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Research Article

Application of Nanotechnology in Health and Environmental Research: A Review

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Abstract: Nano-technology is commonly considered as a new field, however, it's successful application in medicine, cosmetics, energy and the environment has been witnessed during last couple of decades. The use of nano-robots, drug production and drug delivery according to biological requirement within the body, are some of the main achievements of nano-medicine. In environmental science, nano-technology is being applied to smart and/or passive purification systems for air and water of which, zeolites, aerogels, chitosan and zerovalent iron are already in use. Another nano-product, Aerogel, has shown incredible promise in physical cleanup of oil spills and appears to have no deleterious effect on the marine ecosystems. Furthermore, nano-generation provides some solutions for cheap and easily attainable energy in the form of Light Emitting Diodes (LEDs) made from nano-particles. Highly efficient photovoltaic cells of lead selenide and piezoelectric generators are ideas that have already been incorporated in energy producing fabrics and in compact and efficient solar cells. However, nanotechnology has been under intensive investigation, as nano-particles are made up of toxic heavy metals; their physio-kinetic and thermodynamic aspects are questionable; and their bio-persistence in the environment are of scientific concern. Moreover, some studies have also revealed them as a cause for cell necrosis, genetic changes and developmental effects, since nano-particles are capable of crossing cell membranes and the blood-brain barrier. With all its innovations and use in medicine and other sciences, there are repercussions to nanotechnology and nano-particles. This review compiles many of the current and some possible future environmental applications and the consequences that may result from them.

Keywords: Health and environment, health repercussions, nano-generation, nano-medicine, nanotechnology, waste treatment

INTRODUCTION

Nanotechnology is a group of emerging technologies in which the structure of matter is controlled at the nanometer scale to produce novel materials and devices that have useful and unique properties (Freitas, 2004). Current nanotechnologies deal with devices and materials that are at the scale of 1-100 nm or 10^{-9} (one billionth of a meter) and fabricated at macro scale (Reynolds *et al*., 2001; Tratnyek and Johnson, 2006). Although scientific (and even religious critics) of Nanotechnology actively oppose this 'novel' technology, nano-materials exist naturally in the environment, mainly as a result of combustion and due to volcanic activities (Allhoff *et al*., 2010; Stern and McNeil, 2008). It was introduced by the concepts of Dr. Richard Feynman of Caltech in his revolutionary ideas of construction and manipulation of materials at the nanoscale. The early days of Nanotechnology saw many false reports of nanomaterials being incorporated in general every day products. The most representative of these reports are of Teflon and a product known as Magic Nano. Although these products alter proved to have no nanoscale materials at all, it was obvious that Nanotechnology needed to be researched thoroughly to avoid a long term disaster such as Asbestos (Roco, 2003).

Nanomaterials basically include Buckminister fullerene (C60), the simplest known nanoscale structure that consists of carbon atoms forming pentagons, with one carbon atom forming a single double bond and two single covalent bonds (Mnyusiwalla, 2003). Carbon nanotubes are the most commonly used nanostructures, which are tubes made of single fullerenes. Variations include Single Walled Nanotubes (SWNTs) and Multiwalled Nanotubes with each of these structures customized to a great degree by the incorporation of other elements into the primary structures (Mnyusiwalla, 2003). The most attractive feature of all nanomaterials is the change in their conductive and reactive abilities from their nanoscale forms. A material

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will have extremely different chemical properties, thermodynamic abilities (Maynard, 2007). At this scale however, only the resistivity and conductivity of materials. Similarly, the number of factors that affect such particles also increase. Electrical noise and frequencies which typically have no effect on normal scale devices suddenly have a great impact on nanoscale items. This is one major reason why cells operating on metabolic energy and piezoelectric forces can now be produced (Demou, 2008).

Nanotechnology is currently showing a lot of promise in nanogeneration, nanomedicine and quantum computing. All these frontiers promise quick, safe and cheap generation of electricity, optimized drug delivery and surgery and faster, more accurate and energy efficient methods of computing. All in all, with very few databases available to review the materials and technologies currently in existences, incorporation of nanotechnology into everyday products continues with nanomaterials being introduced into sunscreens, food items and clothing (Gur *et al*., 2005). However, in comparison with conventional technologies, there is a lot that remains unknown about nanotechnology with basic concerns are: that nanoparticles made up of toxic heavy metals, their physiokinetic and thermodynamic aspects, their fate and biopersistence in the environment (Masciangoli and Zhang, 2003). The factors that are particularly worrisome right now are the deleterious roles that nanoparticles might play if exposed to the environment or to living organisms (Dreher, 2004; Lone, 2003). Studies reveal that exposure to them cause genetic changes, cell necrosis and developmental effects, as they are capable of crossing cell membranes and the blood-brain barrier (Guzmán *et al*., 2006). Current review examines the application of nanotechnology in human life, potential benefits from its products and consequences of health and environmental concerns.

APPLICATIONS OF NANOTECHNOLOGY

Nanotechnology has already gained a significant ground in the developed countries, particularly in the fields of Environment and Medicine. The areas that require particular attention for the environmentalists are: remediation of soil and groundwater, green generation of electricity and monitoring of various chemical components.

In environment, much of the technology is being applied to smart and/or passive purification systems for air and water of which, zeolites, aerogels, chitosan and zerovalent iron are already in use. Silica-based aerogels, with higher surface area and porosity, sever as a hydrophobic absorbent and have shown incredible promise in physical cleanup of oil spills and have been proven to hold 237 times more oil contaminants than their weight in oil, with no deleterious effects on the marine ecosystems (Reynolds *et al*., 2001). Nanotechnology provides excellent tool of nanomaterials for treatment of surface and groundwater and wastewater contaminated with toxic metal ions, organic and inorganic solutes and microorganisms. One example is the use of Dendrimer-Enhanced Ultrafiltration Technology (DEUF) that completely removes Cu (II) from water (Tratnyek and Johnson, 2006) and DEUF can be used to recover metal ions such as Cu(II) from aqueous solutions (Diallo *et al*., 2005). Groundwater and soil remediation using target specific nanoparticles have been tested with great success and noble metal coated zerovalent iron cleanup organic contamination and are not mobile or reactive enough in the aquifers to pose a risk to the ecosystem (Tratnyek and Johnson, 2006). Similarly, Iron nanoparticles can achieve 99% removal of chlorinated compounds and remain reactive to them for extended periods of time (Zhang, 2003). Practical experiments show the promise of nanoparticles used for *in situ* soil and water remediation and also show that most of the environmental concerns are unfounded. Efficient sensors provide accurate measurements of particular contaminants, in real time analyses, a feat that was previously accomplished in laborious experiments that took days. With the rising prices and reduced availability of fossil fuels, renewable and cheaper sources of energy are far more attractive. Nanoparticles prove to be more efficient at the sequestration of solar energy and its conversion to electricity. Cells incorporating nanoparticles can harness more than one component of the solar spectrum, utilize metabolic energy, as well as mechanical stress. Naturally, such devices are preferable over those that leave behind toxic chemicals that later accumulate in the environment.

The main concerns about nanotechnology arose because of their incredibly small size, which promotes concerns about their mobility and reactivity in comparison with normal scale materials. The behavior of materials differs at such a small scale and questions about their toxicity are usually unanswered. Secondly, there is currently no comprehensive database or inventory of the nanomaterials that have been invented and therefore, no particular empirical method to quantify their effects in a logical sequence. Another major concern is the fact that the development technologies currently in use for this are not as environmental friendly as hoped. It is important to develop methods of detecting the nanoparticles themselves so that appropriate protective measures can be taken and standards can be developed to prevent widespread exposure. The infrastructure for making this should be as 'green' as the technology itself. For a developing country to take the most advantage of it, they need to understand the obstacles they need to cross before they can fully incorporate a relatively new technology in their midst (Thomas and Philip, 2005). The potential benefits of nanotechnology are discussed below with it all advantages and limitations.

ENVIRONMENTAL REMEDIATION TECHNIQUES BY NANOTECHNOLOGY

A large portion of the world's land is contaminated with anthropogenic chemicals. Every single piece of land with human habitation has contaminated either the land, water or air and usually all three. Remediation techniques for removal and/or degradation of the chemicals are essential to prevent the loss of valuable natural capital (Tratnyek and Johnson, 2006).

Remediation with nanoscale iron: The most favorable property of iron nano particles for the use of environmental remediation is their small size of 1-100 nm (Zhang, 2003). This provides them with a great surface to volume ratio and a small amount of nanoparticles can be used to remediate a large area. They are mobile and reactive enough to travel easily within the contaminated media and stray active for extended periods of time (Fig. 1).

Practically all frequently present environmental contaminants have been tested and found to degrade to harmless by products by nano scale iron. A relatively simple method is used to prepare the zerovalent iron, although the major reagent, sodium borohydride is highly corrosive, reactive and explosive and toxic for the respiratory and intestinal tract and may even be fatal as in Eq. (1) (Zhang, 2003):

$$4\ Fe^{3+} + 3\ BH_4^- + 9\ H_2O\ \ 4\ Fe^0 + 3\ H_2BO_3 + 12\ H^+ + 6H_2 \quad (1)$$

One concern presented here is of the reactivity and the high surface to volume ratio of the iron particles. However, on such a small scale, the iron particles tend to clump together to form micron sized particles and are not as harmful as imagined. Secondly, the iron particles do have a high reactivity rate for chemicals, but it is not confined to them and can react even with the water, to form fairly harmless hydrates. This low selectivity means that very little iron remains reactive in the environment for longer periods of time. Their clumping tendency also reduces the extent to which they can travel (Tratnyek and Johnson, 2006). Some concern is present because of the possible creation of unwanted dichloroethylenes by using zerovalent iron, but these can be addressed by using bimetallic nanoparticles, such as palladized iron particles or combining iron with silver, copper, cobalt, platinum or nickel (Zhang, 2003).

Water purification: The global market for nanofiltration membranes increased from $89.1 million in 2006 to an estimated $97.5 million by the end of 2007. It should reach $310.5 million by 2012, a Compound Annual Growth Rate (CAGR) of 26.1% (Stern and McNeil, 2008). Groundwater and soil remediation using target specific nano-particles have been tested with great success with noble metal coated zerovalent iron capability to cleanup organic contamination without being mobile or reactive enough in the aquifers to pose a risk to the ecosystem (Tratnyek and Johnson, 2006). It has been reported as well, that Iron nanoparticles can achieve 99% removal of chlorinated compounds and remain reactive to them for extended periods of time (Zhang, 2003). Other than these, carbon nanotubes are three times more efficient at the capture of dioxins as compared to the traditionally used activated carbon. Zinc oxide nanoparticles that are light sensitive are effective against phenols and are not as toxic as some of the methods used currently (Zhang, 2003). Furthermore,

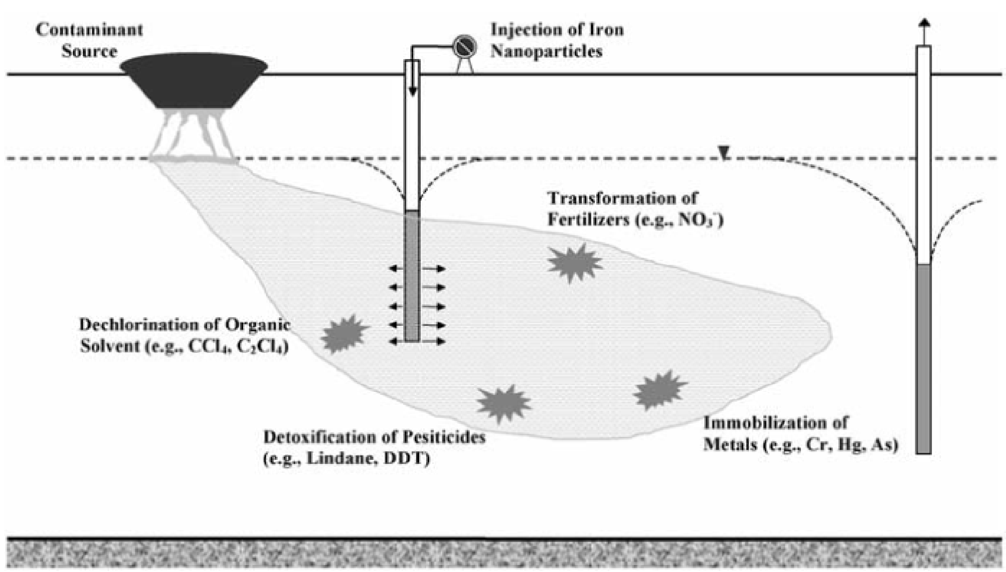

Fig. 1: *In situ* remediation with nanoscale particles, Adapted from: Tratnyek and Johnson (2006)

Dendrimer Enhanced Ultrfiltration Techniques (DEUF) and other Polymer Supported Ultrafiltration (PSUF) techniques are a possible replacement of all water filtration methods because they can be customized to remove specific heavy metals from water, as DEUF can be used for the removal of bi-valent copper from water sources. As far removing the contaminants from water is concerned, PSUF and DEUF can also allow recovery and re-use of some of the contaminants, which will prevent pollution by source reduction.

Silver nanoparticles have long been known for their bactericidal properties and customizing nanotube filters to incorporate silver with other nanomaterials such as titanium dioxide can increase their efficiency by allowing them to capture more contaminants and photo-catalyse degradations to increase the life spans of the filtration. Until now, DEUF are promising techniques because the many branches of the dendrimer polymers offer a better network of interconnected tubes for contaminant capture.

Another promising technique is the use of Self Assembled Monolayers on Mesoporous Ceramic (SAMMs) that consists of 5-15 um diameter individual grains of ceramic assembled on a specific support. It is a very good absorbent material by itself, but when used in SAMM, the ceramic grains are combined with monolayers of specific surfactants that target a particular contaminant (Tratnyek and Johnson, 2006; Roco, 2003). Similarly, Chitosan, a biopolymer derived from chitin of animal source, has been used in industrial and municipal applications for wastewater treatment, water filtration, waste of oil and grease removal etc (Madhukar *et al*., 2012). Its effectiveness arises from combination with acetic acid as solution and has the capability to chelate various ions from water and wastewater. Furthermore, its anti-bacterial properties in water (Chen *et al*., 2002) non-toxic properties, bioadhesive nature make it a good candidate in water treatment science and in environmental spills.

ENVIRONMENTAL MONITORING

Nano-sensors for monitoring: Piezoelectric microcantilever arrays can be developed and used for the detection of extremely small quantities of pathogens. On the whole, development of nanobiosensors that allow insant in situ calculations can help in finding out whether the remediation process was successful or not.

Nanostructured poly siloles for detection of chromium (VI) and arsenic (V) allow fast and efficient field sensing. Sensors are not simply confined to locating contaminants but can also be used in medicine, for measuring chemical changes in the body (Stern and McNeil, 2008).

NANOGENERATION

Solar cells: Traditional solar cells are large, bulky and are capable of capturing only a limited portion of the sun's energy spectrum. Photovoltaics using photocatalytic nanomaterials comprise of a thin film of material on a flexible plastic sheet and offer more efficiency per square inch (Reddy *et al*., 2009).

One basic idea of 'spray on' solar cells is of quantum dots combined with an organic or inorganic polymer that is then sprayed on a thin plastic sheet. once the long term stability of this composite is perfected, such solar cells can offer 30% energy capture efficiency as compared to the 6% of traditional cells according to Peter Peumans of Stanford University (Gaynor *et al*., 2011). This efficiency arises due to the fact that absorption of a single photon of light by a quantum dot will produce 7 excitons, whereas the same photon produces only a single exciton in a normal photovoltaic (Reddy *et al*., 2009).

Although a large number of possible technologies exist for combining nanotechnology with solar energy, one of the most promising frontiers is that of quantum dots. They are semi conductors that have properties between those of ordinary semi conductors and molecules. Although they essentially have no dimensions, their excitons (bound state of electron and electron hole) exist in all three dimensions and the optical properties of the dots allow possible use in lasers and biological sensors.

Other energy sources: The current market already boasts of cloth that produces energy while the user wears them and companies are researching into the commercial development of attractive solar cells that use solar energy as well as kinetic energy by their movement. Both these technologies use piezoelectric generation, where nanowires woven into the fabric or the clothing and the surface of the cells respond to changes in mechanical stress to produce electricity (Gaynor *et al*., 2011). Minute differences in movement, such as the movement of the fabric by the wearer, or the fluttering of the solar cell in the breeze are enough to produce electricity, a feat that is not possible by meso-scale materials. From the medical point of view, nano factories within the body harness the energy released by normal metabolic processes to create and release timed, optimum drug doses.

Development of nano-batteries: A slightly different approach to smart energy comes from hybrid batteries. While hybrid cars are extremely beneficial for the environment, their current limitation is the excessive time it takes for them to charge. Research has brought to light an interesting combination of highly conductive lithium absorbed nanotubes and poorly conducting magnesium oxide. The combination allows efficient charging and discharging and reduces the amount of time that is required for a charge cycle to complete (Hardman, 2006). The basic concept for other faster charging batteries involves the coating of the electrodes with nanoparticles, which increases the surface area available for current exchange.

Nanomedicine: The field of medicine has many limitations; most of them are the result of human limitations. The accuracy of surgery is limited, the amount of drugs administered exceed the body's requirements to escape its detoxifying ability and the life saving tests that need to be done take far too much time. The performance of delicate surgeries being performed accurately with nano-robots, drug production and delivery occurring according to biological requirement within the body are some of the main achievements of nanomedicine (Martel *et al*., 2008; Kubik *et al*., 2005).

Immuno-isolation is a technique being actively pursued today with the goal of protecting grafted cells from the body's own defense system. Therefore, pancreatic cells grafted into the body are protected by a surface covered with nanopores that allows the transfer of molecules like oxygen, but prevents the access of immunoglobins, with the result that the graft cells work efficiently with no fear of tissue rejection (Cristina *et al*., 2007; Freitas, 2004). Drug delivery systems involve nanoshells that encapsulate highly specific drugs. These can be used for targeting tumor cells. The nanoshells once injected into the body can be heated only by a specific frequency of infra red rays, on which they dissolve and release the drug dosage. This technique could be deployed for a number of other treatments, that not only reduces the amount of drug delivered, but also the number of injections, as nanoshell drug carriers can remain active for long periods of time (Freitas, 2004). Another applications of nano-biotechnology or nanomedicine deals with the construction of nano-machines or nanorobots with autonomous functions and has already been in practice for performing diagnostics, target oriented drug dispensation, invasive surgery, respirocytes mimicking the function of erythrocytes and microbivores for destroying microscopic pathogens (Martel *et al*., 2008; Freitas, 2004) and repair of cells and tissues (Sánchez and Pumera, 2009; Sikyta, 2001). Martel *et al*. (2008) described an interventional procedure for directly targeting of tumors with the help of flagellated magnetotactic bacteria without reducing possible intoxication in the systemic circulation. However, the toxicity caused by their byproducts is still under investigation.

CONSEQUENCES OF NANOTECHNOLOGY

As with every technology, Nanotechnology has its own threats. The alarming thing about these is how far reaching these threats can be. The major problem right now is the high level of uncertainty there exists about the nanomaterials. There is no helpful database to consult for the nanoparticles, their uses and their effects, there are few long term health risk analyses and even fewer ecosystem effect analyses (Stern and McNeil, 2008). The factors that are particularly worrisome right now are the deleterious roles that nanoparticles might play if exposed to the environment or to living organisms (Dreher, 2004; Lone, 2003).

Although nanotechnology has been used for purifying water, the particles that are used can spread far and wide and could affect the living components of the environment, biological medium and can persist. The research conducted to observe the effects of nanoscale iron and other particles like ZnVI for remediation were conducted in aquifers and other relatively isolated environments; if these particles were to be introduced into an open and fully functional ecosystems, the particles and their surface coatings could cause significant damage (Guzmán *et al*., 2006). Most metals, i.e., copper and zinc, are toxic on the normal scale and with nano-particles, this toxicity can be greatly magnified on the nanoscale and are extremely cytotoxic. Another compound Titanium dioxide, used as an ingredient of sunscreen, creams, pigments, paints, plastics, papers, inks, foods and toothpastes, is known to cause DNA damage (Guzmán *et al*., 2006), dermal toxicity (Jonaitis *et al*., 2010) and tumors in rats, thus makes it a probable carcinogenic as pronounced by IARC. Carbon based nanotubes, made up of Fullerenes, which are being tested for drug delivery systems, cause lipid peroxidation in sea bass (Stern and McNeil, 2008; Mnyusiwalla, 2003). Multi-walled nanotubes have been shown to cause cytokine-induced inflammation (Hood, 2004) whereas, single-walled nanotubes with a structure similar to that of asbestos fibres, cause inflammation, granulomas and mesolthelioma in lungs (Tejral *et al*., 2009; Reddy *et al*., 2009). In addition to cell damage, adverse effects on cell proliferation and long-term pathological effects in other organs is under investigation (Tejral *et al*., 2009).

Besides the obvious health and environmental risks, the social risks are also sizeable. Nanotechnology can be used to create superior surveillance equipment which will need an entirely new set of laws to control them, efficient weaponry (biological and chemical) and the equity differences which will inevitably arise. Since the introductory Nanotechnology devices will naturally be more expensive than their traditional counter parts, it will create a rift between the social classes who will have access to it and those who can't even imagine the possibility. And here, it is important to discuss the possibility of the 'grey goo' and 'green goo' as proposed by Eric Drexler in 1986, where organic and inorganic nanorobots are capable of taking over and consuming the world (Drexler, 2004). Although it's practical appearance is unlikely, it is important here to consider the perception of the masses as compared with the perception of the scientific community. The critics of Nanotechnology are quite large in number and they already oppose the presence of nanomaterials in the few commodities available. It is important to consider what they will think and do, if nanorobots are being used in medicine.

Furthermore, the materials made up at nanoscale similar to the size range of viruses (~ 10 mm) or even smaller, i.e., pollens, particulate matter (<2.5 mm), serious health risks cannot be ruled out (Masciangoli and Zhang, 2003). Moreover, in comparison with conventional technologies in air and water treatment techniques, there is a lot that remains unknown about nanotechnology. The basic concerns are: that nanoparticles made up of toxic heavy metals; that their physio-kinetic and thermodynamic aspects are not fully understood; and that their fate and bio-persistence in the environment, are few implications of nanoparticles, that are under intensive research (Masciangoli and Zhang, 2003). Several studies have revealed that exposure to nonoparticles could cause genetic changes, cell necrosis and developmental effects, as they are capable of crossing cell membranes and the blood-brain barrier (Tejral *et al*., 2009; Guzmán *et al*., 2006). Immune incompatibility of nano-devices remained another area of concern for scientific community (Shetty, 2005).

PAKISTAN AND NANOTECHNOLOGY

Pakistan is no stranger to Nanotechnology and a large number of scientists and organizations have accomplished a lot in terms of research and development. The only thing that remains now is the practical application of it while keeping all the possible consequences in mind (Dreher, 2004). As Nanotechnology encompasses practically all fields of science, society and environment, even the application in a single field for us will be beneficial. Benefits can be extracted from nanotechnology for purification of water, as the contaminated water flowing through rivers and aquifers not only harms health directly, but through food chain. Besides the lives lost due to water borne diseases, locally-grown vegetables have critical amounts of heavy metals credited to irrigation water contaminated with effluents containing copper, zinc, iron, manganese, nickel, cadmium, lead and chromium. It has been reported extensively that such metals with toxic levels are being found in various edible portions of vegetables (Thomas and Philip, 2005; Dreher, 2004; Lone, 2003). However, if the irrigation water is filtered using even one of the water purification methods mentioned, the contamination levels will fall drastically in our food and the mortality rate of water borne diseases will also decrease (Lone, 2003).

Furthermore for a energy deficient country like Pakistan, benefits can be reaped from nano-generation, with smarter and longer lived batteries with harnessed solar energy. Although It could be incredibly difficult to implement in the cities, but small pilot projects can be started in villages which are suffering from power load shedding or have no electricity at all. This will be a significant step up from solar cookers and water heaters because the instrumentation is less bulky and will be economical in large numbers. In addition, the development of environmental sensors, can greatly decrease the workload of agencies responsible for checking contaminant levels and they will inevitably benefit the environment by using far less number of chemicals that might jeopardize the well being of the lab workers. With better cataloguing of pollutants, remediation and prevention will get more attention than they do currently.

Although traditional technologies do exist for the accomplishing these goals, nanotechnology provides services that are economical, time saving and environmentally friendly. There is still a lot that remains unknown about nanotechnology, but extensive research is being conducted to gain information on every possible aspect of the technology.

CONCLUSION

Nonotechnology is novel technology based on the development of nano-particles. Its application in medicinal science, environmental research and in robotics has proven numerous advantages. Even with the reservations about nanotechnology, it is important to remember that no novel technology is devoid of risk and the possibility of risk should not stop gaining benefit from Nanotechnology. Pakistan and other developing countries will definitely benefit from using nanotechnology now, because enough experience has been gained in developing countries in this regard with all probabilities and possibilities through risk assessment procedures. In order to establish the base for nanotechnology based research, dissemination of knowledge through research and development of nanotechnology, is imperative. With constant energy crisis, water shortage and food crisis, investment in nanotechnology would be short-term and long run achievement. The economy will certainly benefit from a focused implementation of nanotechnology in agriculture, energy and medicine sectors of Pakistan. Apart from innumerable advantages over conventional technologies, it is suggested to start the development of an inventory of nano-materials, their risk assessments and the possibility of using them in as ‘green’ a manner as possible, so that possible risky frontiers could be covered before adaptation of this technology.

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