Estimation of Titanium dioxide and Silver engineered nanoparticles environmental exposure risks in water: a case of Gauteng Province, South Africa

our future through science

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INTRODUCTION

Nanotechnology-based applications have dramatically increased in commercial and industrial applications[1-3] (see **Figures 1**, **2** and **3**). Also, the growth of nanotechnology-based consumer products (nanoproducts) in the global market is expected to increase in future as shown in **Figure 4**. However, there is current limited risk assessment data of engineered nanoparticles (ENPs) in the actual environmental systems[4-6] (see **Figure 5**) due to lack of metrology to quantify their fate, toxicity, and behaviour. To address part of this challenge, the ENPs potential risks to the aquatic systems have been quantified using modelling approaches within a city, country or continental scales[7-9]. In this study, modelling results on the potential risk profiles of ENPs in the Gauteng Province (GP) are presented. The results seek to contribute towards safe, responsible and sustainable exploitation of nanotechnology capabilities for societal good by quantifying the potential risks that can guide in developing appropriate approaches of managing ENPs.

STUDY OBJECTIVE

The study objectives are two-fold. Firstly, to estimate the quantities of ENPs released into the Gauteng Province aquatic environment from nanoproducts. And secondly, to estimate the potential risks of ENPs to the aquatic environment using mathematical models.

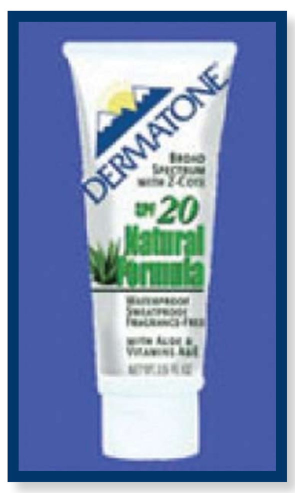

Figure 1: Cosmetic product with $nTiO_2$[1]

Figure 2: Scheme of removal of heavy metals during water treatment with humic acid coated Fe_3O_4 magnetic nanoparticles[2]

Figure 3: NanoTitanium Dioxide and NanoSilver powders: as new light catalysts, anti-ultraviolet radiation agent, photoemission agent, antimicrobial agent, mildew-proof, purifying exhaust, deodorisation, water purification, anti-aging, and other cosmetic fields, etc.

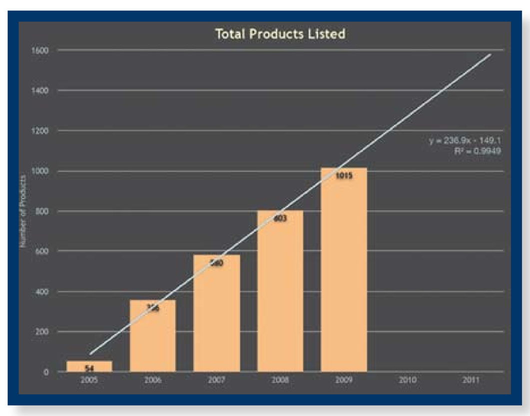

Figure 4: Growth of nanoproducts from 2005 to 2009[1]

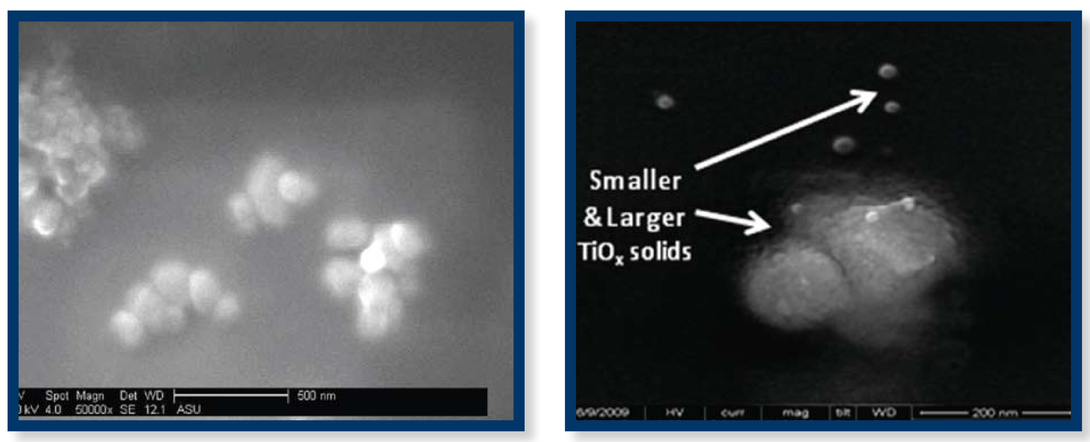

Figure 5: SEM analysis of $nTiO_2$ in wastewater treatment works (WWTW) tertiary effluent[4]

METHODOLOGY

Empirical models have been used elsewhere in the literature[7-9] to derive the environmental concentrations of ENPs, and a similar approach was adopted in this study. **Figure 6** shows the potential pathways of ENPs into the environment, and only results derived via route B are presented. The potential concentrations of ENPs in the GP aquatic environment were calculated using data on the GP wastewater treatment works (WWTW). Estimated quantities of ENPs likely to be released into the aquatic environment through route B were used to calculate the predicted environmental concentrations (PEC) of nanoTitanium Dioxide ($nTiO_2$) and nanoSilver (nAg). The worldwide production volumes of ENPs were used to estimate the quantities in South Africa (SA). The SA values were used for estimating the volumes of ENPs in the GP from nanoproducts. Then, published ecotoxicological data on aquatic organisms for $nTiO_2$ and nAg were used to calculate the predicted no effect concentrations (PNEC). The final risk profile for each ENP type was computed (risk quotient, RQ) as a ratio of PEC to PNEC. If RQ < 1, the risk would be small or negligible, however, if RQ > 1, the risk was considered to raise concerns and merits further consideration.

Due to the uncertainties of input data, three emission scenarios ENPs into the environment (PEC values) were derived using a series of equations (see **Figure 7**); namely minimum (least risk), probable (most realistic), and maximum (high risk). The input data used in modelling the scenarios comprised of; market penetration of nanoproducts in GP, demographic data e.g. population (POP), gross domestic product (GDP), WWTP efficiency, etc. Three dilution factor (Dk) values (0.75, 1 and 3) were employed to model the ENPs risk profile variations due to seasonal changes of water volumes in the GP. The values were based on personal communication with experts in the water sector. Data from peer-reviewed literature on the toxicity of ENPs under question to the aquatic organisms – the no-observed effects concentration (NOEC) values – were used to calculate the PNEC. Thus, the risk profile (RQ) for each ENP to the aquatic environment was computed as a ratio of PEC to PNEC.

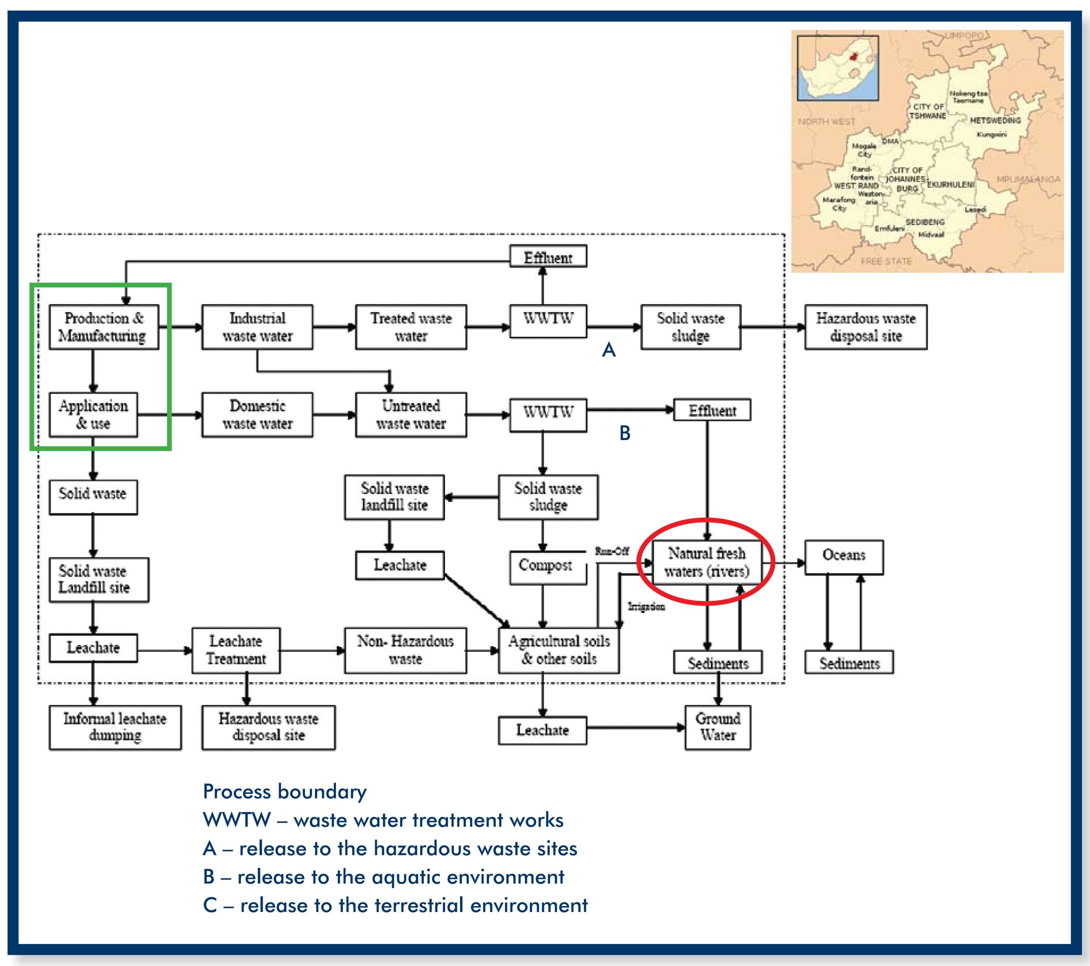

Figure 6: Schematic diagram of potential ENP pathways into the environment for GP

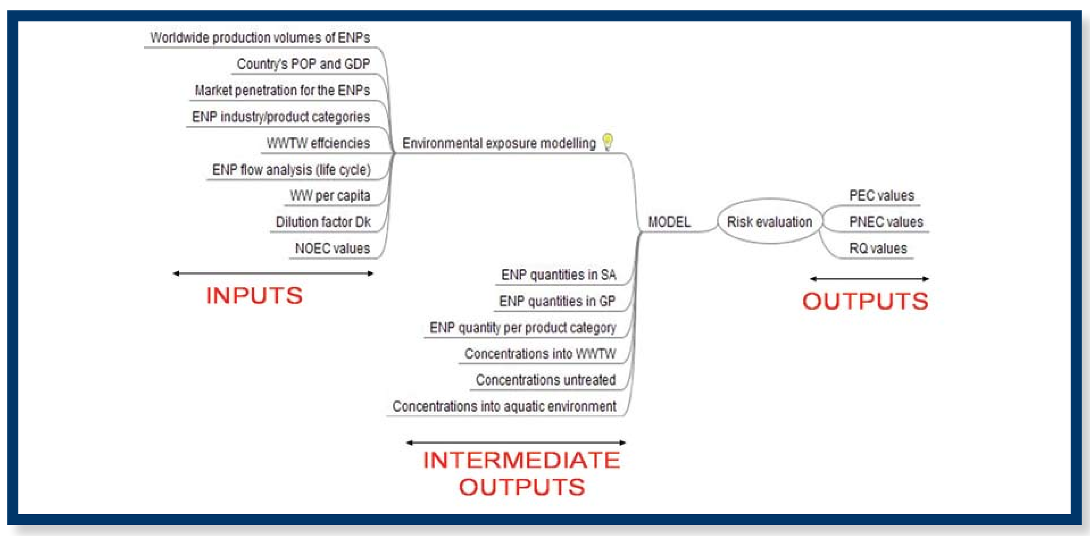

Figure 7: The model input and output variables for characterising risk profiles of ENPs into the aquatic environment.

RESULTS AND DISCUSSION

Results were based on the three modelled possible scenarios (due to data uncertainty), and suggested that $nTiO_2$ posed higher risk to the GP aquatic environment as RQ-values >> 1 (see **Table 1**). Whereas, nAg did not show any risk concerns at present since its RQ-values << 1 (see **Table 2**). The risk increased substantially for $nTiO_2$ when considering the dilution factor (**D_k**) of 0.75 and 1 estimated during the country's dry seasons, where the risk quotient was RQ > 10 for both probable and maximum scenarios.

Table 1: Risk quotient values (RQ) for $nTiO_2$

$nTiO_2$	Min	Prob	Max
RQ (D_k=0.75)	3.415009	14.03774	25.02805
RQ (D_k=1)	2.561257	10.52831	18.77104
RQ (D_k=3)	0.853752	3.509435	6.257013

Table 2: Risk quotient values (RQ) for nAg

nAg	Min	Prob	Max
RQ (D_k=0.75)	8.24E-05	0.000339	0.000604
RQ (D_k=1)	6.18E-05	0.000254	0.000453
RQ (D_k=3)	2.06E-05	8.46E-05	0.000151

STUDY LIMITATIONS

The model is limited by lack of published data on worldwide nanomaterial production volumes and applications (the determining model input parameter) because few companies declare the use and amounts of nanomaterials to date. Thus, the range of available data is broad and introduces very high uncertainty on the published values. The published nanoecotoxicological data used for PNEC evaluation is fragmentary and inconsistent. Hence the modelled values may be highly estimated or even lower than the actual values due to input data errors.

While there is a continuous increase in the use of engineered nanoparticles in consumer products, little is known about their fate, toxicity and behaviour once released into the environment and surface waters. Nanotechnology can be applied in a sustainable and safe way only if it is properly managed.

CONCLUSION

Findings from this study suggest urgent need for risk assessment measures be prioritised for $nTiO_2$ to protect the GP aquatic environment from potential adverse environmental effects of nanoproducts (particularly those containing TiO_2). As the application of nanoproducts containing other ENPs increases, their risk levels are expected to rise as well. Risk assessment of ENPs is expected to support safe, responsible, and sustainable utilisation of nanotechnology capabilities. It is recommended that nanotoxicological data be improved through new research in this field. Also, the development of capabilities for measuring actual concentrations of ENPs in the water systems can provide more effective risk assessment framework where values like those derived from our study can be compared.

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