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A Desktop Evaluation of the Potential Impact of Nanotechnology Applications in the Field of Environmental Health in a Developing Country

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Abstract Nanotechnology is the latest addition to enhancing lifestyles of the human population. It also has an impact on the core parts that are vital to the well-being of humanity and its' sustainability. Nanotechnology has been researched and is implemented in a number of countries at a commercialized level. However, in South Africa, nanotechnology is still being explored at grassroots with a few private industries implementing it. Based on research, the public health sector is expected to benefit the most from the application of nanotechnology. An environmental health practitioner plays a key role in ensuring the health and sustainability of the human population. The purpose of this desktop study is to generally explore the uses of nanotechnology in the Public Health sector with specificity to food, health and water remediation in the context of environmental health in South Africa and evaluate the possible impacts nanotechnology will have in the South African society. Proposed recommendations to be considered on how to address the use of nanotechnology in the current state of South Africa are made along with identifying the gaps in research in nanotechnology pertaining to South Africa.

Keywords: *nanotechnology, health, food safety, water remediation, primary health care, South Africa*

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1. Introduction

Provision of clean purified water, nutritious food and cost effective primary health care are some of the main key areas in South Africa in establishing the assurance of a healthy community. Each one of the above is interlinked to provide for the well-being of a society. The results of developments in Nanotechnology research has the ability to make it possible to meet the increasing demands of food, purified water and health care to the growing masses [1]. According to the [1], the abovementioned, is deemed as a one of the many focus areas which is further categorised into a social flagship project as nanotechnology is seen as a vehicle that could enhance the healthy lifestyle of people in South Africa. Research conducted globally highlights the possible impacts of nanotechnology in various spheres of society and professions. Environmental Health addresses all the physical, chemical, biological and related factors external to an individual and related factors that impact an individuals' behavior [2]. It also comprises of the assessment and control of those environmental factors that can potentially affect health and is targeted towards preventing disease and creating health-supportive environments.

For the purposes of this study, three environmental factors listed in the South African context that are imperative to the creation of health-supportive environments, namely, water quality monitoring, food control and surveillance and prevention of communicable diseases [3] will be further explored in relation to impacts of nanotechnology along with the uses of nanotechnology.

2. Definition of Nanotechnology

Nanotechnology refers to the manipulation, design, precision placement, measurement or fabrication of matter at the nanometric scale, which is about a billionth part of a metre [4]. This is inclusive of the control of the formation of two and three dimensional assemblies of molecular scale building blocks, into well-defined nanostructures [5]. The expectation of nanotechnology to improve the quality of life for humankind, inclusive of the reduction of cost in industrial and commercial processes, had led to the growth of the global nanotechnology industry, from 30 to over a 1000 companies in the 21st century [5]. Studies conducted globally display the potential uses of the multidisciplinary field of nanotechnology opened up by rapid advances in science and technology which can create opportunities and advances in various fields (see Figure 1) [6].

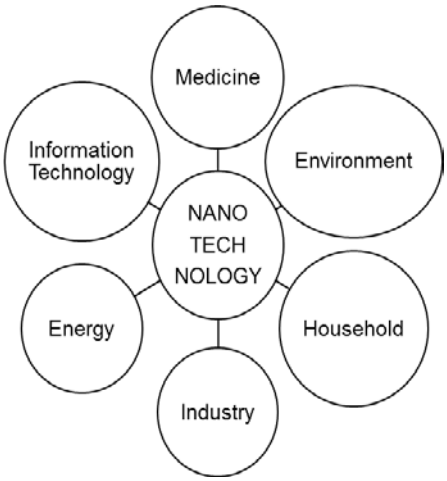

Figure 1. Applications of nanotechnology in various fields

3. Uses of Nanotechnology

3.1. Nanotechnology and Food & Agriculture

Food and Agriculture global population growth has resulted in an increased demand for food. This has led to a need in optimizing the agricultural sector in the production of food [7]. Research conducted in the USA shows an interest in the potential use of nanotechnology applications in the agriculture and food sector, by making use of the different characteristics that nanomaterials exhibit, to produce enhanced packaging, food safety, improved processing and nutrition with reduced agricultural efforts making it possible to promote sustainable agriculture and global distribution of food at a higher quality and standard [8].

In a review conducted by [7], she was of the opinion that the ability to ensure sustainability of food production is dependent on the agricultural sector with the use of pesticides and fertilizers have also grown rapidly to maximize the agricultural productivity [7]. Research has shown that the application of pesticides on a continuous basis has an impact on food quality, generation of waste, the environment, public health and overall cost in food production [7]. It was found that the development of nanosensor systems in the monitoring of environmental conditions, interactions between flora and pathogens and the use of nanomaterial based formulations in chemically synthesized pesticides has the following benefits: 1. Improved efficacy due to a higher surface area being covered by nanomaterials, 2. An increase in systematic activity as a result of smaller particle sizes allowing for higher mobility, 3. Decrease in toxicity from the elimination of organic solvents in comparison to the formulation of conventional pesticides [7].

According to a study carried out in Italy, projected and current nanotechnology applications in food and agriculture were identified by the World Health Organisation and the Food Administrative Organisation. These applications included the use of nanostructured ingredients, nanodelivery systems for nutrients, nanosized inorganic and organic food additives, food packaging, nanofiltration, and nanocoating of food surfaces [9]. However, it was highlighted that although, the use of nanomaterials in the agricultural and food sector might be the answer to improved agricultural sustainability globally, studies conducted reveal that the understanding of plant toxicity from edible plant interactions with nanoparticles is limited [9].

An analysis carried out on the implications of nanotechnology on the food and agricultural sector in the United States [8], revealed that the rise of consumer products containing nanotechnology applications, as identified by the World Health Organisation and Food Administrative Organisation [9], has also raised ethical and societal concerns in a number of countries. These range from possible health risks of consumption of nano-enabled products to the effects on the environment [8]. On the contrary, the Department of Crop Production Technology in Niger Delta University in Nigeria were of the opinion although not much is known about the toxicological and eco toxicological risks connecting to the merging of nanotechnology, it is not related to a great extent for one to be concerned about health and the environment as nanotechnology is currently the most promising technology [10].

3.2. Nanotechnology and Water Purification

[11] state that the availability of clean water is essential for all aspects of efficient production, preparation, distribution and consumption of food. However, the large quantity, intensity and diverseness of water pollution, inclusive of the exhaustion of water resources is a growing challenge, that reduces the accessibility of clean re-usable water safe for consumption a possible water-crisis [11]. Studies in the United States reported the use of engineered nanomaterials for nanotechnology enabled water treatment to yield favourable results irrespective of being at lab scale. However, silver nanoparticles that are engineered nanomaterials have been used in household water filters.

The super paramagnetic properties of magnetic nanoparticles allows for separation under low magnetic fields which qualifies for recycling and re-use of water as indicated by [11]. Research conducted in Mexico revealed the high specific surface area of nanomaterials making them adsorbents which can be used for the removal of pollutants [11]. Magnetic nanoparticles can also be used as adsorbents as they contain a highly adsorbent nature. This nature allows for increased efficiency in removing heavy metals and radionuclides from waste water [11].

Experiments conducted in California explored the possibilities of using nanotechnology as a catalyst to improving the currently existing methods of desalination technologies [12] as seawater is becoming a significant source of water as a result of freshwater reserves deteriorating in various geographical locations of the world. [11] reports that desalination technology is energy extensive. The use of nanomaterials increases the efficiency of membrane based desalination and decreases the cost, therefore desalination of water might be an alternative for agricultural, domestic inclusive of industrial supply.

Perspectives from South African research [13] highlights the concern for engineered nanoparticles that have reached the end of their lifespan from being generated, to remove pollutants from aqueous effluents. The lack of information regarding the toxicity and impact on the environment and human health results in the

quantifying of nanoparticles being exposed to aqueous sources as unqualified [13]. As a result this necessitates a methodical assessment of the potential impacts of the abovementioned technology in the environment and on humans. Viewpoints from India [10] confirm by indicating that there is a need for a technology to remove nanoparticles from the water cycle once purification has taken place. It is suggested that use of a common technology such as membrane filtration which is usually applied for removal of pathogens can be successful in removing nanoparticles from water [10].

[11] is of the opinion that one must determine the feasibility of introducing engineered nanomaterials in the purification of water for either being incorporated or a replacement for existing purification technologies. He recommends the use of engineered nanomaterial enhanced water treatment with the following pre-requisites: 1. When current existing technologies are insufficient for meeting water quality standards, 2. Hazardous and recalcitrant micro-pollutants escape waste water treatment plants which results in inadequate disposal of effluent (agricultural irrigation water), 3. Insufficient infrastructure for conventional water treatment making one reliant on point-of-use technologies, 4. Nanomaterials enhance the cost-effectiveness of treatment processes [11].

3.3. Nanotechnology and Health

The impact of communicable and non-communicable diseases are associated with social, cognitive and behavioural defects in the human population [14]. These disorders not only have an impact on the lives of individuals, but also have immense pressure on healthcare resources [14]. Current approaches and technologies are limiting, hence the rapidly advancing field of nanotechnology provides an opportunity to provide innovation in the drug developmental process for communicable and non-communicable diseases. Evaluations carried out in Ireland show the biomedical application of nanoscale materials, devices and structures can be utilised according to their diverse characteristics in order to target specific functions in the advancement of health care.

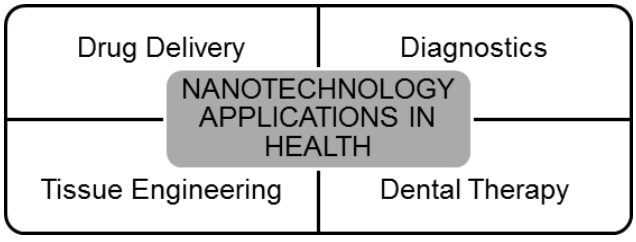

Figure 2. Applications of Nanotechnology in Health

[15] indicates that the largest or second largest application of nanotechnology occurring in most countries is in the field of medicine (see Figure 2). Some examples of the application of nanotechnology are in cancer research, brain medicine interfaces, semi-robotic and robotic implants, artificial kidneys, livers and lung, neural and spinal prostheses which fall under tissue engineering, and the manufacturing of pharmaceuticals referred to as nanodrugs [15]. Reviews conducted in India confirm the monitoring, repair, construction and control of human biological systems at a molecular level as having the capacity to diagnose diseases, deliver drugs at specific sites in the body, which has a positive impact on disease prevention, accurate diagnosis and treatment [6]. Mucosal immunity is vital for the prevention of disease but is limited in the degradation of vaccines [6]. Research conducted in Spain, where the development and encapsulation of suitable animal models were used, revealed that micro-particles and nanoparticles are capable of enhancing immunization [6]. This allows for the delivery of antigens via the use of vaccinations.

Perceptions are that the development of drug resistance might be due the malarial parasites developing drug resistance to the administration of low drug concentrations [16]. Research conducted globally [16] proposed the use of nanocarriers in the diagnosis, treatment and formulation of vaccines against communicable diseases like malaria. Reviews in Brazil [16] suggest this could be due to the ability of nanocarriers targeting malarial parasites at the site of action. Conversely, [17], believes that very little is known about the behavior of nanoparticles in conjunction with the human body, and although carefully controlled studies are carried out by scientists and institutions, one must bear in mind that there still remains an extent of uncertainty and conflicting results when it comes to hazards associated with nanotechnology and the human body.

In a review conducted by the University of Rochester in New York, the role of environmental factors in the interaction of nanoparticles with skin and the potential mechanisms on how these particles may influence the skin were highlighted [18]. Discoveries made from quantitative studies are that the application of nanoparticle skin penetration should be of a small dose [17]. An overview of nanotechnology piloted in the USA showed that adsorption of nanoparticles either by inhalation, ingestion or skin adsorption under extreme occupational, chronic or environmental exposure, is a potential cause for concern as there is evidence by experiment carried out on animals that indicates nanoparticles can cause an increase in oxidant stress in vessels and tissues, which inhibits the ability of dilation in blood vessels. This is consequential of a possible cardiac event from in failure of vessels to deliver blood to the heart [17].

According to [19], diseases in livestock has created a setback in the production for the purpose of increased protein supply for human nutrition among other reasons. The application of nanotechnology for animal disease diagnosis or animal models for diagnosis of human diseases has been an achievement as reports advocate the use of Quantum Dots (QD) where functionalized nanoparticles can provide rapid and direct detection of viruses [19]. Current independent research show the usefulness of nanobiotix technology in the role of cancer therapy, where nanoparticles are injected intravenously into a tumour, to accumulate selectively in them resulting in internalization of the particles by the cancer cells permitting the application of an external energy field to activate the nanoparticles, for the destruction of the tumour cell [19]. However, [19] also indicate the potential hazards associated with nanoparticles can provide an example of lipopolysaccharide-coated nanoparticles inducing lung inflammation.

4. Public Health, Food Control & Water Purification in the South African Context

Research shows the benefits and impacts of the use of nanotechnology globally. Although South Africa has recognized nanotechnology as an interdisciplinary field that involves participation and funding from various departments of government and organisations, nanotechnology in South Africa is not only implemented at a level of research and development but to this end it is applied through private industries and collaboration strategies. Provision of purified water, food supply and primary health care are the forerunners to sustaining the population of South Africa.

Based on research conducted, it can be deduced that the characteristics of nanomaterials and nanoparticles are made use of to the advantage of the human population. South Africa has created a South African Nanotechnology Strategy to address and optimize the opportunities of nanotechnology to assist with the achievement of these goals in this country [1]. As stated in the [1], some of the benefits of applying this new technology at a national level are inclusive of nanotechnology based water purification systems which can help reduce exposure to waterborne diseases such as cholera, improved drug delivery systems through packaging of medicine for communicable diseases, and provision of adequate food supply reducing exposure to bioaccumulation from harmful pesticides and insecticides. However, the application and impact of nanotechnology in the Public Health sectors are yet to be fully explored.

5. Impact of Application of Nanotechnology in South Africa

5.1. Enhancement of Agricultural Productivity and Nanotechnology

If nanotechnology was applied to South Africa on a large scale in order to meet the demands of South Africans, based on the applications of nanotechnology in other countries, at a research or national level, the following can be comprehended:- 1. The development of inexpensive applications to increase soil fertility and crop production with the use of zeolite nanoparticles with pores of different sizes would help in the efficient, thorough release of fertilizers or used for feeding of livestock [20], 2. The release of herbicides in a controlled manner will increase the efficacy of substances delivers resulting in the demands for food, 3. Children and adults will receive sufficient nutrition from food that is safe for consumption, which will in turn impact the health status of communities, reducing diseases caused by malnutrition, 4. A good health status reflects the ability of a person to work, thus creating the capacity for people within communities to be employed, lowering the rate of poverty.

5.2. Water Remediation and Nanotechnology

Cost reduction is another positive impact and in the long term boosts the economy. Meeting the demands of a growing population providing adequate sanitation which will in turn have a ripple effect on health, reducing burden of disease. Efficiency of water purification with the use of nanoparticles allows for heavy metals to be separated within a faster time frame [13]. Nanotechnology can provide inexpensive, easily cleaned portable water from reliable systems that purify, detoxify and desalinate water more effectively than conventional bacterial and viral filters [20]. Nanofilter systems contain intelligent membranes that can be structured to filter out viruses, bacteria and majority of contaminant emanating from water [20]. This increases efficiency at which water is purified making it possible to provide communities with purified water timeously and addressing water shortage with the use of nanoporous zeolites which have the ability to bind numerous polymers that can bind 100,000 times more organic contaminants than when using activated carbon [20].

5.3. Primary Health Care and Nanotechnology

Provision of primary health care with the assistance of nanomaterials could possibly lead to the alleviation of not only symptoms, but of certain diseases, thus resulting in a healthier community, making it possible for people to work and earn a living. Deterioration and immediate replenishing of medical and health resources will no longer be an issue, as community health care centers along with health care facilities, will not be over populated with patients as a result of the use of nanopharmaceuticals, this will also reduce epidemiological outbreaks locally and nationally.

An abundance of nanopharmaceutical and health resources and appropriate provision of health care services with the use of nanomaterials are interlinked to each other, and have a positive impact on South African community. However, it has to be monitored, regulated and strategically applied. Throughout the researches, the cause for concern regarding nanotechnology is its' negative impacts on the human population.

6. Risks and Current Challenges Associated with Full Application of Nanotechnology in South Africa

Consideration ought to be taken when food & agriculture, water remediation, and primary health care are implemented with the backing of nanotechnology at a national level. Although they might be beneficial, limitations in research suggest a lack of information regarding protocols to be followed if nanoparticle exposure had to be exceeded. From an environmental health perspective, environmental health practitioners are classified as professionals who ensure governance and adequate standards of provision of resources to the community are compliant. In the food sector, if there is an exceeding amount of nanomaterials within the food product, this may create bioaccumulation in the biological human system resulting in the increase in burden of disease or the possibility of creating new strains of diseases. Food containing nanoparticles listed as safe for consumption, water containing nanomaterial listed as safe for consumption and nanocapsules for treatment of various diseases could affect the health of humans resulting in cardio events occurring due to the minute nature of these particles constricting blood vessels in the biological system [17].

As much as nanotechnology can have a positive impact, without any control measures or regulating activities consisting of this technology, there can be a negative impact on not only the environment but also on human health. In South Africa, evidently, there are currently no regulations or guidelines on nanotechnology applications for an environmental health practitioner to utilise when out on the field attending to core issues related particularly to the well-being of humans, the agricultural and food sector, primary health care sector and water remediation.

Literature published on the toxicological effects of nanomaterials in relation to humans and the environment has indicated that insufficient data on the above mentioned leads to the inability of a safety assessment being conducted [9]. Reviews have pointed out that third world countries face challenges in the development of nanotechnology, and South Africa being known as a third world country is inclusive of being a participant in the following challenges: 1. Lack of infrastructure and human capacity, 2. Lack of proper legislation/regulatory framework including adequate political drive, 3. Lack of proper education relating to curriculum development matters, 4. Fear of health, environmental and safety risks associated with nanotechnology [21].

7. Conclusion

Since South Africa is known as a third world country, based on an analysis of research conducted abroad, one can conclude that there are aspects that need to be addressed prior to the full application of nanotechnology in South Africa. In a literature review from Africa [21] recommendations were made. The following are recommendations that have been adapted to the current state of South Africa in relation to nanotechnology advancements as proposed by [21]:

1. A national department of Nanotechnology to be established under the department of Science and Technology to permit for attention to be directed toward the activities and development of nanotechnology not only at a research scale, taking into consideration future applications of nanotechnology at a national level and intersectoral collaboration with various departments such as the department of Health.

2. Introduction to nanotechnology, covering all aspects from characteristics, to structure, applications in South Africa inclusive of positive and negative impacts can be entailed in seminars and conventions from the South African government and educational institutions to capacitate professionals and civilians. This should be a form of obtaining information and cascading it to the relevant personnel in the Department of Environmental Health.

3. Focus to be given on the natural resources available in South Africa and how they can be utilised with optimization with nanotechnology to the advancement and benefit of the environmental health of communities.

Prior to the commercial application of nanotechnology in the environmental health sector, these recommendations can be carried out under the governance of a nanotechnology department administered by the Department of Science and Technology in South Africa once these needs are established. Finally, the long-term outcome and effect of the commercialisation of nanotechnology in the core factors that contribute towards the well-being of a South African society, must be researched on the ethical, legal, and socio-economic aspects with the impacts of nanotechnology to support its' legitimate application.

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