16,633.505 kg (vaccination-related) and 53,551.240 kg (related to tests conducted so far) in the Kingdom of Bahrain.

1. Introduction

During the pandemic period, the demand for medical equipment, more specifically personal protective equipment's (PPEs), drastically increased. This increase could be an inevitable consequence of disease

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spread, calling for special consideration to this equipment's network in their lifecycle (Rowan and Laffey, 2020). According to various directives and measures to protect public health, a significant increase in the volume of waste resulting from the enhanced use of PPEs has been documented, including; face masks, hand gloves, rubber shoes, gowns, hand sanitizers and other medically used gears for instance - test sets/kits, syringes, plastic vessels, tissue papers, bandages, etc. (Czigány and Ronkay, 2020; UNICEF, 2020). Most of the COVID-19 related waste comes under medical waste (referred to as "waste" in the following discussion), which is defined as a solid waste generated from diagnosis, treatment and vaccination of human beings and animals, which covers research activities, testing and production of biological products (Nzediegwu and Chang, 2020; Windfeld and Brooks, 2015).

Waste generated during the COVID-19 pandemic is specifically called COVID-19 medical waste (CMW). A huge volume of waste has been produced and is still growing due to the prevailing pandemic situation with unique characteristics, such as lower density than regular medical waste, requiring special attention to be treated before disposal (Purnomo et al., 2021; Chen et al., 2021). The CMW includes PPEs, such as face shields, face masks, gloves, goggles, coverall suits, in addition to other related waste such as disinfectant containers and hand sanitizer (Vanapalli et al., 2021). There is an obligation to use standard PPEs by the health workers (nurses, doctors, and caregivers), patients and healthy people who have close contact with the infected patients. Presently, all the citizens in most countries worldwide are obliged to wear face masks during all outdoor activities (Siddique et al., 2021; Dzekashu et al., 2017). As an inevitable outcome, many disposable PPEs are made available and used, leading to a massive increase in potentially infectious waste, posing further health and environmental threats. It was found that on surfaces of the material, including plastic, steel and glass, the COVID-19 virus can last for several days (Wang et al., 2020; Hantoko et al., 2021). The risks of these threats are increasing in developing countries with an inadequate medical waste management system, which is a threat to humanity (Kampf et al., 2020). Since its inception, the waste is increasing every day by introducing new activities like vaccination, and it needs to be handled properly. Before it is dealt with or processed, quantification is of utmost required for efficient and effective planning. Various statistical models, such as STIRPAT (environmental pressure model) and Autoregressive Integrated Moving Average (ARIMA) model (time series model) have been applied to estimate trend in medical waste which seems to be promising (Wei et al., 2021).

Most countries in the world, including Gulf Cooperation Council, GCC states (Bahrain being a member state) have performed a very mature role in the prevailing pandemic situation; thus, a huge amount of waste (in addition to normal MW) has been generated and is expected to be generated till the pandemic comes to its end, which needs proper attention to be brought in the notice of the authorities for adequate treatment. A comprehensive literature survey reveals that no reports have been presented on CMW in GCC member states, particularly in Bahrain. Here, we have estimated the amount of waste generated during the pandemic period in the Kingdom of Bahrain. The medical waste resulting from the COVID-19 pandemic is estimated by calculating activities like healthcare facilities, diagnostic tests, and vaccination. The environmental impact of so far generated and future waste is also discussed.

2. Data collection and calculations of total waste

Besides the pandemic, the waste being generated is of great concern for environmental scientists. Several groups researched the high risk of a pandemic in various parts of the world. The Asian Development Bank (ADB, 2020) proposed an equation (shown below, Eq. (1)) to associate CMW with the number of infected persons. This equation has already been applied in some studies to estimate the CMW in Asian countries (Purnomo et al., 2021). Eq. (1) seems promising in predicting the waste generated or to be generated in the future until the end of the current pandemic.

$$Amount\ of\ CMW\ (kg/d) = Number\ of\ infected\ persons \times 3.4 \quad (1)$$

The same equation will be applied to estimate CMW in Bahrain since the pandemic started, i.e., February 24, 2020, until May 31, 2021; the same calculations will be extended until the pandemic's possible end.

Data of newly infected persons per day in Bahrain from the first case that appeared on February 24, 2020, to April 4, 2021, was collected from the website "Our World in Data" (OWID, 2021). Trend line referred to a best-fit line, and it's used to characterize a set of data's behaviors to determine a particular pattern. Moreover, the trend line is an analytical tool employed often in conjunction with a two-dimensional graph of ordered pairs. The trend line can predict future data points (Study.com, 2021). Trend line analysis was used to predict the number of newly infected people and the amount of CMW. The mass of all PPEs used in five health care centers was determined for representative samples using an analytical balance. Posteriorly the daily weight of PPEs in each center was calculated by Eq. (2):

$$Daily\ PPE's\ weigh\ (kg/d)\ per\ center = average\ PPE's\ weight\ per\ worker \times total\ number\ of\ workers \quad (2)$$

Online/Call interviews were conducted with several staff members working in dedicated five health care centers during COVID –19. Information about the quantity of each PPE they are using during their duties was collected. The selected healthcare facilities are the Exhibition center, Bahrain International Hospital (BIH), Kanoo center, 5th and 6th floors (6 wards on each floor) in Salmanya Medical Complex (SMC) and Hereditary Blood Disorder Center (HBDC). The following equation (Eq. (3)) has currently been proposed to estimate the quantity of daily face masks (Nzediegwu and Chang, 2020):

$$\text{Total daily facemasks} = \text{population} \times \text{urban population}\ (\%) \times \text{facemask acceptance rate}\ (\%) \times \text{average daily facemasks per capita}/10,000 \quad (3)$$

The data of population size and urban population percentage were collected, taking most of the help from the website world meters (Worldometer, 2021a, 2021b). Following the literature and the Government of Bahrain's strict implementation of facemask policies, it assumes that the face mask acceptance rate is 80%. Based on the literature (Wu et al., 2020), the assumption that everyone in the general population uses one face mask daily was also considered. The estimated data about face masks being used by the general population of the Kingdom at an 80% acceptance rate were calculated and summarized in Table 1.

The vaccination sets, including syringe, glass vial and alcohol swab, have been weighted to estimate the waste generated from vaccination. Data on the number of COVID-19 vaccines in Bahrain was collected from the website https://ourworldindata.org/grapher/cumulative-covid-

Table 1
Important statistics of GCC member states, by 2020, taken from the website world meter.

	Bahrain	Oman	Kuwait	Qatar	Saudi Arabia
Total population	1,701,575	5,106,626	4,270,571	2,881,053	34,813,871
Urban population, %	89	87	100	96	84
Total land, Km^2	760	309,500	17,820	11,610	2,149,690
Population density (persons/Km^2)	2239	16	240	248	16
Yearly change in population in %	3.68	2.65	1.51	1.73	1.59
Median Age, in years	32	31	37	32	32

vaccinations?country=~BHR (Data, 2021a) and (MOH, 2021b). The total waste's weight generated from all the vaccinated people was calculated using the formula.

Total waste′s weight of vaccination in kg
= weight of vaccine set × number of vaccinated people

Lastly, to estimate the weight of waste generating from COVID-19 tests, the items of the test kit comprising nasopharyngeal swab and bottle of a chemical preservative have been weighted. Data on the number of covid-19 tests performed in Bahrain was collected from the website https://ourworldindata.org/grapher/full-list-total-tests-for-covid-19?country=~BHR (Data, 2021b). The total waste's weight generated from all the COVID-19 tests performed was determined using the formula.

Total waste′s weight of COVID−19 tests in kg
= weight of test kit × total number of tests performed (4)

3. Results and discussion

Bahrain is a member of GCC states with a total population of 1,701,575 and a total area of 760 km^2. Its 89% population is urban (comparison with other GCC member states is provided in Table 1). The Kingdom was selected for this study based on its highest population density among GCC member states. The control and handling of COVID-19 in Bahrain are much difficult and sensitive. The Kingdom provides the best health facility to all citizens; several health centers were designated to treat COVID-19 related patients during the pandemic. As stated above, the data were collected from the website and were validated for Bahrain.

3.1. Estimation of CMW

The number of newly confirmed cases since the first case in Bahrain from February 24, 2020, till May 31, 2021, are plotted using Microsoft Excel (Fig. 1). It can be seen that the curve is affected by two components of the time series analysis: the cyclic and irregular components. In time series analysis, the cyclic component is defined as the periodic changes or regular fluctuations around the trend, forming a series of expansion and contraction phases (OECD, 2007). The countries in the world have been hit by the coronavirus waves (Vahabi et al., 2021) and the Kingdom of Bahrain is one of them; it is highly affected by the corona various waves, which formalized a cyclic pattern of high and low slopes in the curve. The other component that causes the variation and irregular movements in the curve of the confirmed cases is the irregular component, and its sudden changes occur in a time series that are unlikely to be repeated (OECD, 2007). Here leading factors for the irregular component are vaccination of publics and lockdown imposed to curb the spread.

Their best-fit line was found using the derived polynomial functions (3rd order) with a coefficient of determination R^2 equals 0.8549; this indicates a good fit-line and reliable model for a future forecast. R^2 measures the "goodness of fit" and represents a value between 0.0 and 1.0 (Investopedia, 2020; Wei et al., 2021). The cubic equation used to estimate the number of newly infected cases is found as: $y = 0.0001x^3 - 19.417x^2 + 856018x - 1E + 10$.

Where y refers to the number of newly infected cases and x refers to the date (number of days).

It is worth mentioning that this study assumes the exact current situation, for instance, without any more advanced precautionary measures. Therefore, the best-fit line reveals that the expected number of newly infected cases is to increase after May 2021; by the middle of July 2021 number of newly infected cases would reach around 3700. However, this could not happen due to the two abovementioned factors (cyclic and irregular components); for instance, a new wave of the deadly COVID-19 could hit the country. Vaccination is a vital factor, where the daily rate of COVID-19 vaccines increased in Bahrain, especially in May 2021 (TRACKERS, 2021). Up to May 28, 2021, the number of COVID-19 vaccine doses administered are 1.67 million (Data, 2021a). Another critical factor is the precautionary measure, i.e., imposition of lockdown. As found in the literature, the lockdown has a significant impact in decreasing the number of infected persons in the Kingdom of Bahrain. It was reported that implementing the lockdown, closing stores and businesses and restricting social gatherings in April 2020, led to a drastic drop in the infected people by 64% (AlSayegh and Iqbalbc, 2021). The Government of Bahrain imposed a lockdown on May 27, 2021, to limit the spread of the coronavirus (MOH, 2021a), which could affect the estimated number of cases.

Consequently, it is expected that the CMW has to increase as well. Therefore, the graph for CMW was drawn to figure out the anticipated quantity of CMW using the same method as shown in Fig. 2. The calculated amounts of CMW (using Eq. (1)) are plotted using Microsoft Excel, as depicted in Fig. 2. Their best-fit line was found using the derived polynomial functions (3rd order) with R^2 equals 0.8582; means it is a good fit-line and reliable model for a future forecast (Investopedia, 2020; Wei et al., 2021). The amount of CMW is expected to increase up to 13,000

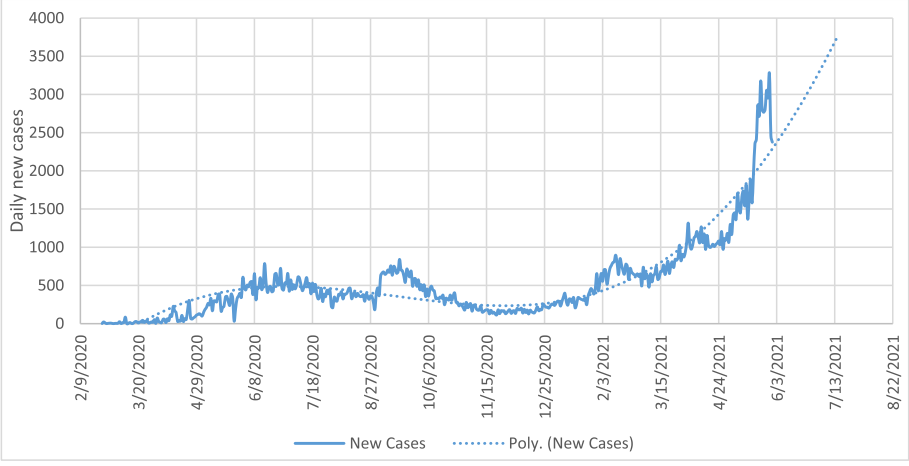

Fig. 1. The number of new daily infected persons of COVID-19 in the Kingdom of Bahrain and forecast of new cases.

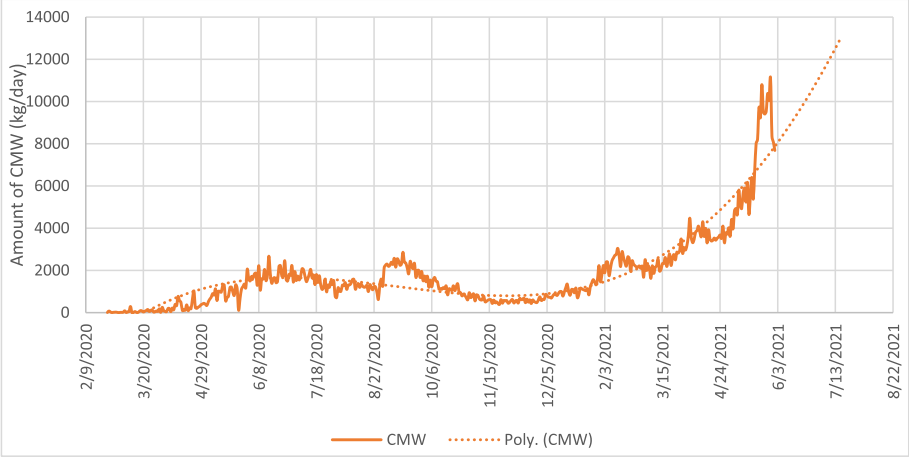

Fig. 2. Amount and expected CMW (kg/day), upper and lower confidence bound are also shown, indicating future possibilities of increase/decrease in cases.

kg/day by the middle of July 2021. The cubic equation used to estimate the amount of CMW was found as:

$$y = 0.0005x^3 - 65.939x^2 + 3E - 4E + 10$$

where y refers to the amount of CMW and x refers to the date (number of days).

3.2. Estimation of the daily protective disposable face mask of the general population

The rapid spread of the COVID-19 virus has prompted people to wear masks daily as a precautionary measure. In this regard, the government of Bahrain has adopted even strict measures to make it compulsory during outdoor activities. A disposable medical mask (surgical mask) is primarily designed and used to protect healthcare workers from hazards during medical activities. However, most citizens wore the medical face mask extensively during the outbreak of infectious diseases, for instance, SARS in 2003, PDM H1N1 in 2009, and current COVID-19, as recommended by the authorities (Elachola et al., 2020). It is believed that the face mask could reduce the risk of transmission from one individual to another. According to a study (Eikenberry et al., 2020), face masks can reduce the rate of disease transmission, resulting in the prevention of disease to a healthy person and the protection of asymptomatic transmission.

WHO has stated that, in response to the current COVID-19 virus, the global requirement for face masks is approximately 89 million per month (WHO, 2021). As of February 2020, the daily production capacity in China has been raised to about 15 million pieces of face masks (Xinhuanet, 2020). The global market for face masks (including respiratory and surgical) was expected to increase from about 14.6 billion in 2019 to 33.4 billion in 2023, with an annual increase of about 23% (Research, 2020). The weight of the surgical mask was measured to be 2.85 g, the calculated total number of facemasks used by the general population of Bahrain @80% acceptance during the pandemic is 12,449 per day. Therefore, the total weight of the face mask used by the general population in Bahrain in one day is 2.85 × 12,449, which is equal to 35,479.65 g = 35.480 kg.

3.3. The number of PPEs used for each staff per day

The SARS-CoV-2 is still novel, and most probably, it spreads by direct contact and droplets. For ensuring routine droplet barrier precautions, generally proper infection prevention practice, environmental hygiene and to minimize the risk of infection when treating COVID-19 patients, the Health Workers are required to use protective gears such as masks, goggles, PPE suits, face shields, shoe covers, etc. after their use, decontamination and discarding should be safe (Adams and Walls, 2020). These protective gears are essential as they play a vital and influential role in controlling transmission.

Most PPEs are mainly organic polymeric material; sustainable plastic and its waste pose risks to biota and environmental segments. Mismanaging the waste threatens human beings and puts a greater burden on the environment, which is already inundated by the current amount of plastic waste generated daily from non-medical sources (Purnomo et al., 2021). The respiratory mask N95 is polypropylene (PP), the surgical mask is PP, and the textile and Fabric mask is cotton. The main components of face shields are polyethene terephthalate (PET), polycarbonate (PC), and polyvinylchloride (PVC). Goggles are made of PC, and the protective gown contains PP, polyester (PEs), or polyethylene (PE). The coveralls (white and blue suites) comprise mainly of high-density polyethylene (HDPE), while the main component of Latex gloves is natural rubber, vinyl gloves is PVC, Nitrile gloves is acrylonitrile and butadiene, neoprene gloves is carbon, chlorine, sulfur, and hydrogen-containing material, See Tables 2 and 3 for details. In Table 2, the COVID-19 centers are arranged by nature of patients, i.e., case severity. Exhibition center receives all suspected persons, Bahrain International Hospital (BIH) receives the mild cases, Kanoo center, 5th and 6th floors (6 wards on each floor) in SMC receive the severe cases, and HBDC receives critical cases (Intensive Care Unit - ICU).

The data in Table 2 were used to calculate the total weights of PPEs in kg per day for each center, as has been summarized in Table 3. Table 3 reveals that the total amount of medical waste is 1849 kg/day. SMC (1243 kg/day) generated the highest amount of PPE waste among the five selected centers. The lowest amount of waste is being caused by Kanoo center (51 kg/day). The variation in the amount of waste generated in these five centers is due to the difference in the number of patients attending the center and the difference in the number of health workers in it.

3.4. Waste generated from COVID-19 vaccination

The vaccination drive against COVID-19 has been started since the beginning of 2021 around the globe and is continuing. The vaccine production has been increased to achieve the general population's desired immunization levels against COVID-19 and meet global needs. Governments worldwide are trying to vaccinate as many people as possible frantically to eliminate the coronavirus pandemic. However, that could lead to some negative consequences on the environment (POLITICO, 2021). The vaccination campaign could cause another concern in raising the waste, which is added to the waste produced by single-use PPE to protect medical staff and general people from the virus. With the

Table 2
PPEs used by front liners in designated five health care facilities of COVID-19 per day.

PPE name	Exhibition center	Bahrain International Hospital (BIH)	Kanoo center	5th and 6th floors in SMC	Hereditary Blood Disorder Center-HBDC	The average weight of the item (g)
Surgical face mask	2	4	4	5	5	2.85
Face mask N-95	1	1	1	1	1	10.46
Face shield	1	1	1	1	1	33.56
White suit	1	1	1	1	1	360
Gown	2	10	15	25	25	60.8
Goggle glass	1	1	1	1	1	34.35
Gloves (pairs)	40	25	25	30	30	20.06
Shoes cover	2	10	25	30	30	27.7

acceleration of vaccine development among the current pandemic and the immunization campaigns growth, a substantial surge in the quantity of plastic, rubber, and glass resulting from vaccine bottles is anticipated (Phadke et al., 2021). It is noted that this resulted burden will be enormous, especially on the poor, low-income areas, which do not have significant waste management resources, with adverse environmental and financial impacts in the short and long term (UCLA, 2014)

In the Kingdom of Bahrain, the Ministry of Health has provided various vaccinations and urged people to take them, as the national campaign for vaccination against COVID-19 continues to preserve the health and safety of citizens and residents by raising and strengthening immunity through vaccinations to provide the highest levels of health security in Bahrain (MOH, 2021c). Indeed, there is a high turnout of citizens and residents to take the Coronavirus vaccination, and the intake is in rapid increase, as demonstrated in Fig. 3. By April 14, 2021, the number of vaccination doses administered reached 1,008,746.

The vaccination drive is at its best, and by May 11, 2021, the number of vaccinated individuals who took two doses was 602,390, and 813,728 vaccinated individuals with the first dose (MOH, 2021b). The time interval between 1st and 2nd dose is 3 weeks (21 days); it is estimated that the given number of an individual will take their 2nd mandatory dose within the stipulated time (This number is also included in calculations as given below). Table 4 shows all the necessary items and required during an individual's vaccination for a single dose. The data depicted in the table can be used to calculate the total weight of the waste produced during vaccination for far. The total weight of waste generated from the vaccine until May 11, 2021, is 16,632.505 g and would reach 23,337,624.64 g, equal to 23,337.62 kg (Table 5).

3.5. Number of COVID-19 tests performed

In March of 2020, the Global Emergency Committee and the World Health Organization called for early exposure to prevent the virus from spreading among people (Catrin Sohrabi et al., 2020). To detect the coronavirus, a swab is used to take a sample from the mouth, nose or lungs, which is kept in chemical preservatives in a plastic tube. Then, the sample is analyzed and extracted by polymerase chain reaction (PCR), precisely, Real-Time PCR (RT-PCR). This procedure uses single-use plastics which are 100% disposable (Tang et al., 2020). The scientific community is becoming increasingly concerned about the environmental impacts related to the current pandemic of COVID-19, like sustainable medical plastic waste.

Diagnostic tests for COVID-19 produce a large amount of plastic waste; It has been estimated that RT-PCR produces 37.27 g of plastic per test (Celis et al., 2021). As of August 2020, all COVID-19 tests used RT-PCR generated 15,439.59 tons of plastic waste globally. Approximately 97% of the plastic residues from Coronavirus diagnostic tests are incinerated because of their dangerous nature to humans (Celis et al., 2021). Still, during the process, toxic chemicals come out and are released into the air. Also, the study evidenced that, in the short term, it is necessary to reduce plastic waste and intensify efforts to improve controls on gas emissions resulting from the incineration process, especially in deficit countries. There is a need to consider biomedical manufacturing in the long term, which should be biodegradable and contain no toxic chemicals when burned.

The Kingdom of Bahrain has been keen to introduce modern technologies in diagnosis and treatment to limit the spread of the coronavirus and strive to develop them in line with global developments, facilitating the methods of examinations and making them accessible to everyone.

The Kingdom of Bahrain provided a medical test facility for COVID-19 at several different points, such as Bahrain International Exhibition and Convention Center in halls and drive-through facilities, government and private hospitals, and at Bahrain International Airport, on arrival from abroad. The ministry of health made it easier for citizens and residents to be accessed in all Kingdom regions through random campaigns. These centers rely on PCR to detect coronavirus, which is one of the most commonly practised tests conducted by hospitals and laboratories to determine the viral strain or otherwise in the human body. The test is done by taking a quick sample from the nasopharynx or throat via a long cotton swab into the nostril or throat (Times, 2021).

Fig. 4 shows the total number of coronavirus tests performed in Bahrain from March 3, 2020, to April 9, 2021; the total number of tests approached 3,724,104. The graph reveals that the number of covid-19 testing is constantly increasing every day. Therefore, this increase leads to a rise in medical plastic waste, which negatively affects the environment. As reported in (MOH, 2021b), the accumulative number of COVID-19 tests is 4,273,842 on May 11, 2021. Table 6 shows the weight of the items used for one COVID-19 test, then the weight for one test was used to calculate the total weight as follows:

$$\text{Total weight generated from the COVID}-19\text{ diagnostic tests} = \text{weight of items required for one test} \times \text{total performed tests}$$

Therefore, it equals $12.53 \times 4{,}273{,}842 = 53{,}551{,}240.26$ g = 53,551.240 kg generated so far (to the date May 12, 2021). Lastly, all the solid waste generated during the COVID-19, mainly from March 2020 to March 2021, is summarized in Table 7.

Table 3
Total PPEs weight in kg/day for the five health care facilities of COVID-19.

	Exhibition center	Bahrain International Hospital (BIH)	Kanoo center	5th and 6th floors in SMC	Hereditary Blood Disorder Center-HBDC
Number of staff engaged/day	240	42	20	365	40
PPE kg/d per center	341.6328	77.12334	51.115	1242.9783	136.2168
Total kg/day = 1849.06664					

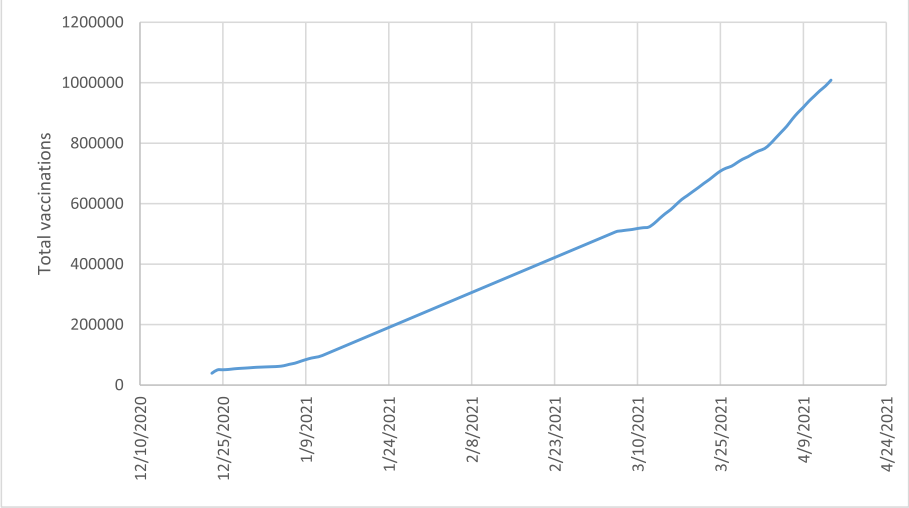

Fig. 3. Total COVID-19 vaccinated individuals in Bahrain; available vaccines are AstraZeneca, Pfizer, Sinopharm and Sputnik.

Table 4
The weight of waste items during one dose of vaccination.

Tool	Weight (g)
Syringe	5.82
Glass vial	1.59
Alcohol swab	0.83
Total	8.24

Table 5
Total calculated waste generated by vaccination till May 11, 2021.

Number of vaccinated (a)	Does (b)	Weight (g) = 8.24
602,390	2	9,927,387.2 g
813,728	1	6,705,118.72 g
813,728	2nd mandatory dose within coming 21 days from the date of their 1st dose	6,705,118.72 g
	Total weight in g	23,337,624.64 g

3.6. Efficient management and treatment of CMW

Medical waste management is a serious threat, particularly in developing countries, 45% of workers on average are trained, and still, many countries need to increase this number to deal with the waste. Segregation of 38.9% of normal medical wastes for proper management has been achieved, and still, a lot is needed to be done. Due to a lack of training and experience, workers get serious injuries during waste management. A major portion of the COVID-19 related medical waste is plastic, which needs to be processed for sustainable resource recovery and recycling. The prevailing pandemic situation invites all the countries to use collective wisdom and adopt environmentally sustainable waste management during and after the pandemic (Singh et al., 2021). There are concerns with CMW to be treated before disposal, particularly in developing countries, to curb the spread. For reusable non-medical material, it is proposed to be treated in accordance with set guidelines by using a 70% alcoholic solution for disinfection (Nzediegwu and Chang, 2020). The virus is novel, and much scientific informations are yet unexplored. Like other associated issues with the virus, the CMW is a serious threat to the environment and the scientific community. There are several techniques already in the field to cope

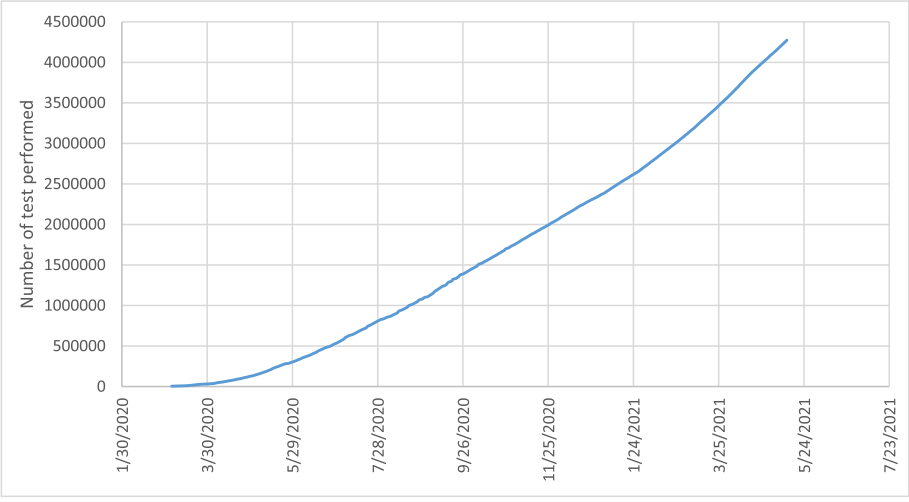

Fig. 4. The total Covid-19 test performed in Bahrain till May 12, 2021.

Table 6
The weight of COVID-19 test items.

Tool	Weight (g)
Nasopharyngeal swab	1.23
Bottle of chemical preservative	11.30
Total weight for one test	12.53

Table 7
Summarized form of solid waste generated during one year of COVID-19 pandemic in Bahrain.

Total waste generated from COVID-19 related activities in Bahrain	Weight
Predicted CMW by July 13, 2021	13,000 kg/day
Face masks used by the general population	35.480 kg/day
PPEs used by medical staff in 5 centers	1849 kg/day
Number of vaccinations, by May 11, 2021	23,337.62 kg
COVID-19 tests, by May 11, 2021	53,551.240 kg

with medical waste in a proper way. Some of them are also being applied to treat and manage CMW during the pandemic period. Three disposal options of plastic waste have been suggested by Kumar et al. through a life-cycle assessment approach, which includes landfill, centralized and decentralized incineration. According to their findings, decentralized incineration is the most viable approach, which creates least environmental and health issues, while the least viable is landfill (Kumar et al., 2021). This approach is still limiting because the waste is converted into gaseous products released to open air, and nothing useful is obtained. Conversely, the most feasible option that deals with recycling the material, scientifically acceptable and recommended practice, is chemical treatment and conversion of the waste into useful materials (Fig. 5).

Pyrolysis among chemical treatments is preferred because useful secondary products are obtained due to the process, and ultimately, a small amount at the end retains for landfill. So far, the technique is efficient, requires the least landfill capacity, is economically viable and is publicly accepted. Since the chemical composition of the CMW is the same as normal waste, the main ingredients are polyethylene, polypropylene, polystyrene, polyethylene terephthalate and nylon (Dharmaraj et al., 2021) which are convertible into useful products. The processes require elevated temperatures ranging from 300 to 581 °C to afford liquid oil and gases (sanitized refused derived fuels (SRDF)) for energy production (Purnomo et al., 2021). Incineration is practically applicable, but it emits CO_2 and other unwanted gases; in contrast, gasification and pyrolysis are promising as these techniques lead to useful fuel products and lesser environmental impact. Insufficient operating temperature limits carbonization for processing the CMW, which must be ensured during the process (Purnomo et al., 2021). The CMW is a challenge for the scientific community; it needs to be disinfected before processing any secondary products.

Policies need to be revised or approved to cope with CMW and any possible pandemic situation in future. The waste poses a risk not only to human health but also its leakage adversely affects the environment. Efficient treatment is required to be plasticized and the community shall be ready to deal with any untoward situation in the future (Ilyas et al., 2020). Positive features of pyrolysis are that waste is completely decomposed, and enough energy is produced, but high investment cost and temperature demand are still to be intelligently answered. Before the CMW is subjected to any treatment, certain steps have to be taken to decline the adverse effects (Zand and Heir, 2021; Vanapalli et al., 2021). The current COVID-19 pandemic is a lesson for scientific community and policymakers which calls for speedy and precise decisions and enhancing the capacity building for medical waste management in future abnormal situations. Some steps are necessary to be taken during/before processing the CMW, for instance, risk of infection and transmission to sanitation workers shall be reduced by scientific sanitization of CMW and use of sealed bags for safe disposal. Transition towards environmentally friendly material such as bioplastic must be worked out extensively for normal use and fighting any possible pandemics in future. Behavioral, social and institutional changes must be developed to reduce plastic waste and manage it efficiently. Circular and sustainable practices, public-private investments in research, suitable infrastructure and marketing can bring this dream true. Collective efforts of individuals, corporate and government policies to keep the world transitioning from one disaster to another (COVID-19 to plastic pollution).

4. Conclusion

The solid waste generated in the Kingdom of Bahrain has been calculated from various COVID-19 related activities. The waste estimated in a smaller country with around 2 million population is considerably high to invite the attention of scientists towards sustainable treatment. Daily use of facemasks, test kits and the number of infected cases is an open-end topic. It is a big kick to the economy of many countries of the world. Now it is time to divert the threat into an opportunity by converting the waste into useful material. The Kingdom is facing solid waste in Face masks 12,950.108 kg/year, PPEs relate waste 1849 kg, vaccination-related 23,337.625 kg, and tests related 53,551 kg. The major portion of the waste is plastic, and it needs serious attention. Small and developing countries like Bahrain may establish a sustainable treatment program as recommended.

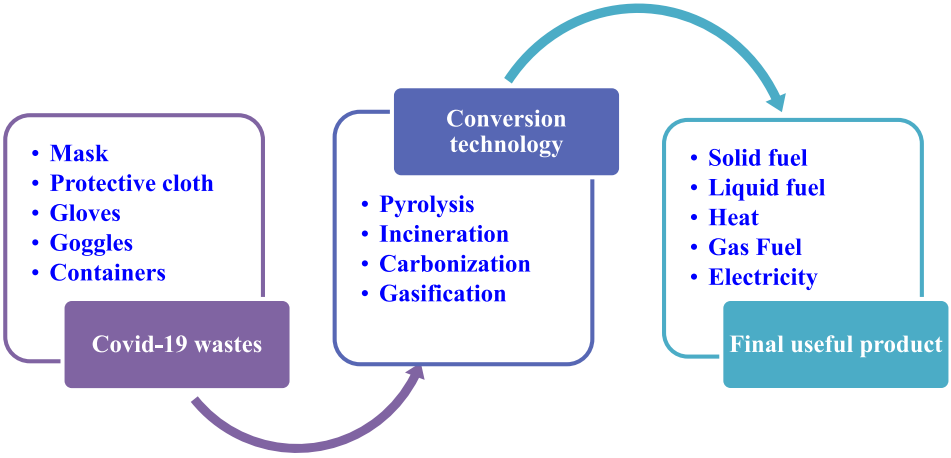

Fig. 5. Possible schematic explanation of medical waste management.

CRediT authorship contribution statement

The authors contributed equally towards conceptualization, data collection, Manuscript writing and reviewing of this study.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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