Review

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Plastic waste as a significant threat to environment – a systematic literature review

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Abstract

Context: Materials which exceed the balance of their production and destruction lead to the deterioration in the environment. Plastic is one such material which poses a big threat to the environment. A huge amount of plastic is produced and dumped into the environment which does not readily degrade naturally. In this paper, we address the organization of a large body of literature published on the management of waste plastics being the most challenging issue of the modern world.
Objectives: To address the issue of the management of waste plastics, there is a dire need to organize the literature published in this field. This paper presents a systematic literature review on plastic waste, its fate and biodegradation in the environment. The objective is to make conclusions on possible practical techniques to lessen the effects of plastic waste on the environment.
Method: A systematic literature review protocol was followed for conducting the present study [Kitchenham B, Brereton OP, Budgen D, Turner M, Bailey J, Linkman S. Systematic literature reviews in software engineering – A systematic literature review. Inf Softw Technol 2009;51(1):7–15.]. A predefined set of book sections, conference proceedings and high-quality journal publications during the years 1999 to September 2017 were used for data collection.
Results: One hundred and fifty-three primary studies are selected, based on predefined exclusion, inclusion and quality criteria. These studies will help to identify the fate of different waste plastics, their impact and management and the disposal techniques frequently used. The study also identifies a number of significant techniques and measures for the conversion of waste plastic materials into useful products.
Conclusion: Five fundamental strategies are used for the handling of plastic waste. These strategies include: recycling, depositing in landfill, incineration, microbial degradation and conversion into useful materials. All of these methods have their own limitations, due to which there is need to explore the studies for optimum solutions of the management of plastics waste.

Keywords: conversion; degradation; fate; impacts; management; plastic waste.

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Introduction

Plastic is a synthetic material which is widely used in a variety of different sectors. The word plastic is derived from a Greek word *plastikos* which means to be formed in different shapes (1). Plastic is a synthetic polymeric material with a high molecular weight (2), made from a wide range of organic compounds such as ethylene, vinyl chloride, vinyl acetate, vinyl alcohol and so on. Plastics can be molded into different shapes in its soft form and then it sets into a rigid or slightly elastic form. The basic precursors for the production of plastic materials are obtained from natural gas, coal and petroleum (3). Owing to the unique properties of plastics such as: light weight, low cost, durability, robust, strength, corrosion resistance, thermal and electrical insulation, versatile fabrication and design capabilities which can easily be molded into assorted products; plastic finds a wide range of applications (4). Most of the common applications of plastic include packaging, construction, electronics, electrical goods, furniture, automobiles, households, agriculture and other industrial usages (3). Their advantageous effect on society is unquestionable and plastics can be judged extreme importance by their applications in public health and medical uses. Being light weight and biocompatible, plastic is a perfect material for once-usage disposable devices, which currently include 85% of medical equipment (5), including intravenous bags, disposable syringes, sterile packaging for tissue engineering as well as in medical instruments, joint replacements, and many more (6).

As an result of their extensive applications, the production of plastics has been expanded, particularly over the past 60 years. The plastics business has grown impressively since the innovation of new technologies for the production of polymers from a wide variety of petrochemicals. Plastics have significant advantages over other materials (i.e. wood, ceramics, metals, etc.) such as their lower cost, durability and low weight (7), therefore their extensive applications and disposal leads to numerous environmental issues. Approximately 4% of the world's oil and gas produced is utilized as feedstock for plastics and about 3–4% is used in their manufacturing to provide energy (8). Despite having a number of benefits for human society, the plastics' materials contribute an assortment of demerits (9). Plastics contains various types of toxic components as additive, such as di-(2-ethylhexyl)phthalate (DEHP), bisphenol A (BPA), poly halogenated compounds and heavy metals which pose a potential health risk to the humans (10). Most of these additives are shown to be easily immobilized in the environment and this leads to harmful effects on human health like the disruption of the endocrine system (6). As plastics are not readily degraded and are very stable in the ambient environment, their disposal in the environment has currently created a considerable pollution problem (11).

Presently, the management of waste plastics is a major environmental issue. Several strategies have been adopted for the handling of plastic waste which includes: recycling, depositing in landfill, incineration, microbial degradation and conversion into useful materials. Recycling of plastic is a costly and tedious practice because of the collection, sorting and processing of waste plastics, beside the low quality of the recycled goods limits their wide application (8). Land filling occupies productive land and renders it unfit for other applications. Incineration and pyrolytic conversion of waste plastic results in the emission of hazardous atmospheric pollutants including the polyaromatic hydrocarbons, CO_2 (a greenhouse gas) and persistent organic pollutants like dioxins (6). A major part of the solid waste dumped into the environment consists of waste plastics, and its quantity is rapidly increasing with increasing widespread use of plastics. This paper focuses on providing the reader with the necessary details (related to the research questions) about waste plastic and will contribute towards developing a thorough understanding about the use and applications of a particular waste plastic management technique.

The following are the main contributions of this research paper:

– The research gives extensive insights about available waste plastics' management techniques.
– The paper outlines distinctive applications and uses of plastics for different purposes.
– The primary concentration of the research is to recognize which methods are utilized for the management of waste plastics management.
– The research also aims to identify available techniques used for converting waste plastics into useful products.

The rest of the paper is organized as follows; the section Research process give details of the research process used which is based on the guidelines for conducting systematic literature reviews (SLRs) (12). The results and discussions along with the answers to the research questions are briefly discussed in the Research questions section. The limitations of the present research work are given in the Limitations section. The paper concludes in the Conclusions section.

Research process

A great deal of research in various areas has been discovered through the SLR (13) and confirmed as an approach to examine and analyze issues objectively. The motivation behind the SLR is to methodically collect, interpret, evaluate and identify all the current examinations applicable to a predefined look into investigations for providing extensive information to the research groups (13). As indicated by the protocol adopted for the SLR (12) the three main phases are reporting, conducting the SLR and protocol development. The following sub-sections briefly discuss the protocol followed in the data collection process and conducting the SLR.

Research definition

The objective of this research was to have a deep understanding about available waste plastic management techniques and their uses, especially when converting them

Figure 1: Principle steps involved in the SLR processes.

into useful products. The SLR gives a concise analysis of the techniques available for the management of waste plastics with a specific goal to encourage the comprehension for various procedures utilized as a part of industry and research. The review also focuses on the possible applications of plastics and different issues associated with waste plastics.

A series of steps were used to perform the SLR and to make the process more efficient and understandable. This formal process plays a fundamental role in the acceptance of the essence of the conclusion presented by the study. Figure 1 gives a preview of the steps followed in the process of conducting the SLR (14).

Research plan and method

Figure 2 introduces the protocol designed and the process for conducting the SLR. The protocol was developed by Barbara et al. (12). This study was conducted to help a PhD research project for planning to make comprehensive derivations on available techniques to lessen the effects of plastic waste on the environment. The writing audit was arranged and followed as indicated by the designed protocol.

The following sections elaborate the protocol and the data collected by following the protocol.

Research questions

The research questions (RQ) addressed through this literature review are given below:

RQ1. What are the different uses and applications of plastics?

RQ2. What are the different environmental impacts of waste plastics? What are the different types of techniques available for the management of waste plastics?

RQ3. How the degradation of waste plastics take place in the environment? Which management technique is typically used for handling waste plastics?

RQ4. Is it possible to convert waste plastics into useful products?

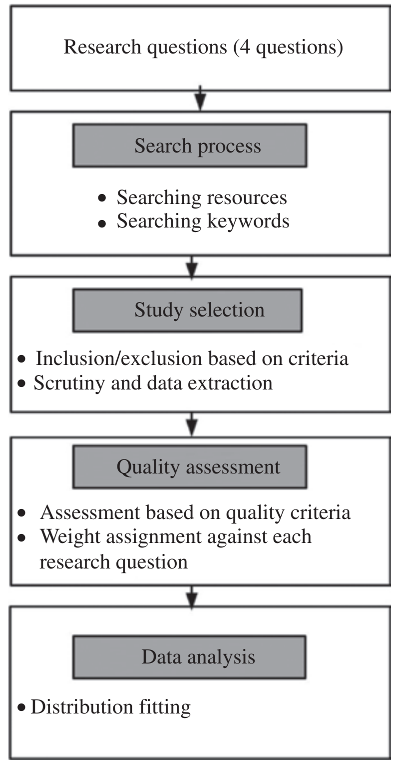

Figure 2: Protocol developed and followed in the proposed study for conducting SLR.

Search process

For a methodical writing survey, arranging and directing a formal pursuit process is extremely vital. A sorted-out pursuit process makes it conceivable to exhume all the accessible advanced assets keeping in mind the goal to locate all related accessible writing that meet the required criteria. For this investigation an inquiry has been led to discovering important papers located in meeting procedures, books, journals, conferences and other online materials. In the present study several keywords related to the design and estimation of waste plastics based on the research questions (provided in the Research questions section) were searched in the digital libraries mentioned below. The search process is shown in Figure 3.

The Following libraries were searched for the studies related to the research (Figure 4):

a. Web of Science (webofknowledge.com/)
b. ScienceDirect (http://www.sciencedirect.com)
c. SpringerLink (http://www.springer.com/in/)
d. Taylor and Francis Online (http://www.tandfonline.com/)
e. Wiley Online Library (http://onlinelibrary.wiley.com/)

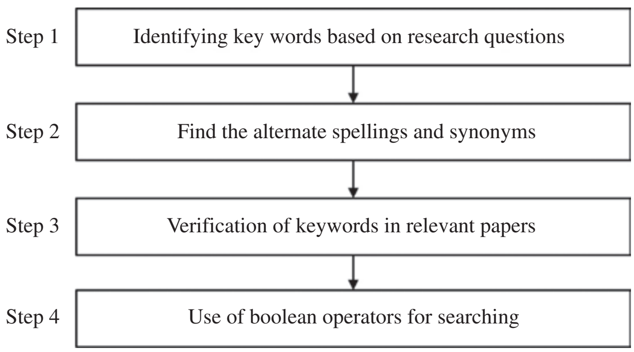

Figure 3: Steps of the search process of keywords in the proposed study.

f. US National Library of Medicine National Institute of Health (PubMed) (https://www.ncbi.nlm.nih.gov/pubmed/)
g. American Chemical Society (ACS Publications) (http://pubs.acs.org/)

The keywords for the search were decided by the authors. These keywords include "waste plastic fate", "waste plastic impacts", "waste plastic conversion", "waste plastic management" and "waste plastic degradation". Most of the papers were found by searching using only the keyword "plastics". Other keyword strings created using terms "OR" and "AND" were also used to make sure that no relevant publication was missed out (14).

The proposed study and search process were for the years 1999 to September 2017. The search exposed a bulk of literature in the form of journal publications, conferences and other published material including books, magazines, etc.. All of the included digital repositories were manually searched using predefined keywords. The necessary bibliographic information and citations were carefully handled using Endnote software (15). It was decided to maintain a separate Endnote library for each digital source in the first search process, and then after filtering and excluding the duplications all of the libraries were merged into a single file library. This bibliographic information contains all the necessary information including author(s) name, title of article, journal/conference name, year of publishing and number of pages of the article.

After filtering, a list containing a total of 202 references were managed in the file of the Endnote library. The details of the overall search process in the specified digital libraries are outlined in Figure 5. A total of 4457 titles were found. The duplications in these publications (more than one version of the paper) were removed. After that the papers were checked manually and then filtered by titles, filtered by abstracts and finally filtered by the contents. The initial selection filtering process was performed manually by titles and a total of 1528 articles were obtained. These 1528 articles were then filtered manually by abstract and a total of 380 articles were obtained. In the last step these articles were again filtered by contents and finally a total of 153 articles were selected. These articles were then used in the literature review based on the research questions defined and the details of these papers are shown in Figure 5.

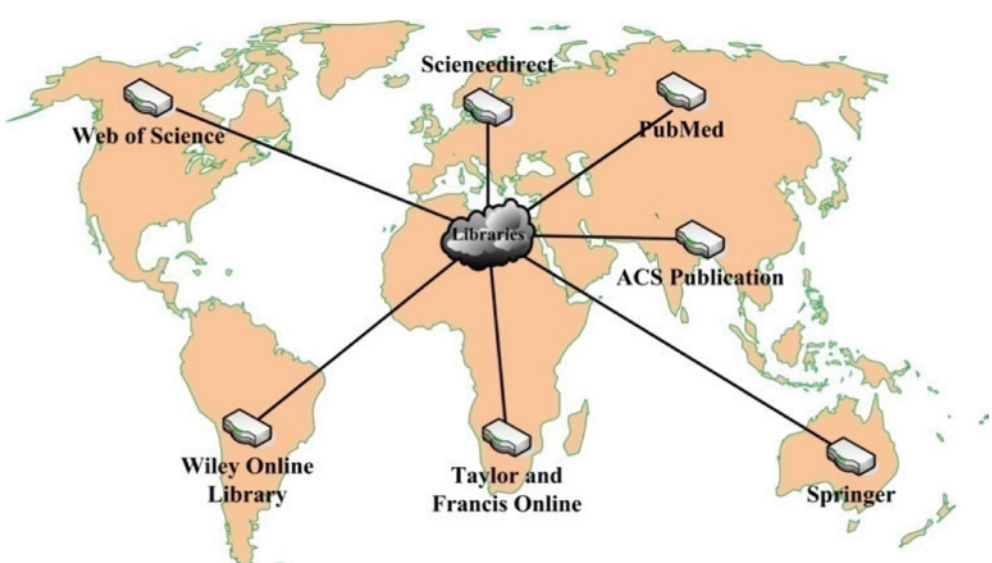

Figure 4: Libraries searched for the studies related to the proposed research.

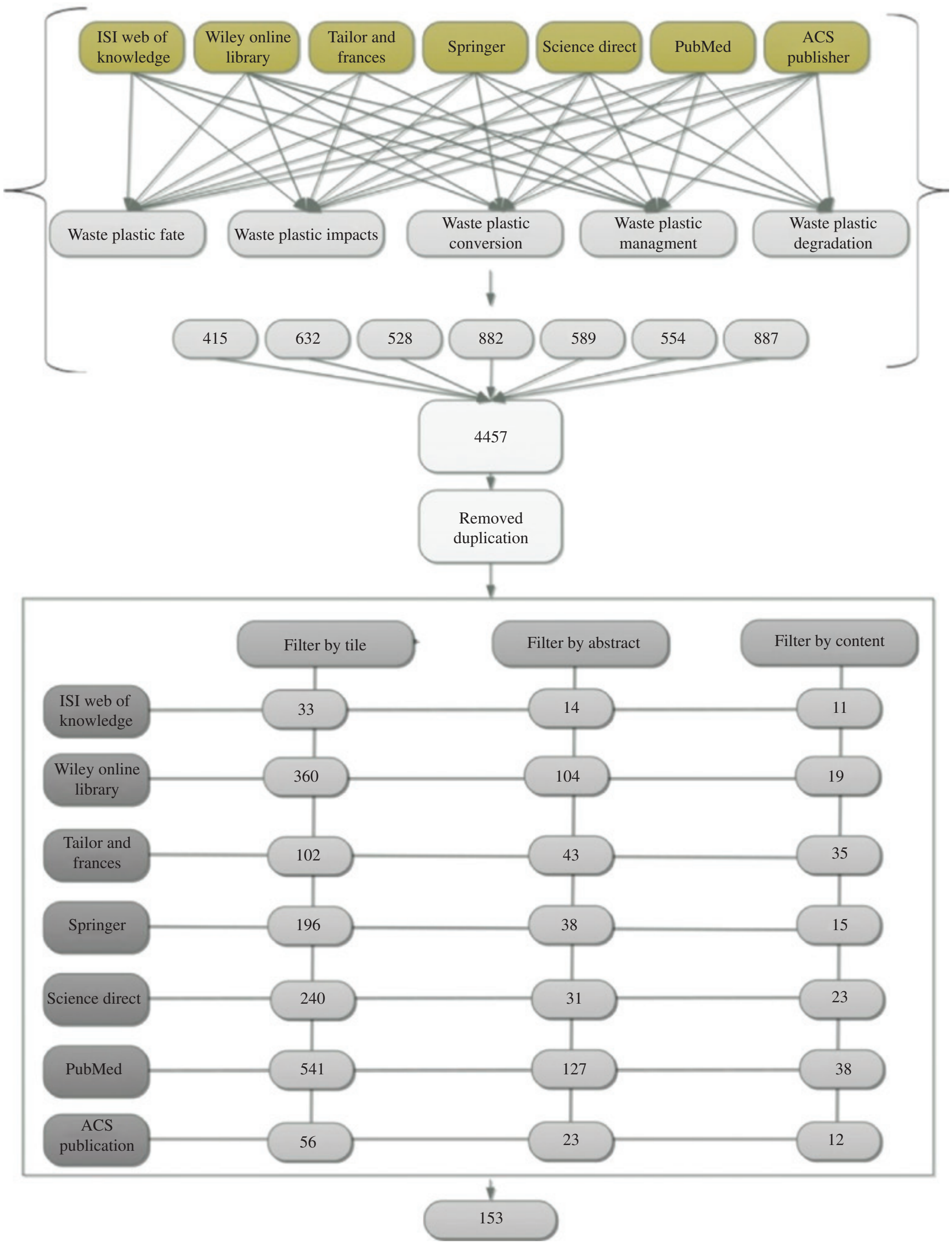

Figure 5: Search process based on keywords for articles in relevant libraries and their filtering.

Study selection

After obtaining a collection of papers through the search process it was considered necessary to further filter the papers according to the predefined inclusion and exclusion criteria, to be able to have only those materials which are exactly focused on the research questions to be answered. It was decided to include the literature sources in the review according to the following criteria:

– These sources clearly discuss the use and application of plastic wastes.
– These studies provide clear descriptions and context which is required to answer the defined questions.

The papers which referenced waste plastic only in the literature review section and were not actually providing any notable material in this context were excluded.

Study selection process

The study selection based on some defined criteria is a very complex process and consists of several steps. For this reason, the study selection was carried out in two stages. In the first stage the titles of the articles were checked manually according to defined inclusion and exclusion criteria and the irrelevant papers were excluded. In the second stage of the search process the articles were filtered by checking the abstract of the papers and as a result some papers were excluded as these were not relevant to the present research. And in the final stage the papers were filtered by checking their contents. Table 1 shows the papers selected after a three-stage filtering process. After that duplications in all individual libraries were excluded. Table 2 shows the final selected papers after excluding duplications and the filtering process. This process resulted in retrieving only the most relevant papers, explicitly passed through the defined inclusion and exclusion criteria (169).

Final selected papers along with the titles and citations are given in Table 2.

Table 3 shows the publication types which are in the form of book sections, conference papers and journal articles.

The graphical representation of year wise publications is shown in Table 4. The time series data was tested with 95% confidence levels. When the p value was less than the significance level (0.05), the null hypothesis would reject it and this meant that a trend (change) existed. Analysis revealed that there is a more significant trend detected in the selected papers having a p-value 0.0001, showing the best analysis results with a standard deviation 13.54. This analysis shows the research in the area of waste plastics in a given range of years. According to the trend detection of the studies, there is a clear increase in research and publications after 2014, marking the increasing importance and application of waste plastics. Figure 6 represents this analysis for the selected papers in the range of the given years.

Quality assessment

After the literature selection process, the quality assessment of the selected papers was performed. In the defined protocol each of the paper was assessed against the quality criteria. All of the research papers were reviewed and the quality of the selected papers with respect to each research question was assessed. The following is the quality criteria (QR) defined against each research question.

QR1. The paper emphasizes different uses and applications of plastics.

QR2. The paper provides in depth detail of the environmental impacts and techniques used in the management of waste plastic.

QR3. The paper provides a clear description of how the degradation of waste plastics take place in the environment.

QR4. The paper clearly states process/technique (in general or for a specific waste plastic conversion into a useful product).

Each of the selected papers was read and analyzed manually by the authors. The separate quality criteria of each research question helped the authors to objectively assess the quality of the answers to the research questions provided in each of the selected papers. To quantify this assessment for further analysis, each paper was assigned weights against each research question based on the assessment of quality against the above-mentioned criteria. The weights were assigned in the following manner.

- 0 when the paper does not provide any information regarding the defined question.
- 0.5 for a question partially but satisfactorily explained in a paper.
- 1 for a question fully explained in the paper.

Table 1: Data sources, their search strategy and filtering of papers

Sources	Total result found (keyword-based search in digital libraries)	First stage selection (title-based filtering)	Second stage selection (Abstract and conclusions-based filtering)	Final selection
ISI Web of Science	415	33	14	11
Science Direct	589	240	31	23
Springer	882	196	38	15
Taylor and Francis	528	102	43	35
Wiley Online Library	632	360	104	19
PubMed	554	541	127	38
ACS Publication	857	56	23	12

Table 2: Details of selected papers after final selection.

Ref. no.	Paper title	Year	Type of publication
(16)	Pyrolysis-catalysis of waste plastic using a nickel-stainless-steel mesh catalyst for high-value carbon products	2017	Journal
(17)	Plastic waste as strength modifiers in asphalt for a sustainable environment	2017	Journal
(18)	Performance of recycled plastic waste modified asphalt binder in Saudi Arabia	2017	Journal
(19)	Production use and fate of all plastics ever made	2017	Journal
(20)	Composite fibers from recycled plastics using melt centrifugal spinning	2017	Journal
(21)	Mechanical and chemical recycling of solid plastic waste	2017	Journal
(22)	Plastic waste problem and education for plastic waste management	2017	Book section
(23)	Energy recovery from pyrolysis of plastic waste: study on non-recycled plastics (NRP) data as the real measure of plastic waste	2017	Journal
(24)	A review on conversion techniques of liquid fuel from waste plastic materials	2017	Journal
(25)	Recycling of plastic waste: screening for brominated flame retardants (BFRs)	2017	Journal
(26)	Microbial enzymatic degradation of biodegradable plastics	2017	Journal
(27)	An experimental study on thermo-catalytic pyrolysis of plastic waste using a continuous pyrolyzer	2017	Journal
(28)	Plastic debris in the Mediterranean Sea: types, occurrence and distribution along Adriatic shorelines	2017	Journal
(29)	Degradation of plastics in the marine environment	2017	Book section
(30)	Plastic waste to liquid oil through catalytic pyrolysis using natural and synthetic zeolite catalysts	2017	Journal
(31)	Plastics in the North Atlantic garbage patch: a boat-microbe for hitchhikers and plastic degraders	2017	Journal
(32)	Biodegradation of polyethylene microplastics by the marine fungus *Zalerion maritimum*	2017	Journal
(33)	What is the right level of recycling of plastic waste?	2017	Journal
(34)	The effect of recycled plastics and cooking oil on coke quality	2017	Journal
(35)	Biodegradation of bioplastics in natural environments	2017	Journal
(36)	Degradation and metabolism of synthetic plastics and associated products by *Pseudomonas* sp.: capabilities and challenges	2017	Journal
(37)	Management of plastic wastes at Brazilian ports and diagnosis of their generation	2017	Journal
(38)	To what extent are microplastics from the open ocean weathered?	2017	Journal
(39)	Consumer attitudes on the use of plastic and cloth bags	2017	Journal
(40)	A review on thermal and catalytic pyrolysis of plastic solid waste (PSW)	2017	Journal
(41)	Advanced chemical characterization of pyrolysis oils from landfill waste, recycled plastics, and forestry residue	2017	Journal
(42)	Learning about the types of plastic wastes: effectiveness of inquiry learning strategies	2016	Journal
(43)	Research and development of a new waste collection bin to facilitate education in plastic recycling	2016	Journal
(44)	Methane generation from anaerobic digestion of biodegradable plastics – a review	2016	Journal
(45)	Recycling of polyethylene terephthalate (PET) plastic bottle wastes in bituminous asphaltic concrete	2016	Journal
(46)	Plastic microfiber ingestion by deep-sea organisms	2016	Journal
(47)	Plastics and microplastics on recreational beaches in Punta del Este (Uruguay): unseen critical residents?	2016	Journal
(48)	The plastics revolution: how chemists are pushing polymers to new limits	2016	Journal
(49)	Biodegradable packaging materials conception based on starch and polylactic acid (PLA) reinforced with cellulose	2016	Journal
(50)	Lab-scale thermal analysis of electronic waste plastics	2016	Journal
(51)	To be, or not to be biodegradable… that is the question for the bio-based plastics	2016	Journal
(52)	Mapping of agriculture plastic waste	2016	Conference
(53)	Review of the partitioning of chemicals into different plastics: consequences for the risk assessment of marine plastic debris	2016	Journal
(54)	Use of different forms of waste plastic in concrete – a review	2016	Journal
(55)	Thermoelectric plastics: from design to synthesis, processing and structure-property relationships	2016	Journal

Table 2 (continued)

Ref. no.	Paper title	Year	Type of publication
(56)	(Nano)plastics in the environment: sources, fates and effects	2016	Journal
(57)	The energy and value-added products from pyrolysis of waste plastics	2016	Book section
(58)	A review on pyrolysis of plastic wastes	2016	Journal
(59)	Recycling of plastic waste: presence of phthalates in plastics from households and industry	2016	Journal
(60)	An overview on the use of waste plastic bottles and fly ash in civil engineering applications	2016	Conference
(61)	Investigation on an innovative technology for wet separation of plastic wastes	2016	Journal
(62)	Waste-to-energy: dehalogenation of plastic-containing wastes	2016	Journal
(63)	Thermal degradation of PVC: a review	2016	Journal
(64)	Hybrid selective surface hydrophilization and froth flotation separation of hazardous chlorinated plastics from E-waste with novel nanoscale metallic calcium composite	2016	Journal
(65)	Toxic pollutants from plastic waste — a review	2016	Conference
(66)	A study on synthesis of energy fuel from waste plastic and assessment of its potential as an alternative fuel for diesel engines	2016	Journal
(67)	Use of plastic waste as a fuel in the co-pyrolysis of biomass Part III: optimization of the co-pyrolysis process	2015	Journal
(68)	Synthesis and characterization of lubricant additives from waste plastic	2015	Journal
(69)	Technical properties of regenerated plastic material bars produced from recycled agricultural plastic film	2015	Journal
(70)	Managing plastic waste	2015	Book section
(71)	Contribution of plastic waste recovery to greenhouse gas (GHG) savings in Spain	2015	Journal
(72)	A new classification scheme of plastic wastes based upon recycling labels	2015	Journal
(73)	Recycling of waste plastics	2015	Book section
(74)	Use of waste plastics in coke oven: a review	2015	Journal
(75)	Influence of waste plastic utilization in blast furnace on heavy metal emissions	2015	Journal
(76)	Reusing waste plastic bottles as an alternative sustainable building material	2015	Journal
(77)	Thermal utilization (treatment) of plastic waste	2015	Journal
(78)	Environmental evaluation of plastic waste management scenarios	2014	Journal
(79)	Behavior of plastic waste fiber-reinforced industrial wastes in pavement applications	2014	Journal
(80)	Melt recycling of poly(lactic acid) plastic wastes to produce biodegradable fibers	2014	Journal
(81)	Processing real-world waste plastics by pyrolysis-reforming for hydrogen and high-value carbon nanotubes	2014	Journal
(82)	Temperature effects on the yield of gaseous olefins from waste polyethylene via flash pyrolysis	2014	Journal
(83)	Recycling of polymers: a review	2014	Journal
(84)	Analysis and thermo-mechanical characterization of mixed plastic wastes	2013	Journal
(85)	Use of recycled plastics in wood plastic composites – a review	2013	Journal
(86)	The incidence of plastic ingestion by fishes: from the prey's perspective	2013	Journal
(87)	Recycling of waste from polymer materials: an overview of the recent works	2013	Journal
(88)	Energy recovery from co-gasification of waste polyethylene and polyethylene terephthalate blends	2013	Journal
(89)	Emerging trends in informal sector recycling in developing and transition countries	2013	Journal
(90)	Laboratory test methods to determine the degradation of plastics in marine environmental conditions	2012	Journal
(91)	Green polymer chemistry and bio-based plastics: dreams and reality	2012	Journal
(92)	Pyrolysis of waste plastic crusts of televisions	2012	Journal
(93)	Pyrolysis and gasification of landfilled plastic wastes with Ni – Mg – La/Al2O3 catalyst	2012	Journal
(94)	A review – synthesis of carbon nanotubes from plastic wastes	2012	Journal

Table 2 (continued)

Ref. no.	Paper title	Year	Type of publication
(95)	Characteristics of starch-filled LLDPE plastic processed from plastic waste	2012	Journal
(96)	Converting waste plastic to hydrocarbon fuel materials	2011	Journal
(97)	Catalytic pyrolysis of municipal plastic waste to fuel with nickel-loaded silica-alumina catalysts	2011	Journal
(98)	The life cycles of plastics	2011	Book section
(99)	Environmental impact of pyrolysis of mixed WEEE plastics part 2: life cycle assessment	2011	Journal
(100)	Using waste plastic bottles as additive for stone mastic asphalt	2011	Journal
(101)	Determination of bisphenol A, 4-n-nonylphenol, and 4-tert-octylphenol by temperature-controlled ionic liquid dispersive liquid-phase microextraction combined with high performance liquid chromatography-fluorescence detector	2011	Journal
(102)	Leaching behavior of bisphenol A from municipal solid waste under landfill environment	2011	Journal
(103)	Hydrogen sulfide production by sulfate-reducing bacteria utilizing additives eluted from plastic resins	2011	Journal
(104)	Low temperature conversion of plastic waste into light hydrocarbons	2010	Journal
(105)	Plastic bags and environmental pollution	2010	Journal
(106)	Degradation of plastic carrier bags in the marine environment	2010	Journal
(107)	Kinetic study of high density polyethylene (HDPE) pyrolysis	2010	Journal
(108)	Production of steam cracking feedstocks by mild cracking of plastic wastes	2010	Journal
(109)	Physical and mechanical properties of mortars containing PET and PC waste aggregates	2010	Journal
(110)	Ubiquity of bisphenol A in the atmosphere	2010	Journal
(111)	Perfluorinated compounds, polychlorinated biphenyls, and organochlorine pesticide contamination in composite food samples from Dallas, Texas, USA	2010	Journal
(112)	Induction of biodegradability in the plastic waste through graft copolymerization	2009	Journal
(113)	Energy recovery from waste plastics by using blends of biodiesel and polystyrene in diesel engines	2009	Journal
(114)	Incineration and co-combustion of waste: accounting of greenhouse gases and global warming contributions	2009	Journal
(115)	Catalytic transformation of waste polymers to fuel oil	2009	Journal
(116)	Conversion of hazardous plastic wastes into useful chemical products	2009	Journal
(117)	CO_2 reduction potentials by utilizing waste plastics in steel works	2009	Journal
(118)	Gasification of waste plastics by steam reforming in a fluidized bed	2009	Journal
(119)	Identification of different type of polymers in plastics waste	2008	Journal
(120)	Quality concepts for the improved use of recycled polymeric materials: a review	2008	Journal
(121)	Fuels from waste plastics by thermal and catalytic processes: a review	2008	Journal
(122)	Recycled/waste plastic	2008	Book section
(123)	Persistent free-radicals, heavy metals and PAHs generated in particulate soot emissions and residue ash from controlled combustion of common types of plastics	2008	Journal
(124)	Thermal degradation analysis of biodegradable plastics from urea-modified soy protein isolate	2007	Journal
(125)	Food packaging – roles, materials, and environmental issues	2007	Journal
(126)	Compostability of bioplastic packaging materials: an overview	2007	Journal
(127)	Biodegradation of compostable plastics in green yard-waste compost environment	2007	Journal
(128)	Development of triboelectrostaic separation technique for recycling of final waste plastic	2006	Journal
(129)	Catalytic upgrading of plastic wastes	2006	Book section
(130)	Separation of individual plastics from mixed plastic waste by gravity separation processes	2006	Journal
(131)	Low-cost processing of plastic waste composites	2006	Journal
(132)	Fluidized bed pyrolysis of plastic wastes	2006	Book section

Table 2 (continued)

Ref. no.	Paper title	Year	Type of publication
(133)	Novel process for recycling waste plastics to fuel gas using a moving-bed reactor	2006	Journal
(134)	Production of hydrogen from plastics by pyrolysis and catalytic steam reform	2006	Journal
(135)	Infrared spectroscopy in analysis of plastics recycling	2006	Book section
(136)	A review of plastic waste biodegradation	2005	Journal
(137)	Polymers, polymer recycling and sustainability	2005	Book section
(138)	Plastics in the marine environment: the dark side of a modern gift	2005	Book section
(139)	Thermal destruction of wastes and plastics	2005	Book section
(140)	Solid waste management and plastic recycling in Austria and Europe	2004	Journal
(141)	Development of waste plastics-based RDF and its combustion properties	2004	Journal
(142)	Laboratory investigation of the products of the incomplete combustion of waste plastics and techniques for their minimization	2004	Journal
(143)	Utilization of red mud as catalyst in conversion of waste oil and waste plastics to fuel	2004	Journal
(144)	Study on the conversion technology of waste polyethylene plastic to polyethylene wax	2003	Journal
(145)	Plastics in packaging	2003	Book section
(146)	Plastics recycling	2003	Book section
(147)	Pyrolysis of composite plastic waste	2003	Journal
(148)	Pyrolysis of polypropylene in a nitrogen plasma reactor	2003	Journal
(149)	Development of a catalytic dehalogenation (Cl, Br) process for municipal waste plastic-derived oil	2003	Journal
(150)	Comparison of the recyclability of flame-retarded plastics	2003	Journal
(151)	Thermal cracking of oils from waste plastics	2003	Journal
(152)	An environmental primer	2003	Book section
(153)	Polythene and plastic-degrading microbes in an Indian mangrove soil	2003	Journal
(154)	Usage of recycled plastic bottles in roadside safety devices	2002	Journal
(155)	Hydrothermal dechlorination and denitrogenation of municipal-waste-plastics-derived fuel oil under sub- and supercritical conditions	2002	Journal
(156)	The pollution of the marine environment by plastic debris: a review	2002	Journal
(157)	Recycling and trade in waste plastics in China	2001	Book section
(158)	Evaluation of material recycling for plastics: environmental aspects	2001	Journal
(159)	Plastic resin pellets as a transport medium for toxic chemicals in the marine environment	2001	Journal
(160)	Biodegradation of polyesters containing aromatic constituents	2001	Journal
(161)	Biodegradation of plastics	2001	Journal
(162)	Biodegradable plastics from cellulose	2000	Journal
(163)	Some new directions of development of polymers and plastics	2000	Journal
(164)	Thermal treatment of electrical and electronic waste plastics	2000	Journal
(165)	Plastics, recycling	2000	Book section
(166)	Plastics, rubbers, and textiles in municipal solid waste in the United States	1999	Journal
(167)	Plastic man and the state of nature	1999	Journal
(168)	Effects of soil temperature and anaerobiosis on degradation of biodegradable plastics in soil and their degrading microorganisms	1999	Journal

Table 3: Publications types (book section, conference papers, and journal papers).

Book section	(22, 29, 57, 70, 73, 98, 122, 129, 132, 135, 137–139, 145, 146, 152, 157, 165)
Conference papers	(52, 60, 65)
Journal papers	(16–21, 23–28, 30–51, 53–56, 58, 59, 61–69, 71, 72, 74–121, 123–128, 130, 131, 133, 134, 136, 140–144, 147–151, 153–156, 158–164, 166–168)

Table 4: Year-wise breakup of selected publications (1999–2017).

Year	Publications
2017	(16–41)
2016	(42–59, 61–64, 66)
2015	(67–77)
2014	(78–83)
2013	(84–89)
2012	(90–95)
2011	(96–103)
2010	(104–111)
2009	(112–118)
2008	(119–123)
2007	(124–127)
2006	(128–135)
2005	(136–139)
2004	(140–143)
2003	(144–153)
2002	(154–156)
2001	(158–161)
2000	(162–165)
1999	(166–168)

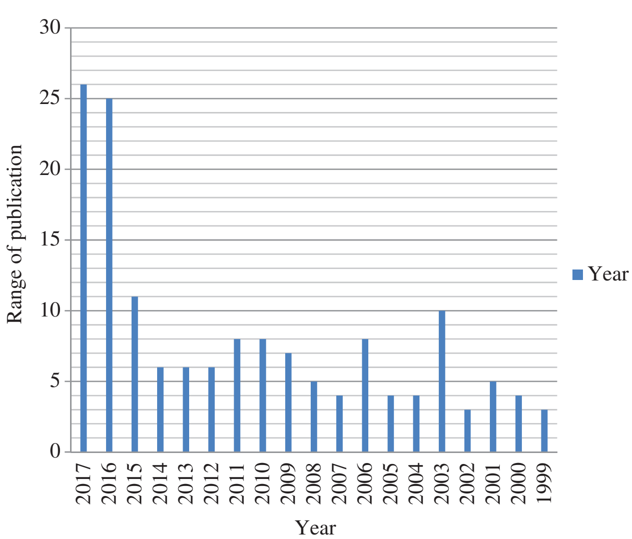

Figure 6: Trend of waste plastic research (publications) from 1999 to 2017.

The total score shows the relevancy of each paper with our research. The percentage of each of the paper is taken out of the total papers selected (153 papers). Table 5 shows the quality assessment of the selected papers for each year (average).

Table 5: Quality assessment of the selected papers for each year (average).

S. no.	Year	RQ 1	RQ 2	RQ 3	RQ 4	Total score (out of 4)	%age out of 4
1	2017	0.15	0.40	0.31	0.29	1.15	28.84
2	2016	0.04	0.44	0.04	0.44	0.96	25.00
3	2015	0.04	0.36	0.09	0.45	0.95	23.86
4	2014	0.00	0.50	0.00	0.75	1.25	31.25
5	2013	0.00	0.50	0.00	0.33	0.83	20.83
6	2012	0.00	0.25	0.17	0.67	1.08	27.08
7	2011	0.00	0.56	0.00	0.56	1.13	28.13
8	2010	0.13	0.44	0.19	0.44	1.19	29.69
9	2009	0.14	0.36	0.14	0.57	1.21	30.36
10	2008	0.20	0.50	0.20	0.40	1.30	32.50
11	2007	0.25	0.50	0.50	0.00	1.25	31.25
12	2006	0.00	0.31	0.31	0.44	1.06	26.56
13	2005	0.00	0.63	0.25	0.00	0.88	21.88
14	2004	0.00	0.13	0.00	0.75	0.88	21.88
15	2003	0.10	0.40	0.20	0.35	1.05	26.25
16	2002	0.50	1.00	0.00	0.00	1.50	37.50
17	2001	0.00	0.30	0.50	0.00	0.80	20.00
18	2000	0.50	0.50	0.50	0.00	1.50	37.50
19	1999	0.33	0.50	0.33	0.00	1.17	29.17

Data extraction

The required data related to the research questions were extracted from the papers after the quality assessment process (Table 5).

The important data extracted is presented in the form of different tables, briefly mentioned as follows;

1. Table 2 identifies all finally selected papers, along with their titles, citation, paper type and year of publishing.
2. Table 3 publication types which are in the form of book section, conference papers, and journal papers.
3. Table 4 presents year wise distribution of the selected papers from the year 1999 to 2017.
4. Table 5 presents the quality assessment of the selected papers (average).
5. Table 6 identifies different types of plastic materials found in the environment.

Table 6: Plastic types commonly found in the natural environment (10, 170).

Type	Health effects	Application/use
Polyethylene terephthalate (PET)	Potential human carcinogen	Packaging foods and beverages
Polyester (PES)	Cause acute skin rashes, respiratory-tract and eye irritation	Textiles, fibers
Polypropylene (PP)		Jugs, tanks, plastic pipe pressure system, bumpers (car fenders), appliances, yogurt containers, drinking straws and bottle caps
High impact polystyrene (HIPS)		Electronics, vending cups, food packaging, refrigerator liners
Polystyrene (PS)	Cause unconsciousness and dizziness, irritate throat, nose and eyes. Stores in fat of the body and migrates into food. Hematopoietic cancers and high lymphatic rates for workers	CD, cutlery, plates, disposable cups, plastic tableware, food containers and packaging foam
Polyvinyl chloride (PVC)	Liver dysfunction, indigestion, vision failure, deafness, skin diseases, ulcers, chronic bronchitis, genetic changes, birth defects and lead to cancer	Films, flooring, window frames, shower curtains, guttering and plumbing pipes
Low-density polyethylene (LDPE)		Films, clamshell packaging, shower curtains, floor tiles, siding and outdoor furniture
High-density polyethylene (HDPE)	Human cells structure changes due to estrogenic chemicals release	Insulation molding, pipes, tubes, milk jugs and detergent bottles
Polyamides (PA) (nylons)	System dysfunction, spine pains, headaches, dizziness, skin allergies and lead to cancer	
Polycarbonate (PC)	brain function, reproductive system, insulin resistance changes, liver function alternation due to leaching of bisphenol-A	Construction materials, lenses, traffic lights, security windows, riot shields, eyeglasses, compact discs

Some measurements for the quality of papers with respect to the research questions

The following calculations were performed for all the four research questions defined. The summary statistics for the research questions of the percentage out of four are shown in Table 7. The standard deviation shows that how the data are away from its means and the standard deviation represents the degree of dispersion. It actually finds out the variation in data. If there is no variation in the data, then the standard variation will be zero. The value of the standard deviation is always positive. It is represented by “σ”.

Statistics estimated based on the input data and computed using the estimated parameters of the normal distribution are shown in Table 7.

The skewness tells us that how the data are skewed. It is the degree of symmetry in the data. The skewness values must be in between the range of 1 and –1. Kurtosis explores the distribution of the frequency of the extreme data. Before finding the kurtosis there should be a need to find out the mean deviation. The statistics show that these values are within the range.

Table 7: Summary statistics for research question on the input data and computed using the estimated parameters of the normal distribution.

	Range	Minimum	Maximum	Mean		Std. deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. error	Statistic	Statistic	Statistic	Std. error	Statistic	Std. error
Percentage	62.50	12.50	75.00	28.431	1.0950	13.5448	183.461	0.722	0.196	0.003	0.390
RQ1	1.00	0.00	1.00	0.141	0.0252	0.3113	0.097	2.042	0.196	2.726	0.390
RQ2	1.00	0.00	1.00	0.448	0.0297	0.3680	0.135	0.167	0.196	−1.129	0.390
RQ3	1.00	0.00	1.00	0.196	0.0301	0.3727	0.139	1.535	0.196	0.592	0.390
RQ4	1.00	0.00	1.00	0.333	0.0362	0.4479	0.201	0.711	0.196	−1.382	0.390
Total score valid N (listwise)	2.50	0.50	3.00	1.1176	0.0427	0.5280	0.279	0.806	0.196	0.303	0.390

Results and discussion

The following sub-sections present a brief discussion on the findings of the proposed study and the literature review. The discussion and review are structured in four sub-sections, each of the sections presenting one of the defined research questions. The discussion encompasses all of the 153 selected papers according to the search criteria and their quality assessment is provided in Table 8.

What are the different uses and applications of plastics?

Natural polymers, for example, rubber, have been utilized by humans for a long time, however, since the 1800s when vulcanized rubber was found (in 1839). Worldwide plastic production has constantly increased (5). From 1950 to 2012 development of plastics arrived at the midpoint of 8.7% for each year, enhancing from 1.7 million tons to almost 300 million tons today. Overall production kept on growing between the 1970s and 2012 as plastics progressively supplanted materials like metal and glass. Plastic production in 2013 was 299 million tons, representing a 3.9% expansion over output in 2012 (171). In 2014 the production of plastics exceeded 300 million metric tons worldwide for every year (172). Demand for plastic due to consumerism and convenience, alongside the similarly low cost of producing plastic materials is growing. Recycling and recovery of plastic however, remained inadequate and huge amounts of plastics end up in oceans and landfills every year (173). Paper, glass and metal are progressively supplanted by plastic packaging, especially for food. Plastic packaging represented 30% by 2009 of all packaging sales (174).

As plastics consists of various types of organic monomers attached end to end their characteristics are determined from the nature and types of the repeating units. The plastic formed usually represents solid or semi-solid materials with various degrees of flexibility, strength, harness and other properties. In order to improve the plastic specific characteristics, durability and strength, various types of additives are also added. These additives and the nature of certain plastics is highly controversial due to health concerns (175). Plastics have become an indispensable resource for humankind, frequently providing a usefulness that cannot be effortlessly or financially supplanted by other materials. Plastic items have given advantages to society in terms of quality of life, employments and the economy. Most plastics are mechanically stable and last for a long time (175). In the medical field and in hospitals plastics play an essential role. In hospitals plastics are utilized on a huge scale. The day to day plastic waste production includes glucose bottles, I.V. sets, disposable syringes, B.T. sets; cannulas, catheters, etc., and disposable plastic aprons are discarded on a daily basis. Plastics might be convenient and easy for everyday use, however, their negative effects on our well-being cannot be neglected. Worldwide plastics continue to be discarded and are making huge amounts of trash, due its non-biodegradable nature (9). The most abundant and commonly used polymers worldwide which present 90% of the total production of plastic are polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), low-density polyethylene (LDPE) and high-density polyethylene (HDPE), polyamides (PA) (nylons) and polycarbonate (PC). The health effects and uses of these commonly-used plastics are summarized in Table 6. Significant amounts of plastic have aggregated in landfills and in the environment. Plastic waste in municipal waste streams represents about 10% by weight (7, 176).

The following is a list of studies including some in Table 8 on the use and application of plastics (5, 7, 9, 10, 17, 19, 24, 26, 39, 45, 48, 49, 51–57, 60, 83, 107, 108, 117, 122, 124, 144, 154, 155, 162–164, 167, 170–176). Keeping in mind the above studies, most of the common applications of plastics include packaging, construction, electronics, electrical goods, furniture, automobiles, households, agriculture and other industrial usages. In addition, a huge part of packaging plastic is disposable and is no longer utilized after its initial usage. Another extensive area of utilization is within the motor vehicle and the electronics industries. Plastic polymers are likewise used to manufacture paints and glues for utilizing in textiles. In modern society plastics satisfies various essential functions and we would not be able to live without plastic materials today. In medical apparatus, from prostheses to blood bags, the particular properties of a plastic decide its application. Plastics can likewise be favorable from an environmental and health perspective.

What are the different environmental impacts of waste plastics? What different types of techniques are available for waste plastics management?

For the last couple of decades, the uncontrolled utilization of plastics for different purposes, such as agriculture, industry, transportation and packaging in urban as well as rural areas has highlighted the significant issue

Table 8: Quality assessment of the selected papers.

S. no.	Ref. no.	RQ 1	RQ 2	RQ 3	RQ 4	Total score (out of 4)	%age out of 4
1	(16)	0	0.5	0	1	1.5	37.5
2	(17)	0.5	0	0.5	0	1	25
3	(18)	0	0.5	0	0	0.5	12.5
4	(19)	1	1	0	0	2	50
5	(20)	0	0.5	0	1	1.5	37.5
6	(21)	0	1	0	1	2	50
7	(22)	0	1	1	0	2	50
8	(23)	0	0	0.5	0	0.5	12.5
9	(24)	0.5	1	0	1	2.5	62.5
10	(25)	0	0.5	0	1	1.5	37.5
11	(26)	1	0	1	0	2	50
12	(27)	0	0.5	0	0.5	1	25
13	(28)	0	0.5	0	0	0.5	12.5
14	(29)	0	0	0	0.5	0.5	12.5
15	(30)	0	0	0	1	1	25
16	(31)	0	0	1	0	1	25
17	(32)	0	0	1	0	1	25
18	(33)	0	0.5	0	0	0.5	12.5
19	(34)	0	0.5	0	0.5	1	25
20	(35)	0	0	1	0	1	25
21	(36)	0	0	1	0	1	25
22	(37)	0	0.5	0	0	0.5	12.5
23	(38)	0	0	1	0	1	25
24	(39)	1	1	0	0	2	50
25	(40)	0	0.5	0	0	0.5	12.5
26	(41)	0	0.5	0	0	0.5	12.5
27	(42)	0	0.5	0	0	0.5	12.5
28	(43)	0	0.5	0	0	0.5	12.5
29	(44)	0	1	0.5	0.5	2	50
30	(45)	0.5	1	0.5	0	2	50
31	(46)	0	0	1	0	1	50
32	(47)	0	0.5	0	0	0.5	12.5
33	(48)	0.5	0.5	0	0	1	25
34	(49)	0.5	1	0.5	0	2	50
35	(50)	0	0	1	0	1	25
36	(51)	0.5	0	0	0.5	1	25
37	(52)	0.5	0.5	0	0	1	25
38	(53)	1	0.5	0	0.5	2	50
39	(54)	1	1	0	0	2	50
40	(55)	0.5	0.5	0	0	1	50
41	(56)	1	1	0	0	2	50
42	(57)	0.5	1	0	1	2.5	62.5
43	(58)	0	0.5	0	0.5	1	25
44	(59)	0	0.5	0	0	0.5	12.5
45	(60)	1	0.5	0	0	1.5	37.5
46	(61)	0	0.5	0	0	0.5	12.5
47	(62)	0	0	0	0.5	0.5	12.5
48	(63)	0	0	1	0	1	25
49	(64)	0	0.5	0	0	0.5	12.5
50	(65)	0	1	0	0	1	50
51	(66)	0	0.5	0	1	1.5	37.5
52	(67)	0	0	0	1	1	25
53	(68)	0	0	0	1	1	25
54	(69)	0	0	0	1	1	25
55	(70)	0	1	0	0	1	25

Table 8 (continued)

S. no.	Ref. no.	RQ 1	RQ 2	RQ 3	RQ 4	Total score (out of 4)	%age out of 4
56	(71)	0	0.5	0	0	0.5	12.5
57	(72)	0	0.5	0	0	0.5	12.5
58	(73)	0	0.5	0	0	0.5	12.5
59	(74)	0	1	0	0	1	25
60	(75)	0	1	0	0	1	25
61	(76)	0	0.5	0	1	1.5	37.5
62	(77)	0	0.5	0	1	1.5	37.5
63	(78)	0	0.5	0	1	1.5	37.5
64	(79)	0	0.5	0	0	0.5	12.5
65	(80)	0	0.5	0	1	1.5	37.5
66	(81)	0	0	0	1	1	25
67	(82)	0	0	0	1	1	25
68	(83)	0.5	0.5	0	0	1	25
69	(84)	0	0	0	1	1	25
70	(85)	0	0.5	0	1	1.5	37.5
71	(86)	0	0.5	0	0	0.5	12.5
72	(87)	0	1	0	0	1	25
73	(88)	0	0.5	0	0	0.5	12.5
74	(89)	0	0.5	0	0	0.5	12.5
75	(90)	0	0	1	0	1	25
76	(91)	0	0	0	1	1	25
77	(92)	0	0	0	1	1	25
78	(93)	0	0.5	0	1	1.5	37.5
79	(94)	0	0.5	0	1	1.5	37.5
80	(95)	0	0.5	0	0	0.5	12.5
81	(96)	0	0	0	1	1	25
82	(97)	0	0	0	1	1	25
83	(98)	0	1	0	1	2	50
84	(99)	0	1	0	0.5	1.5	37.5
85	(100)	0	0.5	0	1	1.5	37.5
86	(101)	0	0.5	0	0	0.5	12.5
87	(102)	0	0.5	0	0	0.5	12.5
88	(103)	0	1	0	0	1	25
89	(104)	0	1	0	0.5	1.5	37.5
90	(105)	0	0.5	0	1	1.5	37.5
91	(106)	0	0.5	0	1	1.5	37.5
92	(107)	0.5	0.5	0	0	1	25
93	(108)	0.5	1	0.5	0	2	50
94	(109)	0	0	0.5	0	0.5	12.5
95	(110)	0	0	0	1	1	25
96	(111)	0	0	0.5	0	0.5	12.5
97	(112)	0	0.5	0	0	0.5	12.5
98	(113)	0	0	1	0	1	25
99	(114)	0	1	0	0	1	25
100	(115)	0	0.5	0	1	1.5	37.5
101	(116)	0	0.5	0	1	1.5	37.5
102	(117)	1	0	0	1	2	50
103	(118)	0	0	0	1	1	25
104	(119)	0	0.5	0	0	0.5	12.5
105	(120)	0	0.5	0	0.5	1	25
106	(121)	0	0	0	1	1	25
107	(122)	1	0.5	1	0.5	3	75
108	(123)	0	1	0	0	1	25
109	(124)	1	0.5	0	0	1.5	37.5
110	(125)	0	1	1	0	2	50

Table 8 (continued)

S. no.	Ref. no.	RQ 1	RQ 2	RQ 3	RQ 4	Total score (out of 4)	%age out of 4
111	(126)	0	0	1	0	1	25
112	(127)	0	0.5	0	0	0.5	12.5
113	(128)	0	0.5	0.5	0.5	1.5	37.5
114	(129)	0	0.5	0	0	0.5	12.5
115	(130)	0	0	0	1	1	25
116	(131)	0	0	1	0	1	25
117	(132)	0	0	0	1	1	25
118	(133)	0	0	0	1	1	25
119	(134)	0	0.5	0	0	0.5	12.5
120	(135)	0	1	1	0	2	50
121	(136)	0	0.5	0	0	0.5	12.5
122	(137)	0	1	0	0	1	25
123	(138)	0	0	1	0	1	25
124	(139)	0	1	0	0	1	25
125	(140)	0	0	0	1	1	25
126	(141)	0	0.5	0	0	0.5	12.5
127	(142)	0	0	0	1	1	25
128	(143)	0	0	0	1	1	25
129	(144)	1	1	0	0	2	50
130	(145)	0	0.5	0	0	0.5	12.5
131	(146)	0	0	0	1	1	25
132	(147)	0	0	0	1	1	25
133	(148)	0	0	0.5	0	0.5	12.5
134	(149)	0	0.5	0	0	0.5	12.5
135	(150)	0	0.5	0.5	0.5	1.5	37.5
136	(151)	0	1	0	0	1	25
137	(152)	0	0	0	1	1	25
138	(153)	0	0.5	1	0	1.5	37.5
139	(154)	1	1	0	0	2	50
140	(155)	0.5	1	0	0	1.5	37.5
141	(156)	0	1	0	0	1	25
142	(157)	0	0.5	0.5	0	1	25
143	(158)	0	0.5	0	0	0.5	12.5
144	(159)	0	0.5	0	0	0.5	12.5
145	(160)	0	0	1	0	1	25
146	(161)	0	0	1	0	1	25
147	(162)	0.5	0.5	1	0	2	50
148	(163)	0.5	0.5	0	0	1	25
149	(164)	1	1	0	0	2	50
150	(165)	0	0	1	0	1	25
151	(166)	0	1	0	0	1	25
152	(167)	1	0.5	0	0	1.5	37.5
153	(168)	0	0	1	0	1	25

of plastic waste disposal and its contamination. Plastic materials are of great concern in the environment because of their accumulation and resistance to degradation (170). Despite having various positive properties, from the waste administration point of view the plastics contributes an assortment of demerits (6). Traditionally, plastics in the ambient environment are not readily degraded and are very stable. Synthetic plastics lead to environmental pollution and are considered a big problem (8). Plastics provide risky human exposure to poisonous components, for example, DEHP and BPA (10). The plastic industry is essential for earning foreign exchange, but the wastewater effluents discharge from the plastic industry is a major problem. Such wastewater effluents result in objectionable odor emissions, surface and groundwater quality deterioration and poisoning the land, which indirectly or directly affects the aquatic life as well as the local inhabitants' health (177). Harmful chemicals are released into the adjacent soil from chlorinated plastics, which seep into other adjacent water sources or groundwater. Landfill regions are continually heaped high with a variety of plastics. Many microorganisms in these landfills carry out biodegradation of some plastics masses. Plastic degradation results in the release of methane (178).

Several ecologically damaging and hazardous effects on the marine environment are caused due to plastic pollution. Wastewater effluents of the plastic industry are characterized by parameters such as turbidity, pH, suspended solids, BOD, sulfide and COD. Plastics are the most common elements found in the ocean. It is harmful for the environment as it does not decompose easily and is often ingested as a food by marine animals (156). In the digestive system of these animals the ingested plastic persists and lead to decreased gastric enzyme secretion, gastrointestinal blockage, decreased feeding stimuli, reproduction problems and decreased steroid hormone levels (179). Plastic waste is disposed of by recycling, incineration and landfill (170). Incineration and pyrolytic conversion of waste plastic results in the emission of hazardous atmospheric pollutants, including polyaromatic hydrocarbons, CO_2 (a greenhouse gas) and persistent organic pollutants like dioxins which causes global warming and pollution (9).

In the ocean organic pollutants are found in high concentrations in plastic particles. The chemicals that are toxic and found in oceanic plastic debris includes; nonylphenol (NP), polychlorinated biphenyls (PCBs) and organic pesticides such as bisphenol A (BPA), polycyclic aromatic hydrocarbons (PAHs), dichlorodiphenyltrichloroethane (DDT) and polybrominated diphenyl ethers (PBDEs) (159). Many of these compounds pose risks to wildlife and human health (180). These toxic chemicals cause health problems such as endocrine disruption, breast cancer, neurobehavioral changes, developmental impairment (hormonal imbalances, growth abnormalities and neurological impairment), arthritis, cancer, DNA hypomethylation and diabetes (101).

Plastics contain a wide range of chemicals, contingent upon the type of plastic. The expansion of chemicals is the principle motivation behind why these plastics have become so multipurpose, however, this has issues related with it. A few of the chemicals utilized in the generation of plastics can be absorbed by people through skin retention. A great deal is still unknown on how extremely people are physically influenced by these chemicals. A portion of the chemicals utilized in the generation of plastics can cause dermatitis on human skin contact. In numerous plastics, these poisonous chemicals are only utilized in trace amounts, yet noteworthy testing is frequently required to guarantee that the dangerous components are contained inside the plastic by idle material or polymers. Plastic contamination can also affect humans in which it may create an eyesore that interferes with enjoyment of the natural environment (178). Hayden et al. (170) carried out a study on plastic degradation and its environmental implications with special reference to poly (ethylene terephthalate). They concluded from their study that plastic accumulation is a major environmental concern in the world's oceans. PET is a major plastic used in food packaging, textiles and many other applications. PETs cause many environmental problems due to their accumulation in environment and their non-biodegradable nature.

The most common techniques used for disposal of plastic are recycling, incineration and landfill, each method has some drawbacks and disadvantages. A large area of land is required for landfill and secondary pollutants are released from incineration and landfill into the environment. Recycling is cost effective but there are less investment incentives for recycling facilities (9). The best option which is efficient and environmentally friendly for plastic waste disposal is biodegradation. On a commercial scale, there is no appropriate disposal of PET by biodegradation. However, significant research in biodegradation of polymers and producing biodegradable polymers is being conducted. Khan et al. (177) carried out a study to evaluate the wastewater effluents of the aminoplast industry situated in the Gadoon industrial estate in Amazai. The wastewater effluents were examined for turbidity, pH, suspended solids, BOD, sulfide and COD. The results showed that the wastewater effluent discharge from the aminoplast industry has a high concentration of BOD, which is harmful to the aquatic life when discharged without treatment. The study suggested that to keep the environment safe from the impacts of industrial effluents in the area, treatment techniques such as chemical adsorption, flocculation, pH adjustment and air stripping, etc. should be used.

Recycling in the solid waste administration hierarchy is considered as the best alternative in order to reduce the effects introduced by end of use and end of life post-consumer plastic packaging wastes (181). Recycling allows the chance to make a new product to utilize the recovered plastics (89). In the plastics industry, a currently available important action to reduce the impact of plastics is recycling. Recycling can reduce quantities of waste requiring disposal and minimize CO_2 emissions and oil usage. The quantity of recycled plastics, that began in the 1970s, vary geographically, according to application and type of plastic. In recent decades, in various countries, there have been rapid developments in the reusing of packaging materials. Progress in innovations and frameworks for recyclable plastics reprocessing, sorting and collection are creating new recycling opportunities, and with the joint activities of governments, industry and the public it might be conceivable that over the coming decade more and more plastics will be recycled (5). The principal disadvantage related to plastic waste disposal is the way in which landfill facilities occupy space that could be used for more gainful means, for example, agriculture (182). This is intensified by the moderate degradability of most plastics, as this implies the used land is inaccessible for long timeframes. Plastic segments of landfill waste appear to exist for more than 20 years (183). This is because of the constrained accessibility of oxygen in landfills; the encompassing condition is basically anaerobic (184, 185). Thermooxidative degradation to a great extent limits the degradation of many plastics (186), and the anaerobic conditions further limit the degradation rates in landfills. In landfill, the plastic debris for various secondary environmental pollutants acts as a source of pollution (182). Volatile organics such as trimethyl benzenes, ethyl benzenes, xylenes, toluene and benzene are contained in the leachate and released as gases (187) and compounds, especially bisphenol A (BPA) which has endocrine disrupting properties (102). BPA in landfill released from plastics can result in the hydrogen sulfide production by bacteria (sulfate-reducing) in the soil populace (103). Hydrogen sulfide in high concentrations is possibly lethal (103). Incineration is another technique routinely used for plastic waste disposal (182). Plastic incineration is advantageous in terms of energy recovery in the form of heat and it does not need any significant space (188). Numerous harmful compounds are formed and released as a result of incineration of plastics to the atmosphere (182). Plastic incineration produces and releases greenhouse gases particularly CO_2, toxic carbon, heavy metals, PCBs and PAHs (114, 123).

The following is a list of studies including some in Table 8 and others providing different environmental impacts and details of the techniques for waste plastic management (5, 6, 8–10, 16, 18–22, 24, 25, 27, 28, 33, 34, 37, 39–45, 47–49, 52–61, 64–66, 70–80, 83, 85, 86, 88, 89, 93–95, 98–103, 103–108, 112, 114–116, 119, 120, 122–125, 127–129, 134–137, 139, 141, 144, 145, 149–159, 162–164, 166, 167, 170, 177–180, 182–189). Keeping in mind the above studies, plastics have turned into a critical element of present day life and are utilized as a part of various sectors of applications like consumer products, building materials, packaging and considerably more. There are 300 million tons of plastics produced each year worldwide. Plastics remain for a very long time in nature and are characteristically resistant and inert to microbial attack. Plastic materials that are disposed of improperly are a critical wellspring of natural contamination, conceivably harming life.

How degradation of waste plastics take place in the environment? Which management technique is typically used for handling waste plastics?

The management of waste plastics through biodegradation is gaining interest among researchers because this technique holds promise to minimize environmental pollution effectively. Most plastics are resistant to biodegradation. In general, plastic materials in the environment do not break down readily and subsequently can litter the environment (190). In the environment plastics degrade through four different mechanisms: biodegradation by microorganisms, hydrolytic degradation, thermooxidative degradation and photodegradation (186). As a rule, degradation of plastics naturally starts with photodegradation, which can then become thermooxidative degradation. The energy from the sun in the form of ultraviolet radiation is necessary for the initiation of the photooxidation of the polymer matrix (191). The oxidation weakens the plastic which breaks up into smaller pieces, until the molecular weight of the of polymer chain reduces enough to be easily utilized by microorganisms (186). The microorganisms either incorporate the carbon in the polymer chains into biomolecules or convert it into CO_2 (192). However, this process can take more than 50 years and is very slow process to fully degrade the plastic (160).

Reduction in the polymer molecular weight is known as degradation. The types of degradation are;

(a) De-polymerization/chain end degradation
(b) Random degradation

Biodegradation is characterized as a molecular weight reduction by naturally occurring microorganisms, for example, actinomycetes, fungi and bacteria, that are involved in both synthetic and natural plastics degradation (193). Plastic materials disposed of improperly are also a critical wellspring of natural contamination, which may harm life on earth. Air and water are prevented from entering the soil by plastic bags or sheets which results in underground water source depletion, soil infertility, prevention of the degradation of other substances and are a threat to animal life (194). According to municipality administrations the key reason for the blocked drains is plastic carrier bags, thus incineration of municipal wastes is prohibited because it can lead to the accumulation of sludge, garbage and junk. Plastic in this biosphere is a furious parasite that eats up and contaminates everything (195). In the mid-1980s the examination on degradability of plastics began. A few types of plastic have been appeared to be biodegradable, and their mechanisms of degradation dynamically moved toward becoming clearer (161). Diverse degradable plastics, for example, starch-filled polyethylene (Griffin process), vinyl ketone copolymers (Guillet process), ethylene-carbon monoxide polymers, poly (3-hydroxybutyrate- 3-hydroxy valerate) and polylactides have been developed (196). These plastics vary in price, application and degradation rate.

In one improvement, plastics resistance and inertness was reduced by microbial attack by joining starch and later prooxidants (oil and transition metals) (197). Kathiresan (2003) analyzed the plastic and polythene bags degradation by using Gram-negative and Gram-positive bacterial and fungal species. The predominant bacterial species were *Micrococcus*, *Staphylococcus*, *Streptococcus*, *Pseudomonas* and *Moraxella*. While the fungal species used were *Aspergillus niger* and *Aspergillus glaucus*. Among bacteria *Pseudomonas* species degraded 8.16% of plastics and 20.54% of polythene in a period of 1 month. Among fungal species *Aspergillus glaucus* degraded 7.26% of plastics and 28.80% of polythene in a period of 1 month. This study also showed that mangrove soil is a decent wellspring of microbes fit for degrading plastics and polythene (153).

The following is a list of studies including some in the above table and others providing degradation of waste plastic (22, 23, 26, 31, 32, 35, 36, 38, 44–46, 49, 50, 63, 90, 108, 109, 111, 113, 122, 125, 126, 128, 131, 135, 138, 148, 150, 152, 153, 160–162, 165, 168, 186, 190–198). Based on the above studies, various techniques used for handling the waste plastic include: land filling, incineration, recycling and conversion into gaseous and liquid fuels, etc. All of these methods have their own disadvantages and exploring the best possible option for the management of waste plastics is required.

Is it possible to convert waste plastics into useful products?

Environmental pollution due to waste plastics can be reduced by using an extruder to convert it into useful building materials which will decrease the waste plastic problem further. Currently useful building materials are made from waste plastics like retaining blocks, paving slabs, railway sleepers, roof tiles, interlocks, bricks, etc., utilizing either a mixture of various wastes plastic alongside rubber powder waste as a filler or single origin waste plastic material. Waste plastics when mixed with calcium carbonate and rubber powder sustains a high load of compression and gives the highest compressive strength (189).

The huge amount of waste plastic that is produced might be treated by appropriately planned techniques to produce substitutes for fossil fuel. The strategy is predominant in all regards (economic and ecological) if financial support and proper infrastructure are given. In this way, an appropriate procedure for production of hydrocarbon fuel from waste plastic can be designed and would be a less expensive petroleum substitute without any of the hazardous emissions if implemented. It would likewise deal with hazardous waste plastic and lessen the amount of crude oil needed (199). Chemical recycling is the conversion of waste plastic into fuel or feedstock which could fundamentally lessen the net disposal cost and has been perceived as a perfect approach (199). Chemical recycling of waste plastics is an adaptive procedure which converts waste plastics into gases or liquids (smaller molecules) which are appropriate for the utilization of new plastics and petrochemical items. In fuel production, chemical recycling has been demonstrated to be valuable. The de-polymerization processes in chemical recycling bring about manageable enterprises which result in less waste and high product. Some of the processes in the petrochemical industry, for example, catalytic cracking or steam, pyrolysis, etc., are similar to the chemical recycling process (200).

Another approach to chemical recycling, which has gained much intrigue as of late, is the plan to use basic petrochemicals production from waste plastics fuel oils or hydrocarbon feedstock for an assortment of downstream procedures (201). There are various techniques for waste plastic conversion into fuels, for example, gasification, catalytic cracking and thermal degradation (202). The process in which waste plastic is heated and decomposed into oils and gases in limited oxygen or the absence of oxygen is known as pyrolysis. Pyrolysis involves the breakdown of plastic polymers into small molecules. Viscous liquids are produced at temperatures <400°C (low temperature) while temperatures >600°C (high temperature) favor gas production. This procedure is a feasible course of the waste plastic conversion into gases and fuels (200).

Waste plastic can be converted into different products, details of the techniques for waste plastic conversion can found in (16, 20, 21, 24, 25, 27, 29, 30, 34, 44, 51, 53, 57, 58, 62, 66, 68, 69, 76–78, 80–82, 84, 85, 91–94, 96–100, 104–106, 110, 115–118, 120–122, 128, 130, 132, 133, 143, 146, 147, 150, 152, 189, 199–202). To develop products and process standards is a challenge of postconsumer reused plastics as is embracing the further development of pyrolysis advancements for waste plastics while alluding to the perceptions of innovative work in this field to suit the mixed waste plastics and middle and low scaled production reactors for pyrolysis. Additionally, the investigation would help decrease operating costs and capital investment, and in this way would improve the process economic viability.

Limitations

The first limitation of this research study is that the search was carried out in only few but the most widely referenced libraries. There are a number of libraries which were skipped during the searching process. This decision was taken to focus on only those papers which were published in high quality peer reviewed journals and conference venues in order to get justifiable results. It was decided to avoid searching in Google Scholar (https://scholar.google.com.pk/), which provides access to all of the papers published in the given libraries and to save time from finding duplicate entries of papers. Secondly, the search was performed using a limited set of keywords (mainly waste plastics) to get only directly related results. There is a chance that a paper might have been ignored which may describe waste plastics but not using the terms searched for. It was decided by the authors during the protocol development to be able to properly control and organize the search and paper selection process. Thirdly, not all of the selected research (papers) are discussed and analyzed. The analysis of the research is based only on most frequently used waste plastic concepts and techniques. Although, an effort has been made to provide references to all of the important and high-quality valued papers for the benefit of the reader.

Conclusion

Different types of waste plastics have been used in plastic waste management research and are being converted into useful products. This information is not yet available collectively as a comprehensive literature review to help in the further development of waste plastic management, specifically to guide practitioners that their choices are dependent upon different fundamental strategies used for handling of waste plastics. This systematic literature review identified 153 primary studies (articles published in journals, books, conferences and so on) defining the uses of plastic, the environmental impact of waste plastics, waste plastic management techniques, and their conversion processes into useful products. This shows that a lot of work is still needed in the direction of the management of waste plastics for a more precise understanding of the extent of methods made in the management of waste plastics. This study also aimed at identifying the applications of plastics, but it was found that almost all other applications are either directly or indirectly related to plastics. The accumulation of all of the information in this systematic literature review will benefit the research community and practitioners in identifying from where they need to start further research and the direction for waste plastics.

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