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Perspective

Nanoscale development and its application in multidisciplinary area: An African perspective

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The need to fulfil and address the United Nations millennium goals in developing countries is essential and recently nanotechnology has proved and shown potential to change and improve many sectors of African industry, from consumer products to health care to transportation, energy and agriculture. In addition to these societal benefits, nanotechnology presents new opportunities to improve how we measure, monitor, manage, and minimize contaminants in the environment. This article then provides an extensive review of research needs for both environmental applications and implications of nanotechnology in Africa countries. The review evaluates water purification technology, nano health, food security and risk assessment. It was concluded that, nanotechnology is the future solution, however, countries must embrace the emerging technology with symbiotic involvement with scientific, industrial and institutional sectors.

Key words: Nanotechnology, nanoparticles, African countries, risk assessment.

INTRODUCTION

Nanotechnology promises significant improvements of advanced materials and manufacturing techniques with vast range of applications, which are critical for the future competitiveness of national industries (Miyazaki and Islam, 2007; Masoka et al., 2012; Naidoo and Kistnasamy, 2015). The manipulations and productions of materials, whilst controlling the optical properties and surface area to a nanosize scale (Schutte and Focke, 2007; Blatchley, 2013) enabled a birth of a new field known as nanotechnology. Furthermore, it provides the technological platform for the investigation and transformation of biological systems, with biology offering inspiration models and bio-assembling components to nanotechnology (Roco, 2003). Nanomaterials (NMs) have different strength, conductivity, colour and reactivity, thereby, can be 'tuned' to build faster, lighter and stronger (Schutte and Focke, 2007; Shetty, 2010). It is therefore not astounding to see the commercialised NMs increasing exceptionally from 54 in 2005 and possible to 3400 by 2020 containing mainly silver materials (Figure 1) (WWICS, 2011; Lopes et al., 2016). At the same time, the global production and usage of nanomaterials is

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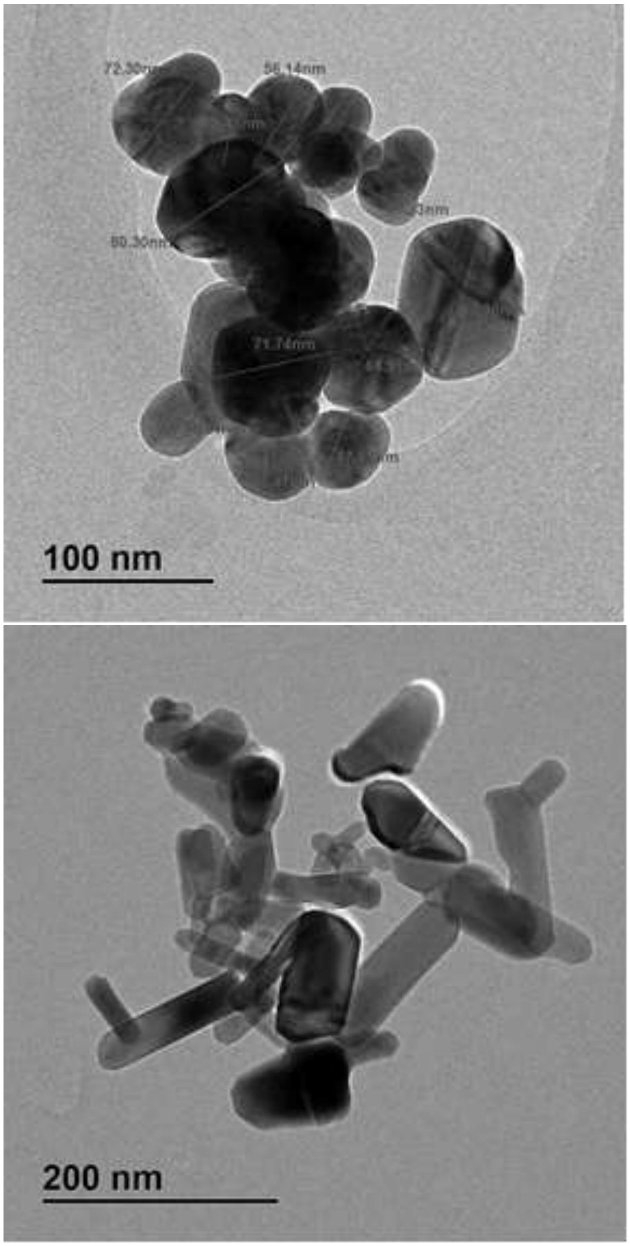

Figure 1. Scanning electron microscope image of silver nanoparticles.

estimated to increase to be thousands of tons in 2004, and projected to increase over half a million tons by 2020 (Maurer-Jones et al., 2013). These predictions therefore, show that nanomaterials will be released into the environment.

The ability to alter these materials' physical and chemical properties to have an enhanced large specific surface area, smaller size and high chemical reactivity has enable NMs to be manufactured and marketed in a wide variety of sectors such as electronics, cosmetics, pharmaceutical, information technology, agriculture, food, medical, water treatment and environmental protection (Naidoo and Kistnamav, 2015; Lopes et al., 2016).

As highlighted by Naidoo and Kistnamav (2015) that most of the pressing issues faced in Africa practically in the fields of health care, food agriculture, electronics, environment, water, industrial and energy can be addressed with the potential uses of nanotechnology. Furthermore, the major concern in the United Nations (UN) is to meet the Millennium Development Goals (MDGs) by 2015, five goals can significantly deal with the applications of nanotechnology for example eradicating extreme poverty and hunger, reducing child mortality rates, improving maternal health, combating HIV/AIDS, malaria and other diseases to ensure environmental sustainability (Singer et al., 2005). For the sake to revolutionise social, economic and environmental as well as scientific and technological sense, developing countries have realized the need to address their pressuring problems, therefore, a massive lead has been taken in developing, usage and marketing of the nanotechnological products (Singer et al., 2005; Schutte and Focke, 2007; Naidoo and Kistnamav, 2015). The multidisciplinary field is becoming an indispensable component of the global development discourse with focus being set on the expectations that the technology will be an instrument in alleviating poverty and promoting sustainable development especially in water, health and food sectors (Saidi, 2009; Grimshaw et al., 2014).

Freshwater resource is essential to be managed sustainably in order to maintain economic, social and environmental functions due to its contribution to the livelihoods of society (Hillie and Hlophe, 2007; Naidoo and Kistnamav, 2015). Even though the available water resource is approximately 1% freshwater and 97% salt water, the drinkable resources is still labeled as "scarce resource" and most of African countries are considered water scares or water stressed. Unfortunately, only 0.01% of water is available geographically for human usage (Hinrichsen and Tacio, 2002; Fenwick, 2006; Schwarzenbach et al., 2006). However, even though population growth and climate change has an effect on rapid rising withdrawals and increased demand per capita. It is the anthropogenic activities which greatly make detrimental effect on the quality and quantity of drinking water, for instance, partially treated industrial waste with toxic substances, agricultural practices and untreated domestic wastewater. The shortage and inefficiency of drinkable freshwater has significantly paralyzed health, social and economic aspects in most countries (Naidoo and Kistnamav, 2015).

Children under the age of five years are mostly the victims of death attributed to unsafe water, inadequate sanitations or insufficient hygiene (Prüss-Üstün et al., 2008). Water insufficiency and poor water quality leads to food shortage due to scenario such as drought and insufficient supply. With human, the population is expected to increase by 34% with respect to the present situation by the year 2050. As a consequence of that, there will be an increase in global demand for foods, water and energy (Gutiérrez et al., 2012; Naidoo and Kistnamav, 2015). Therefore, nanotechnology is capable to improve the productivity and efficiency of crop and livestock production (Naidoo and Kistnamav, 2015; He and Hwang, 2016), remove, minimize pollutants and purify water (Grimshaw et al., 2014; Naidoo and Kistnamav, 2015), reduce drug loading and efficacy in medicine (Abuduxike and Aljunid, 2012), whilst increasing the safety, bioavailability, nutritional value, and affordability to meet with future population growth trends. The advantages of various NMs and their application in water technology, health care and food security including their possible risk associated with their usage will be evaluated. Moreover, the involvement of sectors and the current African countries activities and involvement with regards to nanotechnology.

NANOMATERIALS IN WATER PURIFICATION AND POLLUTANTS REMOVAL

Most of the developing countries are facing formidable drinking water challenges and rising demands (Tiwari et al., 2008). There are 1.5 million deaths each year, 4.3% are water related deaths due to repeated diarrhea or intestinal nematode infections and other diarrheal diseases resulting to a total number of deaths to be 860 000 deaths (Prüss-Üstün et al., 2008). Regardless of the efforts to alleviate poverty, two fifths suffer consequences of unacceptable sanitary condition and one-sixth of the world population lack access of safe water (UNESCO, 2003; Li et al., 2008). In 2002, 1.1 billion people lacked access to a reliable water supply, in other words, 40% of people in Africa lacked access to a reliable water supply (Hillie et al., 2006). It is also reported that most children often miss school because their schools do not have adequate drinking water and/or sanitations facilities (Hillie and Hlophe, 2007). Municipal wastewater and industrial processes often discharge their undesirable effluent which impact the aquatic environment, while the latter requires staggering amount of water to pre-treat the waste prior discharging (Tansel, 2008). However, the main issue related to water pollution is not the cumulative of one contaminant, but it is the synergistic effect of two or more contaminants that become toxic to both the environment and human. Disinfection is not only paramount in the final effluent in wastewater or at the potable treatment but invention such as synthesized dendrimers comprising of antimicrobial agents that inhibits growths of microbes to prevent or reduce biofilm formation in water distribution and storage systems (King and Hill, 2006) .

There are conventional treatments that are currently being used for water and waste treatment such as but not limited to ceramic filters, distillation, biosand filtrations, UV radiation, chemical treatment, reserve osmosis and activated carbon filters. However, there limitations ranges from high maintenance, low flow rates, leaching of toxic chemical into water, time consuming and some produces undesirable taste and odors (Meridian Institute, 2006; Naidoo and Kistamanv, 2015). Furthermore, these treatments are unable to remove dissolved salts, organic and inorganic substances (Hillie et al., 2006). Research is underway to use nanosized advanced new materials of nanotechnology to provide potential application of nanoscience to solve technical challenges associated with the removal of water contaminants (Tiwari et al., 2008; Mpenyana-Monyatsi et al., 2012). This method is inexpensive, portable, more effective, convenient to use, efficient, durable and easily cleaned systems which purifies, detoxify, and the desalinate water more efficiently than conventional bacterial and viral filters (Singer et al., 2005; Qu et al., 2013). Researchers have developed technologies that aims to offer a variety of techniques and applications which most have been extensively used and/or tested in developing countries to purify water, for instance, nanofiltration membranes, nanoadsorbents, nanocatalysts, granules, flakes, magnetic nanoparticles, nanopowder, and nanotubes (Hillie et al., 2006; Tiwari et al., 2008). Nanosensors are used to detect chemical and biological contaminant substances including metals (for example cadmium, copper, lead, mercury nickel, zinc), nutrients (for example Phosphate, ammonia, nitrate, nitrite), cyanide organics, algae (for example cyanobacterial toxins), viruses, bacteria, and parasites (Tiwari et al., 2008).

NANOPOUROUS

Nanoporous materials such as zeolites, attapulgite clay and nanoporous polymers can all remove contaminants in polluted water with high efficiency of greater than 80% (Singer et al., 2005; Water Wheel, 2008). For instance, as illustrated in Figure 2, when ceramic materials are impregnated with reactant materials, they are able to harvest aerobic bacteria which biologically convert pollutants into nontoxic substances and remove phosphate, lead, arsenic, and other contaminants (Meridian Institute, 2006). Nanoporous function can be compared to nanosorbent using zero-valent and nano iron that are proficient in removing solvents from pumped groundwater and are well capable onto adsorbing organic and inorganic molecules (Lukhele et al., 2010; Water Wheel, 2008). Zero-valent iron absorbs and reduce organic contaminates causing them to breakdown into less toxic simple carbon compounds and heavy metals to agglomerates and stick to soil surfaces (Meridian Institute, 2006).

Zeolites nanoporous are inorganic crystalline porous materials with a highly ordered structure (Figure 3). They are comprised of silicone, aluminium and oxygen. These materials are effective sorbents and ionic exchange

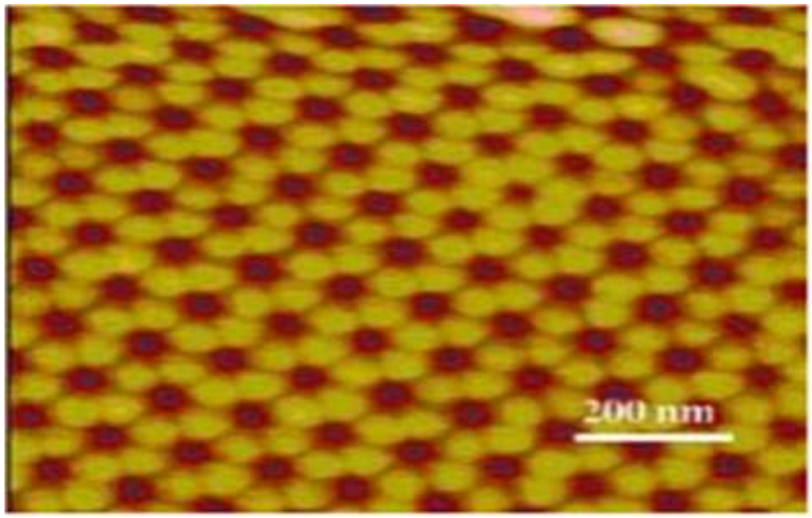

Figure 2. Nanoporous membrane (Holister et al., 2003).

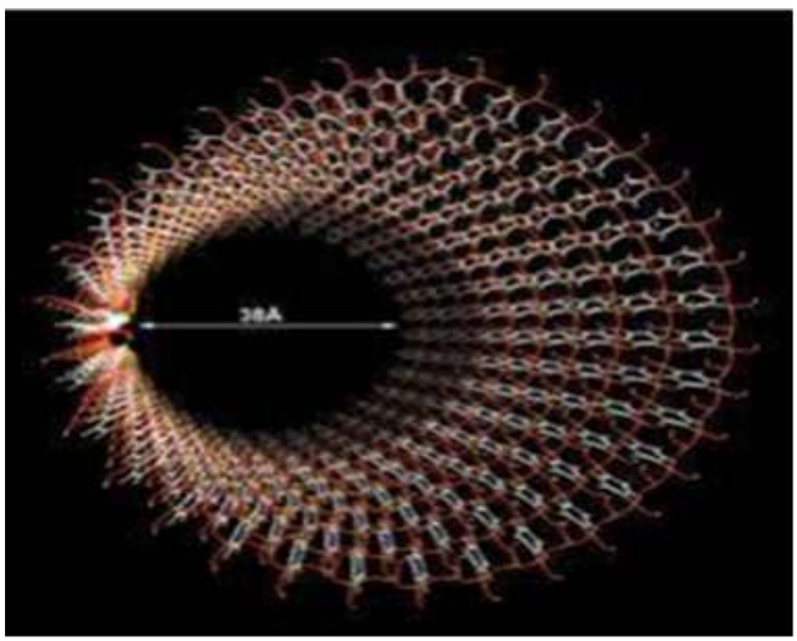

Figure 3. Ordered mesoporous organasilica hybrid material with a crystal like wall structure (Holister et al., 2003).

media for ions separation and catalysis (Tiwari et al., 2008). Consequently, nanoporous zeolites incorporated with fly ash has been used in the removal of heavy metals such as chromium, copper, nickel, mercury, zinc, silver and arsenic from acid mine waste and wastewater (Meridian Institute, 2006; Tiwari et al., 2008; Lukhele et al., 2010). In addition, they are effective absorbent, capacity of which is dependent on composition, pH, concentration and type of pollutant intended to be removed (Meridian Institute, 2006). Research study conducted in Japan demonstrated that ceramic containing silver zeolite had antimicrobial activities that inhibited several functions in the cell and consequently damages cells (Matsumura et al., 2003).

Nigeria, South Africa, and Israel are currently studying nanoporous materials for water filtration, while Algeria is studying the locally available attagulgite clay to filter wastewater from milk factory to offer an economic and effective solution by reducing most organic matters (Hillie et al., 2006).

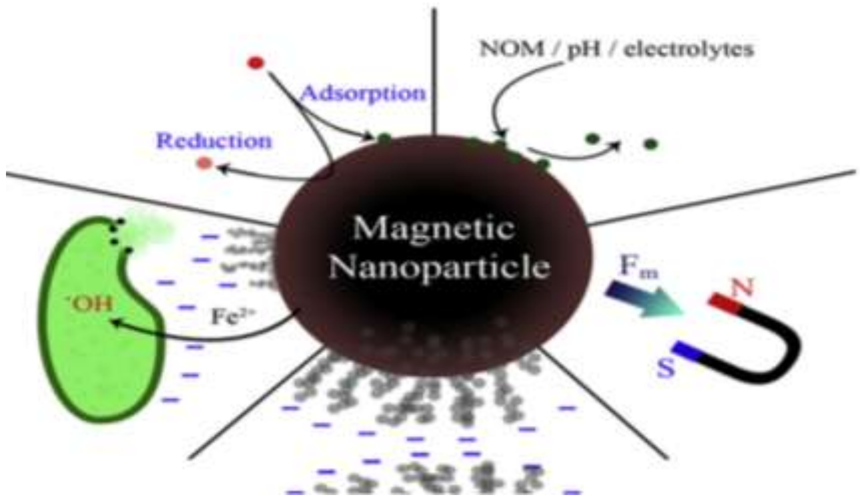

Figure 4. Contaminants removal mechanisms of magnetic nanoparticles (Tang and Lo, 2013).

NANOCATALYST AND MAGNETIC NANOMATERIALS

Catalyst is a substance that promotes the chemical reactions of other materials without becoming permanently involved in reaction (Hillie et al., 2006). Nanocatalysts and magnetic nanoparticles coated with different compounds for instance, natural chitosan have been used to remove pollutants from aqueous environment and ground water due to the presence of selective affinity for diverse contaminating substances (Figure 4) (Singer et al., 2005; Meridian Institute, 2006; Grimshaw, 2009; Hillie et al., 2006).

Nanocatalysts have been found to have a very good degradation and reduction potential, more reactive, remove a wider range of environmental contaminants, easier to inject and achieve deeper subsurface penetration (Meridian Institute, 2006; Lukhele et al., 2010; Qu et al., 2013). Furthermore, additions of chemicals are not required, easy to operate and maintain and it is selective on the substances to be removed (Zhang et al., 2013). They however, require supporting substrates for their application in water treatment (Lukhele et al., 2010). Several research conducted photocatalytic and photodisinfection by Beckbölet and Araz (1996), Matsunaga and Okochi (1995), and Wei et al. (1994) reported inactivation of *Escherichia coli* and other microbial cells with the presence of TiO_2

It has been reported that, combining nanomagnetic materials with citric acid allow metallic ions binding and produce a high affinity, therefore, making able to remove heavy metals from soil and water (Figure 4) (Singer et al., 2005). Furthermore, these materials are recycled and reusable, hence, reduces treatment cost, eliminate energy related cost (Singer et al., 2005; Meridian Institute, 2006; Water Wheel, 2008). Magnetic NMs sorption capacity is higher, therefore, are considered effective adsorbents at low pH and irreversible sorption providing an efficient storage sink for collection of waste (Hillie et al., 2006).

Nanosensors and nanofabrication are some of the technology developed to purify polluted waters. Manipulating nanosized materials to detect and identify the pollutants which allow the nanosensors to progressively remove dissolve salts, degrade broad aspects of water contaminants, capture particles and presence of pathogenic microbes to achieve cleaner water and treat wastewater. It is by the innovation of such technology that gives a real-time detection of the presence of contaminants and pathogens without laboratory testing sample and time consuming technique. Sensors using nanometer scale detectors will enhance and improve health, maintain safe food and water supply, whilst allowing for use of otherwise unusable water resources (Hillie et al., 2006; Qu et al., 2013). Multiwalled carbon nanotubes and single walled carbon nanotubes have been functionalized with cerium dioxide, hydroxyl, phosphate functional groups to remove heavy metals and organics from water (Lukhele et al., 2010). Other NMs that are bioactive, such as silver and magnesium oxide, can kill bacteria and might be used in place of chlorine to disinfect water (Lukhele et al., 2010; Water Wheel, 2008).

NANOFILTERS

The intelligence of nanofiltration (NF) membrane also known as polymeric permeable membrane has made a breakthrough in drinking water production for the removal of pollutants, provides possibility of refining, improving water, speed and accuracy (Figure 5) (Van der Bruggen and Vandecasteele, 2003; Mousavi and Rezaei, 2011). Nanofiltrations are capable to filter both bacterial and viral

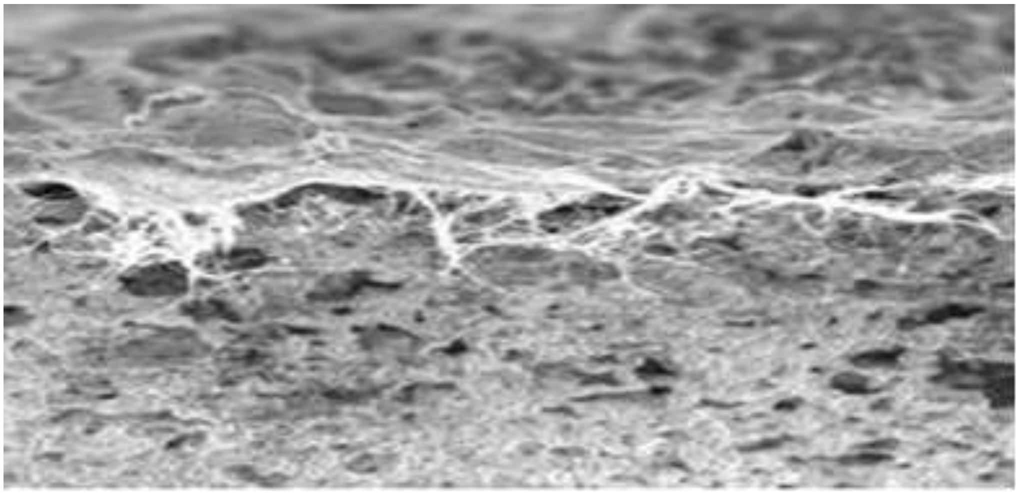

Figure 5. Plasma treated nano filters cross-sectional image of the membrane (adapted from Image courtesy of CSIRO Australia).

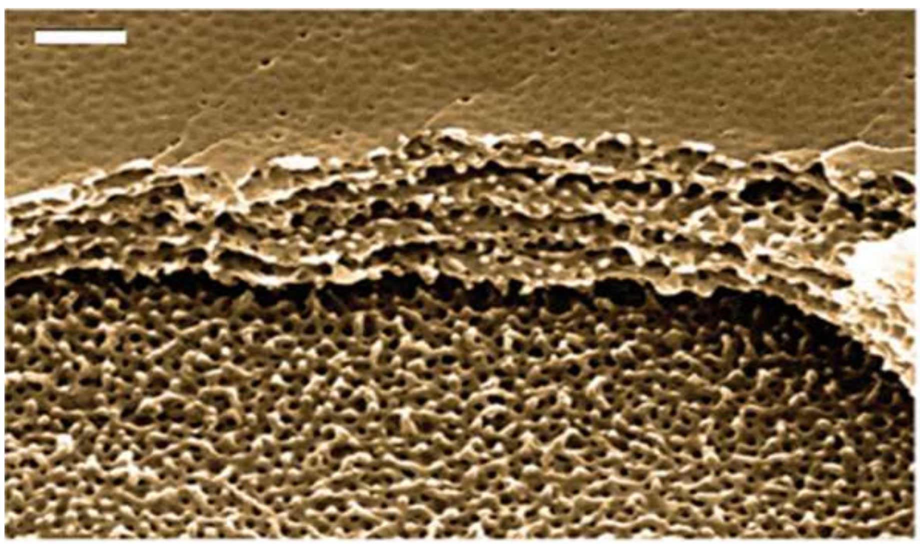

Figure 6. The microstructure of collective osmotic shock generated perforated multilayers (Zava-River et al., 2011).

pathogens (Van der Bruggen and Vandecasteele, 2003; Singer et al., 2005; Grimshaw, 2009), hard, natural organic material (NOM), micropollutants such as pesticides and VOCs, salt, nitrates, and arsenic can be simultaneously or partly removed (Van der Bruggen et al., 2001; Van der Bruggen and Vandecasteele, 2003). These membranes are cheaper to operate, energy saving, have fast flow rate, durable, easy to clean, reusable, and heat-resistance when compared to reverse osmosis membranes (Figure 6), making them to be the latest innovation in the membrane technology and promise to have a huge potential in the desalination of brackish waters (Sonune and Ghate, 2004; Meridian Institute, 2006; Hillie et al., 2006; Lukhele et al., 2010). Research conducted by the Stephen and Nancy Grand Water Research Institutes of Israel on the treatment and conversion of salt water to freshwater for drinking and irrigation purposes using reverse osmosis (Hillie et al., 2006). Indian research have illustrated that the advanced treatment of wastewater used for additional removal of organic and suspended solids, nitrogenous oxygen demand, nutrient and toxic materials (Sonune and Ghate, 2004). Recent development by Green Turtle Technologies Limited has designed to treat acidic wastewater and allows better control over the effluent pH. This innovative system has replaced the need for large tanks, caustic injectors and mixers with a very small-automated system. Similarly, disinfection/filtration systems invented by Lindqvist and Sparrman, demonstrated effectiveness as the primary unit comprising of zeolite filter bed that pass through to UV lamp for further disinfection.

NFs are able to retain nutrients present in water that are essential and required for normal functioning of the body (Hillie et al., 2006). Uniformly vertically aligned and tightly packed carbon nanotubes coated with silicon wafer are able to remove almost all kinds of water contaminates. This technology is currently manufactured by university of Stellenbosch and University of North-West University in South Africa (Hillie et al., 2006). Also, these technologies are suggested to be an alternative for reverse osmosis and can be used for desalination (Meridian Institute, 2006). National University of Science and Technology in Zimbabwe conducted waster filter research using ceramic magnetite from abundance iron ore which was excavated from Buchwa mine in Zimbabwe at Dorowa. These researchers inverted communal ceramic water filters that addressed not only the poor quality water issues but also the social impact (South African Department of Science and Technology, 2003).

Nanotechnology has lessened some of the labour intensive and chemical required techniques to clean water. As a result, more people are expected to access clean drinkable water in African countries and more countries are warning up to water technology. Investment calculation study done by Van der Bruggen et al. (2001) indicated that the final price for treatment of ground water is realistic, showing that nanofiltration is a valuable option for ground water treatment. With regards to water quality and quantity it affects people livelihood and also their health status should be taken into consideration.

NANOMATERIALS IN HEALTH IMPROVEMENT

People depend on water in four key ways: as an input into-production to sustain livelihoods, to maintain health and welfare, and to ensure ecosystems integrity. Lack of drinking water and sanitation kills 4,500 children a day, mostly as a result of waterborne diseases (Hillie et al., 2006). Diseases among others are continuously dealt with in developing African countries such as human immunodeficiency virus infections and acquired immune deficiency syndrome (HIV/AIDS), malaria, and tuberculosis (TB) are major causes of mortality and morbidity (Hauck et al., 2010). The main concerns with the modern medicine are the inability of the human system to absorb the entire dosage of a drug due to low bioavailability (Shetty, 2010).

The effective and efficient nanotechnology has enlighten and encouraged the development of drugs at a nanoscale that are cost effective, more bioavailable, longer lifespan, improved delivery, reduces their toxicity, dosage and drug loading. Furthermore, it improves the patients' compliances to successfully complete treatment and uptake of fewer drugs per treatment. Diagnosis and screening of disease are achieved more rapidly and sensitively through the assimilation of manipulated engineered NMs that are capable to recognize, screen diseases at a molecular and cellular level and henceforth, produce a reliable visual imagining of the affected organs (Musee et al., 2013).

DIAGNOSIS AND SCREENING

There is an urgent need to diagnose infectious diseases at their primary stage in developing countries (Shetty, 2010). The use of gold NMs makes the detection of diseases simpler, whilst fluorescence quantum dots, carbon nanotubes and other nanowires are used as biosensors tagged to antibodies that target infected cells with TB or HIV could also be used for detecting malaria (Hauck et al., 2010; Shetty, 2010). Hauck et al. (2010) postulated that NMs have been used to construct sensors in three different platforms for simple infectious diseases diagnostics: (1) NMs labels in immunochromatographic tests (ICT) assays, (2) NMs aggregation assays and (3) NMs labels of whole pathogens. Diagnosis and screening of infectious disease is followed by drug delivery.

DRUG DELIVERY

There are sensitive aspects taken into consideration with most of the drugs intended to deliver drugs in the human systems. For example, the NMs must be able to degrade naturally at the target site and should not become a biopersistant in the system. Then, the excess drug should be able to be excreted out of the body system. Nanosized drug delivery systems developed to improve and treat varies, namely, polymeric NMs, solid lipid NMs, liposomes nanoemulsion, dendrimers, clydextrins and inclusion, nanosupensions, nanocapsule, buckyballs and drug conjugates (das Neves et al., 2010; Santos-Magalhães and Mosqueira, 2010; Shetty, 2010).

Encapsulated drugs with biodegradable polymers for enhanced and sustained delivery of medicine of TB, HIV and malaria are being studied in South Africa at DST/CSIR at one of the African Network for Drugs and Diagnostics Innovation (ANDI) Centre of Excellence for Health Innovation in Africa, and now is called ANDI Centre of Excellence in Nanomedicine Research (Cele et al., 2009; Musee et al., 2012). Moreover, the Nigeria, Egypt, Botswana, Kenya, Tanzania, and Swaziland are among the African countries that are planning to have national strategies and government funding, having research group engaged or pursuit in nanotechnology (Shetty, 2010). Zimbabwe's government allocated about

60% of new program budget to nanomedicine (Makoni, 2012).

NANOMATERIALS IN FOOD SECURITY

Water is nexus and inter-connectivity with food security as it is imperative to achieve a sustainable use of natural resources, improve the environment and sustain ecosystem functions and services, which addressed the livelihood and malnutrition status (Lal, 2015; Belal and El-Ramady, 2016). Additionally, Belal and El-Ramady (2016) also highlighted that the close relationship is between soil security, water security, energy security, climate security, economic security and political security. Therefore, agriculture is a fundamental aspect connected with all human societies and securities (economic and political) that are characterised more than ever with increasing world population and are closely linked with food security (Mousavi and Rezaei, 2011; Belal and El-Ramady, 2016).

According to Prüss-Üstün et al. (2008), childhood underweight causes about 35% of all deaths of children under the age of five years worldwide. Freshwater withdrawals for agricultural purposes amount to about 88% which is higher compared to other water users of all annual withdrawals (Hinrichsen and Tacio, 2002). Conversely, the food safety and security is still an issue due to the supply and sufficient supply without demeaning soil health and agroecosystems (Shephard, 2003; Kashyap et al., 2015).

The battle to eradicate malnutrition and prevent the toll deaths of children can be resolved by incorporating nanotechnological materials as agrinanotechnology (Belal and El-Ramady, 2016). Nanotechnology in agriculture and food production is intended to improve soil retention; prevent extinction and destruction by means of genetically modified plants and animal species. This technology will provide the efficiency of the agricultural products for higher population growth that is imprisoned by poverty (Mousavi and Rezaei, 2011). Such as, production of the nano-encapsulate for nutrient components alteration, enhance flavours in consumers' food to suits their tastes, food packaging that will detect pathogens, assist in soil retention, soil fertility and production with nano- seeds that have built-in pesticides that is only released on favourable environmental conditions (Scrinis and Lyons, 2007; Belal and El-Ramady, 2016).

Mousavi and Rezaei (2011) postulated that the use of nanotechnology in agriculture and food industry can revolutionize the sector with new tools for disease detection, targeted treatment, enhancing the ability of plants to absorb nutrients, fight diseases, and withstand environmental pressures and effective systems for processing, storage and packaging. Conversely, nanotechnology is rapidly moving from the laboratory and onto the farm, supermarket shelves and the kitchen table (Scrinis and Lyons, 2007), and will be increasingly available to consumers worldwide with large international interest and investments from governments and global corporations (FAO/WHO, 2012; Belal and El-Ramady, 2016).

NANO AGROCHEMICALS FOR SOIL

Soils contains complex matrix such as mineral particles and colloids in pore water, therefore, the adsorption and binding of pollutant with the matrix is of concerns (Sharma et al., 2015; Belal and El-Ramady, 2016). Thus, continuous application of variety of chemical in the fields leads to a loss of UV degradation, hydrolysis, microbiota interaction or leaching. As a result, it negatively affects the environment in the form of soil degradation and water pollution (Gutiérrez et al., 2012). Therefore, the invention of an "intelligent" pesticides which are intended to increase their toxicity, better efficacy, use less solvent in spraying and better control of dose (Scrinis and Lyons, 2007; Chaudhry and Castle, 2011) is more appropriate. Encapsulating the pesticide, herbicides, and fungicides will enable to increase the availability, target and deliver in controlled manner by environmental conditions such as heat levels and moisture. But the mobility of NMs is dependent on the attachment between the soil molecules, shape of the NMs, collector and the different properties that change environment surrounding the particles (Belal and El-Ramady, 2016). Nanopesticides adsorb easily by root systems, increase their effectiveness and reduce the dosage and usage of pesticides (Scrinis and Lyons, 2007). For instance, metal oxides NMs (Fe_3O_4, CuO, ZnO and TiO_2) mobility is influenced intensively by humic acids, aquifers and ionic strength of resident water (Ben-Moshe et al., 2010).

As stated by Belal and El-Ramady (2016), the generation of co-productivity, but anthropogenic use of primary resources (soil, water, climate) and secondary inputs (fertilizers, irrigation, tillage, amendments) must be optimised. This technology promises a production approach in remediation of contaminated soil and groundwater. Nanoporous materials such as zeolite materials used in food agriculture industries have been shown to more efficiently slow, controlled release of fertilizers, efficient in livestock feeding and delivery of drugs (Singer et al., 2005). According to Gutiérrez et al. (2012), less herbicide is required to achieve the desired weed reduction effects. If the active ingredient is combined with a smart delivery system, herbicide will be applied only when necessary according to the conditions present in the field (Singh et al., 2015; Belal and El-Ramady, 2016). Soils infested with weeds and weed seeds are likely to produce lower agricultural yields than soils where weeds are controlled. Improvements in the efficacy of herbicides through the use of nanotechnology could result in greater production of crops and less injury to agricultural workers who are physically removing the weeds if herbicides are not used.

Nanotechnology plays a role in recycling the residual materials of agricultural products to energy and industrial chemicals. With the use of newly-developed solvents and a technique called electro spinning, cotton nanofibers can be used as a fertilizer or pesticide absorbent for encapsulating chemical pesticides, to prevent the scattering of chemical pesticides in the environment, water and soil. Porous nano-polymers have a very similar function to the pollutants molecules, and considered as the most suitable means for separating organic pollutants of soil and water. Nanoporous materials capable of storing water and slowly releasing it during times of drought, therefore, it can be expected to increase yields (Gruére et al., 2011). For example, nanoporous zeolites are used for slow release and efficient dosage of water, fertilizers for plants, release of nutrients and drugs for livestock (Hong et al., 2013). Furthermore, zeolite NMs improves water-retention capacity of soils to increase crop production in areas prone to drought, such as sub-Saharan Africa (Gruére et al., 2011). Similarly, nano fiber-based fabrics are being used as a detection technology platform to capture and isolate pathogens embedded with antibodies against specific pathogens (Mousavi and Rezaei, 2011). Moreover, silica porous membranes are used for filtration to disinfect water and unwanted components in plants extraction and clarifying wines and beers (Chaudhry and Castle, 2011); also, silver and iron nano particles are used in the treatment and disinfection of livestock and poultry (Chaudhry and Castle, 2011; Mousavi and Rezaei, 2011).

NANO FOOD PACKAGING

Nanocomposites, defined as polymers bonded with nanomaterials to produce materials with enhanced properties, have been in existence for years but are recently gaining momentum in mainstream commercial packaging use (Butschli, 2004). Flexible packaging consumption's rapid growth represents a $38 billion market in the global community (Thibeault, 2004). As the demand in the industry continues to rise at an average of 3.5% each year, flexible materials need to meet and exceed the high expectations of consumers and the stressors of the supply chain (Butschli, 2005). The longevity and freshness of foods in shelves are essential; therefore, the composite in nanoscale will be applied on the parking as a barrier. These materials will increase the strength and quality in packaging (Scrinis and Lyons, 2007). NMs applications incorporated for packaging barriers using silicate NMs, nanocomposites, and nano-silver, magnesium- and zinc-oxide and nano-silver, magnesium to increase the packaging quality, improved mechanical and functional properties, improve flexibilities, temperature and moisture, enhance stability, with incorporating metal and metal oxides for antimicrobial agents (Chaudhry and Castle, 2011). Oxygen is a problematic factor in food packaging, because it can cause food spoilage and discoloration (Mousavi and Rezaei, 2011). Food tends to produce the chemical fumes called ethylene gas, which lead to the freshness wearing off and increases the decay, then introduce pathogens and decrease their life span before reaching the retailer shelves and consumers. Therefore, food packaging is essential for national and global transportation distribution. Whilst, delivering fresher, safe and pathogenic free food products, nanotechnology applied in packages will be able to repair small holes/tears, respond to environmental conditions (for example temperature and moisture changes), and can alert the customer if the food is contaminated (Scrinis and Lyon, 2007; Mousavi and Rezaei, 2011). Nanotechnology furthermore, promises to develop and manufacture packaging which are cost effective and that aim to improving the quality, durability and shelf life longevity (Scrinis and Lyon, 2007).

Nanomaterials and polymers are formulated to a boarder variety that exits in forms of nano-textured, nano-carrier, organic NMs, inorganic NMs and liposomes, etc. Processed nano-structured food products are soluble with less fats and emulsion with enhanced taste and it is healthier coupled with antimicrobial effect to pathogens. For instance, nano-encapsulated liposomes or biopolymers and nano-carries with supplements and nutrients are able to mask and protect tastes of ingredients/additives during processing, improve optical appearance, improve bioavailability, uptake and increase adsorption (Chaudhry and Castle, 2011).

Nano radio frequency with identification tags also known as RFid, tracks the deterioration in food quality before the food is sold, it is eco-friendly device that can be consumed (Scrinis and Lyons, 2007). Nanobarcodes are cheap, efficient, rapid, easy decoding and can be used for detection of diseases, moreover, can tag multiple pathogens in a farm which can easily be detected using any fluorescent-based equipment (Mousavi and Rezaei, 2011). RFid can ultimately increase the efficiency of management and buying arrangements for the large-scale retailers able to absorb the costs of these nano-monitoring and identification techniques and, hence, enable tracking food products in supply chain (Scrinis and Lyons, 2007; Chaudhry and Castle, 2011).

On the other hand, nanosensors devices are one of the technologies that will help the agricultural industry to combat viruses, crop pathogens and pests, chemical contaminant, chemical, physical and biological, nutrient content, and plant stress; due to drought, temperature, and lack of nutrients by using the integrated sensors working at the nanoscale meter (Scrinis and Lyons, 2007; Gruére et al., 2011; Mousavi and Rezaei, 2011;

Neethirajan and Jayan, 2011). Additionally, the sensors can detect chemical odours produced by fungi and insect which promote food spoilage in storage; also it is able to measure changes in carbon dioxide to detect incipient and ongoing deterioration (Bouwmeester et al., 2009; Mousavi and Rezaei, 2011). The study conducted by Gonzalez-melendi et al. (2008) explores the possibilities of using carbon coated iron nanomagnetic materials to track infectious disease on plants and crops. Their findings reveal that magnetic nanomaterials can be used for fruit trees and green house plants. The accumulation and guidance of materials to a specific area of interest can be achieved by magnetic gradient in plants.

Nanosensors have the potential to allow farmers to utilize inputs more efficiently by indicating the nutrient or water status of crop plants over fine spatial and temporal scales, by transmitting to a satellite through a signal towers to the farmer's cellphone to alter the present condition in the storages, allowing the farmer to apply nutrients, water or crop protection measures (insecticide, fungicide, or herbicide) only where necessary (Gruére et al., 2011). GPS connected with nuclear links systems to a satellite have put another step closer for farmers to harvest and plant without uncertainties of weather changes. System controller provides information on each growth factor such as nutrition, light, temperature, planting and harvest time to avoid encountering bad weather conditions. Best time to achieve the highest yield, best use of fertilizers, irrigation, lighting and temperature are all controlled by these systems (Mousavi and Rezaei, 2011).

As a result, it increases the security of manufacturing, processing, and the shipment of food, by enabling early detection of contaminants, and the removal of infected products from the food chain. These 'smart' sensors will then alert the retailer by causing the sensor strip to change colour as a result, giving a clear visible signal of whether the food is fresh or not (Scrinis and Lyons, 2007; Neethirajan and Jayan, 2011). Henceforth, providing solutions to modify the permeation behaviour of soils, increase barrier properties (mechanical, thermal, chemical, and microbial), improve mechanical and heat-resistance properties, develop active antimicrobial and antifungal surfaces (Mousavi and Rezaei, 2011).

NANO VETERINARY

Production of materials that are able to protect animals and livestock and poultry is paramount to food manufactures, animal domestication and veterinary. Nanotechnology has the potential and ability to provide appropriate solutions for providing food items, veterinary care and prescription medicines and vaccines for domesticated animals (Mousavi and Rezaei, 2011; Hong et al., 2013).

Mousavi and Rezaei (2011) stated that nano capsules are used to cap and protect some particular enzymes and proteins to render them effective in the livestock and poultry food rations in order to increase yield and effectiveness in the specific context. Taking certain medications such as antibiotics, vaccines, and probiotics, would be more effective in treating infections, nutritional and metabolic disorders, when use in the nano level. Medicine used in the nano level has multilateral properties to remove biological barriers for increased efficiency of medicine. Appropriate timing for the release of drug, self-regulatory capabilities and capacity planned are the main advantages of using nanotechnology in the drug treatment. However, it is paramount that the quality assurance in food and bioprocessing industry because consumers demand safe and wholesome food as well as governments impose stringent regulations to ensure food safety and feed hygiene (Neethirajan and Jayan, 2011).

THE GOVERNMENTAL AND INSTITUTIONAL INVOLVEMENT ACROSS AFRICA

Necessary conditions to the development of adapted and appropriate technologies are the presence of sufficient research and development investments, whether in the public or private sectors (Gruére et al., 2011; Fonseca and Peraira, 2014). Lack of support for nanotechnology science and applications in developing countries could force these countries to either abandon nanotechnology options or import (transfer) existing technologies from other countries (Suri, 2006; Cozzens and Wetmore, 2010; Cao et al., 2013). There is lack of emphasis on societal issues and risk assessment principles yet economies and public sectors have heavily invested in nanotechnology.

Meanwhile, Saidi (2009), emphases the point on strengthening world-wide capacities in science, technology and innovation provide prospects for human development of which nanotechnology is expected to play an instrumental role. Technology developed is paramount as it can be transferred to countries that needs it the most; however, appropriate and effective approach such as, technological adaptations, technical capability, infrastructure and market potential to prevent an unforesee failure for the technology are needed (Hillie and Hlophe 2007; Gruere et al., 2011).

The involvement of private sector is tricky because their main concern is whether there is sufficient infrastructure, basic capital, and sufficient economic incentives to invest into nanotechnology. The uncertainties of investment and technologies make it a little impossible for domestic companies to invest into long-term research and development programs and lack of access to capital (Gruere et al., 2011). However, African countries such as Egypt, South Africa, Botswana, Nigeria, Morocco, Tunisia, Kenya, Sudan, Algeria, Ethopia, and Zimbabwe have invested in local research teams involved in nanotechnology.

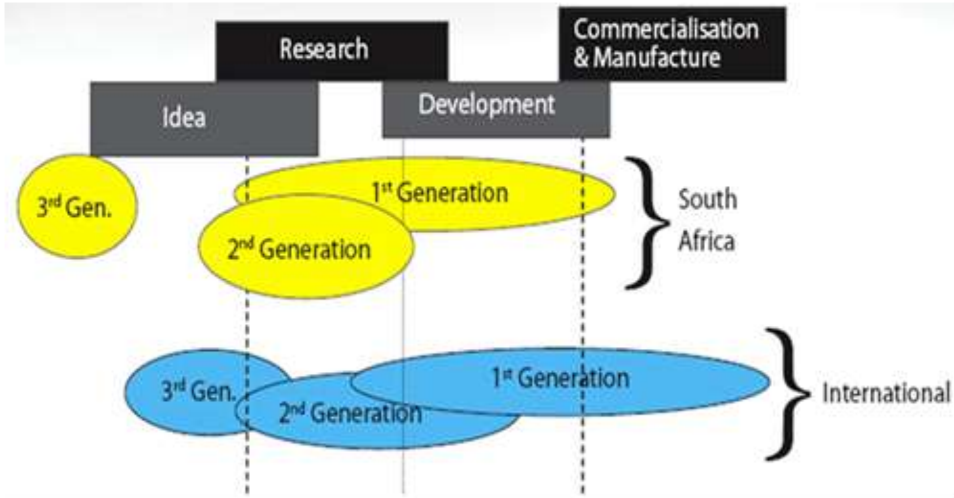

Figure 7. Progress of nanotechnology in South Africa related to the world (South African Department of Science and Technology, 2003).

South Africa

By far South Africa is one of the first African countries that has received the introduction of nanotechnology well (Figure 7). The government entity funded most of the stakeholders, research institutions and academic institutions for more research for its benefits and risk associated with the usage; moreover, Department of Science and Technology (DST) had placed a 10 year plan for nanotechnology that had given birth to other bodies. South African approach to nanotechnology shows how the country's policy is influenced, albeit timidly, by national interests (for example risk assessment, occupational health and strategic social focus) (Musse et al., 2013). The researchers are broader from water purification, energy, health and agricultural practices and mining.

In 2002, South African Nanotechnology Initiative (SANi) was launched, followed by National Nanotechnology Strategy (the Strategy) published in 2006, with the aim to support and promote nanotechnology R&D, develop human capacity in this field and promoting flagship at national level (South African Department of Science and Technology, 2003). Later on, National Innovation Centers (NICs) were developed containing two centres: (i) National Centre for Nano-Structured Materials (NCNSM) at the Council for Scientific and Industrial Research (CSIR), (ii) Mintek, and serve as national multi-user research facilities. Both NICs are financially supported from the DST and have established partnerships with private companies, for example, SASOL, ECO-Structure International, Biomass Corp., and De Beers. CSIR at the Natural Resources and the Environment (NRE)/DST in 2007, collaborated with academic institutions, Water Research Commission, International Academic Institutions to assess the environmental risk assessment and management associated with NMs (Cele et al., 2009).

Researchers based at Mintek NIC researched on the development of nanobased targeted drug delivery systems, nanocomposites materials, nanomaterials for the rubber industry, and modelling. They formed partnerships with the Water Research Commission and the Medical Research Council, Goldfields, 180 degrees, Real World Diagnostics, and other South African academic institutions. It is during the year 2008, when DST launched the Nanotechnology Public Engagement Program (NPEP) implemented by the South African Agency for Science and Technology Advancement (SAASTA) (Musse et al., 2013). South African Bureau of Standards (SABS) approves the International Standards Organization (ISO) and International Electro technical Commission (IEC), while the National Institute for Occupational Health (NIOH) is more concerned with the human and occupational health of workers handling and working with NMs.

South Africa has also signed a number of international agreements related to nanotechnology; above all, an active agreement is a trilateral joint venture consisting of India, Brazil, and South Africa (IBSA) (Musse et al., 2013).

Nigeria

Poverty is a major problem in many developing countries in the world, including Nigeria with reportedly over 70% of the population deriving their livelihood from agriculture. Hunger and malnutrition are aggravated by rapid population growth, influences the food insecurity-adequate quantity and quality of food (Fasoyiro and Taiwo, 2012). Despite socio-economic challenges, Nigeria has implemented a project on environmental remediation carried out as a joint collaboration of the African University of Science and Technology and the Sheda Science and Technology Complex since 2006 (Masoka et al., 2012; Musse et al., 2013). It also has a project for a national nanotechnology initiative and is currently implementing a pilot project of the United Nation Institute for Research and Training (UNITAR).

Egypt

In Egypt, the Nanotechnology Research Centre was funded by the Information Technology Industry Development Agency and the Science and Technological Development Fund in partnership with IBM, and was launched in 2009. This project is probing the possibility of developing devices for enhancing health provision, and water purification, mostly targeting the rural areas. While the UN Department of Economic and Social Affairs (DESA), for example, is engaged in providing support to the construction of high tech R&D and industrial parks in Ghana and Senegal, while Egypt and Kenya already have techno parks and Ethiopia is currently developing a similar project (Masoka et al., 2012; Musee et al., 2012).

Morocco

In Morocco, projects on the implementation of an international laboratory for molecular chemistry, creation of a Euro-Mediterranean competence pool in micro-technology and nanotechnology, purification and preservation of Moroccan water resources, and urban waste treatment have already been started (Khachani, 2005; Bouoiyour, 2006). In the year 2006, National Initiative for Nanosciences and nanotechnologies was launched; an industrial high tech park was built in Rabat (Technopolis) (Masoka et al., 2012).

Algeria

Although, the field of nanotechnology is nascent in Algeria, incorporated nanomicro-electronics in the Microelectronics Division of the Advanced Technologies Development Centre, and a National Centre for Research on Nanomaterials and Nanotechnology was established at the University M´Hamed Bougara of Bourmerdes in 2011 (Musse et al., 2013).

RISK ASSESSMENT FOR ENVIRONMENT, FOOD, AND HUMANS

Researchers report that the worldwide use of engineered nanoparticles can lead to their release into the environment and their effect become a public health concern (Gottschalk et al., 2013). Therefore, assessing and managing the possible risk associated with the production and usage of NMs will reduce risk of toxicity exposure to the environment, animals and humans. There are large knowledge gaps that need to be addressed regarding nanotechnology life-cycle in full, from the production, transportation, uses and disposal. According to Wiesner et al. (2009) managing risks associated with NMs exposure will require the ability to quantify and differentiate the relative importance of manufactured, natural, and incidental sources of NMs at each step of the material's life cycle and understand the processes that govern NMs transport, persistence, bioavailability, and toxicity.

Numerous advantages related to nanotechnology and NMs are always highlighted forth; however, it is their ecotoxicological and nanotoxical information that are still lacking (Savolainen et al., 2010a). In essence, Suh et al. (2009) stated that a fundamental understanding of nanomaterial toxicology (nanotoxicology) is highly desirable both from the material's stand point as well as from the biological system's point of view. This is due to physicochemical characteristics of the material arriving at the receptor; thus, tend to metamorphoses physically and chemically.

The toxicity measure and assessment of NMs are greatly relying on the parameter used for ecotoxicity which give a little insight of the NMs. The main concern with regards to nanotechnology is the uncertainties of exposure and health of occupational, due to, a broad human exposure pathway, through skin, inhabitation and digestion is yet not satisfactory to give a holistic view of the danger and hazard (Savolainen et al., 2010b).

Savolainen et al. (2010a) emphasized that the fundamental elements of risk assessment are likely to remain and will continue to include the elements carefully designed for other chemicals and particles, notably (1) hazard identification; (2) hazard characterization; (3) exposure assessment; (4) risk characterization; these are the four steps of the risk assessment process. However, the features of these materials set new challenges for, for example characterization of test materials. Meeting these challenges would also greatly benefit assessment of risks of other materials. Therefore, as much as nanotechnology and NMs are solving most of the problematic issues, the chance of also bringing unforeseeable hazards to human health and depletion of environmental ecosystems is high. Understanding and filling the knowledge gaps will bring more information on handling and quantifying NMs.

Water

The understanding of abiotic interactions between NMs and natural substrates and solutions; interactions between NMs and living organisms and the longevity, reversibility of ecological sources and sinks; and the resulting consequences of NMs exposure for productivity, organic matter decomposition, and trophic transfer will assist in predicting the ecosystem impacts of NMs (Qu et al., 2013). Manufactured NMs show some complex colloid and aggregation chemistry, which is likely to be affected by particle shape, size, surface area and surface charge, as well as the adsorption properties of the material. Abiotic factors such as pH, ionic strength, water hardness and the presence of organic matter will alter aggregation chemistry; and are expected to influence toxicity (Handy et al., 2008).

While some classes of NMs may be toxic in the lab and inert in natural environments; it is also possible that other classes of NMs will become more lethal as a result of abiotic and biotic processing in complex ecosystems. It has been proposed that passage through the gut of organisms could strip stabilizing coatings of NMs, thus increasing their reactivity and toxicity (for example exposing the Cd-containing core of quantum dots). NMs may also have indirectly detrimental effects on ecosystems through their interactions with existing environmental contaminants (Wiesner et al., 2009).

Health

Toxicology studies on animals and cells raise the possibility of adverse effects on the immune system, oxidative stress related disorders, and diseases such as cancer (tumour formation). However, the doses needed to produce these effects are generally high and it remains to be seen if such exposure is possible via the environment (food, water or air) or in the work place (Handy and Shaw, 2007).

Agro-food

Nanotechnology has numerous advantages such as targeting specific infected area in plants and animals, ability to control or delay delivery, increase the efficiency, reduce dosage and drug loading of nano carriers (Mousavi and Rezaei, 2011). However, the potential for nano carries to alter tissues distribution, insolubility, ingestion and biopersistant is highly possible (Oberdorster et al., 2005).

However, uncontrolled use of pesticides, herbicide, and fungicides has caused many problems, such as adverse effects on human health, adverse effects on pollinating insects and domestic animals, and entering this material into the soil and water and its direct and indirect effect on ecosystems (Mousavi and Rezaei, 2011). Occupational health for farm workers and rural residents who are exposed frequently to these nano-pesticides, due to the size and dissolvability of nanoparticles pesticides must be considered (Scrinis and Lyons, 2007; Chaudhry and Castle, 2011). Most of the times pesticides are applied as a precautionary manner leading to the residual toxicity and environmental hazards and on the other hand application of pesticides after the appearance of disease leads to some amount of crop losses which raised a concern with regards to the controlling the infection diseases (Hong et al., 2013). There is higher possibility that residues of these nanopesticides might be present in products as consumed (Bouwmeester et al., 2009). Meanwhile, the exposure of NMs from animal feeds into consumer's foods (for example meat, milk etc) is also likely (Chaudhry and Castle, 2011). Concisely, the possible toxicological effect of nano-encapsulated pesticides may be soil contamination, environmental pathway and food-chain of living organisms across a wider geographical area (Scrinis and Lyons, 2007). Nanofertilizers have not been linked to increased phytotoxicity or to an increased propensity for eutrophication of surface waters, but little research has been done. It is expected that just as conventional fertilizer products have been associated with some adverse impacts. Conversely, nanofertilizers and nanoherbicides may present some of the same effects (Gruere et al., 2011).

The toxicity studies with regards to active packaging releasing NMs with antimicrobial functions into the food (for example nano-silver and in rare cases zinc-oxide NM), will lead to direct consumer exposure to (free) NMs (Bouwmeester et al., 2009). NMs such as nanoclay that is used as a gas barrier, nano-titanium dioxide for UV protection in transparent plastic and nano-titanium nitrate for mechanical strength bind with polymers to functionalize might migrate into food products (Chaudhry and Castle, 2011).

CONCLUSION

Nanotechnology on its own is a very important field, with countless advantages that improves the traditional medical, agriculture, electronics, fashion, consumers' products, etc. The discovery to enable, to manipulate atoms and molecules at a size of nanometer has given a promise to alleviate and enhance most of the current issues faced by most African societies which cripple the liberty of social and economy. This technology has proved beyond reasonable doubt that MDGs especially faces by Africans could be eradicated and alleviate poverty situation. It is clear that the only resource that is interconnecting all other is water which is an important commodity that affects the balance of all other factors that supports and services a society, addressing water pollution it addresses water stress and water availability issues, hence, agriculture and health will be resolved.

Yet, on the other hand, nanotechnology is making vibration into potential risks for health or environment and determines their fate and behaviour in the environment, humans and other organisms. However, not all materials in nano sized are considered toxic, it is the gap of knowledge with regards to the biopersistant NMs that are of great concerns. There is huge debate on the life-cycle of manufactured NMs, their impact and effect on the environment and especially to human. Those who produce or manufacture NMs, those who utilize products assimilated with nanotechnologies, their safety and awareness requires regulatory bodies that will validate information on relevant characteristics of NMs as present in the product is at least known to risk assessors.

It has been seen that the benefits of nanotechnology over power their toxicological effects as most of the investors turn a blind eye and endanger the consumers as the end-users of the life-cycles of the NMs. It is paramount for a continuous open communication and involvement between the government, private, academic institutions, parastatals and stakeholders to develop a strategic plan and risk assessment plans. It is so clear in countries such as South Africa and Egypt, where the government are funding and encourages extensive research on this technology. Even though such initiative has taken place, an active collaboration with international partners is needed. It is a great achievement that there is an improvement in most of African countries involved with nanotechnology. Although some are still skeptic, major strides have been taken already to render their poverty alleviation issues.

Conflict of Interests

The authors have not declared any conflict of interests.

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