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A comparative study of research and development related to nanotechnology in Egypt, Nigeria and South Africa

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ABSTRACT

It has been proven that nanotechnology has a wide range of applications. This makes it a very significant technology for the future. Because of its scope, nanotechnology is multidisciplinary, requires specialized personnel, and is highly capital intensive. Thus, many nations are increasing their respective activities in fundamental research in nanotechnology intending to develop products and/or processes based on their respective strategies, as shown in more than 60 countries globally, Africa inclusive. This study assesses the current status of nanotechnology in Egypt, Nigeria, and South Africa, focusing mainly on research and development (R & D). Malaysia was selected as a control for comparison with the selected African countries and the top-ranking nations in the factors used. The assessment related to R&D in nanotechnology was conducted based on background information, strategic plans, institutions and researchers involved, publications, and nano-based products. Results obtained indicate that South Africa has the highest ranking (66%) in R & D related to nanotechnology when compared to Egypt (59%) and Nigeria (38%). But the achievement is low for all the countries studied when compared to Malaysia (86%), used as a control, and others that have extremely high rankings in the factors studied. By implication, all the countries studied need to invest more, at different rates, in nano-based R & D to achieve their stated plans in this competitive global world.

1. Introduction

According to the *National Nanotechnology Initiative*, "nanotechnology is the ability to control and restructure matter at the atomic and molecular levels in the range of approximately 1–100 nm, and to exploit the distinct properties and phenomena at that scale as compared to those associated with single atoms or molecules or bulk behaviour. The aim is to create materials, devices, and systems with fundamentally new properties and functions by engineering their small structures [1]. Thus, nanotechnology incorporates synthesis, design, characterization, and application of materials, instruments, and systems through manipulation of shapes and sizes at the nanoscale, as highlighted by . [2]. For quite a while, people have been exploring "nano"-sized existences. But modern research and development can be attributed to several individuals based on their respective definitions of some terms, such as "nanometer" by Richard Zsigmondy in 1925, "There's Plenty of Room at the Bottom" by Richard Feynman in 1965, "nanotechnology" by Norio Taguchi in 1980, and the discovery of a nanomaterial by Kroto, Smalley, and Curl in the mid-1980s using a newly developed scanning microscope, and others [3].

Due to some unique properties, nanotechnology is attracting interest because of its structural capabilities and wide-scale potential applications. Current and potential applications of nanotechnology are widespread in various fields such as Materials and Manufacturing, Nanoelectronics and Computer Technology, Medicine and Health, Aeronautics and Space Exploration, Environment and Energy, Science and Education as enumerated by many others [3–8]; and others). A survey by the [9] indicated that worldwide funding for evolving nanotechnology has been increasing tremendously and that revenue from nano-enabled products increased worldwide from $339 billion in 2010 to $731 billion in 2012 and to more than $1 trillion in 2013. Specific applications of nanotechnology in developing countries and Nigeria have also been highlighted [10–16].

The applications of nanotechnology evolve based on intense research, specialized manpower training, and high capital investment [17]. This evolution has been classified into two phases. Based on several factors, phase 1 (2001–2010) was referred to as "Nano 1″, involving passive nanostructures controlled by a "science-centric ecosystem". The second phase ('Nano 2') is supposed to occur in 2010 and beyond to be "focused on nanoscale science and engineering

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integration, and is projected to transition toward direct measurements with good time resolution, science-based design of fundamentally new products, and general-purpose and mass use of nanotechnology" [1]; 2007, 2010). Applications of nanotechnology are possible via several processes among which is the *Social Construction of Technology approach* as developed by Pinch and Bijker involving significant directness and social contestation over the significance, nature and design of the technology [18] as confirmed by several indicators Arnaldi and Tyshenko [19].

To obtain the basics of nanotechnology and its applications thereafter, detailed information on related research and development (R&D) is necessary. This is because, for proper management and utilization of any form of technology, relevant data on the standing and prospects of developmental growth in a specific sphere is necessary for all those involved in R&D impacts. It has also been established that the utilization of nanotechnology in the form of products and services depends mainly on R&D advances. Thus, as stated by Porter et al. [20]; indicators of any technological development via R & D could make available essential information to building technology roadmaps. According to available information, the majority of academic publications and data on nanotechnology in Nigeria are focused on future policies, potential applications, and facilities available for limited primary research, with insufficient indicators for measuring R&D [12,13,15,16]. As an exception, [14] studied the activities of researchers in Nigeria in some areas of nanoscience and nanotechnology, reviewed numerous related publications, identified institutions for fundamental research, and conducted a limited comparison of research outputs with two other African countries. Scientometrics was used in several studies to obtain quantitative data on relevant documents such as academic journal publications, patents, and policies, as stated by [21–24] and others.

However, most of the scientometrics reviews did not adequately cover African countries and/or required data were not available, as clearly indicated in several studies [25–27]. But a related the study [14] is limited to only the subdivision of green nanotechnology, and the comparisons with other countries are, in most cases, not measurable. To provide the required information and measurable data on R&D in Nigeria concerning nanotechnology and in comparison to two other African countries, this paper identified the key factors for assessment, gathered relevant data, and conducted the statistical analysis. The outcome obtained in this study will hopefully support realistic decision-making and the implementation of relevant policies.

2. Methodology

Egypt, Nigeria, and South Africa were selected due to their geographical location, population, economy, and regional influence. As the analysis is mainly a comparison, key factors for assessment were developed based on similar studies conducted earlier [28,29]. Indicators/factors used for comparing R & D related to nanotechnology in Nigeria with Egypt and South Africa are enumerated below.

i. Background information (population, GDP & PPP, expenditure on education, etc.);
ii. Nanotechnology Strategic Plan(s)
iii. Universities and research centres related to nanotechnology
iv. Researchers in R & D
v. Publications related to Nanotechnology
vi. Nanotechnology-related patents
vii. Nano-based products;

To give the study a global perspective, related information for a country having an emerging economy (Malaysia) was used as a control. In addition, all results from key factors studied were compared with those of the country having the highest ratings and the global averages.

3. Result and discussions

3.1. Background information

Some background information related to this study as gathered from various sources is summarized in Table 1. The data is needed to assess the likely influence of other sectors related to R&D in nanotechnology and other areas of specialization. It was observed that some of the information was gathered at different times and methodologies. In addition, specific information for a particular country may vary widely from different sources.

Some of the data in Table 1 is subjective and may lead to erroneous decisions and/or comparisons. For example, the United States was ranked 65th in terms of GDP/PPP on education expenditure, China was ranked 110th, Kenya was ranked 53rd, and Yemen was ranked 56th [32]. Also, on spending on education, it may refer to expenses by the ministry/department concerned only, without disbursements on educational activities by other ministries/parastatals. Furthermore, the US spends over $700 billion on public education [33,34], which is among the highest in the world but was not ranked concerning expenditure based on the percent of GDP/PPP on education expenditure in most of the sources of information for this study.

Despite some difficulties in directly relating the information in Table 1 to R & D, the Global Innovation Index (*GII*), a joint publication of Cornell University, *INSEAD*, and the World Intellectual Property Organization, concluded that some of the basic indicators influence R & D, ranging from knowledge-intensive employment to the regulatory environment and collaboration between industry and universities (Global Finance, 2018). Using data based on background information, the three countries under study can be ranked in the following order: South Africa > Egypt > Nigeria.

3.2. National strategic plan on nanotechnology

Strategic planning is the process of specifying and outlining a path for a particular area of interest by reviewing previous related activities, evaluating current status and projecting future targets. From the current wide-ranging standpoint, many countries are developing areas in response to their capability and needs by considering roles in the international nanotechnology R & D diversity. The main variation amongst countries is the time scale and areas where R & D are targeted [35]. Strategic plans for the countries under study are summarized in Table 2.

Information on national strategic plans of countries investigated as summarized in Table 2 indicates that South Africa has more

Table 1
Some selected background information for the countries understudy.

Country	Population (rank)[a]	Literacy rate[b]	PPP(Rank)[c]	Expenditure Education (% GDP)[d]
Nigeria	206,139,589 (7th)	59.6%	$5966 (137th)	3.02 (141th)
Egypt	102,334,404 (14th)	75.2%	$13,357 (96th)	3.8 (121th)
South Africa	59,308,690 (25th)	94.4%	$13,629 (100th)	6.2 (31st)
Malaysia	32,365,999 (45th)	94.6%	$31,311 (49th)	4.7 (77th)
Highest	1,439,323,776 (China)	100% (North Korea)	$129,638 (Qatar)	12.9 (Cuba)
World	7,794, 799	86.3%	$18,124	5.0%

[a] United Nations [30].
[b] UNESCO [31].
[c] *Statistics Times* [49].
[d] UNDP [32].

Table 2
Strategic Policies on Nanotechnology in the Countries investigated.

Country	Strategic Plans	Source (s)
Egypt	None, but there is a defined policy within the well-established Science and Technology (S&T) organizational set-up.	[36] [37]
Nigeria	None, but Nanotechnology was approved as the 4th leg of the national development policy on S&T. Draft of strategic policy have been prepared in 2019 waiting for approval.	[36]; [14]
South Africa	Six strategic plans from 2008 to 2016 related to a 10-year research plan, Human and Infrastructure Capacity Development, Grants Management and Systems, Awareness programme, etc.	[36]

comprehensive plans for R & D in nanotechnology when compared to Egypt and Nigeria. This may have more impact on the scope and development of nanotechnology in South Africa.

3.3. Universities and research centres related to nanotechnology

Nanotechnology is multidisciplinary, advanced and capital intensive. Thus highly skilled personnel are required which can only be provided, sustained and retrained by Universities and other specialized institutions. According to Statnano [36]; nanotechnology universities and research centres are those "which published more than 50 nano-articles in the last year and were ranked based on the number of nano-articles, the sum of times cited, average citation per nano-article, and h-Index". Based on these factors, currently, there are 708 universities and 77 research centres directly related to Nanotechnology globally with China having 185 as the highest while Africa has 13 which is only about 1.6% of the global total.

From the study conducted it was found out that concerning universities and/or research centres directly related to nanotechnology, Egypt has 9, South Africa 3 and Nigeria none. Thus Egypt is leading in universities/Institutions where R&D in nanotechnology are conducted; it is even higher than the control country (Malaysia) having 8 universities [36]. Postgraduate programmes leading to the award of Master's degrees and PhD are offered in Egypt and South Africa [37,38]. Although some R&D studies in the area of Nanotechnology are being conducted in Nigeria in some research institutes and tertiary institutions as detailed by Elegbede and Lateef [14]; the undertakings are not appropriately harmonized. The problem of R&D in nanotechnology in Nigeria may be attributed to the lack of a detailed strategic plan and coordinating structure. Contributions to research in nanotechnology can be improved by integrating and utilization of relevant equipment in universities and research centres as was achieved in Iran after the establishment of the Iran Nanotechnology Laboratory Network (INLN) in 2005 [39].

Currently, there has been increasing attention in initiating nanoscience and nanotechnology during the early stage of education, especially at the secondary/high school level. This will assist in creating likely potentials to be in R&D related to nanotechnology. During this study, only Egypt have a similar programme in a place referred to as ***in2nano*** involved in high school outreach activities targeting to encourage scientific literacy and get students ready for the far-reaching transformations associated with nanotechnology [40].

3.4. Researchers in R&D

According to *Stanano (2020),* researchers in R&D are "professionals engaged in the conception or creation of new knowledge, products, processes, methods, or systems and the management of the projects concerned". Information related to individuals involved in R&D for countries under study is summarized in Table 3.

The data in Table 3 may not necessarily represent the actual situation, but when considered comparatively, Egypt has more researchers in various areas of specialization. However, this achievement in Egypt is relatively low when compared to Malaysia used as control and Israel has the highest number of researchers per million globally. In addition, required information during the survey is not available and partly dependent on the population as clearly portrayed in Fig. 1 expenditure on R&D from 2003 to 2017.

Table 3
Researchers (per millions) for Countries understudy.

Country	Researchers in R&D	Year
Egypt	687	2017
Malaysia	2397	2017
Nigeria	39	2007
South Africa	492	2017
Highest (Israel)	8251	2012

Source: extracted from [41].

Fig. 1 shows that South Africa with the highest GDP/PP and expenditure on education (Table 1) spends more on R&D when compared to Egypt and Nigeria. This may not be the actual and/or current rating, for Nigeria's R&D expenditure as a portion of GDP was 0.1% in 2007 [41] - the only year for which the data is available at the moment.

3.5. Publications related to nanotechnology

One of the major outcomes of R&D is to publish outcomes for assessment by others and as a guide for further works. Publications are in various forms with peer-reviewed articles in journals as one of the most acceptable about scientific and technological R&D. Articles published are one of the following types; *Original Research, Review Articles, Short Reports or Letters, Case Studies, Methodologies* [42]. *Thus the level of involvement of countries in nanotechnology can be assessed relative to their publications of related articles some of which are elaborated hereafter.*

3.5.1. Local share in nanoscience

This refers to the portion of "ISI-indexed nano-articles of total ISI-indexed articles of a country" [36]. According to Researchgate [43]*;* ISI "means the Institute for Scientific Information, which developed and produced the Science Citation Index (SCI), Social Sciences Citation Index (SSCI), and the Arts and Humanities Citation Index (AHCI). The levels of local share in nanoscience for the countries under study from 2000 to 2019 are displayed in Fig. 2.

All the countries under study had a significant increase in ISI indexed articles as indicated in Fig. 2 with Egypt having the highest, even surpassing Malaysia in 2017 and thereafter. Nigeria also topped South Africa from 2019 with less number of researchers (Table 2) and less R&D expenditure. Nigeria had the highest relative increase of 56% in ISI indexed articles in the period under study compared to that of Egypt, South Africa and even Malaysia that had 18%, 10% and 14% increases respectively.

3.5.2. Number of nano articles per million people

The reflection of the total nano-articles published relative to the total populations of the countries studied is shown in Fig. 3; it's a ratio of nano-articles to country population. From the data available and analysis conducted thereafter, Nigeria had relatively the lowest ratio of nano-articles per million most likely because her population is twice that of Egypt and more than 350% that of South Africa. Notwithstanding a low rating per million articles, Nigeria countered this with the highest relative increase in the share of nanoscience as a % of total ISI indexed articles as indicated in Fig. 3 as also confirmed in a similar study conducted [14].

3.5.3. Five-year h-index of nano-articles

This indicator shows the *h-index* count and is centred on a list of publications printed in a 5-year period that is categorized in descending

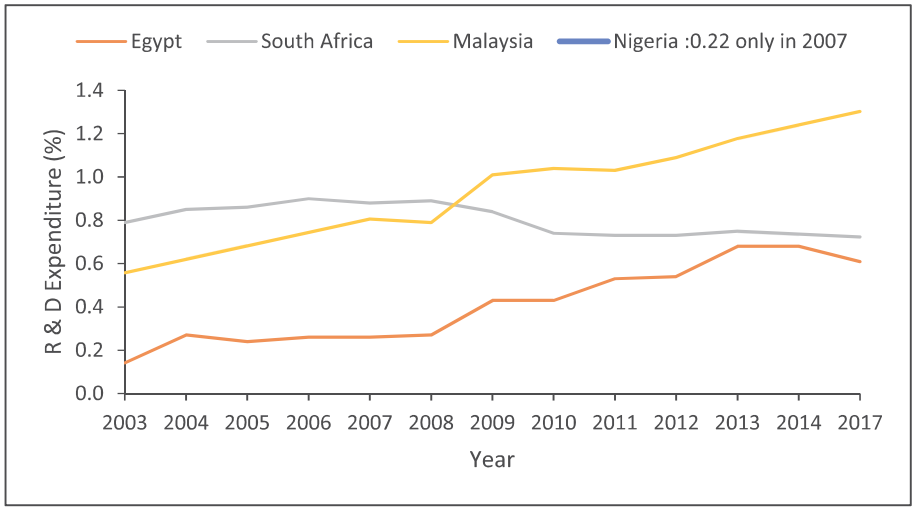


Fig. 1. R&D Expenditure as a % of all expenditures for countries understudy. (Based on data from Ref. [41]).

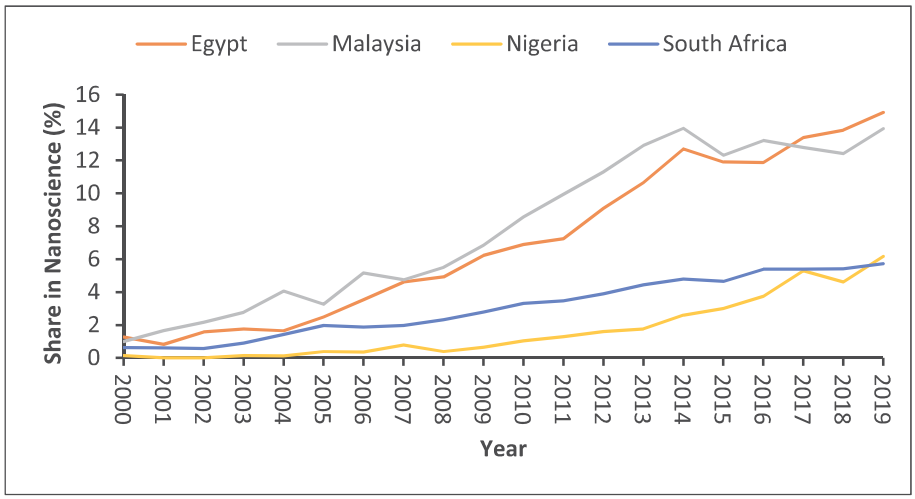


Fig. 2. Share of nanoscience as a % of total ISI indexed articles for countries under review (Raw data extracted from [36]).

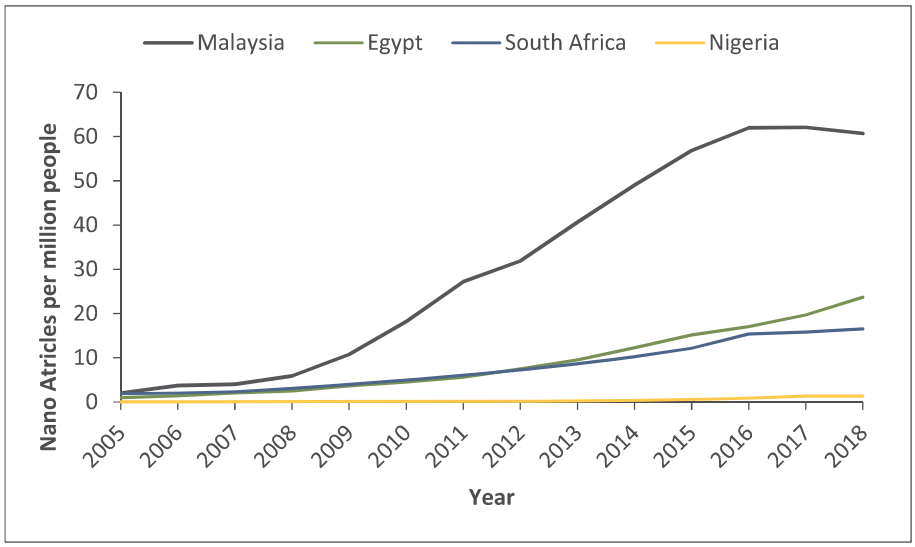


Fig. 3. Number of Nano articles per million people (Source: [36]).

order by the Times Cited count [36]. The h-index, or Hirsch index, assesses the impact of an individual scientist instead of the journal, it is described as the " highest number of publications of a scientist that received h or more citations each while the other publications have not more than h citations each", [44]. For instance, a researcher and/or scholar having an h-index of 5 had published 5 peer-reviewed papers, every one of which has been referred to by others at least 5 times. The five-year h-index of nano-articles for the three countries studied is presented in Fig. 4.

For all the countries studied, the trend in the five-year h-index of nano-articles was progressing from 2005 to 2015 where a peak was reached and thereafter a decline occurred up to 2018; this was also the same trend for Malaysia that taken as a control in this analysis. The decline of the 5-year h-index may not be regarded as deterioration but may be attributed to an increase in publications and higher accessibility which reduces the possibility of more citations of previous articles. The highest global five-year h-index is 589 as achieved by the USA in 2006.

3.6. Nano-based products

The ultimate target of R&D in all fields, nanotechnology inclusive, is to create a product and/or process based on specified aim(s) to be marketed or used by those concerned. The achievement of getting nanotechnology products is systematic and methodical, which must be carried out according to a fixed plan or system from developing nanomaterials to manipulating them into nano-based products and summarized graphically in Fig. 5.

As of May 2020, there are 8874 nano-based products available in the market which were produced by 2454 companies having different capacities in 62 different countries [36,46] using highly demanding resources, both material and human. Summary of products in countries studied and others related are shown in Table 4. The products are in various sectors such as Agriculture, Automotive, Cosmetics, Construction, Electronics, Food, Household goods, Medicine, Printing, textiles and others.

From the information classified in Table 4, it is clearly shown that South Africa currently fabricate more nano-based products. This achievement by South Africa may not be surprising as the country have a comparatively higher technological infrastructure, more expenditure for education (Table 1), comprehensive strategic plans on nanotechnology (Table 2) and other relevant resources that were used positively [47].

3.7. Overall rating of R&D in nanotechnology

It is not always achievable to allocate rankings outstandingly. By reducing exhaustive procedures to an arrangement of ordinal numbers, rankings make it acceptable to assess multifaceted information based on definite criteria [48]. Thus, in this study, a 4-point allocation was adopted with each factor given a point with 4 being the highest and 1 the lowest based on position. The overall ranking on the level of R&D on nanotechnology for countries studied is indicated in Fig. 6.

From the data used in Fig. 6, analysis was conducted for all the countries under study based on marks allocated for each factor leading to an overall ranking for R&D in nanotechnology indicated in Table 5.

The result obtained in Table 5 is a summary of all the rakings conducted on the countries studied concerning R&D in Nanotechnology based on some factors highlighted in Fig. 6. This indicates that South Africa has invested more with several factors that are directly or indirectly related to Nanotechnology with more investments in research [49] as clearly manifested in having more nano-based products.

4. Conclusions

In this paper, a study was conducted on several factors related to R&D in Nanotechnology for Egypt, Nigeria and South Africa based on data available from numerous sources with Malaysia selected as control based on some of her peculiarities. Statistical analyses were conducted to quantitatively assess the level of education, strategic plans, research centres/institutions, peer-reviewed articles published and products in the three countries that are related to R&D in nanotechnology. The main findings of this study include:

i. Nigeria relatively has the largest economy but was rated as the lowest concerning PPP/GDP, literacy rate and % GDP for education expenditure with South Africa being the highest.
ii. South Africa has a detailed strategic plan in several phases for R&D in nanotechnology developed from 2008 to date. But Egypt and Nigeria have R&D in nanotechnology incorporated their respective Science and Technology policies with their strategic plan still in the preparation and approval stage.
iii. From the study conducted it was found out that concerning universities and/or research centres directly related to nanotechnology, Egypt has 9, South Africa 3 and Nigeria none. This outcome is reflected in Egypt having the highest number of researchers related to nanotechnology in comparison to Nigeria and South Africa.
iv. All the countries under study had a significant increase in ISI indexed articles. Nigeria surpassed South Africa in 2019 despite having fewer researchers and R&D expenditures. However, Nigeria has relatively the lowest ratio of nano-articles per million.

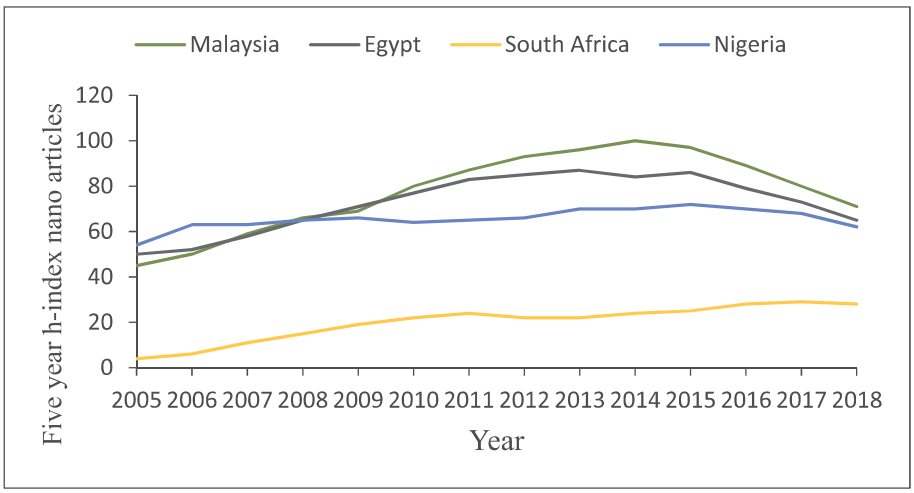


Fig. 4. Five-year h-Index of nano-articles (Source: [36]).

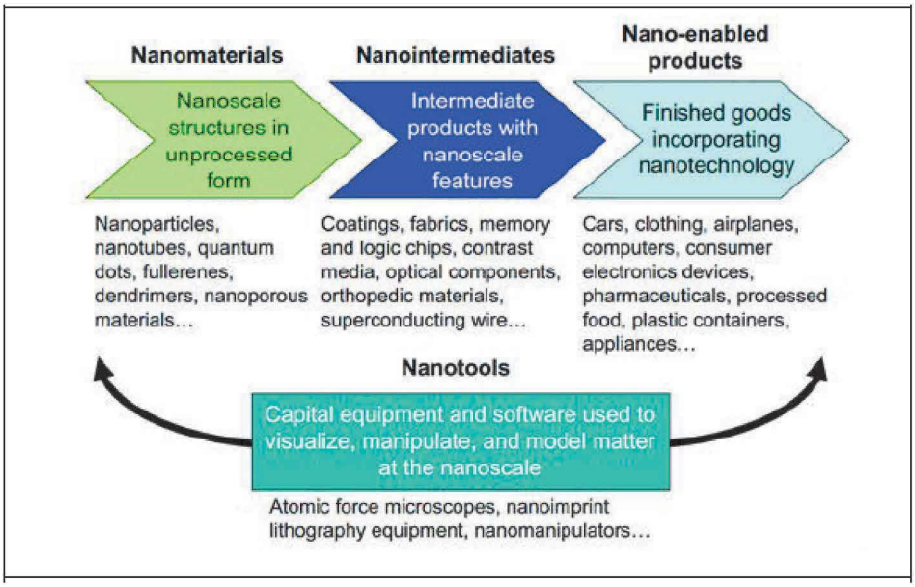


Fig. 5. Evolution of nano-enabled products with examples (Sources: [33,45]).

Table 4
Nano-based products in countries studied (compiled from data in *Statnano*,2010 [36]).

Country	No. of Products	Areas of Applications	Companies
Egypt	8	8	3
Nigeria	0	0	0
South Africa	14	10	9
Malaysia	90	52	28
Highest (USA)	3008	422	660
World	8874	2187	2454

v. South Africa has 14 nano-based products in the market which is the highest relative to Egypt (8) and Nigeria (0). This is the ultimate target of R&D in nanotechnology and any other area of specialization.

vi. Based on all the factors used in this study, South Africa is ranked topmost concerning R&D in nanotechnology followed by Egypt then Nigeria

However, all three countries are far behind Malaysia which was taken as control and other nations that are leading in all the subdivisions of R&D in nanotechnology. Thus Egypt, Nigeria and South Africa must increase their commitment, at their respective strides, in other to benefit

Table 5
Overall Ranking of the countries studied for R&D in Nanotechnology.

Country	Overall Score (30)	Rank
South Africa	21	1st
Egypt	19	2nd
Nigeria	12	3rd
Malaysia (Control)	28	–

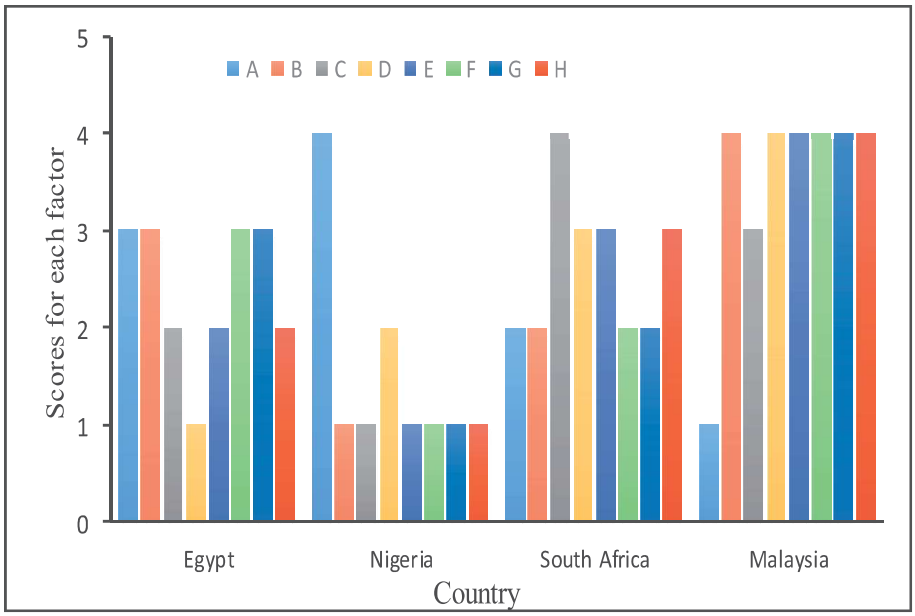


Fig. 6. Estimated Ranking of Countries Studied based on some Factors.

from the wide range of applications in products and/or processes that are based on nanotechnology.

Declaration of competing interest

None.

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