Nanoinformatics: Opportunities and challenges in the development and delivery of healthcare products in developing countries

Wilson Nwankwo¹ and Kingsley Eghonghon Ukhurebor²

¹Software Engineering & Cyberphysical Systems Unit, Department of Computer Science, Edo University Iyamho, Edo State Nigeria
²Environmental & Telecommunication Unit, Department of Physics, Edo University Iyamho, Edo State, Nigeria

ukhurebor.kingsley@edouniversity.edu.ng; wnwankwo@edouniversity.edu.ng

Abstract. The world is witnessing sustained effects of information technologies across all works of life. Though some of these influences are markedly negative and detrimental to the socio-economic prospects and progress of the society, the positive effects are often impressive especially where they are integrated for the betterment and greater good of the larger society. One of the fastest growing technologies is nanotechnology. Nanotechnology has numerous prospects and applicability across various sectors ranging from electronics, telecommunications, agriculture and food production, biotechnology and genetics, oil prospecting and production, remote sensing, drug production, to name a few. This novel technology readily finds usefulness and several researches are ongoing, geared at developing new tools and techniques that would improve its acceptance across the concerned domains. It is this quest that has culminated into the ongoing effort in nanoinformatics, an interdisciplinary study and a subdomain of informatics simply regarded as the conscientious application of informatics tools and technologies to the analysis, design and development of systems on the broad spectrum of nanomaterials including their physicochemical and environmental characteristics as well as their interactions, interrelationships, and applications within a given domain. This paper presents a review of some opportunities for individuals, experts, and the society especially in the production of cost-effective nanotechnology-based healthcare products. Notwithstanding the aforesaid opportunities which could be harnessed and sustained in any developing country like Nigeria, this paper identifies and buttresses core challenges that could confront the adoption of good nanoinformatics methodologies. This paper concludes that a developing country (Nigeria in perspective) could benefit from nanoinformatics if there are stronger ties among the key stakeholders involved in healthcare products delivery in the society.

Keywords: Information technologies; NanoInformatics; Healthcare; Nanotechnology; Nanomaterials

1. Introduction

Nanotechnology is gaining some foothold in the various sectors of the economy including electronics, telecommunications, agriculture and food production, biotechnology and genetics, oil prospecting and production, remote sensing, drug production, etc. [1, 2]. Nanotechnology is a hybrid or rather interdisciplinary study with roots in physical sciences, biological sciences, and engineering. It is a field of study and a set of applied tools and techniques. Generally, nanotechnology involves studying nanomaterials i.e. matter or materials within the nano scale (1-100nm) and utilization of same for the production or synthesis of useful devices, equipment, components, etc. [1]. Nanomaterials cover both physical and chemical compounds, substances, elements, etc. However, a major parameter in determining what constitutes a nanomaterial is its size. Nanomaterials may exhibit physicochemical characteristics
that are inconsistent with the characteristics of the parent materials or matter and in reality, this is what makes nanomaterials interesting. The range of applications of nanotechnology is quite broad. Lately, research studies in nanotechnology as well as nanomaterials have advanced on reckoning with several applications with countless opportunities emanating therefrom in several aspects of human endeavour[1, 3]. Undeniably, one of the furthermost auspicious application of nanotechnology is in healthcare. Nanotechnology-driven healthcare is termed nanomedicine or nanohealthcare [1]. Nanomedicine according to Sahoo [4] implies monitoring, overhaul, creation and management of biotic structures at the molecular stage by means of concocted nanodevices and nanostructures and the deployment of same for healthcare purposes. Simply put nanomedicine is the application of nanotechnology in medical science directed towards diagnostics and management of health-related issues. It includes diagnosis, prophylaxis, therapy, molecular pathophysiology, theranostics, and nanopharmaceutics[2].

Despite the potential of nanomedicine and nanotechnology, some research studies have shown that these technologies are confronted with several challenges [2, 5, 6]. Most of these challenges are sturdily connected to informatics [7] that is, nanoinformatics. Accordingly, the following challenges are documented:

a) Management and incorporation of diverse information
b) Definition of nomenclatures, taxonomies and groupings of the various kinds of nanomaterials
c) Research in new modelling and simulation procedures for nanoparticles [2].

According to Moffatt [1], medical application of information and communication technologies or medical informatics has gained eminence, as an indispensable aspect in nanobiotechnology exploration has emerged predominantly suitable in the generation of appropriate research strategy outlines. This aspect is presently in consistent alignment with nanoinformatics [8]. Nanoinformatics entails the meticulous application of informatics devices, tools, and machineries to aid nanotechnology projects e.g. nanomedicine, drug synthesis/production, etc. It is an extensive and intricate field that requires extraction, processing, analysis and evaluation of enormous information on a domain using informatics [8, 9]. Nanoinformatics is believed to present some potentials for resolving challenges connected to biomedical informatics going by its increasing adoption in several jurisdictions such as the Americas, Europe and Asia [8]. Nanoinformatics play an important role in the advancement and transformation of research in several aspects of nanomedical applications [1]. Such systems assist in the advancement of bulky databases, management of devices, innovative biomedical imaging modalities, computerization of decision sustenance systems, the management and conversation of massive amounts of diverse data and knowledge as well as the creation of models and simulators for the characterization of nanoparticles and their efficiency and poisonousness in the delivery of healthcare services [1]. However, due to its wide scope, several researches are ongoing and geared towards developing novel tools and techniques that would advance its acceptance across the respective domains such as healthcare product development, medicare, drug discovery, product analysis, testing, etc.

This review takes a narrative and analytic approach in presenting some opportunities for individuals, experts and societies especially in the production of cost-effective healthcare products and services, taking into cognizance the exceptional nature of nanoinformatics. We would attempt to briefly identify, describe and buttress the main problems and opportunities of nanoinformatics as may apply to various levels of healthcare products (drugs and medicaments in particular) development and delivery of in a developing country such as Nigeria.

2. Historical background of informatics in healthcare
The application of computers in biomedical programs began to gain more recognition in the 1950s [8]. As reported by Ledley and Lusted [10], biomedical programs were first conducted in hospitals and the use of logical computer programs for modelling in medical problem-solving processes. This gave room to biological computation for problem-solving and molecular logical inquiry. During this period the domain of biomedical informatics steadily advanced and extended to other aspects which include: electronic medical records, artificial intelligence systems for medical analysis and planning, laboratory technologies
and instrumentation, radiology and hospital information systems [8]. In the aspect of biological computation, the development and validation of databases for macromolecular categorizations, structures and roles all came in limelight as a result of these advancements[11]. The Human Genome Project (HGP) was thereafter used in the production of enormous bioinformatics datasets and the systems and software apparatuses advanced in the project were crucial in completing some other further projects [12, 13]. Ever since then, biomedical informatics has unceasing advanced as a discipline encircling both medical informatics and bioinformatics as a result of the boundless number of research developments [14-16]. These developments comprise over a thousand public databases covering omics and disease information, which are vital to biomedical transformational research [17-22]. Note that biomedical informatics which started over seven decades has given rise to the development of more specialized but often interwoven areas to wit: chemical informatics, bioinformatics, health/medical informatics, nursing Informatics, and nanoinformatics. Nanoinformatics is a somewhat convergence of bioinformatics and cheminformatics [1] and designed to drive nanotechnology projects including drug discovery, design, modeling, clinical testing and delivery.

3. Nanoinformatics opportunities in the development and delivery of healthcare services

There is paradigm shift in the design of drugs and other medicaments used in healthcare delivery. Research in nanomedicine have shown the production and potential application of the following nanomedicine products: nano imagers (for imaging operations e.g. iron oxide nanofilm), nano tissues (employed in tissue regeneration/transplant e.g. nanotubes, nanofilms, etc.), nano sensor (for detection/diagnosis e.g. SRP biosensor), nano robots (for detection, diagnosis, destruction of diseased cells, etc.), nano instruments (diagnosis e.g. nanowires, nanoscale resonance imaging), nano drugs (therapeutics/theranostics) [23]. As it relates nanomedical applications, nanoinformatics offers the following toolsets:

- Modelling and design systems (used for modelling and design of drugs. Such include design of nano structures, etc.
- Discovery and synthesis-support systems (used for molecular analysis of models, molecular-interactions, synthesis, mapping, and simulation)
- Characterization systems (from stoichiometry of materials-identified nanomedicine material, to representing chemical structures e.g. molecules, atoms, interactions, models, reactions, etc. and storage in complex chemical databases to be used in guiding extraction of pharmacologically-active metabolites, and subsequent chemical simulation are vital to the synthesis of a drug)
- Validation/Verification systems (applied to nano drug formulation whereby relationships amongst activity, property values, and quantitative structure of metabolites need be established prior to actual nanodrug production)
- Workflow and Collaboration systems
- Monitoring systems

Thus, there is a plethora of opportunities in nanoinformaticss as none of each category of toolset stated above have fully evolved. Research is ongoing in the design and release of such tools for global use or adoption hence it is believed that the design of such tools would afford a rewarding opportunity for nanoinformatics professionals, consultants, and students alike. Such tools would fast-track research and advancement in nanomedical programs and campaigns.

Accordingly, nanoinformatics presents notable opportunities in the development of healthcare products especially nanomedicine products in that:

- Data used for nanomaterial experiments (e.g. drug discovery, identification and formulation, etc.) as well as data emanating from results at nano-level that are often in the form of big data could provide owners of such data with revenue streams from subscribers directly or indirectly. The exponential growth and the large groups of variables arising from continuous studies and advancement in scientific knowledge in nanomedicine would continue to give rise to
such data which would be very valuable in the discovery, synthesis and application of future nanomedicine products.

b) Nanotechnology/nanomedicine projects are characterized by uncertainties and nanoinformatics can provide the needed platform to support such ventures. Nanomedicine projects adhere to the fuzzy principle in which case systematic procedures deployed would require adaptive systems (usually designed for uncertainties) using artificial intelligence (AI), and similar mechanisms[26]

c) Nanomedicine companies and business are data-centric. Informatics presents immense opportunities here, as it is only those who are skilled in informatics that could drive such complex data analysis tasks for such multi-million ventures.

d) There is a very strong likelihood that 99% of all nanomedicine development projects would fail without nanoinformatics.

In the discovery, design, synthesis, production and testing of nanomedical products, nanoinformatics approaches would assist in understanding and management of the toxicity effects on living organisms and the environment. Modelling and simulation are crucial because they are of enormous assistance in mining data from bulky datasets such as that from in silico, in vitro and in vivo experiments[2]. Modelling and simulation are required to facilitate the prediction of their likely side effects. Nanoinformatics approaches play a major role in the integration of the numerous diverse methodologies which encompass distinct and continuous modelling, plan, simulation, investigation, therapy and understanding procedures[2, 25]. All these are geared towards the advancement of needed understanding of the menaces and challenges associated with nanomaterials[2, 25].

An orderly nomenclature for nanoparticle creation and classification is profoundly required for the clarity improvement and standardization in probing, detection and comparison of data on the exact nanostructures within bulky databases from preclinical and clinical studies[2, 25]. The advancement of such a nomenclature requires text mining of the intricate scientific literature[2, 25]. It is obvious that some recent approaches are grounded mainly on simple statistical associations amid brief sections of texts[2, 25]. The use of contemporary visual nano-ontologies would assist in delivering a better semantic content, together with research on more innovative approaches of text mining from the existing literatures[2, 25].

According to Maojo et al. [2] and Kohane [15], the choice of exceptional material identifiers is another significant aspect of the ongoing research studies being carried out by some teams such as the Nanomaterials Registry with NCI, National Institute of Biomedical Imaging and Bioengineering, the National Institute of Environmental Health Sciences. Report from Ostraat [26], has it that with assistance of nanoinformatics the nanomaterials registry has been able to establish a prototype database and user interface and preliminary datasets which are being curated.

Another interrelated significant aspect according to Maojo et al. [2] is that of equivalency issue. This has to do with the determination of whether or not two nanomaterials are fundamentally alike. Nanoinformatics techniques are presently employed in this equivalency issue. As rightly observed by Kuiken [27], inadequacy of information is a major research challenge and the requirements for its mitigation. It is therefore suggested that the following should be put in place to ensure appropriate delivery of healthcare services in developing countries:

a) Innovative reference nanomaterials should be deployed.

b) Enhanced nanomaterial classification as reported in the literature and in databases.

c) Determination of the sensitivity of the analytical procedures to variations in experiments, materials and methodological approaches.

d) Quantifying the error and uncertainty in the approaches and protocols applied in the production of the required data.

e) Assessment and management of various types of risks.

f) Computerization of the whole process to create a single window of operation.

If developing nations must explore and excel in nanomedicine, it is imperative that, like developed nations, the academia, industry, and government respectively should acknowledge that informatics systems should essentially be placed in the right perspective and made to align with other scientific
machineries and approaches [28-35]. This according to Ho et al. [28], could oblige a boundless deal for more efficiency in other research streams such as genomics, proteomics and metabolomics. To this end, the potential impact of nanoinformatics could be felt economically, socially, and scientifically. Indeed, there are much prospects that it could offer for the advancement of a nation as well as individuals and experts.

4. Healthcare products industries in developing countries: the Nigeria perspective

The healthcare products industries in Nigeria could be traced from two main sources: first, home-grown (local) apothecaries which started from the traditional attributes via the distribution of botanical or herbal medications/drugs such as morphine, quinine, etc.; second, comprehensive production that started around the middle of the 19th century [35]. The main purpose of the healthcare industry is to research, develop, generate, distribute and manage drugs and other pharmaceuticals (healthcare products) for the general wellbeing of the society. Its goal is to offer safe and effective solutions ensuring affordability and availability. The possibility of guaranteeing global quality, affordability, and safety is a matter of continuous debate for years hence the segmentation of products into “products certified for local consumption”, and products with international quality labels. The issues necessitating local healthcare products production include but not limited to the following [7, 35-37]:

a) Limited access to healthcare products
b) High cost of imported healthcare products
c) Poor value of most healthcare products

d) Encouraging self-adequacy
b) Attaining independence from international providers
c) Developing home-grown industrial capacity
d) Generating foreign exchange via exportation of locally-produced medicaments and
e) Generating new job streams.

Up until the mid-20th century, several developing countries such as Nigeria only imported finished pharmaceutical products including syrups, tablets, suspensions, creams, ointments, powders, suppositories, capsules, parenteral preparations, etc. These had been regularly imported by international pharmaceuticals industries, government, or some well-to-do home-grown private businesspersons [35-37]. However, not much consideration had been given to local synthesis of raw constituents, dosage procedures or processing instruments. The fact remains that at present the volume of imported medications from technologically advanced countries such as China, India, USA, Europe countries, etc. still outweigh the locally produced products [38-39] as against the National Agency for Food and Drug Administration (NAFDAC)’s desire to have 60% of the volume of medications needed in Nigeria produced locally [40] though some authorities have blamed the ugly incidence on the local consumers’ preference to drugs manufactured elsewhere [41-42]. This is a warning that more effort is needed so that Nigeria could meet the pharmaceutical demands of its citizenry. To achieve such, the nation’s policy makers need to explore new trends and products such as nanopharmaceuticals. However, this would require the full integration of nanoinformatics machinery in such policies [35-37]. Presently, the local pharmaceutical scene in Nigeria is marked by:

a) A significant proportion of the required raw resources are imported
b) Manufacturing may require sophisticated equipment which are often costly to procure
c) Inexpensive labour compared to other climes e.g. Europe
d) High demand and large market
e) Lack of highly competent local content including researchers and research institutes.

According to the report from the World Bank [36], local production of healthcare products in most developing countries is impractical with exception of countries with large home-grown market and
capacities to generate dynamic healthcare products constituents like China, Argentina, Brazil, India, Thailand, Egypt, Mexico and some other which are presently coming up, due to economies of scale and technical necessity for the production of healthcare products. This has led to a trend away from the advancement of local healthcare products production and laid more prominence on the quality control of imported healthcare products and licensed generic products produced by international partners.

The globalization of the healthcare sector and the arrival of global public health funding ingenuities have resulted to a more modest market for generic healthcare products and this has resulted in a substantial reduction in the prices of vital healthcare products. The World Bank in 2005 [37] reported that there are numerous categories of healthcare products manufacturers with diverse commercial models that function industrial facilities in low- and middle-income nations.

Notably, there are three major stages of generation that healthcare products manufacturing industries in Nigeria adopt, viz; primary, secondary and tertiary stages [37]. Primary manufacture (1°) entails the processing of raw constituents of healthcare products and may include additives/excipients or supplementary ingredients employed during product formulation. Secondary manufacture (2°) involves some comprehensive processing of finished pharmaceuticals, e.g. tablets, injections, capsules, etc., from raw constituents or intermediate products, often from both local and imported sources. Lastly, tertiary manufacture (3°) revolves around packaging, marking, and labelling finalised health products from the 1° and 2° stages respectively into substance packs, reduced dispensing sachets, bottles, or course of treatment units for specific use. Another tenable way of categorising manufacturing/production is by way of scale or size or production output. By this, healthcare products manufacturing industries could be small scale, medium scale, or large scale. The small-scale drug manufacturing firms are often owned by private individuals. Ownership of medium-scale entities may involve groups or partners. The large-scale industries are mostly controlled and owned by foreign international corporations [1, 8, 27, 34-37].

5. Challenges of healthcare products manufacturing in Nigeria
Unbridled importation of finished healthcare products, as well as merchandising pharmacy business, had been prosperous in Nigeria. Presently, local healthcare products manufacturing is beginning to grow in response to NAFDAC’s drug production policy which places more burden on local production. Nevertheless, local manufacturing in Nigeria faces the following:

a) Unfair posture on protocols and standards as to raw constituents, procedure, processing, instruments, etc. by regulatory authorities.
b) Undertaking of global healthcare products business by international corporations at the detriment of local outfits
c) Unhealthy competition enthroned against local outfits by importers of healthcare products and international businesses.
d) The necessity to regulate many healthcare products of herbal source now circulating in Nigeria and other developing countries.
e) Failure of developing nations to tap into research outcomes from foreign institutes.
f) Failure on the part of the government in controlling illegitimate importation, production and marketing of counterfeit, adulterated and inferior expired healthcare products.
g) Deficiency of active research and growth due to reduced research funding from both the government and private corporations.
h) Biased government policies, marketing and administrative structure
i) Increase cost of business
j) Inexistent permanence strategy beyond the healthcare products manufacturing owners, etc

6. Prospects of healthcare products industries in Nigeria
Small-scale production entities including those owned by private individuals, government, research and academic institutions, are presently competing with their foreign counterparts even though the country still rely on raw materials and equipment from overseas. It is very clear that the local outfits are up against several odds. To encourage these industries, the government has a great part to play in infrastructural
expansion, functional policies, safety, conducive environment, security, and providing access to financial resources (medium and long-term funds). To drive these prospects further especially towards the local production of competitive products such as nanodrugs, etc., installation of modern nanoinformatics research laboratories is very key [35].

7. Nanoinformatics and challenges in the delivery of healthcare products in Nigeria

Amid the enormous potentials of nanoinformatics, from discovery, characterization, formulation, molecular medicine to public healthcare, nanomedicine and nanoinformatics have received the required attention especially in developing countries [23]. There are enormous challenges owing to the fact that the field of nanotechnology and its biomedical connections are still in infancy in these jurisdictions [24]. In Nigeria, the implementation rewarding nanoinformatics programs is connected to the existing problems hampering local healthcare products delivery. These include:

a) Lack of sound and sustainable policies, strategies and legal frameworks to drive the modern drug manufacturing technologies.

b) Lack of political will on the part of the Government to fund researches and projects in nanoinformatics and nanotechnology.

c) The perennial problem of collaboration between the academia, industry, and government agencies, which are the three key stakeholders whose’ strong and committed collaboration/partnership is needed for every nanomedicine project.

d) The politics of the day that has permeated into the academia, research institutes and learned societies wherein mediocrity is entrenched with leadership bestowed on persons with neither definite vision nor mission.

e) Poor funding of tertiary Institutions.

f) Failure of leadership in tertiary and research institutes wherein novel and evolving disciplines are deliberately neglected for personal reasons.

g) Poor planning and negligence on the part of Government to provide strategic initiatives and direction in the science and technology through its agencies.

h) Corruption and socio-political issues bothering on tribalism, nepotism, religion.

8. Conclusion

Several researches have shown that nanoinformatics despite its enormous potential is also constrained by several challenges [6, 24, 29, 35, 43-44]. To mitigate these challenges, it is submitted that concerted efforts must be made towards investing conscientiously in nanoinformatics infrastructure to promote indigenous research and development. Nanoinformatics is a necessity and a prerequisite to sustainable healthcare products delivery and according to Maojo et al. [2], some of its significant dependencies are connected to what had been previously adopted in post-genomic research projects by biomedical informaticians, where tremendous outcome was recorded. In developed jurisdictions, outstanding progress have been made in this regard but in developing jurisdictions like Nigeria, nanoinformatics requires concerted efforts and commitment among all stakeholders, especially on common agreement on the goals, subfields, research, training needs, ethical requirements and ultimately funding, which could lead to more specific agendas for research and development. In this study, we have presented some key opportunities and challenges that nanoinformatics faces in advancing the course of healthcare products delivery in developing countries. Some points were also raised on the direction of nanomedicine in regard to data and information management. The problems and approaches faced by nanoinformaticians were carefully examined.

Conclusively, we submit that despite the aforementioned opportunities presented by nanoinformatics, which could be harnessed and sustained in developing countries like Nigeria, there are remarkable challenges at the various levels of socio-economic and political strata of the society. Owing to the growing healthcare delivery needs of developing societies, stronger and closer collaboration among all key stakeholders (government, academic, industry, professional societies) is advocated as this would engender the development of skilled manpower and needed resources to drive the ever-growing nanotechnology
industry. Failure to adopt this approach would leave the developing countries at the mercy of the developed countries.

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