Review Paper

Nanotechnology in Agriculture with Elimination of Pollutants from Wastewater: A Review

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ABSTRACT

There is a prediction that around 2050 our globe will be populated by over 9 billion people is quite reliable. This will pose serious problems with food, water, and energy supply, particularly in less-developed countries Due to this burgeoning population and rapid urbanization, farmers across the globe are left with the serious problem of feeding the large population every year from agricultural fields which are shrivelling correspondingly. This alarming situation creates a wide range of challenges to for agricultural scientists, such as stagnation in crop yields, low nutrient use efficiency, declining soil organic matter, multi-nutrient deficiencies, shrinking arable land, climate change, water availability, and shortage of labour besides leaving people from farming. To fulfil the food requirement of a huge population the food grain production needs to be enhanced accordingly. On the other hand, the goal of higher production must not come at the cost of heavy exploitation of natural resources. In order to achieve higher yields, the need of the hour is to develop and promote new technologies and reform agricultural research. To overcome this problem, new ideas or technologies are evolving day by day. Out of the various new ideas, nanotechnology is the innovative approach that resolves multiple issues. Nanotechnology is a boon for modern agriculture farming by improving fertilizer use efficiency by employing nano-fertilizers, control of pests and pathogens using nano-pesticides, etc. It is eco-friendly, cost-effective green technology for sustainable agriculture and also culminates leaching and eutrophication, contamination and residual effects in the crops, the long-term damage of soil, and so on.

Keywords: *Nanotechnology, nanoparticles, nano-fertilizers, nano-biosensor, nanomaterials*

INTRODUCTION

For the development of developing countries, the growth of the agricultural sector is seen as an essential objective. After the green revolution there is a decline in the agricultural products ratio to world population growth, and it is evident that the necessity of employing new technologies in the agriculture industry is more than ever. Recent modern technologies such as bio and nanotechnologies can take part an important role in increasing production and improving the quality of food produced by farmers (Shaimaa H. et al., 2015).
Globally, nanotechnology is growing rapidly and it is gaining impact on in every area of science and technology. It is a science, which is capable of resolving issues and problems that are impossible to tackle in engineering and biological sciences. It involves studying and working with matter on an ultra-small scale that allows us to work, manipulate and create tools, materials, and structures at the molecular level, often atom by atom into functional structures having nanometer dimensions (Subramanian, K. S. 2011).
The application of nanotechnology in agriculture and food production, it builds the agricultural land and returned to its normal position. It minimizes greenhouse gas construction with high performance and productivity, prevents extinction and destruction of plants and animals species, and overall nanotechnology provides the efficiency of agriculture for a higher population. The research and development of nanotechnology in the agricultural sector, is likely to make possible and mount the next stage of development of genetically modified crops, animal production inputs, inorganic pesticides, and precision farming methods (Mousavi and Rezaei, 2011).
Nanotechnology is based on the smallest particles which increases chances for improving agricultural productivity through encountering problems unsolved conventionally, the nanotechnology applications have the potential to change agricultural production by adopting improved management and conservation of inputs of plant and animal production. Nanoparticles have exclusive physicochemical characteristics i.e. high surface area, high reactivity, and tenable pore size, which have applications in the plant nutrition field to help in achieving the future request of the rising population (Abobatta, W. F. 2018). It is a smart and intelligent system that delivers the precise amounts of nutrients and other agrochemicals required by plants, minimizing the use of pesticides and antibiotics (Sharon et al., 2010).

What is nanotechnology?

Nanotechnology is derived from the Greek word “nano” which means dwarf. The concept was given by Nobel American laureate Richard Feynman, a physicist in 1965. He was known as the father of nanotechnology. Later, Norio Taniguchi professor of Tokyo University of Science coined the term nanotechnology in 1974.

Now we can define it as a moderntechnology that includes the use of materials and equipment capable of using physical and chemical properties of a substance at molecular levels to explore the material worlds in the nanometer-scale and use it in various carriers from medicine to agriculture (Fakruddin Md.2012). It is the technology of tiny things that are less than 100 nm in size. Itintegratessolid solid-state physics, chemistry, biochemistry, biophysics, chemical engineering, and materials science.

Nano-scale

What are nanoparticles?

A nanoparticle is a small particle with at least one dimension less than 100 nm.

1 Nanometer = 1 billionth of a meter = 10-9 m

For comparison, a virus is approximately 100 nanometres (nm) in size.

It's tough to imagine just how small nanotechnology is.1nanometer is a billionth of a meter, or 10-9 of a meter.

Properties of nanoparticles

Being smaller particles, it allows better coverage of surface area and also has higher surface energy. These particles can even pass through the cell wall of plants and animals. The property of delivery at the cellular level which is more operative than the conventional method is an important tool that is successfully utilized by nanotechnologists in the research field.

Methods of production of nanoparticles

Production of nanoparticles includes two basic methods i.e. Top-down depending on size reduction from bulk materials and Bottom- a system where materials are synthesized from the atomic level (Abobatta, W. F. 2018).

Top-down: Here tiny atoms or molecules are produced from bulk material, through mechanical-physical methods like grinding, milling, and crushing for producing nanoparticles. In other words, this method uses for producing nanocomposites and nano-grained bulk materials like metallic and ceramic nanomaterials in extensive size distribution (10 - 1000 nm).

Bottom-up: in this method of building up, numerous molecules self-assemble in parallel steps, as a function of their molecular recognition characters, this processing produces more complex structures from atoms or molecules, also, this method produces uniform controlling sizes, shapes, and size ranges of nanomaterials.

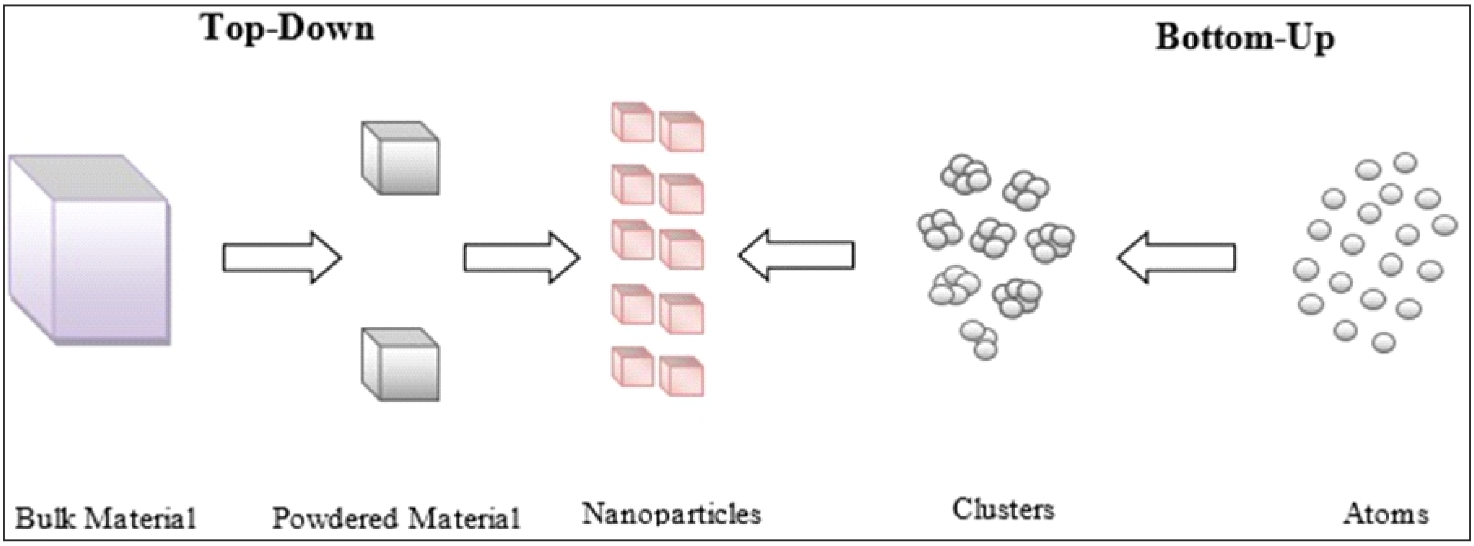

Fig1: method of production of nanoparticles

Source: www.google.com

Nanofertilizer

Nano-fertilizers are prepared from conventional fertilizers, fertilizers bulk materials, or derived from different vegetative or reproductive parts of the plant by different physical, chemical, mechanical, or biological methods with the help of nanotechnology used to enhance soil fertility, productivity and quality of agricultural produces.

Nanoparticles can be made from fully bulk materials (Qureshi, A. et al., 2018). Nano-fertilizer technology is a very innovative approach. By conventional fertilizers, nutrient use efficiencies hardly exceed 30-35 %, 18-20 %, and 35-40 % for N, P, and K respectively. The data remain invariable for the past several decades and research efforts did not yield profitable results. Nano-fertilizers carry nutrients that are being developed using substrates with nano dimensions of 1 – 100 nm. Nanoparticles have a large surface area and are capable of holding a large number of nutrients and releasing it slowly and steadily such that it facilitates the uptake of nutrients to fulfill the crop requirement without any associated bad effects of customized fertilizer inputs.

Research finding on nano fertilizers use for sustainable crop production

Field evidence research finding on nanofertilizers use for sustainable crop production proved that nano nitrogen fertilizers offers instrumental in boosting the productivity of rice. It was revealed that nano nitrogen fertilizer holdsthe potential to use in place of chemical fertilizers. It can also prevent environmental pollution caused by denitrification, leaching, and volatilization. So, in this way, nanomaterials increased the vegetative growth of cereals including barley (Rubio-Covarrubias, O.A et al., 2009). When nanofertilizers applied in addition with toa reduced amount of mineral fertilizers were found enhanced yield attributes and grain yield of cereals. Nanofertilizers of zinc applied as ZnO was found beneficial in boosting peanut yield, increasing in chlorophyll content of leaves, and significant rooy growth (Prasad, T.N.V.K.V. 2012). Table no. 1 shows the boosting impact of different nanomaterials.

Table 1: Impact of different nanofertilizers on the productivity of different crops under varying conditions

Nanofertilizers	Crops	Yield increment (%)
Nanofertilizer + urea	Rice	10.2
Nanofertilizer + urea	Rice	8.5
Nanofertilizer + urea	Wheat	6.5
Nanofertilizer + urea	Wheat	7.3
Nano-encapsulated phosphorous	Maize	10.9
Nano-encapsulated phosphorous	Soybean	16.7
Nano-encapsulated phosphorous	Wheat	28.8
Nano-encapsulated phosphorous	Vegetables	12.0-19.7
Nano chitosan-NPK fertilizers	Wheat	14.6
Nano chitosan	Tomato	20.0
Nano chitosan	Cucumber	9.3
Nano chitosan	Capsicum	11.5
Nano chitosan	Beet-root	8.4
Nano chitosan	Pea	20
Nanopowder of cotton seed and ammonium fertilizer	Sweet potato	16
Aqueous solution on nanoiron	Cereals	8-17
Nanoparticles of ZnO	Cucumber	6.3
Nanoparticles of ZnO	Peanut	4.8
Nanoparticles of ZnO	Cabbage	9.1
Nanoparticles of ZnO	Cauliflower	8.3
Nanoparticles of ZnO	Chickpea	14.9
Rare earth oxides nanoparticles	Vegetables	7-45
Nanosilver + allicin	Cereals	4-8.5
Iron oxide nanoparticles + calcium carbonate nanoparticles + peat	Cereals	14.8-23.1
Sulfur nanoparticles + silicon dioxide nanoparticles + synthetic fertilizer	Cereals	3.4-45

Source:https://www.intechopen.com/online-first/nano-fertilizers-for-sustainable-crop-production-under-changing-climate-a-global-perspective (Iqbal, M.A. 2019).

Zeolites

A naturally occurring mineral group comprise of about 50 mineral types, is considered as a good growing medium substrate for a long period due to its good physical and chemical features (Markovich et al., 1995). These arecrystal crystal-like structuresas well as three three-dimensional structureswith voids and channels of molecular size and high cation exchange capacity (CEC) which is due to the substitution of Al for Si in the silicon oxide tetrahedral units that form the mineral structure (Pickering et al., 2002).

Need of nano-fertilizers

The fatigue of the green revolution exerts a pain or pressure on Indian agriculture. Over the past 50 years, the consumption of fertilizer increased exponentially from 0.5 (1960's) to 24 million tonnes (2013) which corresponds to a four-fold increase in food grain output (254 million tonnes).

In-spite of increased grain growth, it has been found that yields of many crops have begun to stagnate as a result of imbalanced fertilization and a decline in the organic matter content of soils.

The deficiencies of multi-nutrient are alarmingly year by year which is closely associated with a crop loss of nearly 25–30%. The nutrient deficiencies are in the order of 89, 80, 50, 41, 49, and 33% for N, P, K, S, Zn, and B, respectively. That's why the country is in need of a Second Green Revolution. Nano-fertilizers have the potential to reform agriculture (Qureshi, A. et al., 2018).

Advantages of nano-fertilizer

1. It increases nutrient use efficiency: It has a higher surface area. Very less size of particles provides more surface area to facilitate different metabolic process in the plant system result production of more carbohydrates. In other words, more uptake of nutrients leads to increased nutrient use efficiency.

2. Nutritional value: More availability of nutrients to the crop plants help to increase the quality parameters of the plant (such as protein, oil content, and sugar content) by enhancing the synthesis process in the plant system. Zinc and iron application on the plant raises total carbohydrate, starch, IAA, chlorophyll, and protein content in the grain (Mahajan, P. 2013). The growth of the peanut plant increases with the application of Nano-Fe_2O_3 (Mahmoodzadeh, H. 2013).

3. Health: Due to the availability of nano nutrients to the plant it prevents nutrient deficiency, disease, and other biotic and abiotic stress which specify that nano-fertilizers enhance the overall health of the plant. Under stress conditions, ZnO nano-particles also prove to be helpful to plants (Naderi, M. R. 2012). The body weight of P. ricini larvae was reduced drastically by the application of aqueous solutions of Ag^+ and Au^+ (Nadi, E. 2013).

4. Yield: Various research studies showed that the application of nano-fertilizers considerably increases crop yield over control or without the application of nano-fertilizer. This is mainly due to the increased growth of plant parts and metabolic process which leads to higher photosynthetic accumulation and translocation to the economic parts of the plant. When nanoparticle as a fertilizer applied in foliar form increases crop yield (Liu, X.M. 2005).

Nano-Biosensors

These are immobilized bio-receptor probes that are selective for target analyte molecules and are called nano-biosensors. Their applications consist of the detection of analytes like glucose, urea, pesticides, etc. It also monitors metabolites and recognizes various microorganisms/pathogens (Rai et al., 2012). The advantages of nano-sensor are minute, portable, sensitive with real-time monitoring, quantitative, reproducible, precise, reliable, accurate, robust, and stable which can overcome the inadequacy of present sensors.

The crop's growth depends on proper agro-climatic conditions. For effective protection of crops, the fast and sensitive sensors are required to detect plant pathogens. It can be used all over the agricultural fields for monitoring the fertility of the soil and other agro-climatic conditions (Alfadul et al., 2017). In this way, smart nano-sensors have evolved which includes GPS system with real-time monitoring of crop husbandary promising by planting autonomous biosensors.

Nanomaterials

These possess physical, chemical, or biological properties that are different from those of their larger counterparts, and due to their distinct and unique properties, nanomaterials may pose different safety issues than their larger counterparts. Controlled preparation of nanomaterials with desired size and morphology, and newly evolved concepts and methodology have supported the solid bases to solve the unsolved questions in nutrient uptake. The main attention is given in using nanotechnology in agriculture and the food system due to its great prospective as it can improve the quality of different products, also, with the rapid advancement of nanotechnology since the last decade of last century.

Types of nanomaterials

1. Carbon-based nanomaterials: composed mostly of carbon take the form of hollow spheres, ellipsoids or tubes.

2. Metal-based nanomaterials: include quantum dots, nanogold, nanosilver, and metaloxides such as titanium oxide, zinc oxide, magnesium oxide, iron oxide, etc.

3. Dendrimers: nano sized polymers build from branched units.

4. Nanocomposites: combine nanoparticles with other nanoparticles or with larger, bulk-type materials.

Nanomaterials application in agriculture

There are various applications of nanomaterials in agricultural production, in different forms and various procedures such as:

1. Food Technology
2. Agricultural engineering
3. Crop improvement
4. Weed management
5. Post-harvest technology
6. Plant protection ingredients
7. Precision agriculture
8. 8. Seed technology
9. Water management
10. Soil management
11. Plant growth regulator
12. Bioprocessing
13. Nano-fertilizer for balance crop nutrition
14. Nano pesticides
15. Nanosensor
16. Monitoring the identity and quality of agricultural produce

Nanotechnology application in agriculture

1. Improvement of crop
2. Analysis of gene expression and Regulation
3. Plant disease detection
4. Increase efficient fertilizers and pesticides
5. Management of water
6. Management of soil
7. Post-Harvest Technology

Removal of pollutants from wastewater by nanoparticles application

Water is an indispensable part of life and its availability is essential for all living creatures. But in the fast-growing world, is polluted by different pollutants by various anthropological activities of human beings. So, it attracted our attention to it purification or in other words for the removal of undesired materials that have adverse effects not only on human health but also on the environment. In this context, nanotechnology proves to be an excellent technique that water from pollutants and germs. Presently nanoparticles, nano membranes, and nano powder are used for the detection and removal of chemical and biological substances comprise of metals (e.g., copper, Cadmium, mercury, lead, nickel, zinc), nutrients (e.g. Phosphate, ammonia, nitrate, and nitrite), organics, cyanide, algae (e.g. cyanobacterial toxins) bacteria, viruses, parasites, and antibiotics. There are various types of nanoscale particles (such as metal oxides nanoparticles, zinc nanoparticles, Iron nanoparticles, iron oxides nanoparticles, silver nanoparticles, nanocomposite, graphene-coated nano filter, and so on) but generally, they are grouped into four classes of nanoscale materials are used that are being evaluated as functional materials for water purification e.g. metal-containing nanoparticles, zeolites, carbonaceous nanomaterials, and dendrimers. In most cases, it is found that nanomaterials show good results than other techniques used in water treatment due to their high surface area (surface/volume ratio). It is considered that these may be used in the future for large-scale water purification or it will prove to be the best option for the treatment of wastewater.

Different water pollutants with their sources and adverse effects

Heavy metals like Pb, Mo, etc. organic and inorganic pollutants, and several harmful microbes are found to be successfully removed by using different nanomaterials (Mir, N.A. 2012). Currently, WHO (World Health Organization) estimated that almost 1.7 million people died due to water pollution, and four billion cases of different health issues were reported annually due to waterborne diseases (Briggs, A.M. 2016). Table no. 2 depicts different kinds of water pollutants with their sources and adverse effects.

Table 2: Shows different water pollutants with their sources and adverse effects.

Water Pollutants	Source of Pollutants	Effect of Pollutant
Pathogens	Viruses and bacteria	Water borne diseases
Agricultural Pollutants	Agricultural chemicals	Directly a ect the fresh water resources
Sediments and suspended solids	Land cultivation, demolition, mining operations	Damaging fish spawning, a ecting aquatic environment of insects and fishes
Inorganic Pollutants	Metals compounds, trace elements, inorganic salts, heavy metals, mineral acids	Aquatic flora and fauna, public health problem
Organic Pollutants	Detergents, insecticides, herbicides	Aquatic life problems, cacogenic
Industrial Pollutants	Municipal pollutant Water	Caused water and air pollution
Radioactive Pollutants	Different isotopes	Bones, teeth, skin and can cause
Nutrients Pollutants	Plant debris, fertilizers	Effect on eutrophication process
Macroscopic pollutants	Marine debris	Plastic pollution
Sewage and contained water	Domestic wastewater	Water borne disease

Source: Yaqoob, A. A. et al., 2020.Role of Nanomaterials in the Treatment of Wastewater: A Review

Water purification method

The below fig. 2 shows the basic purification method. There is a big challenge to develop cost-effective and environmentally acceptable separation and reactive media that can be efficient in composite packed-bed reactors for the purification of water contaminated by mixtures of (i) metal ions, (ii) organic solutes, and (iii) bacteria. The wastewater passes through three different mediums viz. bacteria filtering medium, organic filtering medium, and at the end, it passes to metal ion filtering medium. By this method, the pollutants are removed by the different mediums and we get the purified water. There are various other methods that treated the wastewater like

Nano photo catalysts: It is derived from the Greek word "photo" which means the decomposition of compounds in the presence of light. It activates or stimulates the substance by using light (UV/visible/sunlight). It changes the rate of reaction without any involvement by itself during the chemical transformation process. The main difference between the traditional thermal catalyst and photocatalyst is that the former activates the heat while the latter activates the photon of light energy.

Nano and micromotors: Nano/micromotors have been considered that can convert the energy from several resources into machine-driven force, empowering Nanotechnology, an area of research that has progressed at such a quick pace in early decades to achieve special goals through various mechanisms. These innovative motors are motorized in and offered many approaches to water treatment. In the modern era, nano/micromotors have been both cases by using fuel or without fuel sources (acoustics, magnetic field, electric field) have several considered that can convert the energy from several resources into machine-driven force, significant exciting applications (Jurado-Sánchez, B. 2018). They show more speed, high power, and specific control movement, empowering them to achieve special goals through various mechanisms. These innovative motors have the self-mix ability, etc. The removal of contaminants from polluted resources is a significant focus for are motorized in both cases by using fuel or without fuel sources (acoustics, magnetic field, electric environmental stability, and sustainability (Moo, J.G.S. 2015).

Nano membranes: It is a unique type of membrane formed with different nanofibers which remove unwanted nanoparticles present in the aqueous phase. It contains a porous support with composite layers. This composite layer is carbon-based material (grapheme oxide/CNT) dispersed into a polymer matrix for significant practice.

Nanosorbents: It has a high sorption ability that is more powerful for water treatment.

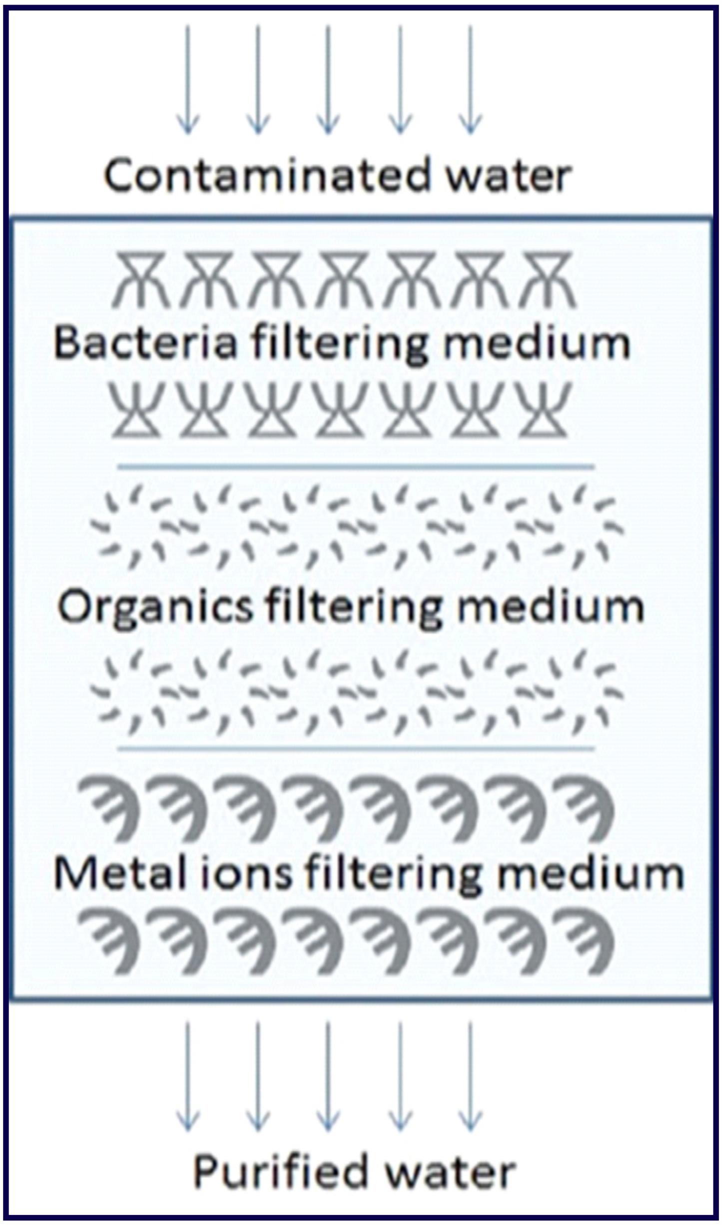

Fig 2: Schematic of a composite nanomaterial packed bed reactor for purification of water Contaminated by mixtures of (i) Metal ions, (ii) Organic solutes and (iii) bacteria

source: www.google.com

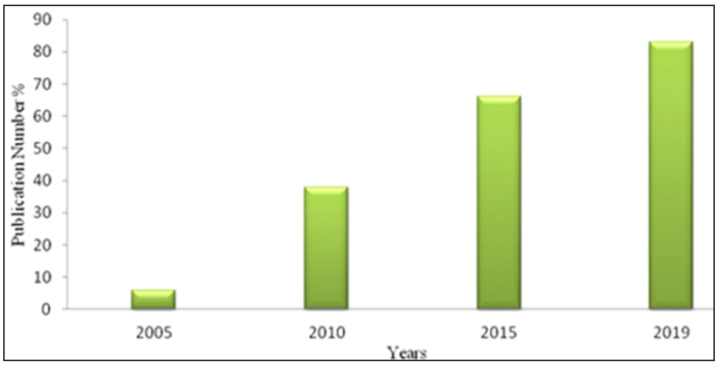

Fig 3: Publication trends in the field for wastewater treatment.

Presently, nanomaterials demands more attention of researchers in the way of wastewater purification. The above study (fig. 3) trend of nanomaterials shows that the trend is increasing day by day. Publication number in nanomaterial was less than 5% in 2005 but in 2019 report showed that more than 80% of work is recorded (Gao, W. 2012).

Challenges

Toxicity: However, nanotechnology has great future potential, its originality and its pace of development cause uncertainty regarding the long-term effects of nanoparticles on the environment and human health. In the short-term, no hazards are identified but in the long-term, they might affect humans through the bio-accumulation of toxins in plants and animals (Rana, S. et al., 2013).

Risk assessment: It consists of testing potential risks and exposure associated with it. The great variety of nanoparticles and the lack of data on their toxicity under various conditions obstruct the creation of standardized risk assessment tools. The combination of nanoparticles with the same properties increases the feasibility of risk assessment, but is not yet reliable (Landsiedel, R. 2016).

Regulation: Because of their size-related properties, which may differ from their bulk counterpart, adopting regulatory frameworks that adequately deal with nanotechnology can be challenging. While some argue current regulatory frameworks are sufficient to deal with the risks and uncertainty of nanotechnology, according to others point of view, there is a need for nano-specific provisions and regulation (Kookana, R. S. 2014).

CONCLUSION

Nanotechnology is an innovative approach of growing agricultural production through implementing nutrient efficiency, and improve plant protection practices. It also may have real-time solutions for several agricultural problems like improved plant protection, crop varieties, detect diseases and monitoring plant growth. It provides generous visions for the development of the agricultural sector through advanced applications and the probability of products and increases global crops production volume to feed the world population in the next decades. Promising results and applications are already being developed in the areas of nano nutrients, implementing crop productivity, protecting plants (herbicides and pesticides), nano-packing and nano sensors.
However, it is in the building stage and further studies are required to overcome its long-term deterimental effect.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any potential conflict of interest.

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