Environmental Science and Pollution Research (2020) 27:12953–12966
https://doi.org/10.1007/s11356-020-08194-5

REVIEW ARTICLE

Plastics in municipal drinking water and wastewater treatment plant effluents: challenges and opportunities for South Africa—a review

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Received: 27 June 2019 / Accepted: 21 February 2020 / Published online: 2 March 2020

Abstract

Pervasive plastic wastes, pollution and detrimental environmental ethics are a serious threat in South Africa. Compared with global trends, most studies undertaken on plastic pollutions in water bodies across South Africa have generally been limited to marine and coastal waters. A literature review, for the last 40 years, demonstrated the scanty studies on the economic, social, health and cost implications of plastic entrainment into fresh water (sources of drinking water) and wastewater systems in South Africa. Hence, demonstrating a knowledge gap on this imperative issue, the inadequate and limited frameworks needed in assessing, evaluating and re-evaluating the menace of plastic pollution and entrainments into consumable water and wastewater treatment plants. This has hampered the local capacity, manpower, knowledge and understanding direly needed for mitigating these challenges. This work is necessitated because of the dire need in bridging the knowledge gap locally by adaptively reviewing possible challenges and opportunities for South Africa in meeting up the mandate of addressing this global threat. The emerging agreement amongst global policy-makers, educators and scientists is that environmental challenges, such as this, require, now more than ever, renewed ways of effective knowledge production and decision-making in tackling, holistically the menace of mismanaged plastic wastes and pollutions. These include but not limited to plastic education curriculum, synergised policies in fostering a circular plastic economy, overriding political will, innovative waste management systems, inclusive independent monitoring of plastic wastes, robust laws and effective enforcement strategies that are needed to promote better environmental ethics, mitigation and a sustainable environment.

Keywords Plastics pollutions · Microplastics · Municipal water and wastewater · Wastes management · Plastic education curriculum · Plastic economy · Policy frameworks · Safe drinking water · Environmental sustainability

Introduction

Plastics are polymeric materials with interesting properties that have made them materials of choice in many industrial and domestic applications. These characteristics include versatility, lightweight, flexibility, moisture resistance, strength, amenability and low-cost implications. These interesting features make them to find useful applications in a broad range of industry, ranging from construction, body care products, aerospace, maritime and the auto industries, to name but a few. With developments and emerging innovations in engineered and re-engineered polymeric materials, coupled with the fact that an estimated output of 335 million metric tons of plastics, produced globally as at 2016, plastics clearly remain, unarguably, one of the outperforming materials of choice when compared with other competing materials, such as wood, metal and glass (Bomgardner et al. 2015; Sanda et al. 2016; Statista.com 2017).

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Notwithstanding these advantages associated with plastics, therein lies the attendant environmental, health and economic challenges of plastic (i.e. macro-, micro- and nanoplastic) pollution, which have demonstrated the dire need for the re-evaluation and re-assessment of the plastic economy (Cole et al. 2011; da Costa et al. 2016; Nguyen et al. 2019). The intricacy of plastic pollution is that it traverses various aspects of human activities, inclusive of the all-important environmental, biological, social and economic considerations (Parker 2018). For example, a study by Karami et al. (2017) has demonstrated that most commercial salts, widely consumed by humans across the globe, contain microplastics in them. In its concluding remarks, the study advocated the necessity for a regular quantification and characterisation of microplastics in various sea products.

In another report, micro (nano) plastics have been noted as emerging contaminants acting as vectors for the accelerated diffusion of organisms into the environment and increasing the gene exchange between attached biofilm communities, thereby enhancing the transfer of pathogenic and antibiotic resistance genes (Shen et al. 2019).

Plastics are considered recalcitrant pollutants due to the fact that they are generally chemical and corrosion resistant, non-biodegradable and are ubiquitous, thereby accumulating in the environment (Hu et al. 2019). Furthermore, consequent upon the fact that the thermal conductivities of plastics are relatively low, ~ 0.0004 (cal–cm/^{0}C-cm^2–sec), it is believed that as the volume of these debris increases in water bodies, the amount of solar thermal energy being trapped within the given body of water will decrease per unit volume. This will thereby result in the dissipation of the excess energy to the immediate environment, hence, affecting global warming. Consequently, according to the well-known Archimedes principle, it remains inarguable that the volume of plastics in our seas, and oceans will displace an equal volume of water, resulting in the change in volume of these water bodies, thus, advancing the risk of environmental flooding and shrinkage of the aquatic habitat (Chanda and Roy 1998; Poso 2018).

It is evident that the environment is heavily polluted with plastic from all possible sources. These sources include, amongst others, the leaching of marine paints into the open waters (Nakashima et al. 2016) leaching of plastic particles into the soil via plastics employed in mulching (Jarosiewicz and Tomaszewska 2003; Steinmetz et al. 2016) and everyday cosmetics and toiletries (Petersen 2016; Clarke 2017). The disintegration of macroplastic into microplastics and the consequent disintegration of these microplastics into nanoscale plastics (Chen et al. 2017). These are further inundated in every aspect by the mismanagement of plastic waste employed in packaging and carrier bags, which further constitute an environmental eyesore (Guastella 2017; Hall 2017; Hall et al. 2015; Hanafi 2018; Phys.Org 2018), as shown in Fig. 1.

The oceans have become a colossal refuse dumpsite for all manners of mismanaged plastic debris that have been estimated to exceed 250,000 metric tons of plastic-based materials afloat at sea. This, consequently, results in serious multiplier threats to aquatic habitat, the food-chain, human health and environmental sustainability (Cozar et al. 2014; Eriksen et al. 2014).

Studies have further demonstrated the fact that pollutants and contaminants, such as polycyclic aromatic hydrocarbons (PCAHCs) and polychlorinated biphenyls (PCBPs), are associated with plastic pollutions. As a result, these contaminate the marine biota by presenting a pathway for these unwholesome

Plastic pollution in Bulaawayo, Zimbabwe (Phys.Org, 2018)

Plastic pollution in Lagos, Nigeria (Hanafi, 2018)

Plastic pollution in Durban, South Africa (Guastella, 2017)

Plastic waste in Accra, Ghana (Hall, 2017)

Fig. 1 Realities of mismanaged solid plastic wastes across Africa

chemicals to enter the food chain. Of course, when human beings consume sea creatures that have ingested these plastic debris (Elliott and Elliott 2013; Rios et al. 2007), there are attendant health consequences, some of which, may not be manifested immediately. These studies have been supported by the work of Haq and Raj (2019). Styrofoam products, which are polymeric materials, are known to contain carcinogenic chemicals, such as styrene and benzene. These are two highly toxic chemicals, which if ingested can damage the nervous systems, lungs and reproductive organs. Cases arise whereby plastics wastes are burned for either heat, cooking or for disposal, thereby exposing the surrounding environment to toxic emissions such as furan and dioxin (Pettipas et al. 2017; UNEP 2018).

It is worthy of note that although, while we discuss the issue of plastic (macro-, micro- and nano) pollution challenges in a broader perspective, our particular interest remains on the emerging challenges microplastics presents for South Africa, such as: the presence of microplastics detected in municipal drinking water and wastewater treatment plant, and the consequent opportunit plastic pollution holds for the country. Moreover, due to the fact that there are scarcely any studies on nanoplastic pollution in South Africa to the best of our knowledge, this will only be mentioned briefly. In addition, the studies carried out so far on microplastic pollution, in South Africa, has been restrictive in nature; in that, they are narrowed, focusing on water bodies such as coastal areas, thereby, reinforcing the huge knowledge gap presented herein, despite microplastic pollution being a trending global issue (Klingelhöfer et al. 2020).

Microplastics have been defined as plastic matter lesser than 5 mm in particle size, more often, as a result of possible photo-oxidation or mechanical degradation/fragmentation pathways of larger (macro) plastic materials (Mason et al. 2016; Thompson et al. 2009). These degraded plastic matters are, however, referred to as secondary microplastics, in contrast to the primary microplastics particles, which are the resultant products of designed manufacturing processes that find various applications, both industrially and domestically (Eerkes-Medrano et al. 2015). A range of applications for these primary microplastics, include industrial scrubbers and in personal cleaning products, such as toothpastes, plastic powders employed in plastic moulding processes (Oluniyi and Palanisami 2016). Moreover, these primary microplastic materials (i.e. microbeads) are also employed as exfoliants and fillers in consumer products, such as facial cleansers and body washes, thus creating a pathway for the entrainment of these microbeads into municipal drinking water and wastewater systems, as shown in Fig. 2.

Given the nature of these microbeads, it has been shown that wastewater treatment plants are not efficient enough to solve the problem of microplastic in municipal drinking water and wastewater treatment plants (Browne et al. 2011; Fendall and Sewell 2009; McCormick et al. 2014; Wilson et al. 2013; Ziajahromi et al. 2017). For example, municipal wastewater treatment facilities are typically designed based on the common schematic depicted in Fig. 3 with slight difference in the exact configuration (Mason et al. 2016). In here, the primary treatment section is employed in the removal of large debris items with screen mesh sizes of 6 mm or larger. The secondary treatment compartment is used to remove suspended and dissolved organic material and nutrients, largely through the incorporation of microorganisms within large aeration tanks. The settling tank section separates the sewage sludge from the post-processing effluent, prior to any disinfection, and possibly for further advanced treatment, before being discharged into a nearby waterbody.

Despite all these procedures, so employed, microplastic beads still count within the effluent stream so discharged (Carr et al. 2016; Magnusson and Norén 2014; Murphy et al. 2016).

Hence, it is posited here that humans are tentatively consuming plastics when they eat meat, vegetables or marine food and/or drink water that has been contaminated by microplastic debris (Eerkes-Medrano et al. 2015; Pal et al. 2014; Schymanski et al. 2018). This position is supported by a 2019 study report, released by the World Wide Fund for Nature, Gland, Switzerland (de Wit and Bigaud 2019).

Environmental contamination and subsequent ingestion of microplastics pose possible health, economic and environmental challenges. These challenges urgently need intervention by way of unambiguous scientific explanations that must be put across through a well-curriculated education system, solution-focused researches, enforcement of meaningful waste management procedures, strong political will of governments, the engagement in local research studies that proffer solutions and attainable/achievable policies. These are necessary in order to motivate and inculcate sound ethical disposition through well-defined interdisciplinary engagements of all actors on the moral relationship of human beings and their responsibilities to the environment and the non-human contents, inclusive of the conservation of natural resources and environmental sustainability (Sterling 2002; Taneja et al. 2015; Wright and Kelly 2017). The foregoing necessitated this review paper, which through adaptive reflections of global trends, seeks to bring to the fore the dire need for South Africa to bridge this knowledge gap. This will require meeting up with the nation's challenges and pursuing opportunities on the mandate for a safer drinking water, sustainable inland and fresh water circles and pursue holistic methods to mitigating the menace of microplastic pollutions in South Africa.

Moreover, the choice of this review focusing on South Africa is based on the following facts: (1) although classified as a developing country, it is still ranked as one of the developed nations on the continent of Africa; (2) it has a relatively stable economic growth rate compared with most of African Nations; (3) it has the highest standard of living on the continent; (4) and with regard to level of technological advancement, investment

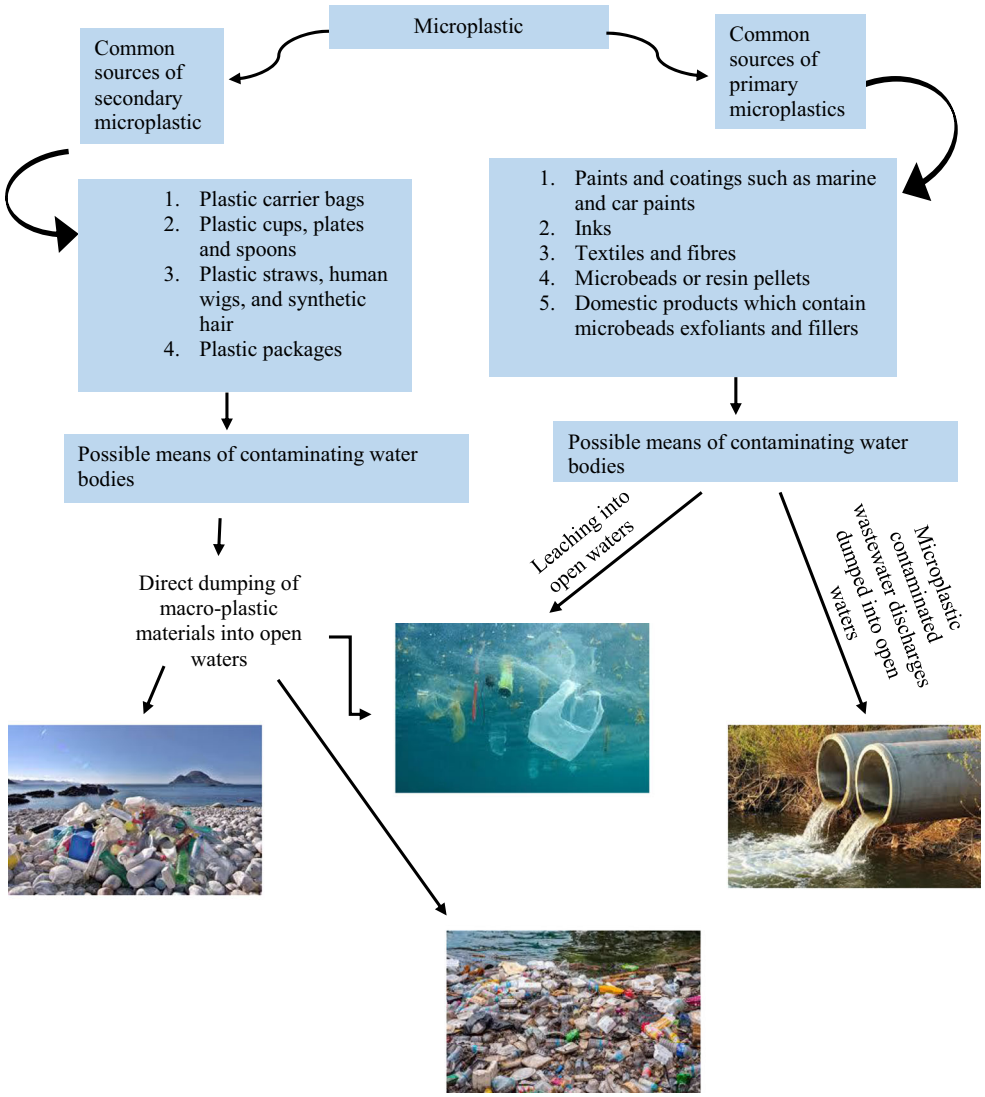

Fig. 2 Possible pathways by which microplastics and plastics particles end-up in water bodies (CCB 2017; Oluniyi and Palanisami 2016)

in research and education, the country tops the list. Therefore, South Africa would be an appropriate regional benchmark for the purpose of investigating the process of technological catching-up within the region on this global trend (Taylor et al. 2007; World Bank 2017; You et al. 2019).

Methodological approach

As part of the literature review, a scrutiny of existing studies on microplastic pollutions in South Africa within the last 40 years (January 1980—January 2020) subdivided into a 5-

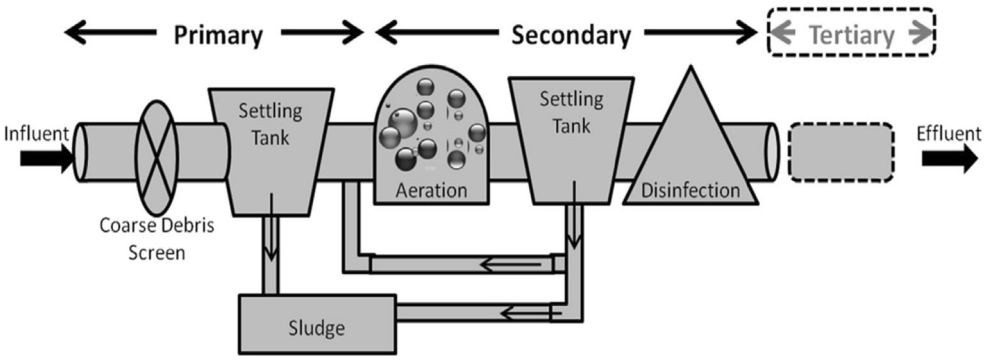

Fig. 3 Schematics of a typical municipal wastewater facility showing the different stages of processing. The tertiary treatment included here is usually optional and, if present, usually varies from facility to facility (Mason et al. 2016)

year interval, is shown in Table 1. The 40-year period was selected so to give a wider spread in literature sample inclusion. Even though it was observed that there has been a lot of studies, dating as far back as the 60s and early 70s on microplastic and plastic debris pollutions in the marine and coastal environments in South Africa (Bennett 1960; Rothstein 1973), there has, however, been scanty studies carried out on microplastic pollution in drinking water sources, such as freshwater and inland water cycles. This observation is worrisome for South Africa where there are limited or no reliable local data on the sources, particle identifications, their occurrences, environmental and health implications, life cycle and impact assessments of the presence of these macro- and microplastics in municipal drinking water and wastewater treatment plant effluents. Hence, this limits the local capacity and opportunities for mitigating these challenges and evaluating and re-evaluating the required risk-assessments for the country's water safety plan from catchment to consumer with a focus on high priority risks, inclusive of the key challenges within each municipality and proffering a comprehensive approach to same.

Howbeit, consequent upon the number of studies surveyed and the dissimilarities in the various sampling methods employed, it posed some serious challenges localising these concepts. Hence, recommendations and conclusions were reached, based on the categorisation of similar literature themes, as put in perspective of the peculiarity of South Africa's freshwater and inland water systems, including municipal drinking water and wastewater treatment effluents.

Table 1 Literature review of microplastic pollution in Africa's water and wastewater treatment plants

Year under literature review (5-year interval)	Number of available studies focusing on presence of microplastics pollution in freshwater, municipal drinking water and wastewater treatment plant effluents in South Africa	References
1980–1985	0	
1986–1991	0	
1992–1997	0	
1998–2003	0	
2004–2009	0	
2010–2015	0	
2016–2020	4	(Bouwman et al. 2018; Reynolds and Ryan 2018; Umlauf 2019; Verster et al. 2017)

As shown in Table 1, it is evident that the only 4 report/studies exists, in the last 40 years, on the presence of microplastics in freshwater and inland water cycles in South Africa, i.e. a spread of 1 study per 10 years. This demonstrates the stark reality on ground in South Africa the so-called advanced country in Africa. However, it is worthy of note that of the existing literature, two studies are not indigenous (local) to South Africa. While the other 2 are from the same research group in North West University, South Africa

Global approach to plastic pollutions and wastes

Rising global commitments across Europe, America and Asia against single-use plastics underline a worldview on decisive actions in mitigating the menace of plastic wastes and pollutions. The United Nations Environmental Programme (UNEP) report of 2018 showed that the economic damage resulting from plastics pollution is very telling. For example, in Europe, cleaning plastics waste from coasts and beaches alone, gulped about 630 million Euro (€), yearly. While in the Asia-Pacific region, plastic wastes litter, costs the tourism, fishing and shipping industries ~1.3 billion United States dollar ($US), yearly. The report further showed that the total summed-up economic damage caused by plastic wastes and pollutions to the global marine ecosystem amounted to approximately 13 billion United States dollar ($US), yearly. This points the fact that a more comprehensive approach should be embraced by member countries for longer-lasting results in tackling the impacts of plastic wastes and pollutions on the environment. However, the ban on single-use plastics was yielding positive results across many countries (UNEP 2018).

In 2017, Indonesia (the world's second-largest ocean plastics polluter, after China) initiated an ambitious goal to reducing marine plastics wastes by 70% by the year 2025, as part of their commitment to the United Nation's Seas program. The campaign was initiated by Melati and Isabel Wijsen, two sisters from the Indonesian Island of Bali, who started campaigning to ban plastic bags locally and reduce the impact of plastic wastes globally (Prisco 2017). Consequently, in 2018, England recorded an 85% drop in the use of plastics bag after the introduction of a 5 pence charge per bag across board (Rebecca Smithers 2016). The European Union (EU) is currently, moving decisively towards a more prosperous and sustainable plastics economy that is envisaged to deliver considerable benefits to its member states. In order to achieve and reap these benefits, the EU has marshalled out strategic visions and goals, encapsulated in a workable plan across the EU, thus setting out what a 'circular' plastics economy could look like in the decades ahead. This vision-strategy envisages the promotion and investment in innovative solutions by turning the current challenges of plastics wastes and pollutions into opportunities for jobs creation, energy production and environmental sustainability. Furthermore, the working document proposes concrete measures to achieve this vision. However, making it a reality will require synergistic actions and involvements of various players and stakeholders, from

producers and designers, down to brands and retailers, through to recyclers, in the plastics value chain. Similarly, the civil society, the scientific community, businesses and the local authorities, all will have decisive roles to play in making this achievable, working together with regional and national governments in order to bring about this positive change (European Commission 2018).

Current challenges in South Africa

Inconsistencies in enforcement of policies

The relevance of environmental legislations to the economic, social and political wellbeing and development of any nation cannot be overemphasized (Panayotou 2016). South Africa, for example, has more than enough legislations covering the entire range of laws, concerned with regulation, management and protection of the environment. This is inclusive of waste management laws and environmental pollutions. However, there have been inconsistencies in the effective enforcement of these laws and policies. For example, an agreement was reached sometimes in 2002 between the South African government and the representatives of organised labour, where a memorandum was signed concerning the limiting of single-use disposable plastic shopping bags. However, a 2012 study demonstrated that the consumption of single-use plastic shopping bags was increasing and persistent, coupled with the recalcitrant behaviour of the average consumer (Dikgang et al. 2012).

Systemic corruption

Systemic corruption is a prominent menace across the African continent and has been pointed out as amongst the banes to Africa's development, be it political, social, scientific and economical (Ghalwash 2014; Lawal 2007; Mbaku 1996). Moreover, since it is well-known that laws do not operate in a vacuum, because men are mandated to enforce these laws, findings from scenario experiments, conducted in South Africa, demonstrated that the perceived corruptibility tendency of the enforcing authority corrodes any willingness to comply with regulations. This study further showed that both the grand and petty types of corruption, have significantly, impacted on people's psyche, hence hampering any progressive attitudes related to support the regulations put in place by constituted authorities (Sundström 2012). A similar study further supported the fact that both petty and grand corrupt practices of regulatory and law enforcement officers in South Africa, remain a key challenge in increasing the effectiveness of regulations in natural resource management and conservation (Sundström 2013).

Political patronage and interference

Political patronage, cronyism and party above the state have been viewed as one amongst the many bedevilling challenges to South Africa's development. It has been argued that political leaders derive support and legitimacy by distributing patronage whether through informal or deeply patron–client networks, built on mutual expectations of reciprocity. Hence, elevating incompetence and ineptitude in government and most often, without any possible consequences. This encourages the lack of political will, insincerity and pervasive political interference and lack of genuine commitment by government officials and their agencies to pressing issues, such as plastic and microplastic pollutions (Beresford 2015). Thus, given this background, it has been suggested that environmental policies and legislations, irrespective of how good its intention, will at best, be an exercise in futility and of little significance, unless and until they are accompanied by effective means of enforcement and compliance and with minimal political interference (Obi 1994).

Poor environmental values, risk perception and education

It has been demonstrated that there is a direct link between people's values, their environmental attitudes and behaviours (Schultz et al. 2005). Heberlein (2012) argued that human behaviour remains the key challenge in proffering solutions to environmental issues. This is further reinforced by a study that demonstrated that human attitudes are reflections of their behaviour, i.e. attitudes have a lot to do with behaviour, irrespective of colour, societal status or race (Ljung et al. 2012). Hence, people or persons reflect their environmental values through their attitudes and behaviours towards their environment. Therefore, the observed negative environmental ethics and behaviours demonstrated by many South Africans, is in fact, a serious challenge for science and government, which need intervention by key actors.

Furthermore, research studies have evidenced that recognising the interdependence between humanity and the environment are hinged on proper education and awareness of a people. Therefore, environmental sustainability and sound ethical disposition of any society correlate with the necessary and adequate awareness and education so received by the populace, by so doing, therefore, supporting the argument that conceivable education and public awareness always play an impactful role in the risk perception of the people, which helps to shape, motivate and reflect on societal behaviour and their possible collaboration with the scientific community (Moore et al. 2001; Sola 2014; Wright 2002). Thus, reflecting the fact that poor environmental ethics, as observed in developing nations, such as South Africa, are directly related to poor environmental values, risk perception, awareness

and poor or improper education (Auta et al. 2017; Ityavyar and Thomas 2012; Omanga et al. 2014; Tlabela et al. 2007).

Poor waste management

In most developed nations, plastic wastes are often separated from other wastes at source, before they are disposed (Feil et al. 2017). This is, however, not the case in the management of solid wastes in many developing nations, hence creating serious environmental challenge, often due to inappropriate/poor technology and infrastructure (Matete and Trois 2008). Hence, while a meaningful portion of waste plastics are captured, collected and recycled, prior disposal in most developed countries (Hopewell et al. 2009), the same cannot be said to be the general case in South Africa. Even in the presence of reuse and/or recycling practices, effective plastic waste management often lacks strong reflection of government support (Ongatai et al. 2015); thus, resulting in mixed solid wastes from urban and industrial sites being lumped-up and dumped or disposed at a single site (Nemathaga et al. 2008; Parrot et al. 2009). This type of dumping of refuse has been documented as a major cause of plastic wastes floating in South African waters and a recognized source for plastic pollution (Tutman et al. 2018).

Opportunities for South Africa

Improving laws, legislations and policies

A progressive re-evaluation and review of extant laws bordering on plastic synthesis, including conceptualisation, production, waste disposal and the attendant environmental contaminants should be initiated where necessary, in order, to make them more effectual, amenable and attainable. It should encapsulate holistic waste management strategies, devoid of political patronages. These laws, legislations and policies should provide incentives to motivate improvement in changes, such as the designing and development of benign plastic materials and additives that are biologically and environmentally friendly after life cycle.

Notwithstanding, it also should encourage (significantly) private-sector initiatives and investments with all levels of government. This should address succinctly, the plastics issue through the provision of legal assurance of governmental support to enhance opportunities and adoption of pro-environmental behaviours by individuals and corporate bodies. Hence, this initiative will lay a foundation for a new plastic economy, where the development and production of plastic products and materials will comply with international best practices of reuse, repair, recycle and reclamation (recovering energy from waste) for a more sustainable plastic materials and environment (European Comission 2018; Harrison 2014). Moreover, apart from the foreseeable positive multiplier effect, this will further foster product benefit, business prosperity and job creations across Africa and will further boost innovative creativity in the polymer sector. Howbeit, all these will be exercise in futility if governments, at all levels across South Africa, do not show strong political will towards enforcing these laws, legislations and policies. These must strictly be applied to the multinational organisations through a just and fair concerted effort in mitigating systemic corruption, encourage patriotism amongst its citizenry. This will be achieved by encouraging and advancing national interests above parochial and selfish desires, hence shunning all forms of favouritism and bribing/corruption by possible defaulters of these legislations, policies and laws (Hawley 2000; Luiz and Stewart 2014; Osuji 2011).

Furthermore, other policy instruments that should be optimised across South Africa should include: a review of taxation on plastic materials and additives, which are detrimental to both, the living and non-living components of the environment. This should be inclusive of landfill tax, incineration taxes and levies, extended producer responsibilities (i.e. manufacturer/producers should, to a large extent, be held accountable/responsible for wastes generations that emanate from their products and services), precycling and recycling insurance policies, optimisation of taxes and levies on products and packages, e.g. plastic bags and plastic bottles. Taxation has been shown to impact positive behavioural changes in users of single-use plastic bags that can be optimised from reusable bags to garbage bags (Pires et al. 2018). Howbeit, part of the levies and taxes collected on plastic bags and bottles by government can be used to pay-out incentives to the people who collect the littered plastic bags and bottles. Such pay-outs can be made at supermarkets or designated recycling points within a given community. Alternatively, instead of monetary incentives, a method of trade-by-barter could be implemented whereby South Africans can exchange waste plastic materials for goods and service delivery, such as pay for water rates, electricity bills or even school fees. This is will in no small way add value to waste plastic materials littering the streets of townships and rural areas, hence, creating a value on these wastes and, subsequently, environmental awareness.

Bridging the knowledge gap

Because of the consistent and persistent call for a more engaging role of science education in bridging the knowledge gap in environmental sustainability, a circular economy and improved environmental ethics have been on the increase. Hence, the expediency to devise a feasible framework that would take into cognisance these challenges at all levels is long overdue. Such framework should provide the appreciation of the principles of sustainability, as it relates to biodiversity, non-renewable resources and the quality of human life, which currently, the coverage of life science education does not reflect (Bashir 2013; Engelbrecht et al. 2013; Nneji 2010;

Ramnarain and Padayachee 2015). As previously highlighted, the dearth of relevant education, awareness and risk perception amongst most South Africans needs to be addressed as a matter of urgency. There is an emerging agreement amongst educators and scientists that environmental sustainability challenges require now, more than ever, new ways of knowledge production and decision-making by involving interdisciplinary actors in order to integrate the available knowledge, to reconcile values and preferences, as well as, to create ownership for problems and solution options (Braaten and Windschitl 2011; Lang et al. 2012). The pursuit for environmental responsibility and sustainability remains the mandate of all and the institutions of learning remain amongst the best preference for acceptable and relevant incubation and dissemination of the cogency and urgency in mitigating plastic wastes and pollutions, in the environment, across South Africa. Hence, scientific knowledge should not just end up isolated as academic exercises in repositories, but should have impactful role on formative education, in both the formal and informal education curricula and management policies (locally, regionally and nationally), facilitating sustainable development and mitigating detrimental environmental ethics (Alberts 2005; Hamilton-Smith 2011; van Eijck and Roth 2007).

Where curriculum, in principle, results from social and behavioural activities, it should therefore, be designed for both present and emerging purposes and objectives. Curriculum, as a dynamic field, helps in illustrating a people's or nation's educational priorities, by articulating what policy-makers and authorities may regard as important knowledge for students (learners) and society. There should be minimum knowledge, skills, and values that students (learners) should possess and set-out guidelines, underscoring this knowledge acquisition through formulated subject contents and learning outcome should be clearly spelt out. Irrespective of how one desires to consider a curriculum, whether narrowly, as subjects taught in schools, or widely, as experiences that individuals require for full participation in society, it remains undeniable that a curriculum is the fundamental principle for educators and students (learners) and consequently, reflects its consequences on the society. Moreover, it is well-agreed that the way curriculum is defined, also reflects the approach to it, which can be behavioural, managerial, systemic, academic, humanistic or postmodern. Hence, it encompasses ideologically, the following definitional concepts (du Preez and Simmonds 2014; Fahey 2012):

1. It can be viewed as a plan for achieving set objectives and goals through a sequence of steps;
2. It can also be defined, widely, as dealing with the leaner's experiences. This definition underscores almost anything planned in and/or outside of school as part of the curriculum;
3. It can also be viewed as a field of study encompassing its own foundation, knowledge domains, theories, research, principles and specialists. Those who subscribe to this definition, conduct curriculum discourse in theoretical framework rather than in practical terms;
4. Curriculum can also be defined in terms of subject matter, such as mathematics, history, physics, environmental education and chemistry where such subject matter or content can be discussed at various grade levels to reflect the ideology being propagated.

Moreover, education outreach and awareness can effectively promote social change and improve environmental appreciation by involving psychologists and behavioural scientists to develop interventions through the structuring and crafting of environmental programs and messages. Such applied work should be empirically tested theories and principles and in the area of environmental issues, with emphasis on plastic pollutions (Schultz et al. 2005).

Furthermore, it is hereby suggested that the promotion and inclusion of plastics education and awareness in school curriculums in the South Africa's education system, would be a valuable tool in mitigating plastics pollution and wastes. By targeting societal behaviours of learners, this curriculum policy can be designed in such an effective manner to foster awareness, to enhance the basic understanding of the consequences plastic wastes and pollutions presents, and to promote and inculcate the civic duties in citizens. These, if meticulously followed, will protect the environment, thereby encouraging behavioural and social changes for improved ethical dispositions towards the environment and sustainable development (Kennedy 2007; Pettipas et al. 2017; Rowe 2007). As a matter of urgency, the government should initiate national actionable plans and policies, devoid of ambiguity and political interference, to synergistically embed plastics education for sustainable development in the education curriculum. No doubt, this will be a significant achievement for plastic education reform in South Africa.

Moreover, funding for environmental issues, education and awareness, should, as a matter of urgency, be the priority of governments across Africa. Whilst, the non-governmental organisations (NGOs) and other advocates on environmental concerns should collaboratively engage with communities (through their clan heads, local chiefs, traditional rulers and town union leaders), churches, mosques and local government authorities by initiating outreaches and awareness programs, both in rural and urban areas. These efforts should be inclusive of campaigns for citizens' right on proper knowledge and risk perception on plastics waste disposal, recycling, reuse and reclamation, amongst others.

Improving waste management strategies and systems

Municipal waste has been noted as the source for various pollutants, inclusive of suspended particulate matter and dissolved solids (Mishra et al. 2019). Howbeit, it has been

demonstrated that in order to improve solid waste management strategies and systems, environmental sustainability approaches should be priorities at all levels of governance, which requires sincere, dedicated, and genuine efforts and sacrifice (even if inconvenient). Such approaches have been suggested to include the establishment of permanent recycling centres through collaborations with communities and hence, promoting recycling mentality amongst the people.

Notwithstanding, it has been shown that for freshwater pollution by microplastics, a quick assessment of the impact of plastic waste in the environment through appropriate data collection and analysis is by using the rapid environmental assessment (REA) criteria. This has proved to be effective in scoring the abundance of key indicator species and their magnitude of environmental pressure, concurrently on the same logarithmic assessment scale. Hence, this assessment will inform better policy-making and decision taking due to the fact that REAs, not only capture low-resolution data but they also do provide a means of grading levels of management urgency and response required to be enacted. Thus, REAs for site-specific thresholds with tailored criteria (pressures and species indicators) can become an invaluable tool in determining which freshwater locations require remediation from plastics pollutions (Boldgiv et al. 2014; Khan et al. 2018; Price et al. 2014).

Furthermore, it is a common knowledge that prevention is better than cure, hence lending credence to the fact that capturing of plastic wastes at source will be more impactful in controlling plastic pollution rather than trying to address the problem after it has leaked into the environment. It has been posited that a comprehensive waste prevention strategy should include substitution, i.e. finding alternatives to hazardous materials or components employed in the product design. This is further supported by another study that argued that waste reduction at source should also occur during the design and production of materials by applying the concept of eco-design, which incorporates the idea of removing environmental associated problems from the product, without compromising cost or quality (Bârsan and Bârsan 2014; Hutner et al. 2017). Hence, by finding alternatives for plastic materials that are ecofriendly or possibly greener plastics, where possible, would be a good waste management strategy. In addition, such ecodesign should include the following concepts: environmentally benign materials or recyclable materials, reduction of material input, minimise wastes as possible during production processes, reduce packaging volume, optimise products functionality, prolongation of product's life (lifecycle) and generate minimal waste during usage (Wimmer and Züst 2001).

Promotion of a circular economy

As available resources dwindle and human activities build up wastes, the well-known linear model of economics of "take, produce and dispose" is becoming unsustainable and hence, requires new ways of thinking to surmount the current environmental challenges. Hence, the promising possibilities of a circular economy (a non-linear economic model) as a way for mankind to increase prosperity, whilst reducing demands on scarce raw materials and directly minimising the concomitant negative impacts on the environment, should be the way to go for South Africa (Ellen MacArthur Foundation 2016). Moreover, the unprecedented population growth in Africa, with predictions of its people exceeding over a 1 billion by 2050 (UNEP 2015), coupled with the projected growth in economies and the consequent usage of plastic by the growing middle-class (Deloitte 2014), make it impossible to ignore the urgency on the issue of rethinking South Africa's plastic economy. Generally, a model circular economy should summarily encompasses the following (Skene and Murray 2015):

1. Turning goods and materials that are at end of their service life into resources for other usages and applications by either breaking them down into energy sources or repurpose them into goods or supplying them as services;
2. Closing the energy and material loops in industrial ecosystems and minimizing waste by replacing production with sufficiency;
3. Reuse what we can, recycle what we cannot reuse, repair what is broken and re-manufacture what cannot be repaired.

In addition to being the ultimate low carbon economy and sustainable, a circular economy will also create more job opportunities (Di Maio and Rem 2015), by creating opportunities for infrastructural advancements, improve local economies, collaborative researches and even energy security (ESAUK 2018). Thus, a circular economy is the way to go for South Africa.

Innovations

The existing and emerging sustainable methodologies and processes employ one or a combination of mechanical, thermal and chemical treatments for the production of value-added products, from post-consumer plastic wastes into reusable virgin or second-grade plastic feed stocks. These include monomers, synthetic fuel/gas, hydrocarbon feedstock, generation of crude oil, electricity generation or as a heat source (energy recovery), and this is illustrated (Aishwarya and Sindhu 2016; Al-Salem et al. 2010; Brems et al. 2013; Dewangan and Yenkie 2018; Panda et al. 2010), in the schematics of Fig. 4.

Other alternative approaches have embraced the recycling and reuse of plastic solid wastes in the construction of roads (road-surfacing), making of roofing sheets, in building of houses, in making of polymer concretes and cementitious composites amongst others (Allam and Jones 2018; Appiah et al. 2017; Dissanayake et al. 2017; Muyen et al. 2016; Singh

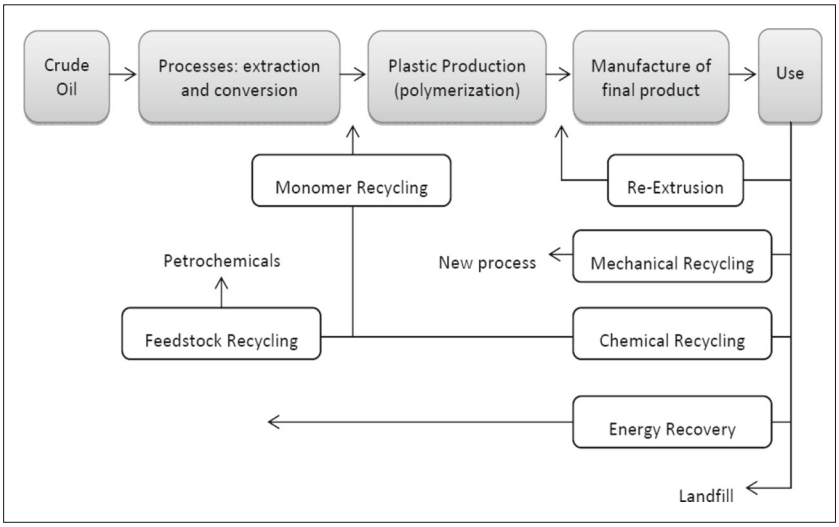

Fig. 4 Simplified schematic of recycling methods and their position within the processing line (sourced from Brems et al. (2013))

et al. 2016). These innovative ideas give South Africa the opportunities to harness her plastic wastes into wealth, while salvaging the environment and creating jobs and improving her plastic economy.

Monitoring and future research

Science and environmental studies across South Africa should as matter of urgency, reprioritise their research focus areas to addressing short- and long-term challenges that face the country. Researches should be more solution-oriented than abstract and/or academic exercises that add no value in proffering solutions to pressing societal and environmental challenges. Government and private sector funding for researches should be reviewed accordingly, in such a way to channel a better part of these funds towards researches that address national and possibly regional challenges of plastic pollutions.

Furthermore, more focused research is needed for data collection and risk-assessment of waste plastic debris in municipal drinking water, fresh water sources and recycle water plants. This will help bridge the knowledge gap in understanding the sources, quantities, and impacts of macro-, micro- and nanoplastics in the environmental and water systems (such as groundwater/surface water, drinking water and waste water treatment plants effluents). These studies would also enable adequate prioritisation and the effective deployment of land-based, coastal, and marine waste monitoring and management strategies.

In light of the foregoing, it is also important for studies on the life cycle impact assessment (LCIA) and life cycle costing (LCC) of plastics. It is therefore important that its wastes and pollution in South Africa be researched in order to develop a baseline for the management and remedial strategies to be employed. Where possible, priorities studies should not only focus on local studies but they should also include regional investigations on possible sources and circumstances responsible for transnational plastic pollutions of South Africa and her neighbouring countries. This is to enhance the capabilities and mitigation strategies. In addition, appropriate knowledge of various plastic composition (via widespread monitoring programs and strategies) will help to develop concrete policies involving a broad spectrum of plastic contamination and their environmental impacts.

It is also suggested that an understanding of the degradation pathways of different plastics in different environmental conditions will be invaluable and critical to help in developing workable frameworks and policies that need to be implemented nationally and/or regionally (Jambeck et al. 2018; Pettipas et al. 2017).

Conclusions

The menace and challenges presented by plastic pollution is a subject of global concern. The pollution of plastics transverses both the macro-, micro- and nano-levels. Although, there are limited studies in the areas of nanoplastic pollution, that of macro- and microplastic have been extensively reported. However, on the African continent, South Africa in particular, there are scarcely any studies or comprehensive data to assess, evaluate and mitigate the challenges of plastics pollution. For example, we have presented here the entrainment of plastics into consumable water and effluents of wastewater treatment plants and demonstrated that this area remains understudied in South Africa, and requires, not just a short-term approach but a more comprehensive approach that would involve all key players in meeting this challenge. And the threats plastic pollution pose in the demand of safe-drinking and sustainable consumable water system.

There is a need to bridge the knowledge gap in the study of plastic matter entrainments into consumable water cycles, including freshwater. A re-assessment of the filtration systems of South Africa's municipal wastewater treatment plants

remains paramount in order to ascertain ways and manner to improve on its filtration systems. There is still a local knowledge gap in the complexity of plastic debris entrainment into the food chain, which we have shown transverses many sectors, such as the textile, auto, cosmetics and marine industries. Furthermore, there is an urgent need for South Africa to use local scientific knowledge to develop comprehensive methods and techniques in tackling this emerging global threat locally. We have also demonstrated that there is no better time for South Africa to rethink her plastic economy than now. This is so, since it will in no small measure, comprehensively improve the mitigation of plastic pollutions from the source and its eventual entrainment into consumables such as water and wastewater treatment plants effluents.

In summarising the challenges and opportunities:

1. Implementation of a progressive re-evaluation of the approaches that are to be designed and developed to meet these challenges,
2. The continuous review of her (South Africa) circular economy of plastic materials by employing effective policies, laws and legislations that foster risk awareness and to put in place (and implement) collaborative engagements between the society and the scientific community,
3. Promote economic prosperity and initiate improved ethical behaviour via the trade-and-barter exchange of plastic wastes for goods and services, by its locals in townships and rural areas,
4. Refocus research priorities on solution-based studies, conceptualization and design of plastic materials employed both industrially and domestically and also build local capacity in meeting local challenges,
5. Finally, the re-evaluation of the education curricular in South Africa. This will have to reflect, motivate and effectively contribute to a sustainable future and nurture the drive for a circular economy by promoting improved environmental awareness and change ethics through learning, facilitated by sound education reform documents that are consistent with contemporary ethos, expectant of human beings, who are an essential integral part of the environment, which is long overdue.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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