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Biomedical Waste Management Using IoT Tracked and Fuzzy Classified Integrated Technique

Surinder Gopalrao Wawale[1], Mohammad Shabaz[2,*], Abolfazl Mehbodniya[3], Mukesh Soni[4], Nabamita Deb[5], Mohamed A. Elashiri[6], Y. D. Dwivedi[7], and Mohd Naved[8]

Abstract

Improper handling of biomedical waste from a healthcare facilities and common biomedical waste treatment facilities can lead to serious implications like causing mass infections and significant environmental damage in terms of air, water, and land pollution. Every year there is an increase of about 8% of the biomedical waste generation in comparison to previous years. To effectively and efficiently manage the biomedical waste in a proper manner, several attempts have been taken to make the waste management system more improved through the implementation of an automated waste management system comprised of wireless systems. Segregation of waste helps in minimizing large loads of hazardous waste that is potentially hazardous to the environment as a whole requiring a treatment process that is costly and requires skilled manpower. It also helps in labeling and packaging of waste in a proper manner. In this paper, we will discuss how Information Technology and Internet of Things play a crucial key role in detecting and tracking of biomedical waste along with treatment and disposal of biomedical waste in best possible manner. The fuzzy system is used to categorize the waste according to four parameters. Then the fuzzy acts as feedback to Internet of Things based tracking system.

Keywords

Internet of Things (IoT), Fuzzy System, Biomedical Waste, Radio Frequency Identification (RFID)

1. Introduction

Employees working in the healthcare sector along with handlers of waste and common people usually are frequently exposed to the injuries and toxic effects of waste management from healthcare facility (HCF). For protecting the environment today, sound biomedical waste (BMW) practice is an important aspect. In today's era, a number of countries globally have very good sound and effective biomedical waste management (BMWM) best method of practice. To bridge the gap between the countries

***Corresponding Author:** Mohammad Shabaz (mohammad.shabaz@amu.edu.et)
[1]Department of Geography, Agasti Arts, Commerce and Dadasaheb Rupwate Science College, Akole, Maharashtra, India
[2]Model Institute of Engineering and Technology, Jammu, India
[3]Department of Electronics and Communication Engineering, Kuwait College of Science and Technology, Doha, Kuwait
[4]Department of CSE, University Centre for Research & Development Chandigarh University, Mohali, India
[5]Department of Information Technology, Gauhati University, Guwahati, India
[6]Computer Science Department, Faculty of Computers & Artificial Intelligence, Beni-Suef University, Beni-Suef, Egypt
[7]Department of Aeronautical Engineering, Institute of Aeronautical Engineering, Hyderabad, India
[8]AIBS, Amity University, Noida, India

effectively managing BMW and the countries lacking behind the practices in managing those wastes in a proper manner, gap need to be identified and immediately given prior attention at the earliest possible time. Programs relating to proper management of BMWM practices where gaps are identified need to be addressed and resolved through effective policy and best management practices at the grassroots level at all medical units. Every day there is an increasing amount of generation of BMW across India and this trend is rising rapidly due to the rise in the number of HCFs along with lots of patients admitting them on a regular basis. As per the Central Pollution Control Board (CPCB) yearly report information 2017, the number of HCFs in India were identified as 238,254 amongst which only 87,282 fell under the bedded facilities with the total number of beds coming out to be 2,094,858 [1]. Collection along with transportation followed by management of the BMW from each location possesses a large challenge in the present-day period. Guidelines issued earlier by the Ministry of Environment and Forests, in July 1998 for governing the BMW in India contain the definition categories of segregation of waste protection along with protection and handling and treatment of waste generated in India [2].

Deepak et al. [3] says that the waste in health care facilities is very dangerous. It can cause many health hazards and plays a major role in polluting the environment. The paper points to setting up an effectiveness index for assessing the performance of biomedical waste management. In [4], the use of waste ash in cement is being occurred due to which its workability is decreased. Devi et al. [5] reveals to avoid the health risks through proper management of biomedical waste. Patil et al. [6] also reveals that the soil fertility can also be increased using organic biomedical wastes. The authors of [7] reveals that if the biomedical waste is burnt then it produces an ash which is called as incinerated biomedical waste ash. Biomedical waste is hazardous to human life in many ways. In [8], a technique is used in which the wastes from different hospitals are managed and the technique is an analytical hierarchy process (AHP). Kokkinos et al. [9] analyses that the waste management is also done by recycling different products. The recycling process can also help us to manage waste. Patil et al. [10] proposed that we can make fertilizers with organic biomedical waste by using plant extracts and it could be very profitable to farmers. In [11], the authors reveal that biomethane gas is used in various industries such as renewable resource like food manufacturing, aerospace, etc. Belhadi et al. [12] reveals that many of the African countries face many difficulties of waste management worldwide and this waste should be managed properly. More revisions of the BMWM rules were issued in the coming years in the year 2016, thereby easing the classification along with authorization and better handling generated daily across India [1]. Requirements for sound BMWM clearly defining the sources of BMW along with its proper categorization and disposal were elaborated by Mathur et al. [13]. Improper treatment and disposal of BMW directly impacts human health by spreading infection through the microbial hazards present in BMW as per Salkin [14]. According to the study conducted by Tony et al. [15] in the clinics in Udupi Taluk in 2018, it was confirmed that most of the BMWM equipment's were insufficient and were lacking proper training relating to its operation & maintenance and thereby failed to meet the standards prescribed under the BMWM guidelines. Case studies relating to the BMWM disaster occurred in Gujrat in 2009 in which approximately 240 people were reported being infected and about 70% of them were victims to the disease during this outbreak as per Seetharam [16]. Utilization of syringes and needles that were not sterilized properly and which were stolen from medical equipment's that were already used were identified to be the main reason for the occurrence of this outbreak. For evaluating the current status of BMWMS throughout the entire India, INCLEN Program Evaluation Network (IPEN) Study Group [17] conducted a study in which data collection was done from around 20 states within India and it was further found out that approximately 82% of the primary health centers along with more than 50% of the total number of secondary, tertiary HCFs are in shortfall of proper BMWM. In fact, it is quite noticeable that the majority of the workers working in HCF in India had inadequate knowledge about good BMWM practices but at the same time less injury reporting cases were found amongst them as per Matthew. The role of IoT in the effective monitoring of BMWM has been successfully demonstrated by Soni and Kandasamy [18] through the integration of smart sensors that gather all information from the garbage bins and transfers the data in the form of live monitoring. Several technologies relating to automatic waste management in the form of collecting and storing data through IoT based smart sensors have been discussed by Raundale et al. [19]. These smart IoT based sensors help in improving the process of BMWM. In India, collective gaps have been observed in the collection, treatment, and disposal of BMW even though quite a number of guidelines have been issued by the government and regulatory agencies. Gaps were mainly in the form of implementation of the best BMWM practices as outlined in the statutory requirements mentioned under the government published set of guidelines. The main purpose of this pilot study is the identification of the problems along with pain points in BMWM system through exploratory surveys and finally making the BMWM system more digitalized through Internet of Things (IoT) architecture. All this is done as there is an urgent requirement to effectively manage the BMW generated daily through the implementation of proper collection, treatment, and disposal systems in place.

The upcoming section introduces the process involved in biomedical waste management, followed by the categorization of BMW, its segregation, disposal and treatment, and limitations of the previous management techniques. Finally, the methodology adapted is discussed and lastly the conclusion.

2. Biomedical Waste Management – Process

The best way to segregate the waste is to keep separate containers for different wastes, categorizing them on the basis of solid and liquid or biodegradable and non-biodegradable. The BMWM process, illustrated in Fig. 1, starts with the generation of waste which is basically as a by-product of healthcare services like treatment, diagnosis, etc. Starting from the source of waste generation, the waste is firstly identified, followed by segregation and disposed of into the right colored bin according to the color code shown in Fig. 2. The red color code determines the disposal of waste in black color bin, yellow color code determines the disposal in yellow color bin, and blue color code for disposal of waste in blue color bin.

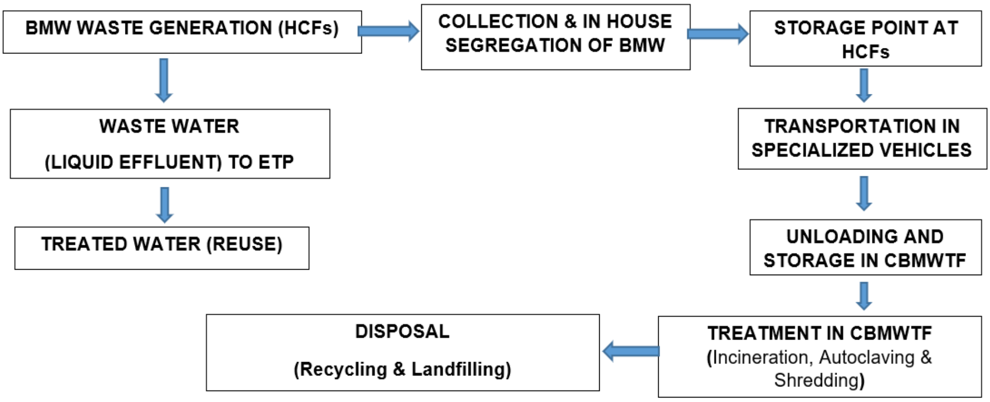

Fig. 1. Biomedical waste management process.

Firstly, waste from all points of the HCFs are collected and then segregated in different colored bags black, red, yellow, blue, and white and then shifted to BMW storage facilities within the HCFs premises or in the basement. The BMW is temporarily stored in the HCF unit until 48 hours. After that, it is transported in specialized vehicles fully sealed and covered with the nearby (CBMWTF) for the next stages of processing, followed by treating and disposing the waste matter. Under the set of regulations by the Indian Government, the BMW cannot be stored in the storage point beyond 48 hours.

BMW generated at HCFs is treated and disposed in Common Biomedical Waste Treatment Facility (CBMWTF). In case of nonavailability of CBMWTF within a radius of 75 km from the HCF, it is either treated onsite at the HCFs premises or at offsite beyond the HCFs premises. Usually, all waste collected and separated into different colored bags category wise, bar code is pasted on each bag/container for tracking it from the starting source of generation till disposal for making sure that the waste is not disposed improperly causing further harm to the environment. In any case of disparities in segregated colored bags, the respective state pollution control board must be immediately informed.

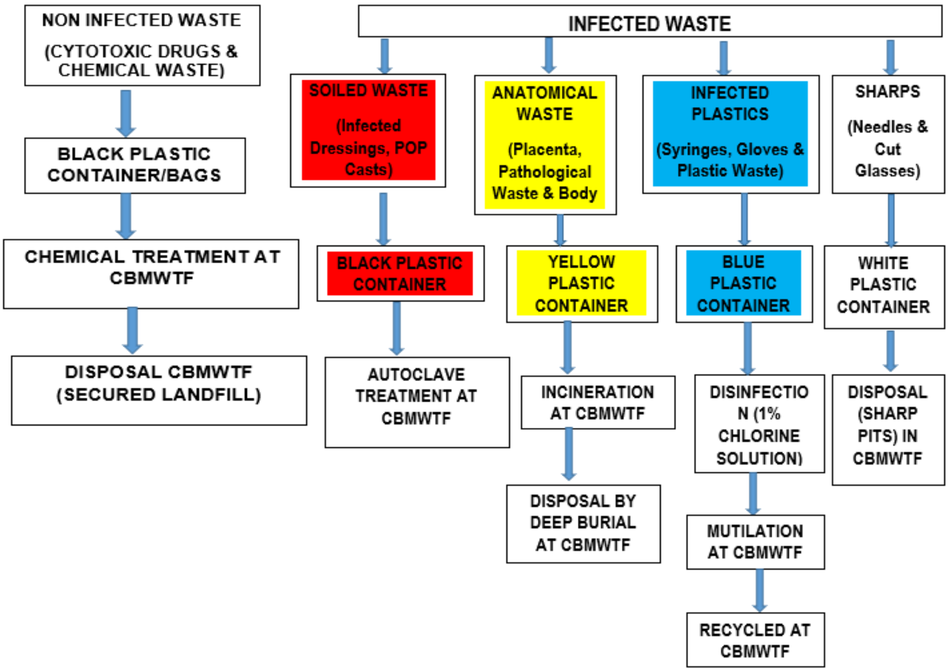

Fig. 2. Segregation of biomedical waste & its disposal methods.

3. Categories of Biomedical Waste

Diverse classes of BMW produced at source from the HCFs that include hospitals, clinics, nursing homes, biomedical laboratories, and diagnostic centers are at first manually segregated into different bags that are color coded into yellow, red, blue, white, and black by the workers of each HCF. After that, BMW is manually separated into different categories of waste, namely, 1, 2, 3, etc.

It is then transported in specialized vans with centralized facilities called CBMWTF. CBMWTF are fully centralized and integrated plants that can do everything from quantifying to record keeping to proper treatment & disposal of BMW in an effective and efficient manner. CBMWTF are monitored strictly by governing bodies like the State Pollution Control Boards to make sure they are properly operated and are in full compliance. Table 1 shows biomedical waste categorization and its disposal methods.

4. Biomedical Waste Segregation, Treatment and Disposal

Separation of waste helps in reducing the level of hazardous waste requiring treatment and disposal technologies that are costly and limited. Medical waste should be separated from the solid waste as it cannot be disposed like the general waste. Before inserting into color coded bags/containers, the sharp waste containing both needles and syringes must be destroyed to prevent the rag pickers from picking them up for reselling purposes. In this manner, recycling of the needles at a later stage in CBMWTF is prevented. Disinfection of waste containing sharps should be done at the source by utilizing chemical disinfectants. BMW in general consists of different types of medicines, drugs, cottons, needles, etc. that cannot be simply decomposed or burned. The color codes and type of containers used for segregation of biomedical waste can be classified in Table 2.

Table 1. Biomedical waste categorization and its disposal methods

Waste category	Treatment and disposal
1. Human anatomical waste Human tissues, organs, body parts	Incineration, deep burial
2. Animal waste Animal tissues, organs, body parts, carcasses, bleeding parts, fluid, blood and experimental animals used in research, waste generated by veterinary hospital, colleges, discharge from hospitals, animal houses	Incineration, deep burial
3. Microbiology and biotechnology wastes Wastes from laboratory cultures, specimens of microorganisms live or attenuated vaccines, human and animal cell culture and infectious agents from research and industrial laboratories, wastes from production of biological, toxins, dishes and devices used for transfer of cultures	Local autoclaving, micro-waving, incineration
4. Waste sharps Needles, syringes, scalpels, blades, glass, etc. that may cause puncture and cuts. This includes both used and unused sharps	Disinfection by chemical treatment, auto clave, microwaving, and mutilation or shredding
5. Discarded medicines and cytotoxic drugs Wastes comprising of outdated, contaminated, and discarded medicines	Incineration, destruction, and drug disposal in secured landfills
6. Soiled waste Items contaminated with blood, and body fluids including cotton, dressings, soiled plaster casts, lines, beddings, other material contaminated with blood	Incineration, autoclaving, microwaving
7. Solid waste Wastes generated from disposable items other than the waste (sharps) such as tubing, catheters, intravenous sets, etc.	Disinfection by chemical treatment, autoclaving, microwaving, mutilation, shredding
8. Liquid waste Waste generated from laboratory and washing, cleaning, housekeeping, and disinfecting activities	Disinfection by chemical treatment, and discharge into drains
9. Incineration ash Ash from incineration of any biomedical waste	Disposal in municipal landfill
10. Chemical waste Chemicals used in production of biological chemicals used in disinfection, such as insecticides, etc.	Chemical treatment and discharging into drains (liquids), secured landfill (solids)

Table 2. Medical waste segregation in HCFs category wise using colored containers or bags

Color coding	Type of container	Waste category
Yellow	Plastic bags	Waste comprising of human along with animal wastes, microbial, biological waste, and soiled waste
Red	Container/plastic bags that is disinfected	Microbiological along with waste of biological composition, waste that is soiled and solid wastes
Blue	Plastic bag, Puncture proof containers	Infected plastic waste like syringes, gloves, and plastic waste
Black	Plastic bag	Waste comprising of disposed medicines, drugs that are cytotoxic along with ashes from incineration and chemical waste
Green	Plastic container	Waste from office , along with kitchen waste and waste from gardens
White	Plastic bags or containers that are puncture proof	Sharp waste consisting of needles and cut glasses

The following treatment processes must be followed for effectively treating the biomedical waste in a proper manner as follows:

Chemical processes: For managing liquid waste, chemical disinfection is applied to dispose the waste properly. Mostly chlorine is a regular choice and is mixed with liquid waste as it attacks microorganisms and pathogens. The chemical process involves basically using of chemicals as disinfectants. To measure samples of such chemical's sodium salt, dissolved bleaching agent per acetic acid, oxide, dry inorganic chemical, and gas are used.

Thermal processes: Extreme high temperature in the form of heat is used in the thermal treatment process to disinfect the waste. Based on the level of temperature used for operation, they are further classified into two classes: low-heat systems and high-heat systems. Low-heat system (operates between 93ºC and 177ºC) and utilizes steam hot water along with radiation to clean and heat the waste matter. Autoclave and microwave are classified as low-heat systems.

Autoclaving: Autoclaving is the process of sterilizing the medical waste through high temperature and steam that is high in pressure. In the process of sterilization, the bacteria, viruses, spores, fungi, and other pathogenic microorganisms are destroyed very effectively. Usually, regular autoclaves are made up of vessels that are cylindrical having a provision of loading and unloading of the waste matter. In the vessel jacket steam is injected that is high in pressure and temperature. Heat is rapidly transmitted into the waste, thereby generating steam of its own. In this process, pathogens are destroyed in the maximum amount and dry waste is generated. Usually, the autoclave operates in the temperature range of 121°C and pressure of 105 kPa in a timeframe of 1 hour duration. The most commonly used method for autoclaving includes the vacuum method that is induced in which is characterized by the introduction of steam into the vacuum and the method is gravity-based called gravity displacement method in which steam is introduced to the vacuum displacing the air. Introduction of steam into the waste is very essential for its effective treatment and hence proper care should be taken while packing the waste in order to promote penetration. The liquid waste generated during this process requires further treatment at effluent treatment plant (ETP).

Microwaving: Disinfection using microwave is a recently developed improved technology in the field of medical waste management. In this process, microwave radiation is utilized for heating and destroying the microorganisms contained in the waste. Shredding and moisturization of the waste occurs through steam before exposing them to microwaves for promoting a uniform rate of heating and disinfections. This process is characterized by loading of waste from a hoisting bucket that is automatic to a hopper and then ultimately treating it all together to higher temperatures of around 94°C for at least a time frame of 25 minutes. In this manner, a high levels of treatment results are obtained in the form of higher disinfections and sterilization. Microbiology based laboratory waste along with human blood, fluids from body and waste containing sharps can also be treated very effectively in this treatment technology.

Incineration: In the process of incineration of medical waste, complete combustion of the compounds containing carbon occurs in the presence of fuel and oxygen. Heat is provided through the fuel in the form of energy to produce higher temperatures in the incinerator and combustion inside the incinerator occurs in the air containing oxygen in it. In this process, the waste that is combustible comes out as ash as by-product. The emissions generated from the incinerator are directly dependent on the category of waste it is incinerating and along with the conditions of the incinerator. This process is very effective only when the waste can be fully combusted. During the process of incineration, the medicines are effectively destroyed by the high heat produced within the incinerator. Incinerators must maintain at least 1,200°C temperature to operate as per government regulations and waste must be exposed to it for a minimum timeframe of two seconds.

Sharp materials disposal: Usually sharps containing needles are destroyed through needle cutters which are available in the market in both mechanically and electrically operate able. Usually, these kinds of equipment's are portable and light and easy to operate and usually are used at locations like center's collecting blood samples, hospitals, nursing homes, clinics, etc. These instruments are utilized for preventing the reuse of syringes that are disposable. Usually the mechanical devices are operated through a lever that cuts off the needle from the syringe. In this process, only one needle at a time can be destroyed. After separation of the needle from the syringes, the separated needles were collected in a box that are punctured then disinfected before disposing them. In the electrically operable model, the needles are either burned or separated or destroyed from the syringes, generating steel as a byproduct. Usually electrically operable needle destroyers are considered safer to operate but electricity is required to operate it. Needles of diversified sizes can be destroyed using both types of destroyers. Period required for needle destruction is one minute. Sharp waste containing blades along with the needles must be disposed in pits of rectangular or circular shape in CBMWTF. These kinds of pits are constructed using the linings of brick, masonry, or rings that concrete in size.

Radioactive waste from healthcare units: Wastes that are radioactive in nature generally comes out in liquid form as a by-product from research facilities that are chemical or biological in nature and from diagnostics centers with body organ imaging devices like X-Rays, during the process of decontamination of radioactive spills from urine of patients along with scintillation liquids utilized in the process of radio immunoassay. Radioactive waste in the form of liquid waste forms the majority of the radioactive waste generated from HCFs. Strict guidelines and procedures must be followed while accumulating the mercury spilled from disposed thermometers and bulbs and storing it. Proper attention and focus must be given to avoid the mixing of the spilled mercury with medical waste. Mercury waste containing 50 ppm should be strictly disposed as per the government issued guidelines and norms.

5. Limitations of Current Biomedical Waste Management Systems

Although the existing system of BMWM has been in place and is working well for years, there are quite a number of defects that pose a potential hazard to the environment as a whole and lives of living organisms like human beings and animals. Some of the defect area is as follows:

1) Occurrence of unnecessary expenses in transportation contribute to about 43%.

2) Presence of limited decision-making capabilities and along with mechanisms to transport the waste.

3) Human error: Current practice of quantification and separation are completely manual in nature; hence higher chances of error occur.

4) Fraud: Sources like hospitals sometimes don’t reveal the actual facts and often mislead the authorities through false information to acquire the license.

5) Delay: There is often a delay in terms of more time consuming as the mechanisms are mostly manually oriented, thereby taking more time for segregating and measurement of the data.

6) Bureaucracy: The system of government hierarchy in India as with any other government authorities, is often slow and time consuming.

7) Corruption: The BMWM can be further hampered through the presence of employees in the HCFs that are corrupt and often take bribes. Non real time: Since data is collected on a yearly basis, it is not considered real time means not providing the authorities an instant plan of action.

6. Proposed Methodology

At present, most of the HCFs are facing difficulties in controlling the costs associated with the BMWM along with providing sound services to its customers and resolving the issue of waste management properly. Therefore, monitoring of the proper disposal of waste is utmost essential for the HCF for ensuring the safety patients along with staff members. Existing systems available in most of the HCFs require a lot of paperwork along with hours of manpower to manage the biomedical waste on a day-to-day basis. Often this existing system is unable to effectively and efficiently manage the BMW in many instances. The newly introduced proposed system aims to solve this problem by introducing a fuzzy-based system to classify the waste and then tracking the waste through IoT server.

Fuzzy-based classification

The type of waste category according to the color coding of the bag as explained in Table 2. Then it categorizes in terms of four parameters as described below:

- P1 (Cost generator): Any waste which can be used for cost recovery
- P2 (Health risk): Waste having high health risk
- P3 (Bio/Non-bio-degradable): Is the waste is bio-degradable or not
- P4 (Environmental effect): Is any harm to environment

According to the category, the hidden layer (HL) in the fuzzy chooses the appropriate process. In this paper, only five processes are taken into consideration, but it can extent to nine if required. Only the first categorization of color bag is node manually, the other process is done through an automated IoT based tracker system. The other processes that are carried automatically by IoT involve tracking the biomedical waste both indoor and outdoor, continuing monitoring whether the waste is classified properly or not, alert systems, etc. The IoT devices involved in the methodology include tracking sensors like RFID, GPS, etc., cloud computing for data storage and data transmission, mobile application for monitoring and tracking, etc. After collecting all bags, the fuzzy-based categorization is done. Then after selecting the appropriate end process, the IoT plays a vital role (Fig. 3).

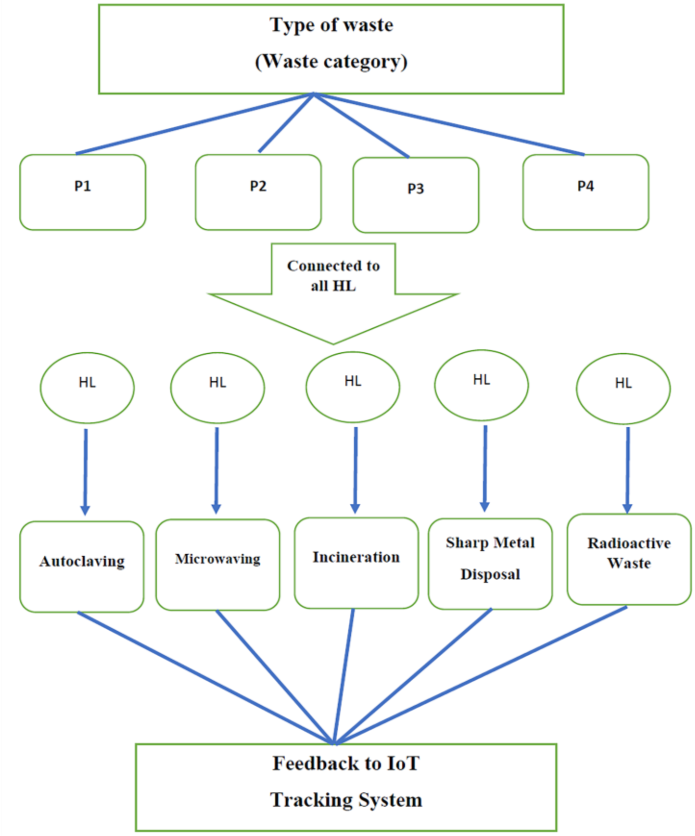

Fig. 3. Fuzzy based categorization.

The HL is assigned with weights. Here, weight means priority to certain points. The P2 is given the highest priority and the cost generation is given the last priority. The order is given in Equation (1).

$$P2 > P4 > P3 > P1 \quad (1)$$

By having five trials for fuzzy-based categorization, P2 parameter were given preference in the range of 80%–90%, similarly for P1 the range is 0%–20%, P3 having the range of 20%–40% and P4 having the same range as of P3. Fig. 4 indicates that the trial is successful in categorizing the waste by considering all four criteria stated in Equation (1).

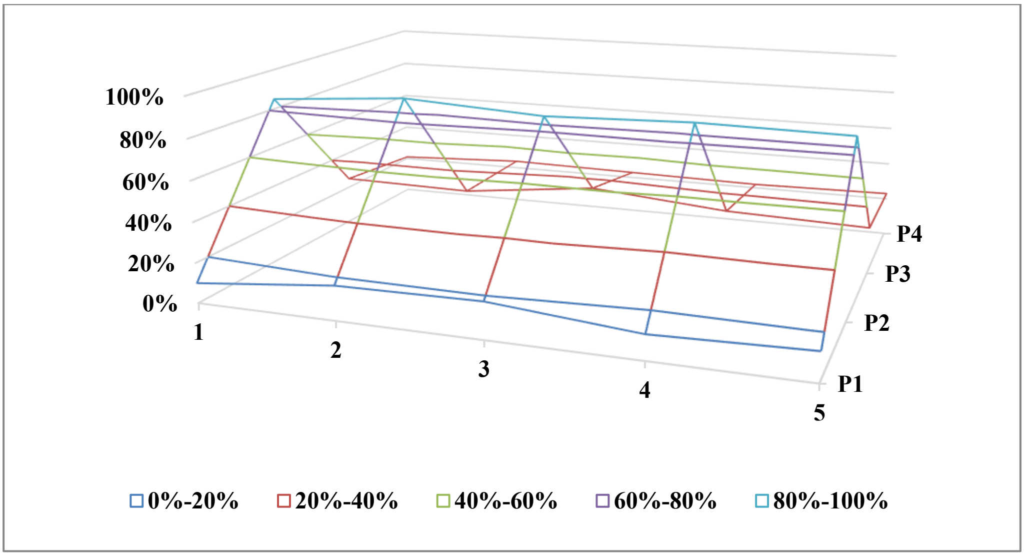

Fig. 4. Effectiveness of fuzzy system.

IoT-based tracking with policy enforcement for proper management

After getting the input from the fuzzy system, the IoT-based tracking system gets activated and monitors the in-door, out-door, and radioactive material monitoring. The details are given below:

In-door tracking: Interestingly, the most innovative method for tracking BMW in the HCF is through the implementation of RFID system that tracks the indoor garbage present in the waste bins in the HCF premises. This system is automatic and it helps in identifying, storing, retrieving important data via wireless communication channels between electromagnetic wave (EMW), transmitters, and receivers. This system has attained quite a lot of attention and interest amongst the commercially localized systems and is at the same time very cost effective, readily available and generates smaller footprints in comparison to the other systems available in the market today. Usually, RFID tags are coded in color to match the colored segregated waste bags/containers of BMW. RFID system components consist of an RFID tag composed of an antenna together with a chip, an antenna equipped with a reader, and a transceiver, along with a workstation for hosting middleware and a database. The generic platform of this system is a complete integration solution for high-level HCF systems consisting of an architecture that is flexible along with application programming interfaces (APIs) for multisystem integration. RFID hardware, software, tags, receivers, repeaters, etc. are all components of this system. Monitoring and tracking of the real-time movements, tampering, temperature, and humidity of the waste generated by healthcare centers can be done through this system. The proposed system consists of both hardware and software components. Hardware system architecture contains RFID active/passive tags along with a RFID tag reader integrated with web and database servers. Web together with the database servers are placed at one location or main station within the healthcare center. Within the center, the tag readers are distributed. The tags are programmed in a way for containing information of all items planned to be tracked, mainly bins along with the tags that are fixed to the items. Line of communication between tag readers and web servers are done via LANs that are wireless. Communication driver takes care of all communication functions done at the main station along with APIs for analyzing and handling the data and a GUI for storing all information about all items that are tracked are all components of the software architecture. Medical waste information management system is shown in Fig. 5.

At present, this technology has already been in place in many HCFs in the European countries and in the United States. In India, this technology also has been used in HCFs as well as for managing Solid Waste in several smart city projects especially in states like Gujrat, Maharashtra, by the respective municipalities and private contractors like companies. Moreover, the price of RFID tags will decrease in the coming years due to improvements in technology and designing experiences. There is an increasing demand for RFID based systems daily in the waste management sector. In the coming days, RFID technology will be not replaced by barcodes as the performance of the barcode can be continuously increased through the addition of more functions as shown in Table 3.

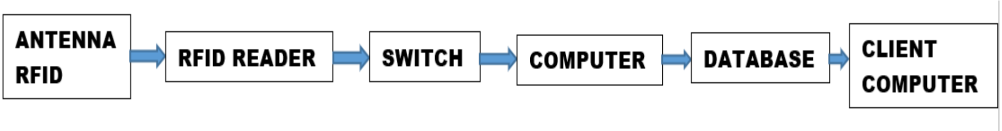

Fig. 5. Diagram of medical waste information management system procedure based on RFID technology.

Table 3. Advantages of RFID and GPS based BMWM systems in comparison to current manual practices of BMWM

RFID & GPS based BMWMS	Existing BMWM practices
High speed	Slow and time consuming as it has manually based
Multipurpose and many format	Not multipurpose and multi format since manual log books and registers are used instead of digitally storing and sending data via computers and mobile devices
Reduce man-power due to automatic processing of data	Hours of manpower required due to increasing loads of waste generated in HCFs on a daily basis
High accuracy due to full automation	Prone to lot of errors as manually operated by human beings
Complex duplication	No such feature exists
Multiple reading	Often the readings cannot be done as accurate facts and figures of BMWM is hard to obtain since the process is manually done

RFID patient and RFID radioactive material tracking: There is an increase in the utilization of radioactive materials in healthcare centers because of the rising number of patients suffering from diseases like cancer and tumors, all requiring radiotherapy to kill the cancer cells present in their bodies. Improper disposal of radioactive waste poses a serious hazardous threat to the environment, staff members and other patients present inside the HCF. Reports of serious accidents caused by the spread of radioactive radiation in the form of contamination of the environment have already been confirmed in countries like Brazil in 1988, resulting in the killing of four people and injuring 28 more and similar cases in Mexico, Morocco in 1983 and Algeria in 1978 [2]. All these accidents and incidents are well documented and researched. Radioactive waste comes in solid, liquid, and gaseous forms but the majority of it consisting of 80%–85% comes in liquid form as liquid waste. Higher level of radioactive waste is generated in the HCF through radioiodine therapy, body organ imaging, and treatment of cancer and tumor patients. Proper attention must be taken in the form of more precautionary measures for treating radioactive materials with care. The proposed system tracks the radioactive waste right from the point they are generated until the stage the radiotherapy department receives them, uses them, and disposes them as per government regulations. The number of patients getting treated and admitted to the healthcare centers has been increasing daily making it more difficult for the medical staff to properly keep a check on all patients. The system will help in regulating the process through automatic tracking of the patients in such bigger healthcare centers. Not only this ensures the proper service being provided to the patients, but at the same time the system also keeps track of the locations of the medical staff. Tracking of the staff is done to enhance their efficiency at work and at the same time protecting them from certain threats. Quite a number of HCFs use RFID technology, but their software is limited to the hardware that is used. The proposed system bridges the gap. The proposed system consists of a powerful parameterization tool, enabling the implementation of the RFID tracking project easily without any risky specific developments. Being an end-to-end RFID tracking software solution or system and at the same time open to any RFID hardware, the proposed system significantly reduces any total cost of RFID medical waste tracking implementation, without compromising on the RFID hardware selection and without taking any risk.

Out-door tracking: The proposed system consists of a GPS that is able to track the capabilities thereby enabling it to monitor the waste more easily starting from the point of their generation, collection, transportation, and disposal. [8]. Moreover, the GPS system is very cost effective and at the same time provides real-time location of the medical waste, mapping and reporting unlike any other GPS devices installed in vehicles. Through this system, hospitals and other HCFs can effectively and efficiently control the BMWM system to provide proper services to their services along with ensuring their safety. It is recommended that the HCFs acquire the RFIDs and GPS in a state of recycled/reused for reducing their running cost of this system.

Statistical module

By using the proposed system, each medical waste container is labeled, scanned, located, tracked, and documented from “cradle-to-grave.” Hence, it can be utilized for tracking the amount of medical waste generated by each department of a healthcare center on a day-to-day basis. The statistics data analysis module of the system further enables the system administrator to estimate and predict any harmful or improper disposal of waste, and at the same time estimating the proper amount of the produced waste and disposing them in a particular period of time.

Policy enforcement

Policies must be strictly enforced while utilizing this proposed system for the sake of managing the medical waste from the HCFs properly. Without an evolution, exercise organizations might find that certain policies are actually impeding people’s ability to get their work done; quite noticeably, rise in the number of cases having a lot of violations is an indicator that policies need to be adjusted.

7. Discussion

Inadequate biological waste management generates major environmental issues such as air, water, and land contamination. As a result, efficient biomedical waste management is critical to minimize the transmission of potentially hazardous illnesses and infections to the general population. The most frequent problems relating to healthcare waste [9, 10] are due to the lack of knowledge and awareness of the harmful effects of medical waste, inadequate training of staff for waste treatment and management, absence of smart or proper systems to detect and dispose the medical waste, inefficient financial and human resources to manage the waste as well as the least importance and attention given to the topic. Many countries are lacking proper regulations and are not concerned about enforcing them [11, 13]. The main and most important issue is taking in charge of the responsibility for handling and disposing BMW. According to the “polluter pay” principle, the responsibility lie within the waste producer, mostly the medical staff of any healthcare center or unit involved with such related activities. To achieve proper disposal and treatment of the medical waste, the financial cost estimation of the same must be taken into consideration. Improvements in healthcare waste management mostly rely on building a comprehensive system that addresses the responsibilities, allocation of resources, handling and disposal. The proposed system provides services like RFID tags, RFID reader, GPS, database management, third party integration, user permission, etc. This guarantees the robust performance of the architecture. Moreover, this system is quite scalable, evolving user’s requirements. The proposed system can be used in small scale as well as large-scale facilities. The system is basically an open system consisting of exhaustive APIs which easily integrates itself with the presently running system of the center. This is an innovative, new developed approach for the management of medical waste. It reduces the headache of unnecessary paperwork, its harmful effect on the staff and patients as well as the whole environment surrounding it. The system is also highly cost-effective, thereby providing an end-to-end solution for effective and efficient waste management. The comparison with the traditional system is shown in Fig. 6.

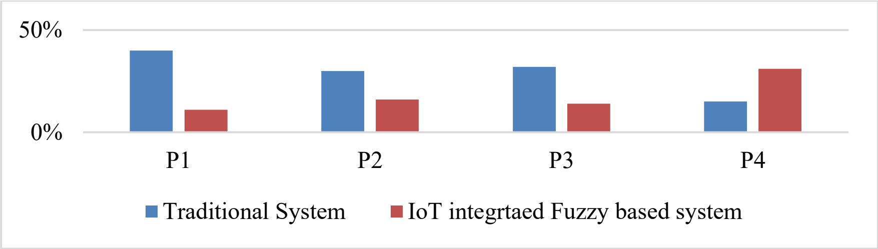

Fig. 6. Comparison of traditional system with the proposed system.

8. Conclusion

For optimizing the biomedical waste management, the new information and communication technology system that is proposed has various advantages. Tracking different types of waste, even hazardous ones in real-time, tracking and locating more thousands of waste items, separation of waste in real-time can be done through this system. At the same time, this system further ensures that proper separation of wastes occurs and is collected into different colored bags based on their categories before processing and treatment in CBMWTF. In addition, this system has real-time rule-based alerts to notify the staff of any radioactive and hazardous waste, thereby ensuring that the waste is stored far away from the populated areas within the healthcare center for avoiding the storage areas. This system also provides a properly engineered design plan and at the same time ensures real-time checking of the temperature of the waste produced, along with producing regular reports. Moreover, this system enhances the productivity and efficiency of the waste management staff, thereby reducing the manual work, so that the staff can concentrate on providing proper services to the patients and give more attention to the customer problems. This system has an alert system to alert the staff if there is any problem with the hardware or software of the system. This system works daily 24-hour continuous cycle. It locates, tracks, and maintains the statistical data of the same. Lastly, the proposed system also ensures that the BMWM leads to hazard-free environment of the healthcare facilities. It also ensures that an automation of the system proves to be a boon to the facility, to the general public and the environment as a whole. The proposed model can be further improved in the future by introducing a more efficient and accurate models to identify and segregate the BMW.

Author's Contributions

Conceptualization, MZ. Funding acquisition, MZ. Investigation and methodology, MZ. Project administration, MS. Resources, AM. Supervision, AM. Writing of the original draft, SGW. Writing of the review and editing, ND, MAE, YDD. Software, ND, MAE, YDD. Validation, ND, MAE, YDD. Formal analysis, MS. Data curation, MN. Visualization, MN.

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Competing Interests

The authors declare that they have no competing interests.

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