# A SPACED-BASED CONCEPT IN MUNICIPAL SOLID WASTE MANAGEMENT AND MONITORING IN DEVELOPING COUNTRIES

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## ABSTRACT

Lack of proper framework, ineffective policies, limited basic facilities and weak technological approach in the solid waste management sector have raised environmental concerns in major cities of most developing countries. Also, uncoordinated disposal pattern of municipal solid waste in the society contributes to the emission of greenhouse gases and other forms of pollution that is detrimental to human health and the environment at large. In bid to achieve an aesthetic and sustainable environment, the study aims to promote the optimization of space-based technologies as a tool in municipal solid waste (MSW) management and sanitation monitoring using a conceptualized model. The approach employed the use of geographic information systems (GIS) and remote sensing (RS), building a geodatabase in municipal solid waste management as baseline data for the nation, radiofrequency identification (RFID), GPS and GPRS/GSM and other ancillary data in solid waste management and monitoring. The incorporation of geospatial data with technology and integrated communication technologies in MSW management and monitoring for developing countries will enhance environmental sustainability and budget planning for contingency plan to assist decision-makers build a sustainable platform in the solid waste *sector.*

*Keywords: environment, GIS, management, monitoring, MSW, RFID.*

## 1 INTRODUCTION

The world will continue to generate municipal solid waste (MSW) in high quantities and varieties as a result of rapid urbanisation, industrial development and socio-economic impact which in turn has become an environmental issue that requires urgent attention by every nation. In 2009 [1], in its report stated that the estimated total amount of MSW generated globally is increasing by some 8% per year. A recent study by the World Bank [2] estimates that the global MSW generation is approximately 1.3 billion tonnes per year or an average of 1.2 kg/capita/day. Currently, as a result of industrialization and rapid population growth in many cities and towns in most developing countries, MSW are generated faster than they are collected, transported and disposed [3]. The significance of waste management has been a global issue such that in 2002, the World Summit on Sustainable Development focused on waste minimization, recycle and reuse followed by the safe disposal of waste to minimize pollution [4] in [5]. Inefficiency in MSW management in most developing nations is attributed to lack of appropriate technology, weak institutional framework, poor staff welfare, environmental indiscipline and non-ethical disposal methods, among others. Improperly sited open dumps have defaced several cities, thereby endangering public health by the spread of odour and diseases, and also the pollution of surface and ground water sources [6]. Presently, it is evident that pollution transforms the environment into an epidemiologic space [7]. The World Health Organization (WHO) had its concern about poor sanitation in member countries such that in a resolution by the Regional Committee for Africa during the Forty-Third session, stated in its document AFR/RC43/R2 of 7 September 1993, that it is expedient to affirm that proper sanitation and sound waste management are crucial in the


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promotion and protection of human health and of the environment, both of which are necessary for sustainable development [8]. In most African cities, issues of the proper management of solid waste still exist such that MSW are buried, burnt or disposed haphazardly. MSW, when left in the open dumps for a long time, constitutes serious health hazard, causes offensive odour, pollutes underground water sources and decreases environmental aesthetics, and quality [9] reported that MSW management planning is important to ensure that the future generation inherits a pollution-free environment given the present scientific, economic, social and political constraints. It is unfortunate that in most developing countries, statistical data on MSW and management records are inconsistent due to lack of funds, low-level coverage of MSW collection, lack of technical know-how, limited technology employed and infrastructural inadequacy. The use of geospatial technology has been an integral part of the developed nations all over the globe used in solving environmental-related issues. Geospatial technology can be described as a combination of equipment used in visualization, measurement and analysis of earth's features typically involving such systems as GPS, geographic information systems (GIS) and remote sensing [10]. It is popularly used in the environmental monitoring, military operations, national and internal security, socio-economic and urban management and health mapping, among others. GIS can simply be described as an informative system that collects, manages, analyses, manipulates and retrieves geographically referenced data. GIS was also used as a framework for mapping and displaying information about waste sites and processes [11]. On the other hand, remote sensing is the technology used in the acquisition of spatial information about an object or phenomenon through a device in order to identify, classify, map, monitor, plan, mitigate and manage the environment without being in contact either the object or the phenomenon under study. Space-based information is used in developed nations to assist public agencies and other stakeholders to prepare and mitigate the consequences of environmental sanitation issues. Therefore, it is imperative to explore geospatial techniques to solve socio-economic and environment needs such as solid waste management and environmental sanitation monitoring. In the light of this, the study aims to promote the optimization of geospatial technology as a supportive tool in MSW management and sanitation monitoring in developing countries using a conceptualized framework.

## 2 REMOTE SENSING SATELLITE AND APPLICATIONS

Remote sensing data from the Earth Observing Satellite Systems (EOSS) now constitute a major source of primary data for diverse studies and mapping, monitoring and management of natural resources and environment. Since the beginning of space science in the 1960s, satellite remote sensing has been recognized as a valuable tool for viewing, analysing, characterizing and making decisions about our environment [12]. Satellite remote sensing can be described as the use of satellite-borne sensors to observe, measure and record the electromagnetic radiation reflected or emitted by the earth and its environment for subsequent analysis and extraction of information [13]. It was from this point countries adopted the usage of satellite imageries for inventory, assessment, monitoring and management of resources from local to global scale. Remote sensing satellites are either active sensors (self-generating energy source) or passive sensors (dependent on the sun for energy). Satellites with active sensors operates during the day and night while those with passive sensors operates only during daytime. Images from remote sensing satellites are known as digital images which may be viewed as an array of numbers or matrix whose row and column indices identify a point in the array. The matrix element value is between 0 and 255, which corresponds to the brightness level at that point on the image [14]. The size of each pixel on the ground (called the spatial resolution of any given imaging system) differs from one imaging system to another. The ground coverage of a complete image scene and also the total number of pixels per image scene vary from one satellite system to another. The improvement in the spatial resolution of the remotely sensed imagery has provided a channel for geospatial data acquisition in the generation of essential geoinformation needed in many earth-based disciplines for various applications. Remote sensing satellite application areas include environmental management and monitoring; disaster management; military and security; infrastructure mapping; settlement classification; precision agriculture; border security and access control mechanism, regional planning and development.

## 3 GLOBAL POSITIONING SYSTEMS (GPS) AND GENERAL PACKET RADIO SERVICE (GPRS) TECHNOLOGY

Global Positioning System (GPS) can be described as a satellite-based navigation system placed in orbit to transmit signals to a device (GPS receiver) which allows land, sea and airborne users globally to determine their exact location and distance on the earth in real time and all season. GPS receiver can be used to determine an object's position in three dimensions. GPS receivers require an unobstructed view of the sky, so they are used only outdoors and they often do not perform well within forested areas or near tall buildings [15]. In recent times, GPS is extensively being used in motor vehicle to determine vehicles' position on an electronic map display, help drivers to keep track of their position, and also for providing emergency roadside assistance [16]. Modern systems automatically create a route and give turn-by-turn directions to designated locations [17]. Hence, GPS will be an effective tool in MSW management and monitoring by its use in tracking the position of waste collection trucks and bin location. GPRS is a packet-based data bearer service for wireless communication services that was developed from the existing GSM system which is related to the internet. Furthermore, GPRS applies a packet radio principle to transfer user data packets in an efficient way between GSM mobile stations and external packet data networks at the rate up to about 117 Kbits/s [18]. It provides an immediate and continuous connection set-up to the internet. GPRS network has a wide coverage and can truly achieve real-time sending and receiving [19].

## 4 RADIO FREQUENCY IDENTIFICATION TECHNOLOGY

Radio frequency identification (RFID) technology has already proven its use in various sectors such as agriculture and production; products supply chain; education; animal forms; sports; military and security; hospitality and tourism; health-care services; and airline. This technology can simply be described as an automatic identification method that uses wireless electromagnetic fields to transfer data for purpose of automatic recognition, thereby tracking tags attached to objects. Abiona in [20] also defined RFID technology as an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags or transponders. RFID reader generates magnetic fields through antennas for getting acknowledgement from tags [21]. The reader generates query (trigger) through electromagnetic high-frequency signals (this frequency could be up to 50 times/second) to establish communication for tags [22]. Hence, this technology enables readers to capture information on tags and transmit it to a central control system without any physical contact. A typical RFID system component is displayed in Fig. 1.

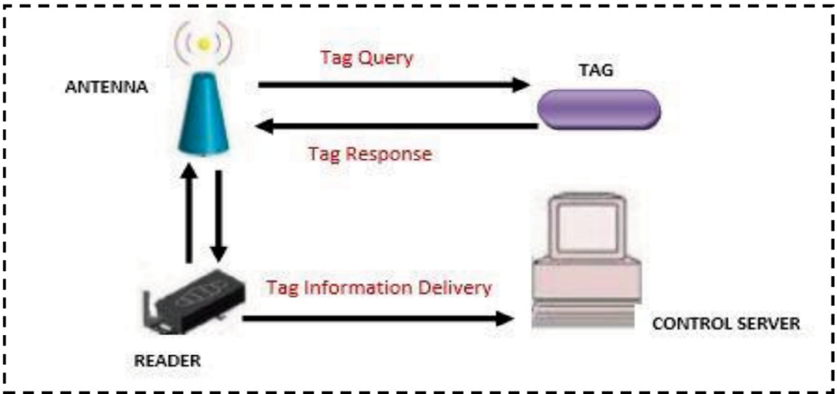


Figure 1: A typical RFID system component; Source: Author.

## 5 METHODOLOGY AND DISCUSSION

This proposed method is a conceptualized approach which includes a GIS and remote sensing component, and the integrated technology (GPS, RFID and GPRS) component. This system is a combination of the above-mentioned components to enhance an effective and efficient MSW management and monitoring in the society. The schematic in Fig. 2 describes

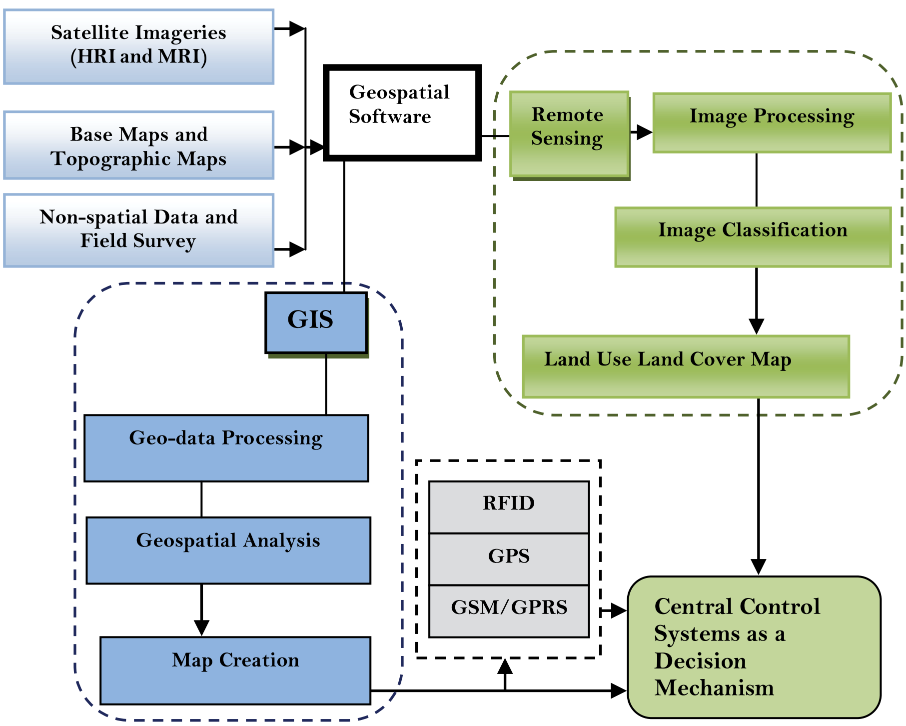


Figure 2: Geospatial model for MSW management and monitoring; Source: Adopted from [23].

the workflow of the conceptualized approach towards attaining a sustainable and effective MSW collection and monitoring in developing nations.

The conceptual model (see Fig. 2) is an approach designed for developing countries having known that it has capacity to pursue the task and achieving the goal of the study. This methodology requires spatial and non-spatial data, geospatial software, hardware and other ancillary information for the monitoring and management of MSW. The conceptual model is of two phases, namely the remote sensing and GIS phase, and the RFID phase.

### 5.1 Geospatial component

In the first phase, satellite imageries (high-resolution imageries (HRI) and medium resolution imageries (MRI)), base maps and topographic maps are the inputs into the central control system otherwise known as the system server. The presence of geospatial software (remote sensing and GIS) in the server provided gives room for various task to be executed such as image processing, georeferencing, geodatabase creation, geoinformation extraction, geospatial analysis, route network and proximity analysis can be done as a baseline data and information for the real task ahead. Validation exercise is imperative by conducting field investigation to confirm the reality of some feature as observed in the satellite images. This in combination tends to the generate various maps such as land use land cover maps, route maps, bin location maps, proximity maps and landfill suitability maps. Furthermore, spatial query can be demonstrated having created a geodatabase with information from spatial and non-spatial data sources. This will enable checks on operations, monitoring bins distributions and maintenance of the operations and sustainable management in general. Table 1 contains typical data required for a geodatabase in an MSW management and monitoring operation. The geodatabase uses the concept of database systems (DBS) in its operation. DBS are leveraged for managerial understanding of process relationship, inventory management and prediction [24] in [25]. Hence, this will improve the quality of decision-making in the planning, evaluation, forecasting scenario and alternatives in MSW management and monitoring. Tables 1 and 2 shows a typical database for proper monitoring and management in the MSW sector. The database consists of both spatial and non-spatial data component.

Table 1: Spatial database in MSW management.

| Data | Type | Geometry |
|---|---|---|
| Road network | Vector | Line |
| River | Vector | Line |
| Contour map | Vector | Line |
| Waste bins location | vector | Point |
| Study area map | Vector | Polygon |
| Buildings | Vector | Polygon |
| Landfill | Vector | Polygon |
| Existing run routes | Vector | Line |
| Topographic map | Vector/Raster | |
| Base map | Vector/Raster | |
| Satellite imageries | Raster | |

Table 2: Non-spatial database in MSW management.

| Data | Type |
|---|---|
| Street addresses | Tabular |
| Road network attributes | Tabular |
| Waste bins attributes | Tabular |
| Land use data | Tabular |
| Population data | Tabular |
| Service provider's data | Tabular |
| Client's data | Tabular |
| Street addresses | Tabular |

### 5.2 Integrated technology component

Phase two of this study is the integration of the RFID system into the remote sensing and GIS phase. First, a preliminary geospatial analysis involving remote sensing and GIS would have been carried out to identify the existing land use of the study area, suitable locations in the study area for waste bins at defined distances before the placement of RFID tag on the bins. Geo-coding of bins is done manually through field investigation to identify and validate the best locations proposed by the GIS software by using a GPS receiver. RFID tag is attached to each bin with different unique identification code (serial number) in different location [26] and [27] in their research reported that low frequency passive tags are usually recommended because they offer long-term low-cost solutions and are operational in extreme conditions resistant to environment hazards. For the purpose of real-time monitoring of the evacuation of MSW, a combination of devices (GPS, GPRS, weighted sensor and RFID reader) are mounted of the collection trucks which is linked to the available database of land use and digital maps of the area of interest that is residence in the control server. When these collection trucks are within the defined radius of any bin with a tag, the reader placed on the truck sends signal communicating with the tag to capture the tag's serial number which contains information about the bin and it relays the collected data to the control server in real time. Similarly, the locations of the bins are identified by a GPS device on the collection trucks which also serve as a way point for all the routes of the trucks in altitude, distance and time. Consequently, this transmits location data to the control server through GSM/ GPRS network which can be viewed in real time on a display map in a GIS environment. Data collected from the tags are connected with a timestamp in which the type of bin and weight sensor mounted on waste collection truck monitors the weight of garbage collected for each bin, truck's identity, load description and customer information. This information is stored in the truck's on-board computer and later transferred to the control server for data processing or directly to a central computer. The control server receives information from the RFID reader and compares it with the reference information on each bin in the existing geodatabase. After data processing, it is transferred to the GIS terminal. The real-time information can be shared with clients through a web-based solution. The entire system used is a combination of RFID system, GPS module, and GPRS network which is connected to the internet Protocol(IP) – fixed control center. Fig. 3 is a typical picture of an RFID system in MSW management and monitoring.

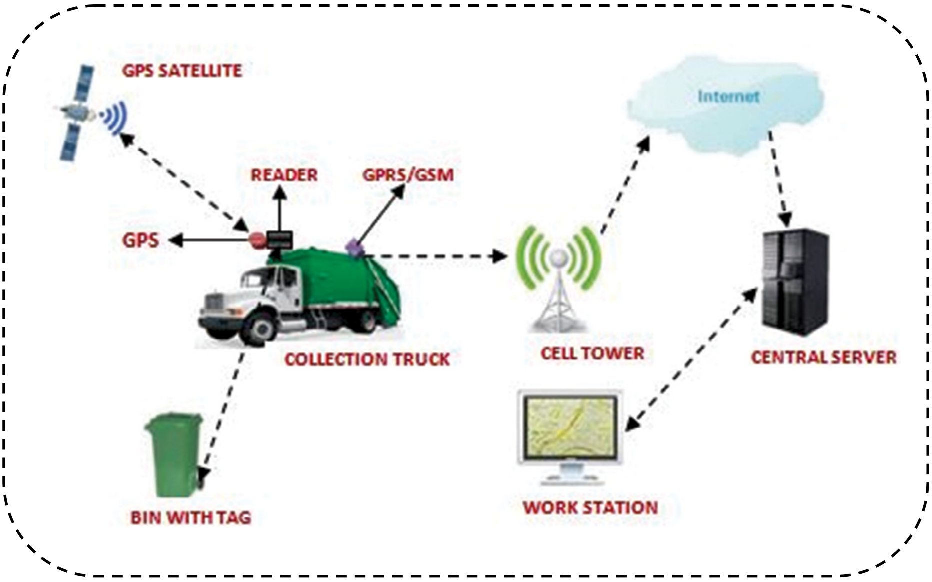


Figure 3: RFID system in MSW management and monitoring;
Source: Author.

## 6 CONCLUSION

As seen in recent times, the use of space-based data and other forms of information and communication technologies (ICT) for providing solutions in environment-related problems has been a formal practice by developed countries. This study has developed a conceptual model which comprises geospatial techniques and integrated communication technologies for MSW management and monitoring in developing countries. The model demonstrates a unique capacity to improve the quality of environment in MSW collection, transportation and disposal which tends to save energy, time and cost with a very high efficiency and effectiveness. The adoption and utilization of this model will generate multiple socio-economic sustainability and opportunities in terms of job creation, revenue generation, eco-friendly society and, most importantly, identifying MSW as a resource out of place. The outcome of the utilization of this model through a well-coordinated synergy among stakeholders is expected to yield positive deliverables such as proper map updates on road network, truck routes for MSW collection, best location for waste bins and siting landfills, statistical data and updates on waste quantity in tonnes, subscribers information, waste characterization and identification codes in accordance to source of generation. Lastly, this study provides all stakeholders in the solid waste sector a decision support system in terms of budgetary, planning and contingency plan to build a sustainable platform to tackle both present and future MSW management issues.

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REFERENCES

[1] UNEP/IETC, *Developing Integrated Solid Waste Management Plan Training Manual; Waste Characterization and Quantification With Projections for Future*, Vol. 1, pp. 1–77, 2009, available at http://www.unep.org.jp/ietc/publcations/spc/iswmplan_Vol.pdf (accessed 8 July 2016).

[2] World Bank, *"What a Waste": A Global Review of Solid Waste Management, Urban Development Series Knowledge Papers*, 2012, available at http://www.worldbank.org/INTURBANDEVELOPMENT/resources.../What_is_waste/Chapter1.pdf (assessed 17 November 2016).

[3] Federal Ministry of Environment, *Policy Guidelines on Solid Waste Management in Nigeria*, Policy Guidelines on Solid Waste (2005), Developed by Federal Ministry of Environment: Abuja, Nigeria, 2005.

[4] UNWSSD, *World Summit on Sustainable Development Implementation Plan: Johannesburg Declaration Report*. United Nations Publications, 2002, available at http://www.un.org.esa/sustdev/documents/johannesburg%20Declaration.doc (accessed 7 August 2015).

[5] Aderoju, O.M., Salman, S.K., Ajonye, S.E., Nwadike, B., Jantiku, J., Adebowale, R.K., Fagbemiro, O.A., & Agu, N.V. A geo-spatial approach for solid waste dumpsites for sustainable development in Minna, Niger State, Nigeria. *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, **8**(**10**), Ver. I, pp. 16–28, 2014. e-ISSN:2319-2402, P-ISSN: 2319-2399. www.iosrjournal.org

[6] Adegoke, O.S. Waste management within the context of sustainable development, the environment and sustainable development in Nigeria. Proceedings of a Workshop, 25–26 April, NICON NOGA Hilton Hotel, Abuja, pp. 103–117, 1989.

[7] ENDA-Tiers Monde, *Waste and Human: Experiences of Recycling in the Third World*, In French, ENDA-Tiers Monde, Dakar, 300p., 1990.

[8] WHO, Report on environmental sanitation in African Region; trend and analysis. *The 43rd Session of the World Health Organization Committee for Africa; AFR/RC43/R2*, Gaborone, Botswana, 1993.

[9] United States Environmental Protection Agency (USEPA), *Report of the Municipal Solid Waste in the United States: 2005 Facts and Figures*, pp. 5–15, 2005, available at https://archive.epa.gov/epawaste/nonhaz/municipal/web/pdf/mswchar05.pdf (accessed 29 August 2016).

[10] Cimons, M., *Geospatial Technology as a Core Tool; National Science Foundation, USA*., available at http://www.usnews.com, 2011 (assessed 25 November 2015).

[11] Wong, A.K. & TenBroek, M. PC-based GIS framework for the management and analysis of hazardous waste site remediation projects. *Annual Conference on the Urban and Regional Information Systems Association*, Boston, Massachusetts; Published by Washington, DC, Urban and Regional Information Systems Association, Vol 2, 5, pp. 358–366, August, 1989. OCLC Number: 502622293.

[12] Zhou, G. & Kafatos, M. Future intelligent Earth observing satellites. *Pecora 15/Land Satellite information IV/15 PRS Commission 1/FIEOS 2002 Conference Proceedings*, 2002. Denver, CO, USA, Conference Proceedings of the International Society for Photogrammetry and Remote Sensing (ISPRS).

[13] Levin, N. *Fundamentals of Remote Sensing*, Unpublished Book for Maritime Academy, Trieste, Italy 1999, available at https://www.pdfdrive.net/fundamentals-of-remote-sensing-e11435669.html. (accessed 12 September 2016).

[14] Oyinloye, R.O., *Image Interpretation (Information Extraction from Aerial and Satellite Imageries)*, Unpublished Student manual of the Regional Centre for Training in Aerospace surveys (RECTAS), Obafemi Awolowo University Campus: Ile-Ife, 2009.

[15] Devyani, B. & Neelesh, G., GPS based automatic vehicle tracking using RFID. *International Journal of Engineering and Innovative Technology (IJEIT)*, **1**(**1**), pp. 31–35, 2012. ISSN: 2277-3754.

[16] Arebey, M., Hannan, M.A., Basri, H., Begum, R.A. & Abdullah, H., Integrated technologies for solid waste bin monitoring system. *Environmental Monitoring and Assessment*, **177**(**1**), pp. 399–408, 2011. DOI: 10.1007/s10661-010-1642-x.

[17] Kumar, S. & Kevin, B., The evolution of Global Positioning System (GPS) technology. *Journal of Science Education and Technology*, **11**, pp. 59–80, 2002. ISSN: 1059-0145.

[18] UCT (Usha Communications Technology), General Packet Radio Service (GPRS), A White Paper, 26 June 2000.

[19] Kia, Q., Jianping, X., Grang, C., Linjian, W. & Jie, Q., The design of intelligent bus monitoring and station reporting system. *IEEE International Conference on Automation and Logistics*, pp. 209–216, 2008. Qingdao, China. DOI: 10.1109/ICAL.2008.4636656.

[20] Abiona, O.J., *Adoption Possibilities and Use of RFID in Nigeria Health Sector*, B.Sc thesis Department of Business Information Technology, Lahti University of Applied Science: Lahti, 2012.

[21] Garfinkel, S. & Rosenberg, B., *RFID Application, Security, and Privacy*, Boston, Mass.; London: Addison-Wesley, 2005. ISBN: 0-321-29096-8, 2005.

[22] Srivastava, L., *RFID: Technology, Applications and Policy Implications, Spectrum Management Workshop, International Telecommunication Union*, available at http://www.itu.int/osg/spu/presentations/2005/srivastavaRFID2005.pdf (accessed 18 September 2016), 2005.

[23] Aderoju, O.M., Dias, A.G. & Guimarães, R., Geospatial technology as a tool in municipal solid waste management and monitoring in Nigeria. *Journal of Solid Waste Technology and Management*, **42**(**1**), pp. 644–655, 2016. Widener University School of Engineering, Chester, Pennsylvania, USA. ISSN: 1088-1697.

[24] Aquilina, C.A., Everette, S.E., Jouse, C.A., & Smiley, L.J., Low-level waste management database system. *Transactions of American Nuclear Society*, **41**, p. 86, 1982, available at http://www.ans.org/pubs/journals/nse/.

[25] Chang, N.B. & Pires, A., *Sustainable Solid Waste management: A Systems Engineering Approach, The Institute of Electrical and Electronic Inc*, John Wiley and Sons Inc./ IEEE, New York, USA; 920 pp., 2015. ISBN: 978-1-118-45691.

[26] Wyatt, J., *Maximizing Waste Management Efficiency through the Use of RFID*, available at http://www.rfidproductnews.com/issues/fall2008/waste.php, 2008 (assessed 20 July 2015).

[27] Wyatt, J. & Gouldbourne, J.A., *RFID Technology Selection for Waste Management Applications*. Texas Instruments Application Report; SCBA026, 2009, available at https://www.rfidjournal.com/whitepaper/download/275 (accessed 19 September 2016).