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NANOTECHNOLOGY IN MILITARY DOMAIN: GLOBAL PERSPECTIVE IN CONTEXT WITH BANGLADESH ARMY

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ABSTRACT

Nanotechnology is one of the fastest-growing fields of science, playing a revolutionary role in various industries, including healthcare, transportation, communication, space technology, agriculture, environmental pollution management, and the defense sector globally. Nanotechnology is an interdisciplinary science that offers a significant beneficial impact on society as well as a huge advantage in the military industry. In recent years, cutting-edge developments in nanotechnology for defense have become an indispensable part of ensuring a country's national security. Defense sectors will remain obsolete and ineffective without the appropriate application of nanotechnology. Nanoparticles, nanorods, nanowires, and nanotubes are currently used to develop various advanced deference applications. It is currently applied in all the sectors of defense like land, naval, and air-based defense systems development. It plays a pivotal role in developing optical materials, smart ammunition, stealth technology, air defense systems, heat management, communication and surveillance, systems for command and control, innovative sensors, automation and robotics, and materials for energy storage, etc. Nanotechnology enables the development of small-sized lightweight weapons with higher efficiency and greater precision. Developed countries are significantly increasing their funding in nanotechnology research to capitalize on the opportunities for incorporating innovations in nanotechnology for the betterment of their military industries. However, Bangladesh is still in a rudimentary stage in terms of research activities to apply nanotechnology in the military sector. This review article focuses on the innovations and applications of nanotechnology in the defense sector, with a global perspective and an emphasis on Bangladesh.

Keywords: *Nanotechnology, Altered Property, Defense, National Security, Bangladesh Army.*

1. INTRODUCTION

Nanotechnology is an emerging branch of science that is considered a key technology for national economy and security. It utilizes the properties of matters at the atomic and molecular levels with nanoscale size approximately in the range of 1–100 nm, as shown in Figure-1. The dimension of nanometer can be understood by comparing it with the fact that it is 100,000 times smaller than a strand of hair. Nanotechnology in general terms, employs matter at the atomic, molecular or macromolecular levels to produce and control objects at nm scale in order to fabricate novel materials, devices and systems that have new properties and functions due to their small size (Khan and Rehman, 2016). Nanotechnology can be divided into various types, such as nanostructures, nanoparticles, nanowires, nanotubes, nanorods, and nanoporous materials. The fundamental basis behind nanotechnology is that materials with nanosize show different thermal, chemical, electronic, and magnetic properties and effects compared to the same materials with larger sizes (Ahire *et al*., 2022). These differences in properties primarily arise due to the high surface-to-volume ratio of nanoparticles in comparison to their bigger-sized particles. The ultimate result is that many effects are observed in nanosized particles that are not observed in large particles, which can be utilized to benefit mankind in various aspects. For example, alteration of size of the nanoparticles may make the use of paramagnetic and ferromagnetic properties suitable for a particular application.

Basically, advancements in technology occurred at the very beginning with large shapes and sizes; a notable example is a computer, which needed an entire room and a sizable number of electric equipment with power supplies to enable it to function in regular use. However, over the years, huge research and analysis reduced the shape and size of scientific innovations, even in some fields' particle size interfaces. Visualizing the amplitude of modern science, scientists identified nanoscience and nanotechnology as the fastest-growing areas of modern technology, apprehending the entire spectrum of technology wave (Malik *et al*., 2023). It has been assumed that application of nanotechnology will be the core concept of scientific innovations irrespective of domains with particular alteration in basic structure (Chafiq *et al*. 2023; Lucarini *et al*., 2022). The alteration basically manipulates substance at the atomic, molecular, or macro-molecular level in order to develop and regulate objects. This modification in properties of nanomaterials have created vast applications in Chemistry, Computers, Physics, Engineering, Biosciences and medicine, etc. The confinement of electrons within particles of dimensions smaller

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than the bulk electron delocalized length is the primary reason of the emergence of the physicochemical and optoelectronic properties of nanoparticles (Kolahalam *et al*., 2019). The slight change in the size of nanoparticle is particularly attractive in engineering the bandgap of materials to desired levels as well as the growth of quantum dot which enable these materials to tune the optical absorption or emission properties (quantum dots) (Mandal *et al.*, 2005). The application of the unique properties of nanomaterials is diverse, especially in altering mechanical strength, chemical reactivity, optical properties, electrical properties, thermal properties, and durability, as well as quantum effects (Khan *et al*., 2019). The main purpose of nanotechnology manipulation is to apply the properties of small-sized particles to fabricate devices, substances, and systems with innovative properties and functionalities (Sim & Wong, 2021). Over the last couple of years, nanotechnology has become a lucrative and major area of research and development activities worldwide, due to its comprehensive and large-scale applications, which yield obvious investment returns and technological supremacy (Bhutkar & Sonawane, 2023).

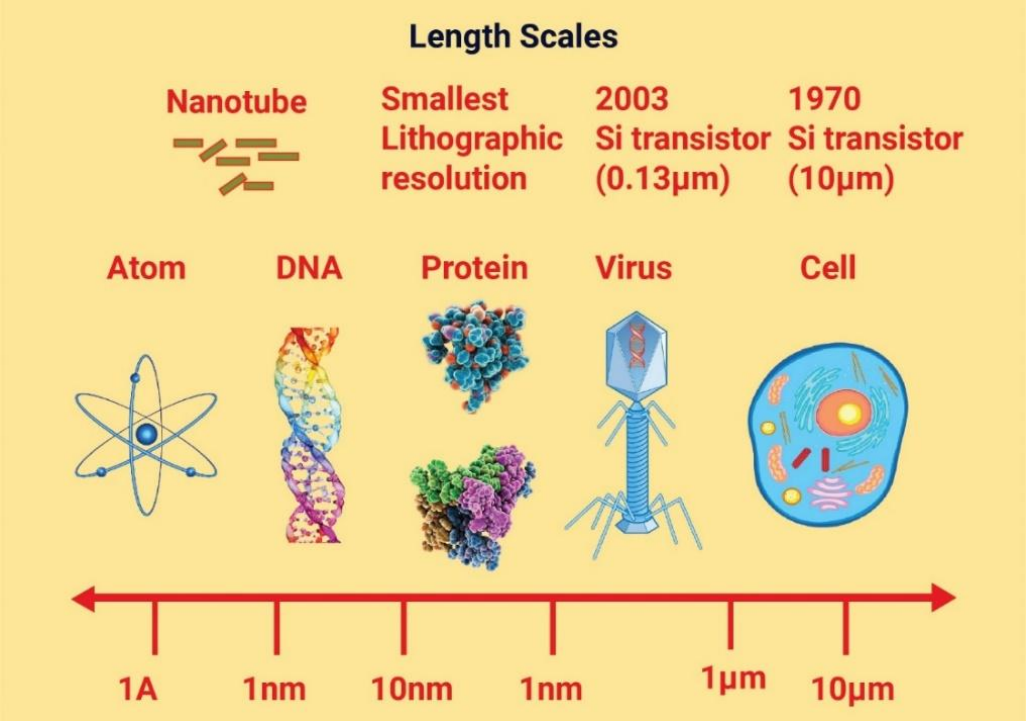

Figure 1: Atoms having sizes from 1-100 nanometers (redrawn from Khan and Rehman, 2016)

Soon after the emergence of nanotechnology applications in various fields, they opened up new avenues in the defense sector, enhancing the military might of superpowers and shaping the basic design of military equipment (Soni & Jha, 2024). Military and security authorities start spending their investment to grab the fruit of nanotechnology innovation in order to cement their superiority in military might. The basic idea of this unprecedented technology is the precision in science and engineering with smaller particles, which favours military campaigns regarding the effectiveness of modern weaponry systems in all weather and terrain (Krelina, 2021). Scientific community worldwide started to realize that nanotechnology has the potential to make big difference in numerous areas of defense high-speed conveyance and capacity, like troop functionality, the safety of soldiers, automation and robotics, advanced war fighter and battle systems capability, betterment of aircraft, systems for command, control, communication and surveillance, innovative sensors, electrochemical power, such as batteries or fuel cells, and many more. Expected benefits of nanotechnology also include smart materials with lighter and stronger properties that need less power to function and also more powerful and strong diagnostics at the single-cell level, which offer great promise in the field of defense applications that provide its cross-discipline domain (Suja & Mathiya, 2024; Javaid *et al*., 2021). Therefore, nanotechnology can provide direct benefits to combat forces in various fields of weapon technology, such as electronics and communication, stealth, smart uniforms, mobility, and adaptive structures (Kumar & Dixit, 2019). Obviously, the dominance of nanotechnology will be freighted in battle space systems like situational awareness systems, geo-intelligence environments, and the intelligence and information processing arena to a large extent. Nanotechnology is now become an indispensable part of various areas of defense sector. This review article focuses the current status of research and applications of nanotechnology in defense sector globally in context to Bangladesh with historical background. Probable fields for Bangladesh Army where the research and application should be emphasized are also illustrated in this article. Furthermore, the challenges that can be arisen and policy support required to undertake nanotechnology initiatives for Bangladesh Army are also discussed.

2. NANOTECHNOLOGY IN EARLY AGE

Although structured research and large-scale applications of nanotechnology have begun only in recent decades, the incidence of the application of nanotechnology is much older. In fact, 400 A.D. artifacts have been discovered. One of the most intriguing displays of nanotechnology was made by the Roman elites in the fourth century AD (Bayda *et al*., 2020). The Lycurgus cup, the earliest example of dichroic glass that transforms into two colors—green and red-purple—in different lighting situations (Fig. 2), is said to be the earliest example of nanotechnology However, from the ninth to the seventeenth century, ceramic glazes known as "lustre" were utilised in the Islamic world. These ceramic glazes sparkled and glistened naturally because they contained nanoparticles. The Italians used nanoparticles in the 16th century to create Renaissance pottery influenced by the Islamic world (Poole & Owens, 2003). In 13th to 18th century, the Ottoman's invented 'Damascus Saber Blade', cementite nanowires and carbon nanotubes predominantly to prolong the capacity, elasticity, and capable of comprising a keen edge (Altmann, 2004). In 1987, Micheal Faraday revealed how gold nanoparticles yield multi-colored solutions in particular lighting situations (Hammami *et al*., 2021; Tweney, 2006).

Figure 2: Nanotechnology in Dicroic Glass (Bayda *et al*., 2020).

3. NANOTECHNOLOGY IN THE MODERN ERA

Nanotechnology enables us to develop products at the nanoscale, like atoms, which can be used to manufacture products that work at a deeper scale. In a meeting with American Physicists' Society in 1959, renowned American physicist Richard Feynman initiated the idea of contemporary nanotechnology first. In his outstanding presentation, Feynman gave a vision of using the machine by ultra-modern technology, which he designated as nanotechnology, to develop smaller machineries that are down to the molecular level (Pisano & Durlo, 2023). Later, in the year 1981, the "Scanning Tunneling Microscope" (STM), a fully new microscope, was invented by Gerd Binning and Heinrich Rohrer at the IBM Zurich research (Binnig *et al*., 1986). The development of this microscope leads scientists to innovate more novel techniques such as atomic force microscope (AFM) and scanning probe microscopes (SPM). These modern-day tools have become parts and parcel of contemporary nanotechnology researchers. As for example, in 1990, Don Eigler of IBM in Almaden and his colleagues used an STM to manipulate 35 individual xenon atoms on a nickel surface and formed the letters of the IBM logo (Bayda *et al*., 2020). Transmission Electron Microscopy (TEM) has been used in 1991 for the first time to observe hollow graphitic tubes, also known as carbon nanotubes to enhance the thermal, mechanical and electrical properties of the bulk product in the current nanotech era (Iijima, 1991). Hollow graphitic tubes or carbon nanotubes have the potential in the fields of energy storage materials, emitters, catalysis, and molecular electronic components (Syduzzaman *et al*., 2025). Nanotechnology provides a link between conventional and quantum mechanics in a gray area called a mesoscopic system. Additionally, this system can be used for the manufacture of products of nano assemblies' types that can be applied in agriculture and medical industries, such as agricultural products, nanotools for patient treatment and diagnostic purposes, and nanomedicine.

3. RESEARCH AND DEVELOPMENT ACTIVITIES ON NANOTECHNOLOGY IN THE CONTEMPORARY WORLD

Considering the current level of progress in the fields of nanotechnology and their applications, it can be inferred that nanotechnology (NT) will remain at the core of the fundamental technological wave in human civilization, regardless of the fields involved (Joseph *et al*., 2023). The global nanotechnology market size was valued at $1.76 billion in the year of 2020 and is likely to reach $33.63 billion by the financial year 2030 and also register a CAGR

of 36.4% from 2021 to 2030 (Mehta *et al*., 2024). This CAGR factor will be the controlling multiplication of the global economy in the 21st century. The race among governments as well as major and small business entrepreneurs of different nations accelerates the expansion of nanotechnology research and development (R&D) worldwide, considering the significant market value of different applied fields (Pokrajac *et al*., 2021). Developed countries are investing billions of dollars to grab the opportunities of innovations in nanotechnology to uphold their political, economic, and security interest (Tawiah *et al*., 2024). That is why the development in this field is quick and intense and also evolves a multiple range of contents and industrial values (Fig. 3). It has vast modern utilities and many other applications that are yet to be discovered. The USA, Russia, Germany, UK, and China are the leading countries in the contemporary world of nanotechnology in terms of innovation and market size (Fig. 4). However, instead of a vivid description, the nanotechnology status of different countries is described shortly in the following sub-sections.

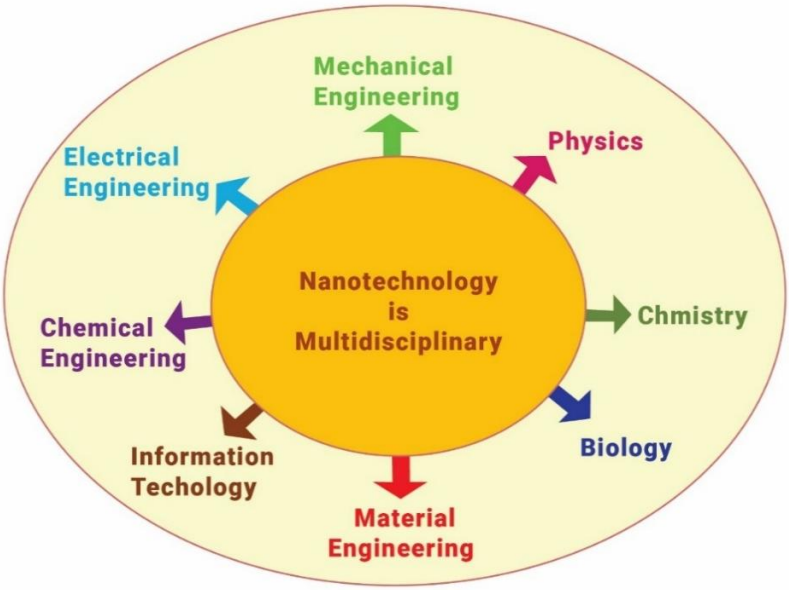

Figure 3: Fields of Nanotechnology in the modern age (Khan, 2016).

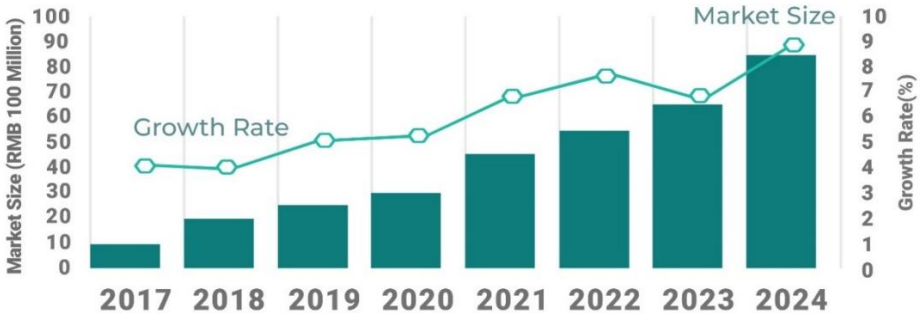

Figure 4: Worldwide Market Size of Nanotechnology (Adiguzel, 2019).

3.1 The United States of America

In 2000, the US National Nanotechnology Initiative was established with a $ 500 million US dollar budget, along with four forward-looking goals (Dong *et al*., 2016). The country has allocated roughly 17.9 billion dollars from fiscal year 2001 to fiscal year 2013 on research and development programs (Sargent Jr, 2009). Approximately one quarter of a trillion dollars have been in invested in the field of nanotechnology by the government and private sectors collectively by 2015 (Dong *et al*., 2016). However, to be the world leader in strategic advantage, the US Defense Department made huge investments in military-specific nanotechnologies with the purpose of improving existing systems' effectiveness with light, flexible, and resilient materials and also revealing new applications. It was reported that USA alone had published 4725 patents in 2017 (Panina *et al*., 2023). The emphasis by the US government on fundamental research, advanced applications, devices, and systems can be seen in NNI investments from 2019 to 2021 and also proposed investments in the year 2022 (NNI budget, 2022), as shown in Fig. 5.

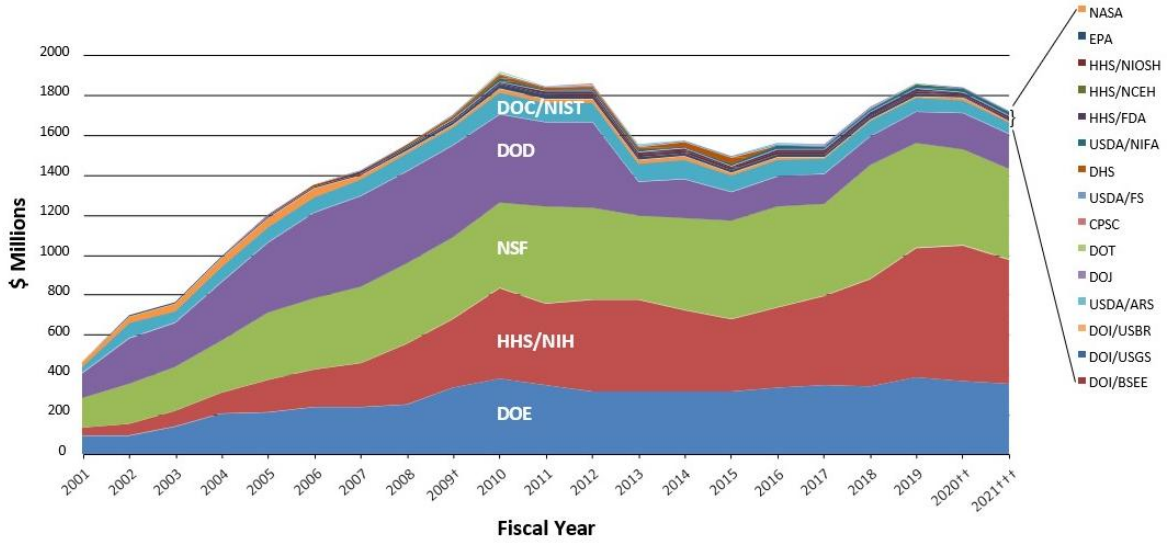

Figure 5: NNI Funding by Agency, 2001–2021 in USA (NNI budget, 2022)

3.2 China

China, the potential superpower, embezzled a heavy investment in nanotechnology, mainly in the medium- and long-term scientific programs (Qiu, 2016). It has now become an important leader in global nanotechnology research. In the year 2000, the US was in the highest ranked position, accounting for 27 percent of the nanotechnology papers, whereas Japan and China both published approximately 14.5 percent of documents only. However, in 2009, China ranked number one and accounted for 23 percent of papers, whereas the number of papers published by both the USA and Japan were downgrading, accounting for 21 percent and 8 percent, respectively (Bhattacharya & Bhati, 2011). China's nanotechnology market is one of the fastest-growing in the world (Fig. 6), reaching US$ 31 billion by 2010 and estimated to reach US$ 145 billion by 2050 (Bhattacharya & Bhati, 2011). The country launched a strategic pioneer program on nanotech in the year of 2012 budgeting around 152 million US$ over five years (Qiu, 2016). The People's Liberation Army (PLA) of China has also made significant investments, showing its recognition of the importance of transformative military technology (Desai & Kewalramani, 2022). China made her primary focus on coatings, nano-fabrics and catalysts for military and non-military use. One of the significant achievements of nanotechnology research in China is the creation of the world's smallest carbon nanotubes (0.5 nm in diameter) in 1999.

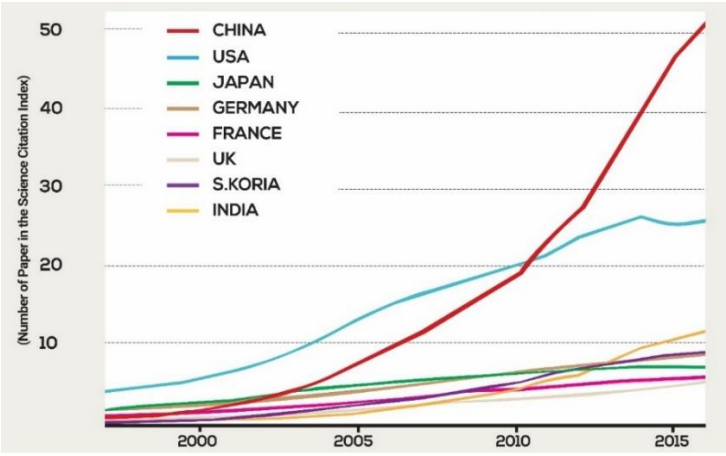

Figure 6: Growth of Nanoscience in China compare to others
(Source: http://www.nanoctr.cas.cn/qydt2017/201709/P020170929619825058495.pdf)

3.3 Russia

Russia initiated an extensive government program in the field of nanotechnology in the year of 2007. Russia's strive to be a leader in the global nanotechnology industry resulted in the allocation of considerable public resources, and by 2009, Russia had become the world's second-largest public spender on nanotechnology

(Connolly, 2013). Presently, more than 1,183 organizations are working to ensure the eventual development of nanotechnology in Russia (Golubev, 2018). The consumption of nanopowders by Russian industries is increasing at a rapid pace, and its forecast is presented in Fig. 7. Nevertheless, Russia has approved the Federal Targeted Program (FTP) with a budget of over $ 3.3 billion, of which two-thirds are allocated for research and development. It has made significant contributions to the development of military applications for nanotechnology in the areas of military uniforms, nanomaterials in military use, and nano-coatings for MiG and Sukhoi aircraft, etcetera (Tomar, 2014).

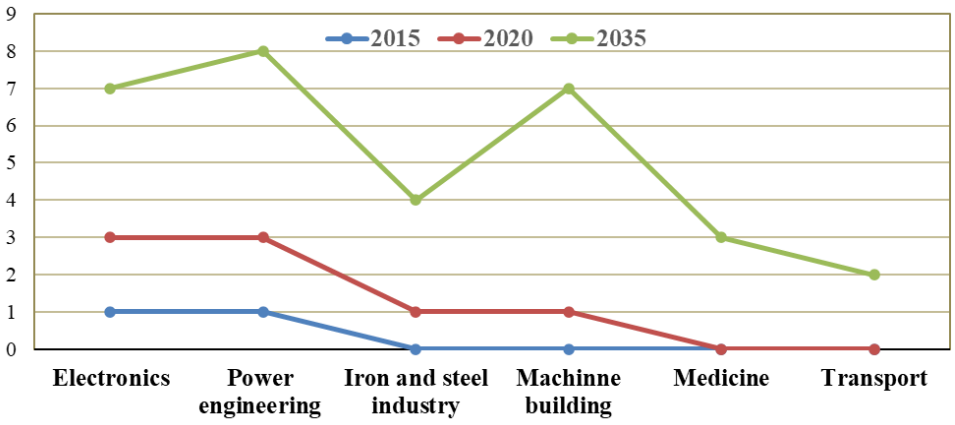

Figure 7: Forecast rating of Russian industries consuming nano powders for 2015-2035 (Golubev *et al*. 2015).

3.4 Japan

The support of nanotechnology by the Japanese government started in 2001 with the 2nd Science and Technology Basic Plan (STBP) (Steeghs, 2011). Major investments were mainly targeted at clean energy and electronics. The government's interest was mainly focused on the research areas of nano-electronics, nonmaterial, and nano life-sciences (Fig. 8). In the last STBP (4th), the main focused area has been confined to the development of green and life innovations (Mirzayev, 2024). With this purpose, more than 38 companies are engaged in nanotechnology-based commercial activities. In addition, around 57 nanotech and nanoscience-related research and community organizations are working to win the collective country goal.

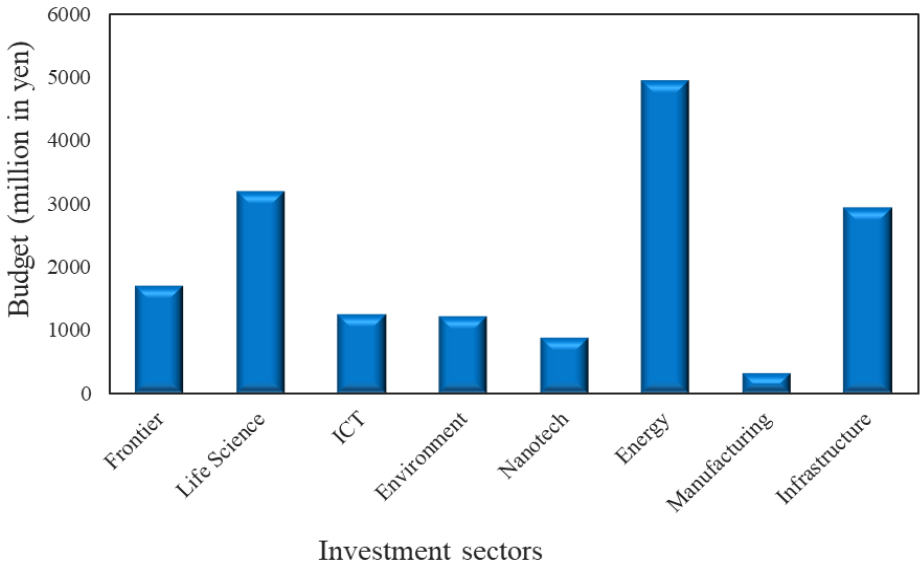

Figure 8: Investment of Japan in Nanotechnology (Žagar, 2014).

3.5 India

India launched the "Nano Science and Technology Initiative" with an initial financing of Rs. 60 crores in an effort to boost nanotechnology research in both military and non-military domains (Fig. 9). But by launching a 5-year program dubbed nano mission with funding of USD 250 million in 2007, India expanded its nanotech mission and ambition (Ghosh & Krishnan, 2014). The main body in India promoting the development and utilizing the

potential of nanotechnology in the defense industry is the Defense Research and Development Organization (DRDO), which is actively conducting R&D in nanotechnology in 30 of its facilities for defense use.

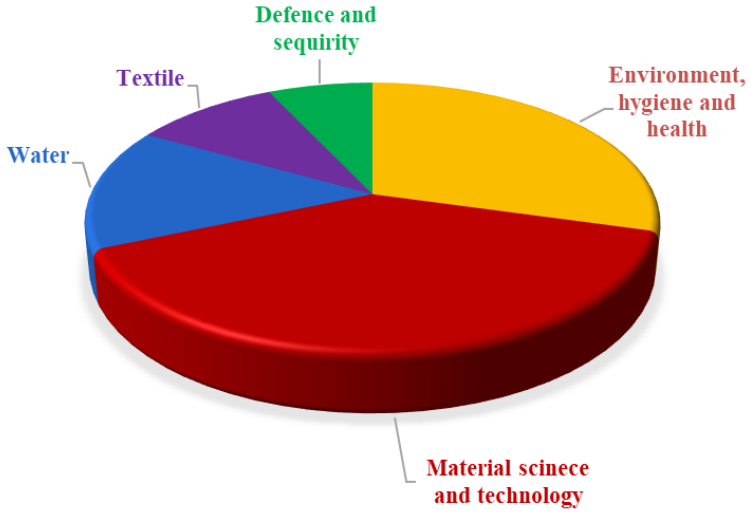

Figure 9: Field of nanoscience and nanotechnology in India (Samal, 2019)

3.6 Pakistan

The three-year nanotechnology initiative in Pakistan was launched in the year 2003. The L.E.J. Nanotechnology Center in Pakistan is working on projects such as nanomedicine, nano-catalysis, nano-filtration, and nano-coating on glass, ceramics, and textiles. Most notably, a comprehensive plan with a $25 million fund was developed by the government in December 2013 for upgrading all national nanotech effort. Pakistan is upgrading their military equipment with the collaboration of friendly developed nations. As shown in Fig. 10, Pakistan's research on nanotechnology is increasing significantly.

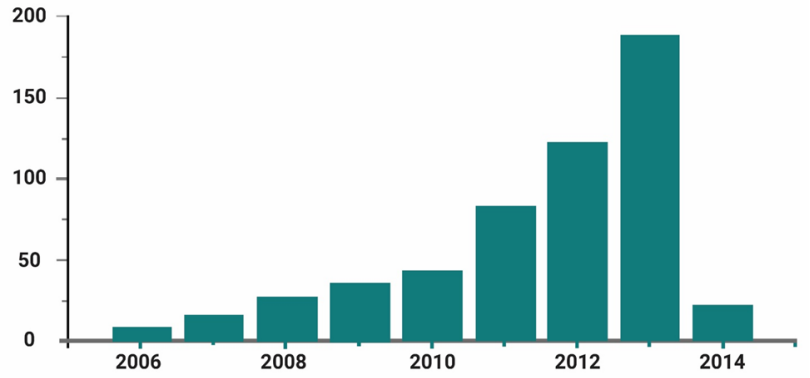

Figure 10: Trend of nano research publications in Pakistan

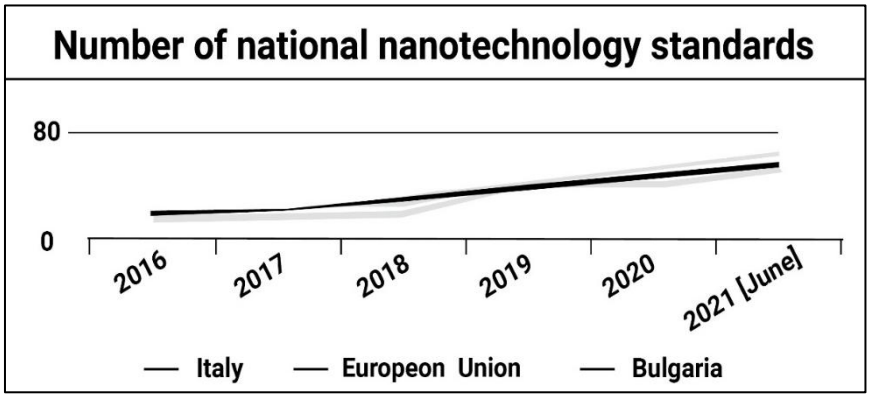

Figure 11: National Standard of Nanotechnology in European Nations (Adapted and reproduced from https://statnano.com/country/european-union)

3.7 European Union

European Union started its nanotech journey at the very beginning of this new tech in the year of 1996 (Tomar, 2014). Fig. 11 shows the number of national nanotechnology standards in European Nations. An action plan named 'Nanoscience and Nanotechnology: An Action Plan for Europe (2005–2009)' was also formed in the year of 2005. The purpose of this endeavor was to prescribe a series of articulated and interconnected functions for the contiguous accomplishment of a definitive, compact, and responsible technique for nanoscience and nanotechnology (Alian, 2009).

4. NANOTECHNOLOGY AND ADVANCEMENT IN WARFARE

All forms of modern weaponry, such as micro-robotic apparatus, supra-responsive fulminate, hyper-reactive explosives, and electromagnetic super-components, have undergone rapid development with the application of nanotechnology. Nanotechnology has a significant impact on aerodynamics, dynamics in operation, stealth technology, material composition, and robustness, among other effects. Modern information system and unmanned combat vehicle technologies are highly influenced by nanotechnology (Lavers, 2021). However, in some cases, the ascendant of nanotechnology in modern warfare may create security hazards in different domains, like the worldwide security environment, the safety of social living, etcetera (Taiwah *et al*., 2024). Keeping aside the security hazard, the modern armies are raising funds for exploring nanotechnology (Figure 12), calculating the potential blessings and setbacks of the ultra-modern blessings.

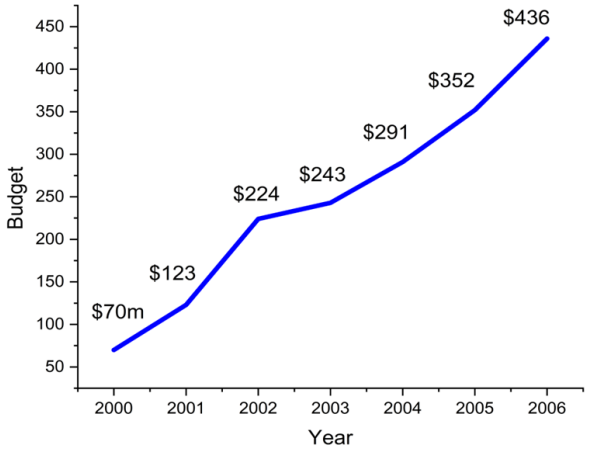

Figure 12: Increasing Budgets in nanotechnology for military purpose (https://www.nanowerk.com/spotlight/spotid=1015.php)

5. CURRENT TRENDS OF NANOTECH IN WARFARE AND DEFENSE

The generation of new defense stuffs by current research has mostly evolved into military nanotechnology weapons, including the production of defensive and combat machines, with the purpose of upgrading existing designs of lightweight, pliable, and durable materials. Obviously, these innovations will ennoble the fighting capabilities of a force, specifically in mountains and high-altitude areas, by moving a number of arsenals in response to circumstances.

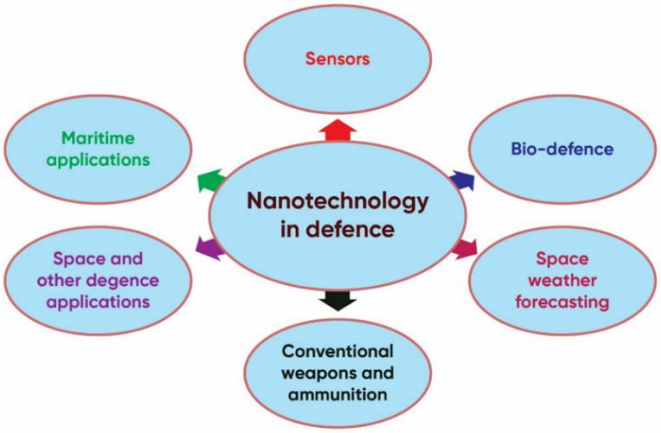

Figure 13: Applications of Nanotechnology in Defense

5.1 Military Intelligence and Communication Devices

The application of nanotech-made communication gadgets lower power consumers, slim in size and shape, mild in weight, and also cheaper in industrial manufacture, therefore simplifying defense-related communication parameters (Riaz *et al*., 2021). Developed nations are already advanced in the potential military applications of nanotechnology in aerospace, such as solid oxide fuel cells, surveillance cameras on microchips, and performance monitoring cells. Sensors, portable and efficient in nature, will be extremely worthy to the military field of operations. Noteworthy nanotech advancements in these areas include highly sensitive infrared thermal sensors, small and lightweight accelerometers, and Miniature high-performance camera systems used in GPS for motion and position sensing, as well as health-monitoring sensors, biochemical sensors, and drug/nutrition delivery systems (Majumder *et al*., 2017).

5.2 Nanotechnology for Developing Ballistic and Anti-Impact Materials

5.2.1 Military Uniforms, Battle Suits, and Body Armour

Nanofibers and nanocomposite-based textile materials offer enhanced protection by lightweight anti-ballistic textile wear, chemical and biological protection, and self-decontamination with thermal control in extreme battle environments (Selim *et al*., 2024; Tomar, 2015). Nanocomposites consisting of a matrix material, usually a polymer with a dispersion of nanoparticles/fibre, provide enhanced thermal, mechanical and electrical protection to the soldiers (Thilagavathi *et al*., 2008; Rashid *et al*., 2024). Researchers exhibited a type of carbon nanotube smeared with swanky fibre susceptible to propulsion electric current and also able to be woven into textiles to unearth blood or monitor health (Rdest & Janas, 2021). Developed countries are forming partnerships between the army and information research centres to focus on developing armour for the enhancement of soldiers' survival in battle environments. The governments are allocating big funds for this type of collaboration. This results from the innovative enhancements of various concerns of future soldier's body suits. Surprisingly, power spongy materials that defend against blasts or ammunition shocks, sensors to detect chemicals and toxins, and built-in nano-devices to identify haemorrhages and fractures have seen significant development from these research collaboration initiatives. In the subsequent phase of development, the battle suit would be possible to make with advanced nanomaterials like carbon nanotubes woven into fibres with enhanced structural characteristics and a lot of flexibility (Haq & Reddy, 2021). Nanotechnology has enabled the development of body armour using Shear Thickening Fluid (STF), which offers double anti-ballistic performance in terms of absorbed energy, along with greatly enhanced flexibility (Wiśniewski, 2007).

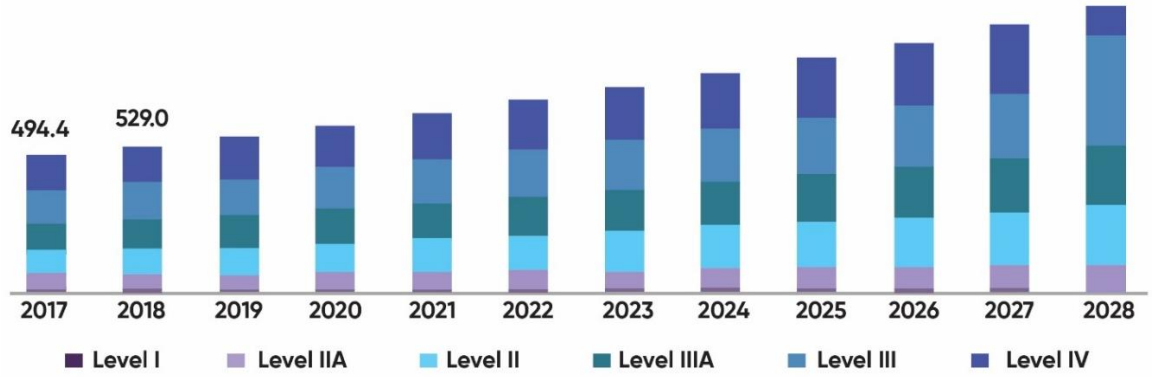

Figure 14: Estimated Global Body Armor Market (https://www.grandviewresearch.com/industry-analysis/body-armor-market)

5.2.2 Biological and Chemical Protection

On the battlefield, soldiers are mostly vulnerable to the hazardous state, leading to a high rate of battle casualties. To get protection against hazardous conditions like chemicals, gases, or biological agents, soldiers use conventional protective suits, which are heavy in weight, big in size and shape, and less comfortable for prolonged periods. The application of nanotechnology in the form of electro-spun nanofibers ensures features such as sensing, decomposition, and filtering of harmful toxins. Therefore, nanofibers, being highly sensitive to chemical or biological warfare agents, are excellent candidates as sensing surfaces (Al Faruque *et al*., 2021). Nanoparticles that can greatly decompose toxic warfare agents can be embedded with nanofibers, giving the soldier operational advantages (Wiśniewski, 2007).

5.2.3 Wound Care

Nanomaterials offer self-healing mechanism to imitate regeneration that can be applied for the healing of wounds. Nanomaterials coated wound dressings allow for the control the release of drugs and proteins for a specified period of time (Anand *et al*., 2024). This unique property of nanoparticle aggregate wound dressings offers the exciting opportunity to control the release of growth factors and other actives, thereby accelerating wound healing (Barroso *et al*., 2020; Lin *et al*., 2022). When wound dressing is integrated with metal nanoparticles like gold, silver and zinc, they possess outstanding stimulation of wound healing and antibacterial activity. For example, silver nanoparticles can alter anti-inflammatory cytokine release, which enhances wound healing (Vijayakumar *et al*., 2019). Furthermore, organic nanomaterials, polymeric nanoparticles, and various inorganic nanomaterials are developed for numerous applications of wound care, as shown in Figure 15.

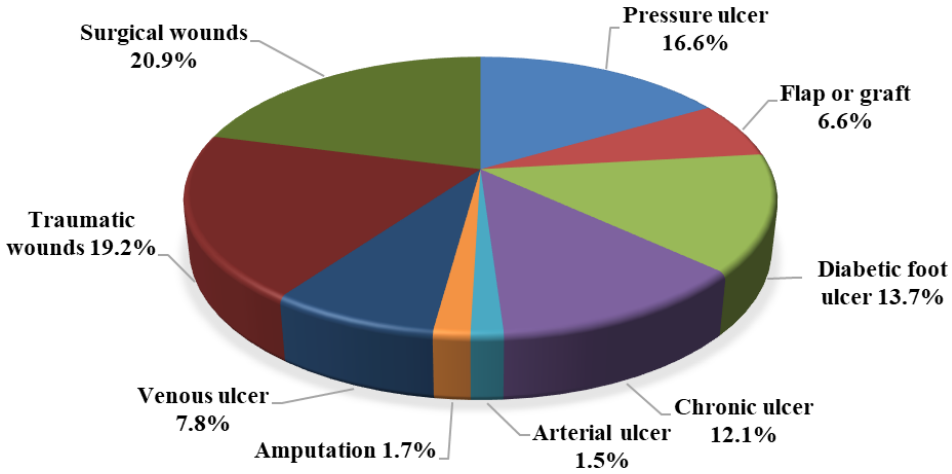

Figure 15: Application of Nanotech in Wound Care (Barroso et al., 2020)

5.2.4 Military Sensors

Sensor-based equipment is mostly effective on the battlefield for intelligence collection and is being rapidly enhanced by nanomaterials-based smart sensor technology. The Wireless NanoSensor Network (WNSN) can be considered one of the most important military applications of sensors (Tomar, 2014). To locate the detrimental chemicals and biological weapons, nanosensors can be the best solution. Nanosensors can be deployed on the battlefield or behind enemy lines in order to identify and differentiate between own troops, aircraft, vehicles, and other objects. They can also be used as damage detection systems-physical nanosensors could detect fractures in military equipment. The network of sensors can also be embedded in bridges, roads, vehicles, tanks, arms, guns, and uniform of soldiers (Rashid *et al*., 2023).

5.2.5 Adaptive Camouflage

Current mode of camouflage is determined by the use of disruptive clothing, nets, paints and other equipment facilitate to merge with the surrounding background (Regar *et al*., 2020). Nanotech-based camouflage and concealment processes are becoming more effective as fibre coating, light emitting diodes (LED), optical sensors, and power sources are being used by the modern armies of the world. In this process, signals based on the surrounding areas are being received by the optical sensors, and the fibre changes color accordingly. Implicating an outer magnetic field, the researchers have achieved grand success in changing the colour of nanosized particles of iron (Rajendran, 2012).

5.2.6 Smart Helmet

Regular Helmets used by the Bangladesh army are made of synthetic fibre. These helmets are designed to offer improved protection against small arms fire and blast shockwaves from explosions on the battlefield. Presently, modern armies are working on reducing the weight of helmets to enhance ballistic performance against small-arms fire, as well as to mitigate the effects of a massive blasts from heavy explosions. Nanoparticle-based helmets will serve this purpose (Tomar, 2015).

5.2.7 Nano-Nuclear, Chemical, and Biological Weapons

Nanotechnology is likely to offer qualitatively new options for inducing biological or chemical weapons that would make biological/chemical warfare much more effective and manageable. This technology could be utilized

to facilitate easier entry into the body or cells, as at the same time, mechanisms could be developed to limit or prevent damage to one's own force, such as self-destruction, after a defined period of time.

5.2.8 Unmanned Aerial Vehicles

Unmanned vehicles are considered as the major tools for modern warfare. Nowadays, unmanned aerial vehicles (UAVs) and unmanned combat vehicles (UCVs) have become a crucial and vital component of a country's defense. The prime advantage of this system is that there is no risk of human mortality even if the vehicle is intercepted by enemy fire. Both UAVs and UCVs can be operated effectively in mountainous areas, where it is land-based vehicles cannot move easily. Lightweight and stronger materials needed for unmanned aerial vehicles are manufactured by the applications of nanotechnology (Abed & Jawad, 2022). For example, smaller, more mobile, more agile, and more reliable military platforms, such as light armoured vehicles, fighter jets, tanks, and man-transportable and micro-unmanned aircraft in the defense industry, can be developed with the application of nanostructured materials. Nanotechnology enables the development of all weather and climate adaptive platforms, such as platforms that could be operated from land bases or sea-based carriers more easily and feasibly in the future, regardless of environmental constraints (Neve, 2014).

6. BANGLADESH AND NANOTECHNOLOGY

Bangladesh has been left well enough alone for the adventure of the nanotechnology domain in comparison to the modern world, while others are obviously ahead in this regard. Despite the minimal governmental support, the nanotechnology society of the country has made good efforts to highlight the profound advantages across a variety of fields. Bangladesh has the opportunity to launch bilateral joint research collaborations with its neighbours, including India and Pakistan, as well as multilateral regional partnerships with the EU, BRICS, and other reputable organizations. These international collaborative projects cover a range of nanoscience and nanotechnology basic and applied research in areas having diverse applications. Agriculture, food and allied industry, health care, wastewater treatment, textile industry, and cosmetics are the projected fields where the application of nanotechnology is in progress.

6.1 Probable Application Areas of Nanotechnology for Bangladesh Army

Considering the modern nanotechnology wave and its powerful impact on military equipment and armaments, due attention can be concentrated on five areas for the Bangladesh Army. These most expected and projected areas can be described as follows:

6.1.1 Gears for Combat Soldier

A combat soldier with light and accurate gears can adapt to the battleground more effectively than a regular combat setup. Gears made of nanomaterial combined with micro and macro fibre to face bullets, grenades and bio-chemical agent attacks will have a strong influence over moral strength. The helmet, backpack, and food-water carrying box would be as light as possible.

6.1.2 Nanotechnology in Information System

In order to improve upon the exclusive quality of the signal equipment as well as signal gadgets, the obvious use of nanotech is ahead for dominating the future of information warfare. Additionally, in the field of electronics, it will lead to lower power consumption of electronic appliances, particularly in relation to microchips and other electronic components, for extended periods of time. The cases of higher processing speed, less noise, higher human applications by machines, better command functions, etcetera, will be stepwise led by nanotech products in the near future, and the Bangladesh army needs to think about the issue.

6.1.3 Weapons

Of course, nanomaterials will support strongly to get smoother control of discharging energy and make concise diffusion paths for the blasts of High Explosive ammunition in effective use. Nanotechnology would provide lightweight structures for guns, rifles, and automatic firing systems, increasing the sustaining capability in future warfare (Siengchin, 2023). Modern armies are even exploring nano-weapons, which are capable of altering the bullet path due to body vibration during firing in active duty.

6.1.4 Fighting Vehicles and Platforms

Bangladesh would focus on developing lightweight nanocomposite plates for the longevity of sophisticated parts of tanks, AFVs, or other fighting vehicles used to cover them. Most importantly, nanoparticles are lightweight and capable of scattering Infra-Red. Obviously, this will add the extra value of stealth technology.

6.1.5 Logistics Supply Management

Being the very few most vital requirements on the battlefield, the supply chain management system must be effective and sustainable, which is likely to facilitate operations by ensuring food, water, ammunition, and fuel supply. For the accomplishment of tasks, modular containers of various sizes are an integral part of being moved to the desired destinations. A proper endeavour in nanotechnology would make these containers lightweight and easy to transport by air, facilitating the delivery of items in the battle space.

6.1.6 Remote and Unmanned Guidance

Unmanned Aerial vehicle technology runs with remote control devices or software applications enabling the operators steering, monitoring and controlling the device from the around. With nanotechnology advanced sensors and wireless communication capabilities, Bangladesh Army can take endeavour to develop UAV protocols considering the future battle field and advancement of potential adversary in science and technology.

6.1.7 Explosive Detection

Nanotechnology stands for huge advancement in identifying explosive devices and its detonation capability. In the battle field, identification of any sorts of explosive material is a great success. Utilizing the unique properties of nanomaterials to ascertain the volume of explosive may drastically change the mode of war. Therefore, with the purpose of making a safer battle environment, Bangladesh Army should exploit the explosive detection method by nanotechnology as part of future battle preparation.

6.1.8 Quantum Stealth

Quantum stealth are the substances offering the objects to be purely invisible creating a strong light wave around the object. These particles steal the visual intra-red and thermal signature including the objects shadow. Obviously, this ultra-modern technology will enable an Army to achieve supremacy over its opponent. Therefore, Bangladesh Army may carry out huge research and development work on this nanotechnological benefit.

6.2 Challenges and Limitations for the Bangladesh Army in Adopting Nanotechnology

Adopting nanotechnology in the Bangladesh Army faces few core challenges affiliated with both technological and development contexts of the country. The mentionable challenges can be derived as follows:

6.2.1 High Research & Development (R&D) Costs and Limited Funding

Research and development work of nanotechnology requires highly specialized and expensive equipment, laboratory and also cleanroom facilities. This research works also run with a long gestation period before yielding the practical applications. These are obviously significant financial burdens for a developing country like Bangladesh.

6.2.2 Lack of Skilled Manpower

Nanotechnology is a hefty interdisciplinary field which blends experts in physics, chemistry, biology, engineering and so on. Bangladesh runs with a severe shortage of highly qualified scientists and engineers in the field of nanotechnology.

6.2.3 Limited Domestic Industrial and Manufacturing Capabilities

Jumping from laboratory-scale nanotechnology prototypes to large-scale, cost-effective military-grade production is a complex process for any sorts industrial production and definitely Bangladesh's industrial sector lacks the necessary infrastructure, expertise, and precision manufacturing capabilities.

6.2.4 Ethical, Safety, and Environmental Concerns

Few major issues like toxicity and health risks, dual-use dilemma and public acceptance are heavily involved with nanotechnology. Therefore, developing robust regulatory frameworks and ethical guidelines is a pre-requisite for applications of nanotechnology especially in military use.

6.2.5 Lack of Inter-Agency Coordination and Strategic Vision

Fragmented research efforts, clear strategic goals, integration with existing systems are the key factors of inter-agency coordination and strategic vision against the ground application of nanotechnology. This is obviously a great challenge for the Bangladesh army adopting nanotechnology for noble uses.

6.2.6 Geopolitical and Procurement Challenges

Diversifying sources and cost vs. capability are the two major factors of geopolitical and procurement factors. As Bangladesh is dependent on few countries for military weaponry system, shifting towards nanotechnology enabled systems might require diversifying procurement sources and building new partnerships.

6.3 Strategies Needed to Grasp the Result of Nanotechnology Application

The following are the likely steps that can be taken by the Bangladesh army to make an effective nanotechnology application:

6.3.1 Effective Research and Development Work

Of course, a lack of scientific R&D work is likely to put a strong barrier in the way of the armed forces' technological development in the long run. To attain the organizational goal, the military must arrange funding from the national budget, including the annual defense budget.

6.3.2 Organizational and Structural Development

With the change in the nature of modern warfare, the armed forces must transform into more combined, flexible, and mission-oriented outfits with multifunctional capabilities. The existing organizational setup of the army is not sufficient enough to meet the future operational requirements.

6.3.3 Collaboration with Friendly Advanced Nations

Bangladesh needs to enhance its collaboration with tech-advanced, friendly nations. Besides, strong collaboration between the army and the civil stakeholders is also required. Strong collaboration with modern armies will facilitate her transformation into a technologically advanced army.

6.3.4 Reduce Dependency on Tech Setup

Sophisticated weaponry and C4ISR systems will be software-based, high-tech structures. The tech setup will stand with a combination of resources of the army and nationwide backbone. It requires integrating multi-standard equipment and platforms. As such, the system will totally depend on the network and hardware/software, which will be a significant constraint. However, with proper integration and awareness, the dependency can be reduced.

6.3.5 Increase Budgetary Sanction

In order to standardize the technological outlook of the army, budgetary constraints would be a major barrier. Most of the equipment and platforms need to be procured from foreign countries, which involve a huge amount of budget. However, phase wise, switching to a standard platform vis-à-vis developing the core development on tech and networking structure will integrate through a time plan.

6.3.6 Efficient Training at All Levels

The potential adversaries will pose strong threat in modern battle field. Commanders at all levels must ensure the proper and efficient electronic training to the under command. However, commanders, staffs, and electronic gadgets experts of a sub-unit need to be well efficient in planning, coordination and directing all activities of future battle field environment.

6.3.7 Willingness of the National Leadership

Visionary leadership uplifts the country by stating clear goals; outlining a strategic plan for achieving those goals; and equipping and empowering each member to take action at the organizational, team and individual levels. Leadership of Bangladesh must have the clear vision to transform Bangladesh army into tech efficient, strong ICT structured and professional with modern equipment. By setting a vision and mission to fulfil, empowering able expert in related field, creating a system to develop and taking calculated risks visionary leaderships can shape the tech outlook of Bangladesh Army.

7. CONCLUSIONS

Nanotechnology and nanoscience have turned into an astound focusing issue in military parameters which includes medical, textile, biotech, food, agricultural, electronics, engineering, energy, diagnostic biosensors, medication delivery systems, imaging probes, and other industries. Today's technology is developing toward new engineering and scientific challenges in fields like assembling nanosystems, nanobiotechnology, and nanobiomedicine, developing cutting edge tools, protecting the environment, and pursuing societal implications studies that have a substantial influence on the origin. Considering the exciting potential of nanotechnology, research and development activities are being undertaken by the developed nations, and in some cases, they are spending the majority of the research budget of nanotechnology on the innovation of military equipment by applying nanotechnology for the gradation of military hardware. Bangladesh, a rising economic and military power of sub-continental nations, should take advantage of the promising future of nanotechnology to improve both its economic and military prowess. The introduction of relevant laws, regulations, modifications to college and university level curricula, and reframing of research goals in developing and least developed countries, Bangladesh in particular, is extremely slow. Therefore, Bangladesh's government and its policymakers should understand the present technological trends and their future impact in the long run. Clear long-term government policies and investment facilities on this technology are vitally needed. The Bangladesh Army should also consider the potential opportunities to provide military elements using the noble blessing of nanotechnology in the future. It also needs to understand the challenges that come with the rapidly evolving battlefield due to technological revolution and use every available resource to take advantage of the nanotechnology innovation for moving forward with the modern armies.

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