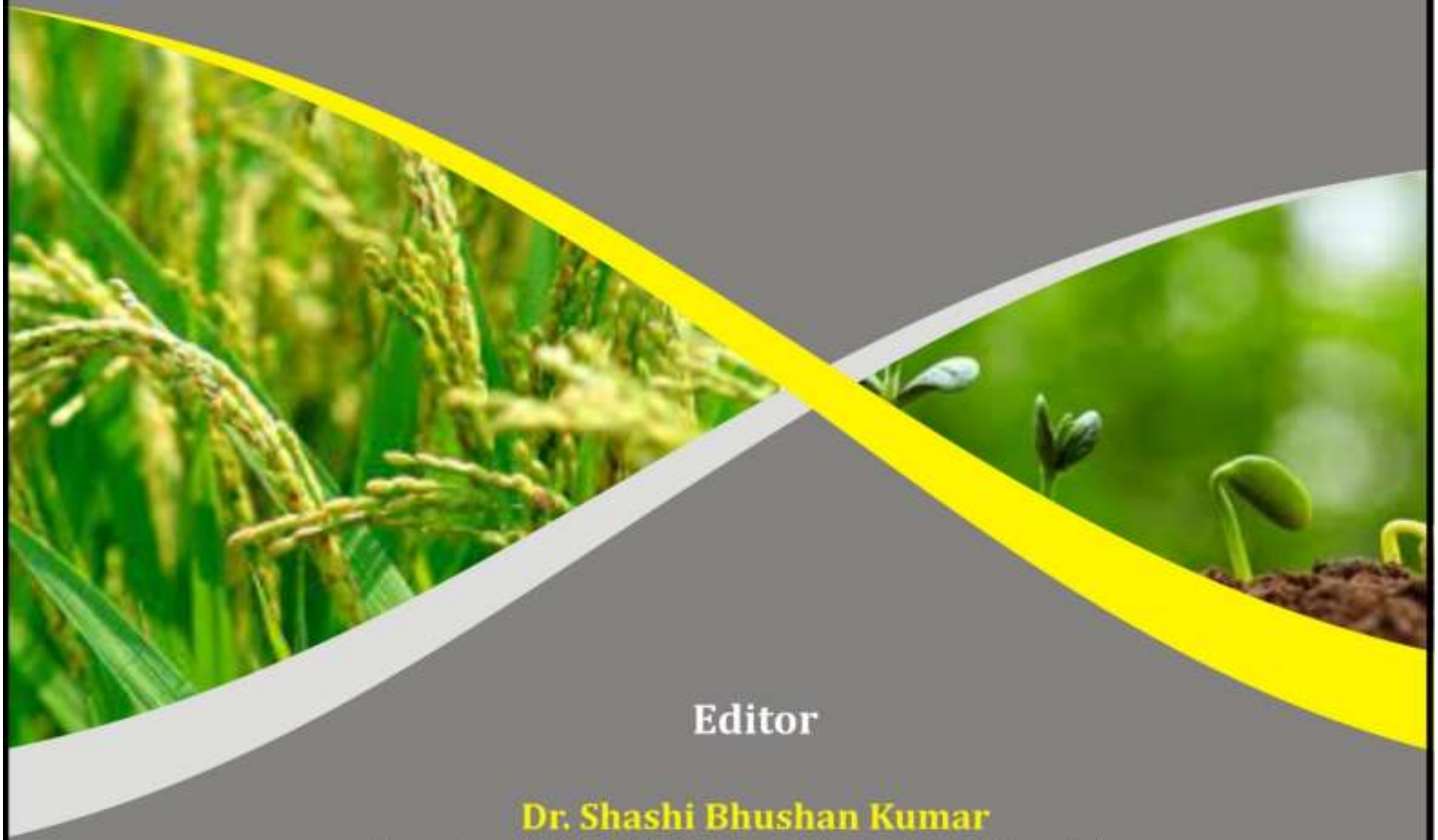
# KEY NOTES ON AGRICULTURE CHEMISTRY AND SOIL SCIENCE



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# CONTENT

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# 1. Impact on Soil Erosion in Sustainable Agriculture

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## Abstract

Soil erosion is agriculture's enemy: a major environmental threat to sustainability and productivity with knock-on effects on the climate crisis and food security. Soil is the most fundamental and basic natural resource for all life to survive. Water and wind erosion are two main agents that degrade soils. Runoff washes away the soil particles from sloping and bare lands while wind blows away loose and detached soil particles from flat and unprotected lands. Geologic erosion is a normal process of weathering that generally occurs at low rates in all soils as part of the natural soil-forming processes. Magnitude and the impacts of soil erosion on productivity depend on soil profile and horizonation, terrain, soil management, and climate characteristics. There are so many factors and processes are responsible for soil erosion. For sustainable agriculture and environment, it is pertinent to protect the soil resources against erosion. Different control measures should be adopted to protect the soil resources against erosion.

**Keywords:** Soil, Soil erosion, Conservation, Control measures.

## 1.1 Introduction:

Soil is the most fundamental and basic natural resource for all life to survive. Soil erosion, the removal of soil by water and wind, is the most common and extensive. Natural or geologic erosion ranges from very little in undisturbed lands to extensive in steep arid lands. Geological erosion takes place, as a result of the action of water, wind, gravity and glaciers and it takes place, at such slow rates that the loss of soil is compensated for the formation of new soil under natural weathering processes. It is sometimes referred to as normal erosion. Accelerated erosion caused by the disturbances of people (cutting forests, cultivating lands, constructing roads and buildings etc.) and is increasing as the population increases. In this erosion, the removal of soil takes place at a much faster rate than that of soil formation. It is also referred to as abnormal erosion.

It is impossible to stop all erosion completely but can be minimized. Human activities have increased by 10–50 times the rate at which erosion is occurring globally. Excessive (or accelerated) erosion causes both "on-site" and "off-site" problems. On-site impacts include decreases in agricultural productivity and (on natural landscapes) ecological collapse, both because of loss of the nutrient-rich upper soil layers. In some cases, the eventual end result is desertification. Off-site effects include sedimentation of waterways and eutrophication of water bodies, as well as sediment-related damage to roads and houses.

Water and wind erosion are the two primary causes of land degradation; combined, they are responsible for about 84% of the global extent of degraded land, making excessive erosion one of the most significant environmental problems worldwide.

Intensive agriculture, deforestation, roads, anthropogenic climate change and urban sprawl are amongst the most significant human activities in regard to their effect on stimulating erosion. However, there are many prevention and remediation practices that can curtail or limit erosion of vulnerable soils.

Techniques to control water and wind erosion usually result in maintaining or increasing soil productivity also.

## 1.2 Gravity Erosion:

Mass-Wasting is the down-slope movement of rock and sediments, mainly due to the force of gravity. Mass-wasting is an important part of the erosional process, as it moves material from higher elevations to lower elevations where transporting agents like streams and glaciers can then pick up the material and move it to even lower elevations. Mass-wasting processes are occurring continuously on all slopes; some mass-wasting processes act very slowly. Slumping happens on steep hillsides, occurring along distinct fracture zones, often within materials like clay that, once released, may move quite rapidly downhill. Surface creep is the slow movement of soil and rock debris by gravity which is usually not perceptible except through extended observation.

## 1.3 Water Borne Soil Erosion:

Water erosion of soil starts when raindrops strike bare soil peds and clods, resulting the finer particles to move with the flowing water as suspended sediments. The soil along with water moves downhill, scouring channels along the way. Each subsequent rain erodes further amounts of soil until erosion has transformed the area into barren soil.

- **Causes of Water Borne Soil Erosion:**

Water erosion is due to the dispersive action, and transporting power of water-water as it descends in the rain and leaves the land in the form of run-off.

Water erosion caused by people who remove protective plant covers by tillage operation, burning crop residues, overgrazing, over cutting forests etc. including loss of soil.

## 1.4 Forms of Water Soil Erosion:

The major forms of water-borne soil erosion are:

a. Raindrop splash erosion
b. Sheet erosion
c. Rill erosion

a. Gully erosion
b. Bank erosion
c. Stream channel erosion

### a. Raindrop Splash Erosion:

Raindrop splash erosion results from soil splash caused by the impact of falling rain drops. There are four factors that determine the rate of rain drop erosion namely, climate (mostly rainfall and temperature), soil- (its inherent resistance to dispersion and its infiltration rate), topography particularly steepness and length of slope, and vegetative cover-either living or the residues of dead vegetation.

The continued impact of raindrops compacts the soil and further seals the surface- so that water cannot penetrate into the soil and as a result causing more surface run-off. The impact of the raindrops per unit area is determined by the number and size of the drops, and the velocity of the drops.

### b. Sheet Erosion:

Sheet erosion is the movement of soil from raindrop splash and runoff water. It typically occurs evenly over a uniform slope and goes unnoticed until most of the productive topsoil has been lost.

It is common on lands having a gentle or mild slope, and results in the uniform “skimming off of the cream” of the top soil with every hard rain. Deposition of the eroded soil occurs at the bottom of the slope or in low areas. Lighter-coloured soils on knolls, changes in soil horizon thickness and low crop yields on shoulder slopes and knolls are other indicators. In this erosion, shallow soils suffer greater reduction in productivity than deep soils. Movement of soil by rain drop splash is the primary cause of sheet erosion.

### c. Rill Erosion:

Rill erosion is the removal of soil by concentrated water running through little streamlets, or head cuts. Detachment in a rill occurs if the sediment in the flow is below the amount the load can transport and if the flow exceeds the soil's resistance to detachment. As detachment continues or flow increases, rills will become wider and deeper. Rill erosion mainly occurs as a result of concentrated overland flow of water leading to the development of small well-defined channels. These channels act as sediment sources and transport passages, leading to soil loss. Rill erosion is more apparent than sheet erosion. This type of soil erosion may be regarded as a transition stage between sheet and gully erosion.

### d. Gully Erosion:

Gully erosion is an advanced stage of rill erosion. A gully is a distinct channel, carved into a hillslope or valley bottom by intermittent or ephemeral runoff. Such channels are carved where the force exerted by flowing water – a function of its mass.

During every rain, the rain water rushes down these gullies, increasing their width, depth and length. Gully erosion is more spectacular and therefore, more noticeable than any other erosion.

- **The Development of Gully Occurs Due to Following Four Stages:**

a. Formation stage- with channel erosion by a downward scour of the surface soil.
b. Development stage- consisting of upstream movement of the gully head and enlargement of the gully in width and depth.
c. Healing stage- beginning with the growing of vegetation in the gully.
d. Stabilization stage- the gully reaches a stable gradient, gully walls reach a stable slope, and vegetative cover spreads over the gully surface.

- **Classification of Gully Erosion:**

a. Very small gullies (G1) - deep up to 3m, width not greater than 18m, side slopes vary.
b. Small gullies (G2)- deep up to 3m, width greater than 18m, side slopes between 8 to 15%
c. Medium gullies (G3)- deep between 3 to 9m, width not less than 18m, side slopes between 8 to 15%
d. Deep and narrow gullies (G4) - deep 9m, width varies, side slopes mostly steep or even vertical with intricate and active branch gullies.

**e. Bank Erosion:**

Bank erosion is the wearing away of the banks of a stream or river. This is distinguished from erosion of the bed of the watercourse, which is referred to as scour. Natural streams and constructed drainage channels act as outlets for surface water runoff and subsurface drainage systems. Bank erosion is the progressive undercutting, scouring and slumping of these drainage ways. There are three main processes that cause bank erosion (scour, mass failure and slumping), and it is essential to determine which are operating at any particular site because the management required to slow or prevent them may differ. Bank scour is the direct removal of bank materials by the physical action of flowing water and is often dominant in smaller streams and the upper reaches of larger streams and rivers. Mass failure, which includes bank collapse and slumping, is where large chunks of bank material become unstable and topple into the stream or river in single events. Mass failure is often dominant in the lower reaches of large streams and often occurs in association with scouring of the lower banks.

## f. Stream Channel Erosion:

Stream channel erosion is the scouring of material from the water channel and the cutting of banks by flowing or running water. This erosion occurs at the lower end of stream tributaries and to streams that have nearly continuous flow and relatively flat gradients. Stream but erode either by run-off flowing over the side of the stream bank, or by scouring or undercutting. Scouring is influenced by the velocity and direction of flow, depth and width of the channel and soil texture.

### 1.4.1 Effects of Water Erosion On- Site:

- The main on-site impact is the reduction in soil quality which results from the loss of the nutrient-rich upper layers of the soil, and the reduced water-holding capacity of many eroded soils. The breakdown of aggregates and the removal of smaller particles or entire layers of soil or organic matter can weaken the structure and even change the texture.
- Textural changes can in turn affect the water-holding capacity of the soil, making it more susceptible to extreme conditions such as drought. Crop emergence, growth and yield are directly affected by the loss of natural nutrients and applied fertilizers.
- Seeds and plants can be disturbed or completely removed by the erosion.
- Organic matter from the soil, residues and any applied manure, is relatively lightweight and can be readily transported off the field, particularly during spring thaw conditions.
- Pesticides may also be carried off the site with the eroded soil.
- Soil quality, structure, stability and texture can be affected by the loss of soil.

### 1.4.2 Effects of Water Erosion Off-Site:

In addition to its on-site effects, the soil that is detached by accelerated water or wind erosion may be transported considerable distances. This gives rise to 'off-site problems'.

- Water erosion's main off-site effect is the movement of sediment and agricultural pollutants into watercourses. This can lead to the silting-up of dams, disruption of the ecosystems of lakes, and contamination of drinking water. In some cases, increased downstream flooding may also occur due to the reduced capacity of eroded soil to absorb water.
- Sediment can accumulate on down-slope and contribute to road damage. Sediment that reaches streams or watercourses can accelerate bank erosion, obstruct stream and drainage channels, fill in reservoirs, damage fish habitat and degrade downstream water quality.
- Pesticides and fertilizers, frequently transported along with the eroding soil, contaminate or pollute downstream water sources, wetlands and lakes.
- Rapid bank erosion leads to loss of valuable land, reduced water quality as sediment and nutrients enters the stream, as well as threatening infrastructure such as roads, bridges and buildings.
- Stream bank erosion is the dominant source of sediment in many river systems.

### 1.4.3 Harmful Effects of Water Erosion:

Water erosion causes various damages to the land as follows:

- Loss of top fertile soil.
- Accumulation of sand or other unproductive coarse soil materials on other productive lands.
- Silting of lakes and reservoirs.
- Silting of drainage and water channels.

- Decreases water table.
- Fragmentation of land.

### 1.4.4 Factors Affecting Water Erosion

The rate and magnitude of soil erosion by water is controlled by the following factors:

a. Rainfall and runoff
b. Soil Erodibility
c. Slope gradient and length
d. Cropping and vegetation
e. Tillage practices

### a. Rainfall and Runoff:

The greater the intensity and duration of a rainstorm, the higher the erosion potential. The impact of raindrops on the soil surface can break down soil aggregates and disperse the aggregate material. Lighter aggregate materials such as very fine sand, silt, clay and organic matter are easily removed by the raindrop splash and runoff water. Soil movement by rainfall (raindrop splash) is usually greatest and most noticeable during short-duration, high-intensity thunderstorms. Surface water runoff occurs whenever there is excess water on a slope that cannot be absorbed into the soil. Reduced infiltration due to soil compaction, crusting or freezing increases the surface runoff and soil erosion. Runoff from agricultural land is greatest when compared with other land areas.

### b. Soil Erodibility:

Soil Erodibility – susceptibility of soil to agent of erosion - is determined by inherent soil properties e.g., texture, structure, soil organic matter content, clay minerals, exchangeable cations and water retention and transmission properties. Climatic erosivity includes drop size distribution and intensity of rain, amount and frequency of rainfall, run-off amount and velocity, and wind velocity. Important terrain characteristics for studying soil erosion are slope gradient, length, aspect and shape.

Ground cover exerts a strong moderating impact on dissipating the energy supplied by agents of soil erosion. Soil Erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. Texture is the principal characteristic affecting Erodibility, but structure, organic matter and permeability also contribute. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion.

Sand, sandy loam and loam-textured soils tend to be less erodible than silt, very fine sand and certain clay-textured soils. Tillage and cropping practices that reduce soil organic matter levels, cause poor soil structure, or result in soil compaction, contribute to increases in soil Erodibility. The formation of a soil crust, which tends to "seal" the surface, also decreases infiltration.

### c. Slope Gradient and Length:

The steeper and longer the slope of a field, the higher the risk for erosion. Soil erosion by water increases as the slope length increases due to the greater accumulation of runoff. Consolidation of small fields into larger ones often results in longer slope lengths with increased erosion potential, due to increased velocity of water, which permits a greater degree of scouring (carrying capacity for sediment).

### d. Cropping and Vegetation:

The potential for soil erosion increases if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of runoff water and allows excess surface water to infiltrate.

The erosion-reducing effectiveness of plant and/or crop residues depends on the type, extent and quantity of cover. The effectiveness of any protective cover also depends on how much protection is available at various periods during the year, relative to the amount of erosive rainfall that falls during these periods.

Crops that provide a full protective cover for a major portion of the year (e.g., alfalfa or winter cover crops) can reduce erosion much more than can crops that leave the soil bare for a longer period of time (e.g., row crops), particularly during periods of highly erosive rainfall such as spring and summer.

### e. Tillage Practices:

The potential for soil erosion by water is affected by tillage operations, depending on the depth, direction and timing of plowing, the type of tillage equipment and the number of passes. Minimum till or no-till practices are effective in reducing soil erosion by water.

Tillage and other practices performed up and down field slopes creates pathways for surface water runoff and can accelerate the soil erosion process.

## 1.4.5 Techniques for Control of Water Borne Soil Erosion:

Soil erosion caused by water is lessened by reducing either soil detachment or soil sediment transport or both.

### a. Controlling Soil Detachment:

Soil detachment can be controlled by cropping or other vegetative cover practices that keep the soil covered as possible. As rain drops fall on the vegetation then the water gently slides off to be absorbed into the soil. The practice of using deep or subsurface tillage implements that leave much of the crop residues standing on the surface of the soil is stubble mulch farming, an effective techniques of wind erosion control.

### b. Controlling Soil Sediment Transport:

Soil sediments transportation is hindered by slowing the eroding water, decreasing the steepness of slope, and by erecting barriers namely brush dams, terraces, contour cultivation and contour strip cropping. Terracing is generally recommended only for intensively used eroding crop land. Contour cultivation means tilling and planting at right angles to the natural slope of the land.

### c. Wind-Borne Soil Erosion:

Wind erosion is the detachment and transportation of soil particles by wind when the airstream passing over a surface generates sufficient lift and drag to overcome the forces of gravity, friction and cohesion. Once a particle has been dislodged from the surface, it may be transported in suspension or by saltation or by surface creep. Loss of topsoil by wind erosion over a relatively short time period can significantly decrease soil fertility and crop yield.

### d. Movement of Soil Particles by Wind

Movement of soil particles is caused by wind forces exerted against or parallel to the surface of the ground. Wind erodes the soil in three steps namely, saltation, suspension, surface creep.

- **Saltation:**

It is a process of soil movement in a series of bounces or jumps.

- **Suspension:**

It represents the floating of small sized particles in the air stream.

- **Surface Creep:**

It is the rolling or sliding of large soil particles along the ground surface.

### The Rate and Magnitude of Soil Erosion by Wind is Controlled by The Following Factors:

a. Soil Erodibility
b. Soil surface roughness
c. Climate (wind patterns, precipitation, frost action)
d. Unsheltered distance
e. Vegetative cover
f. Topography (exposure, elevation, terrain roughness, localized funneling of wind)
g. Cultural practices (cultivation, vegetation depletion).

### a. Soil Erodibility:

Very fine soil particles are carried high into the air by the wind and transported great distances (suspension). Fine-to-medium size soil particles are lifted a short distance into the air and drop back to the soil surface, damaging crops and dislodging more soil (saltation). Larger-sized soil particles that are too large to be lifted off the ground are dislodged by the wind and roll along the soil surface (surface creep). The abrasion that results from windblown particles breaks down stable surface aggregates and further increases the soil Erodibility.

### b. Soil Surface Roughness:

Soil surfaces that are not rough offer little resistance to the wind. However, ridges left from tillage can dry out more quickly in a wind event, resulting in more loose, dry soil available to blow. Over time, soil surfaces become filled in, and the roughness is broken down by abrasion. This results in a smoother surface susceptible to the wind.

### c. Climate:

The speed and duration of the wind have a direct relationship to the extent of soil erosion. Soil moisture levels are very low at the surface of excessively drained soils or during periods of drought, thus releasing the particles for transport by wind.

### d. Unsheltered Distance:

A lack of windbreaks (trees, shrubs, crop residue, etc.) allows the wind to put soil particles into motion for greater distances, thus increasing abrasion and soil erosion. Knolls and hilltops are usually exposed and suffer the most.

### e. Vegetative Cover:

The lack of permanent vegetative cover in certain locations results in extensive wind erosion. Loose, dry, bare soil is the most susceptible; however, crops that produce low levels of residue (e.g., soybeans and many vegetable crops) may not provide enough resistance. In severe cases, even crops that produce a lot of residue may not protect the soil.

## Effects of Wind Erosion:

- Wind erosion damages crops through sandblasting of young seedlings or transplants, burial of plants or seed, and exposure of seed. Crops are ruined, resulting in costly delays and making reseeding necessary.
- Plants damaged by sandblasting are vulnerable to the entry of disease with a resulting decrease in yield, loss of quality and market value.
- Soil drifting is a fertility-depleting process that can lead to poor crop growth and yield reductions in areas of fields where wind erosion is a recurring problem.
- Continual drifting of an area gradually causes a textural change in the soil.

- Loss of fine sand, silt, clay and organic particles from sandy soils serves to lower the moisture-holding capacity of the soil. Also, soil nutrients and surface-applied chemicals can be carried along with the soil particles.

## Control of Wind Erosion:

There are generally four basic methods that can control or reduce soil erosion caused by the wind.

- Protection of the soil surface with a vegetative cover or crop residues.
- Bringing aggregates or clods to the surface soil because aggregates or clods are larger enough to resist the wind force.
- By making surface roughness for the reduction of wind velocity.
- Establishment of barriers or trap strips and wind breaks at suitable intervals at right angles to the most erosive winds to reduce wind velocity and soil drifting.

## 1.5 Tillage Erosion:

Tillage erosion is the redistribution of soil through the action of tillage and gravity. It results in the progressive down-slope movement of soil, causing severe soil loss on upper-slope positions and accumulation in lower-slope positions. This form of erosion is a major delivery mechanism for water erosion. Tillage action moves soil to convergent areas of a field where surface water runoff concentrates. Also, exposed subsoil is highly erodible to the forces of water and wind. Tillage erosion has the greatest potential for the "on-site" movement of soil and in many cases can cause more erosion than water or wind.

The rate and magnitude of soil erosion by tillage is controlled by the following factors:

a. Type of Tillage Equipment
b. Direction
c. Speed and Depth
d. Number of Passes

## a. Type of tillage equipment

Tillage equipment that lifts and carries will tend to move more soil. As an example, a chisel plow leaves far more crop residue on the soil surface than the conventional mold board plow but it can move as much soil as the mold board plow and move it to a greater distance. Using implements that do not move very much soil will help minimize the effects of tillage erosion.

## b. Direction:

Tillage implements like a plow or disc throw soil either up or down slope, depending on the direction of tillage. Typically, more soil is moved while tilling in the down-slope direction than while tilling in the up-slope direction.

### c. Speed and depth:

The speed and depth of tillage operations will influence the amount of soil moved. Deep tillage disturbs more soil, while increased speed moves soil further.

### d. Number of passes:

Reducing the number of passes of tillage equipment reduces the movement of soil. It also leaves more crop residue on the soil surface and reduces pulverization of the soil aggregates, both of which can help resist water and wind erosion.

## 1.5.1 Effects of Tillage Erosion:

- Tillage erosion impacts crop development and yield.
- Crop growth on shoulder slopes and knolls is slow and stunted due to poor soil structure and loss.
- Of organic matter and is more susceptible to stress under adverse conditions.
- Changes in soil structure and texture can increase the Erodibility of the soil and expose the soil to further erosion by the forces of water and wind.

## 1.6 Conservation Measures:

Soil conservation is the preventing of soil loss from erosion or reduced fertility caused by over usage, acidification, salinization or other chemical soil contamination. Soil conservation is about solving the problems of land degradation, particularly soil erosion. Soil conservation is fundamentally a matter of determining a correct form of land use and management. Soil conservation can be defined as the combination of the appropriate land use and management practices that promote the productive and sustainable use of soils and, in the process, minimizes soil erosion and other forms of land degradation. Slash-and-burn and other unsustainable methods of subsistence farming are practiced in some lesser developed areas. A sequel to the deforestation is typically large-scale erosion, loss of soil nutrients and sometimes total desertification. Techniques for improved soil conservation include crop rotation, cover crops, conservation tillage and planted windbreaks and affect both erosion and fertility.

## 1.7 Notable Methods of Soil Erosion Control:

- Contour ploughing.
- Terracing or terrace farming.
- Keyline design.
- Perimeter runoff control.
- Windbreaks.
- Cover crops/crop rotation.
- Soil-conservation farming.
- Salinity management.

There are five main techniques that can be used in controlling soil erosion are.

They are as follows:

a. Contour bunding and Farming
b. Strip Cropping
c. Terracing
d. Gully Reclamation
e. Shelter Belts.

Soil erosion can be controlled by adopting land management practices and also by changing the pattern of some human activities which accelerate soil erosion. One such idea is to minimise disturbance.

## 1.8 Land Disturbing Activities:

The most effective form of erosion control is to minimize the area of disturbance. The land disturbing activities are the following:

**a. Quarries:** Quarries are places of naturally occurring hard rock that is mined for rock and gravels. The products from quarry operations are used for roading, building and in rock. Protections measures, i.e., rip-rap.

**b. Trenching:** Trenching (usually for installing utility services), often occurs at the end of bulk earthworks. Topsoil and sub-soils should be stockpiled separately adjacent to the trench so that at the completion of the operation these soils can be replaced in the appropriate order and vegetation established.

**c. Clean fills:** Clean fills dispose of unwanted fill material which may contain other material.

**d. Roading:** The linear nature of roading poses challenges for erosion and sediment control measures. They need to be planned to ensure controls are successful.

## 1.9 Minimise Disturbance:

The most effective form of erosion control is to minimise the area of disturbance, retaining as much existing vegetation as possible. This is especially important on steep slopes or in the vicinity of water bodies, where no single measure will adequately control erosion and where receiving environments may be highly sensitive. Match land development to land sensitivity. Watch out for and avoid areas that are wet (streams, wetlands, springs), have steep or fragile soils. Analyze all the “limits of disturbance”.

**a. Stage Construction:** Temporary stockpiles, access and utility service installation all need to be considered.

**b. Protect Steep Slopes:** Steep slopes should be avoided where practicable.

**c. Protect Water bodies:** All water bodies and proposed drainage patterns. Map all water bodies and show limits of disturbance and protection measures.

**d. Stabilize Exposed Areas Rapidly:** Conventional sowing to mulching. Mulching is an effective instant protection.

**e. Install Perimeter Controls:** Perimeter controls above the site keep clean water runoff out of the worked area. Common controls are diversion drains, silt fences and earth bunds.

**f. Employ Detention Devices:** Earthworks will still discharge sediment-laden runoff during storms.

**g. Runoff Diversion Channel/Bund:** This is a non-erodible channel or bund constructed for the conveyance of runoff constructed to a site-specific cross section and grade design. It is done to either protect work areas from upslope runoff, or to divert sediment laden water to an appropriate sediment retention structure.

**h. Contour Drain:** It is a temporary ridge or excavated channel, or combination of ridge and channel, constructed to convey water across sloping land on a minimal gradient. To periodically break overland flow across disturbed areas in order to limit slope length and thus the erosive power of runoff and to divert sediment laden water to appropriate controls or stable outlets.

**i Rock Check Dam:** Small temporary dam constructed across a channel (excluding perennial water bodies), usually in series, to reduce flow velocity. It may also retain coarse sediment. Check dams are constructed in order to reduce the velocity of concentrated flows, thereby reducing erosion of the channel. Rock check dams will trap some sediment, but they are not designed as a sediment retention measure.

**j. Level Spreader:** A non-erosive outlet to disperse concentrated runoff uniformly across a slope. The level spreader provides a relatively low-cost option, which can convert concentrated flow to sheet flow and release it uniformly over a stabilized area.

**k. Pipe Drop Structure / Flume:** A temporary pipe structure or constructed flume placed from the top of a slope to the bottom of a slope. A pipe drop structure or a flume structure is installed to convey surface runoff down the face of unestablished slopes in order to minimise erosion on the slope face.

**l. Benched Slope:** Modification of a slope by reverse sloping to divert runoff to an appropriate conveyance system. To limit the velocity and volume and hence the erosive power of water flowing down a slope and therefore, minimizing erosion of the slope face.

**m. Surface Roughening:** Roughening a bare earth surface with horizontal grooves running across a slope or tracking with construction equipment.

To aid in the establishment of vegetative cover from seed, to reduce runoff velocity, to increase infiltration, to reduce erosion and assist in sediment trapping.

**n. Stabilized Construction Entrance:** A stabilized pad of aggregate on a filter cloth base located at any point where traffic will be entering or leaving a construction site. To prevent site access points from becoming sediment sources and to assist in minimizing dust generation and disturbance of areas adjacent to the road frontage by giving a defined entry/exit point.

**o. Geosynthetic Erosion Control Systems (GECS):** The protection of channels and erodible slopes utilizing artificial erosion control material such as Geosynthetic matting, geotextiles or erosion matting. To immediately reduce the erosion potential of establish protective vegetation. There are both Temporary and Permanent Non-Degradable GECS.

## 1.10 Revegetation Techniques:

**a. Top Soiling:** The placement of topsoil over a prepared subsoil prior to the establishment of vegetation. To provide a suitable soil medium for vegetative growth while providing some limited short term erosion control capability.

**b. Temporary and Permanent Seeding:** The planting and establishment of quick growing and/or perennial vegetation to provide temporary and/or permanent stabilization on exposed areas. Temporary seeding is designed to stabilize the soil and to protect disturbed areas until permanent vegetation or other erosion control measures can be established.

**c. Hydroseeding:** Hydroseeding is a planting process that uses a slurry of seed and mulch. It is often used as an erosion control technique. The application of seed, fertilizer and a paper or wood pulp with water in the form of a slurry which is sprayed over the area to be revegetated. To establish vegetation quickly while providing a degree of instant protection from rain drop impact.

**d. Mulching:** Mulches are loose coverings or sheets of material placed on the surface of cultivated soil. Organic mulches also improve the condition of the soil. As these mulches slowly decompose, they provide organic matter which helps keep the soil loose. This improves root growth, increases the infiltration of water, and also improves the water-holding capacity of the soil. The application of a protective layer of straw or other suitable material to the soil surface. To protect the soil surface from the erosive forces of raindrop impact and overland flow. Mulching assists in soil moisture conservation, reduces runoff and erosion, controls weeds, prevents soil crusting and promotes the establishment of desirable vegetation.

**e. Turfing:** A surface layer of earth containing a dense growth of grass and its matted roots; sod. Turfing is an artificial substitute for such a grassy layer, as on a playing field. The establishment and permanent stabilization of disturbed areas by laying a continuous cover of grass turf.

To provide immediate vegetative cover to stabilize soil on disturbed areas.

### 1.11 Sediment Control Measures:

**a. Sediment retention pond:** A temporary pond formed by excavation into natural ground or by construction of an embankment and incorporating a device to dewater the pond at a rate that will allow suspended sediment to settle out. To treat sediment-laden runoff and reduce the volume of sediment leaving a site, thus protecting downstream environments from excessive sedimentation and water quality degradation.

**b. Chemical flocculation systems:** A treatment system designed to add a flocculating chemical to sediment retention ponds. Used to increase the sediment capture performance of sediment retention ponds by causing suspended. Sediment to "clump" resulting in faster settling rates.

**c. Silt fence:** The purpose of a silt fence is to retain the soil on disturbed land. The three principal aspects of silt fence design are: proper placement of fencing, adequate amount of fencing, and appropriate materials.

A silt fence is a temporary sediment barrier made of porous fabric. It's held up by wooden or metal posts driven into the ground, so it's inexpensive and relatively easy to remove. The fabric ponds sediment-laden stormwater runoff, causing sediment to be retained by the settling processes. A temporary barrier of woven geotextile fabric is also used to intercept sediment laden Runoff from small areas of soil disturbance.

**d. Super Silt Fence:** A temporary barrier of woven geotextile fabric over chain link fence used to intercept sediment laden runoff from soil disturbance in small catchment areas. A super silt fence provides more robust sediment control compared with a standard silt fence and allows up to four times the catchment area to be treated by an equivalent length of standard silt fence.

**e. Stormwater inlet protection:** A barrier across or around a cesspit (stormwater inlet). To intercept and filter sediment-laden runoff before it enters a reticulated stormwater system via a cesspit, thereby preventing sediment-laden flows from entering receiving environments.

**f. Decanting Earth Bund:** A temporary berm or ridge of compacted earth constructed to create impoundment areas where ponding of runoff can occur and suspended material can settle before runoff is discharged. Used to intercept sediment-laden runoff and reduce the amount of sediment leaving the site by detaining sediment-laden runoff.

**g. Decanting Topsoil Bund:** A temporary berm or ridge of track rolled topsoil, constructed to create impoundment areas where ponding of runoff can occur and suspended material can settle before runoff is discharged. Used to intercept sediment-laden runoff from small areas (less than 0.3 ha) and reduce the amount of sediment leaving the site by detaining sediment-laden runoff.

**h. Sump / Sediment Pit:** A temporary pit which is constructed to trap and filter water before it is pumped to a suitable discharge area. To treat sediment-laden water that has been removed from areas of excavation or areas where ponded sediment-laden water cannot drain by other means.

**i. Riprap:** Rock pieces are piled up to create a structure called as rip-rap. These are rubble composed of a variety of rock types including limestone and granite, which are used to armor embankments, shorelines, bridge abutments, streambeds and other seaside constructions to prevent soil erosion due to concentrated runoff or other water-related causes. A limitation of riprap arises when the slopes of the considered area are greater than 2:1; the rubble becomes unstable and is itself prone to erosion. In these circumstances, gabions are used.

**j. Gabions:** Gabion is an Italian word gabbia meaning “cage”. The gabions are riprap encased in galvanized, steel-wire mesh cages or cylinders. These are used to stabilize slopes, stream banks, or shorelines against erosion. They are usually placed on slopes at an angle—either battered or stepped back, rather than stacked vertically. The life expectancy of gabions rely entirely on their wire frames, and premium ones have a guaranteed structural consistency of fifty years.

**k. Buffer Strip:** These are narrow areas of land maintained in permanent vegetation to trap sediment, slow down runoff, and even control air, soil, and water quality. The root systems of the vegetation anchor soil particles together which help stop the soil from being eroded by winds. They also reduce the risk of by this landslides and other slower forms of erosion by stabilizing stream banks.

**l. Soil Binders:** Soil binders bind soil particles together in order to make the soil matrix more water and pressure resistant. Soil binder has two functions: erosion control and soil stabilization. The success of common soil binder applications varies significantly depending on the local conditions and use of stabilized soil. Soil binders have multiple purposes: soil stabilization, dust control and erosion control. Some soil binder products can combat all these issues at the same time. Cement is commercial soil binder although it has numerous drawbacks. Lime soil binder products are quicklime, hydrated lime and lime slurry. Fly ash is typically used to stabilize subbase or subgrade, and is not among soil binder products suitable for surfacing due to low resistance to abrasive action of traffic. Fly ash application has adverse effect on environment.

## 1.12 Soil Conservation Methods:

The preeminent methods of soil conservation are:

a. Expansion of vegetative cover and protective afforestation,
b. Controlled grazing,
c. Flood control,
d. Prohibition of shifting cultivation,
e. Proper land utilization,
f. Maintenance of soil fertility,

g. Land reforms, reclamation of wasteland,
h. Establishment of soil research institute and training of soil scientists, and
i. Effective agencies for soil management

## 1.13 Conclusion:

Erosion is the loss of soil. As soil erodes, it loses nutrients, clogs rivers with dirt, and eventually turns the area into a desert. Although erosion happens naturally, human activities can make it much worse. Erosion can turn once healthy, vibrant land into arid, lifeless terrain and further cause landslides and mudslides. Erosion can be controlled easily on a construction site when the right means, tools, and methods are used at the right time. The most natural and effective way to prevent erosion control is by planting vegetation. Roots from plants, especially trees, grip soil and will effectively prevent the excess movement of soil throughout the ground. Another popular erosion control method is the use of a silt fence. A silt fence is a long fabric barrier that is installed along a hill, and collects any stormwater that would carry loose soil. Another effective technique used for soil erosion control is erosion control matting. Erosion control matting is laid on top of loose soil and is secured into place. Fertility of soil is the future of civilization. So, we should conserve it for us and also for our generation.

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# 2. Chemical Hazards of Soil Pollution Due To E-Waste

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## Abstract

Accelerated growth in the digital industry in the last few years has revolutionized today's world and led to enormous changes in our life style, society and economy. Substantial increase in the production, utilization and subsequent disposal of electric and electronic items leads to global environmental problem of e-waste. Soil is the most important and dynamic biogeochemical resource supporting numerous life forms and is the main receptor of e-waste. Severe soil pollution due to e-waste treatment, recycling and disposal causes manifold problems of environmental degradation, ecological imbalance, loss of biodiversity and risk to mankind. E-waste causes soil contamination due to a number of toxic chemicals such as polychlorinated biphenyls, dioxins, dibenzofurans, brominated flame retardants, polyaromatic hydrocarbons, mercury, lead, arsenic, cadmium, nickel and chromium etc. The toxic pollutants of e-waste causes a number of adverse health effects such on neurological complications, kidney damage, endocrine disorders, allergies, anaemia, genetic mutations, birth defects, lung disorders, digestive problems and skeletal deformations etc. This section deals with the different types of pollution caused by the hazardous chemicals during e-waste processing activities and the chemical toxicology of these pollutants.

**Keywords:** Soil contamination, e-waste, toxic chemicals, health hazards

## 2.1 Introduction:

Soil is a vital and versatile natural resource composed of inorganic minerals, organic matter, air, water and living organisms. Soil acts as a complex biogeochemical system and its dynamic composition in a particular area is a resultant sum of many factors such as parent rock materials, topography, climate, time and the living organisms inhabiting it. In ecological systems, soil serves many important functions such as water absorption, storage and purification; as a medium for plant growth; habitat to numerous micro and macro-organisms; nutrients storage and recycling; breakdown of organic matter; atmospheric alternations by absorption and emission of gases and water vapours and as a strata for construction and mining (Cachada et al., 2018)

Several natural and anthropogenic factors are responsible for soil pollution such as forest fire, volcanic eruptions, industrialization, acid rain, urbanization, mining, use of agrochemicals, metallurgical operations, disposal of waste, nuclear discharge, landfilling, discharge of sewage and accidental leakage etc. (Koul and Taak, 2018).

Soil pollution due to e-waste treatment and disposal is emerging as a crucial problem at global scale since potential accumulation of hazardous chemicals of e-waste in soil has a direct impact on food chains resulting in bio toxicity, bioaccumulation and bio magnification of toxic chemicals in living beings (Tang et al., 2010).

E-waste is the fastest growing problem of developed and developing economies as several metric tonnes of e-waste is generated globally every year. Use of electric and electronic items is exponentially increased in the last few years due to rapid advances in digital industry, urbanization, economic reforms, changed life style, numerous design options, low cost and high demand of electronics.

Proper and scientific treatment and recycling of e-waste has both environmental and economic significance as on one side e-waste contains numerous toxic chemicals that need treatment and disposal and on other side it contains some valuable and non-renewable metals such as platinum, gold, copper, silver and palladium which should be recovered and reused again (Pinto, 2008).

Unfortunately only one third of e-waste is systematically and scientifically treated and almost two third is treated in informal and unscientific setting imposing multiple problems of environmental pollution, ecological imbalance, loss of biodiversity and human health concerns.

E-waste is generally recycled by primitive techniques in poorly protected, unauthorized and informal settings especially in developing economies due to lesser scientific awareness, low labour cost, and greater Tran's boundary movement of electronic waste and less stringent environmental regulations (Perkins et al., 2014).

## 2.2 Complex Composition of E-Waste:

Various electric and electronic devices which are defective, outdated, discarded and requires disposal and recycling are termed as e-waste. All the type of house hold appliances, telecommunication devices, information technology gadgets, medical equipment's and electronic toys which are rejected are included in e-waste such as air conditioners, televisions, remotes, refrigerators, washing machines, microwaves, mobile phones, chargers, telephones, fax machine, computers, laptops, i-pods, DVD players, VCRs, typewriters, printers, copiers, compact discs, cameras, X-ray machines, thermometers, oximeters etc.

Due to rapid scientific growth in design and development of electric and electronic items, the chemical composition of e-waste is ever changing and complex (Tsydenova and Bengtsson, 2011). Chemically e-waste contain hazardous heavy metals, metalloids, plastics, glass, brominated flame retardants (BFRs), polychlorinated biphenyls (PCBs), ceramics, polymers, polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and polyaromatic hydrocarbons (PAHs) (Oguchi et al., 2013). Details of varied toxic chemicals present in e-waste is shown in Table 2.1.

**Table 2.1: Various chemicals in e-waste**

| **Chemicals** | **Electric and electronic waste** |
|---|---|
| BFRs | Plastic covering of electronics, printed circuit boards, electric wire and cables |
| PCBs | Electric motors, capacitors, transformers, generators, ceiling fans, fluorescent lightning, dishwashers |
| PCDDs and PCDFs | Combustion by products of electric and electronic devices |
| PAHs | Combustion by products of electric and electronic devices |
| Mercury | LCD panels (gas discharge lamps) used in televisions, computers, projectors, photocopiers, cameras, calculators, fax machine, sensors, printed circuit boards, batteries, switches, ovens, heaters |
| Lead | Batteries, printed circuit boards, cathode ray tubes, light bulbs, plastic materials, switches, mobile phones, televisions, lasers |
| Cadmium | Batteries, cathode ray tubes, printed circuit boards, semiconductor chips, photocopier, switches, mobile phones, alloys, plastic materials |
| Arsenic | Semiconductor diodes, LCD panels, solar cells, cell phones, CD players, printed circuit boards, cameras, plastic materials |
| Chromium | Magnetic tapes, anticorrosion coating, plastic paint and pigments, cathode ray tubes, cell phones, solar cells, LCD panels, switches, wires, disk, CD players |
| Antimony | Cathode ray tubes, printed circuit boards, LCD panels, fax machine |
| Nickel | Batteries, cell phones, alloys, LCD panels |
| Beryllium | X-ray machine, ceramic component of electronics, power supply boxes |
| Lithium | Batteries, laptops, clocks, cell phones, cameras, toys |
| Aluminium | Air conditioners, cathode ray tubes, LCD panels, digital cameras |
| Barium | Microwave ovens, fluorescent lamps, cathode ray tubes, printed circuit boards |

| Chemicals | Electric and electronic waste |
|---|---|
| Iron | Microwave oven, LCD TV, printers, telephone, washing machine |
| Copper | Alloys, printed circuit boards, electrical and communication wirings |
| Zinc | Batteries, metal coatings, alloys, cathode ray tubes |

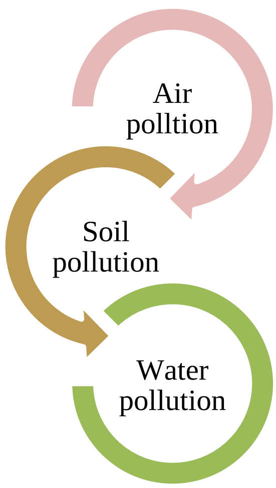
Note. Modified from Oguchi, M., Sakanakura, H., Terazono, A., 2013. Toxic metals in WEEE: characterization and substance flow analysis in waste treatment processes. Sci. Total Environ. 463–464, 1124–1132.

### 2.3 General Methodology of E-Waste Treatment and Associated Pollution Problems:

E-waste treatment causes release or emission of hazardous chemicals in aerial, aquatic or terrestrial systems which results in "correlated" contamination of air, water and land. Sometimes initial aerial emission of toxic chemicals causes air pollution, but settlement of these pollutants on surface soil and water bodies through dry and wet deposition causes water and soil pollution also. Similarly many pollutants from e-waste possess volatile to semi volatile nature and leaching tendencies.

Therefore release of toxic chemicals in soil initially causes soil pollution, but eventual vaporization or leaching of pollutants to ground water results in air and water pollution respectively. Moreover contaminated soil can widely translocated to other areas through winds, floods and by ground water transport which further intensify the contamination effects. (Moeckel et al., 2020). The general methodology of e-waste treatment and the associated pollution hazards is discussed here.

**Figure 2.1: Correlated air, water and soil pollution due to e-waste**



## a. Open burning and incineration:

Open burning of electronic and electric items is a common practice during informal e-waste treatment causing release of numerous toxic and carcinogenic chemicals. Burning of printed circuit boards, wires and cables in order to recover important metals results in severe contamination of air and soil by toxic heavy metals and organic pollutants (Zhou et al., 2013).

Plastic and polymer components of electronics are invariably associated with polychlorinated biphenyl and brominated flame retardants which on open burning causes heavy release of hazardous polychlorinated and polybrominated dibenzodioxins and dibenzofurans (Chen etal. 2012; Chan and Ming, 2013).

Incomplete combustion of e-waste results in emission of a large number of toxic persistent aromatic hydrocatrbons (PAHs) such as anthracene, chrysene, pyrene, naphthalene, fluoranthene, phenanthrene, benzo(a)anthracene, benzo(b)fluoranthene, acenaphthylene, benzo(a) pyrene and fluorine etc. In addition to air contamination, the soil samples near open burning sites of e-waste treatment areas also shows high concentration of persistent aromatic hydrocarbons (Moeckel et al., 2020).

Incineration is also most widely used thermo decomposition technique for electronic waste employing high temperature conditions in specially designed incineration chambers for complete combustion of waste materials along with subsequent release of ash, flue gas and heat. Incineration helps in significant reduction of volume of e-waste, utilization of generated heat for energy production and partial detoxification of hazardous chemicals, but generation of large amount of fly ash and bottom ash impose serious health risk though inhalation, dermal exposure and ingestion. Occurrence of various toxic heavy metals in fly ash in bio accessible forms is reported indicating toxic emissions through incineration (Tao et al., 2015).

## b. Landfilling:

Waste electric and electronic items are generally discarded in landfill sites on a large scale which leads to the problem of leaching and evaporation of hazardous chemicals (Ikhlayel, 2017). Landfilling causes formation of leachate i.e. liquid waste product containing diverse mixture of toxic chemicals which can percolate and cause severe contamination of soil and water resources (Li et al., 2009).

Leaching of dangerous chemicals such as Be, Cd, Co, Pb, Ni, Cr, Cu, B, Al and brominated flame retardants is reported due to disposal of e-waste through landfilling (Kiddee et al., 2013). Evaporation of volatile and semi volatile toxic chemicals from landfilling cause ambient air pollution in the surrounding areas (Lindberg et al., 2001).

## c. Dismantling, Shredding and Crushing:

Dismantling or disassembly includes manual or mechanical sorting of various part of discarded devices into valuable, reusable and waste items.

Several health risk and pollution problems are associated with these activities such as explosion of cathode ray tubes, accidental release of toxic chemicals, dermal exposures, spill of dangerous chemicals, inhalation of toxic fumes, burns and cuts (Tsydenova and Bengtsson, 2011). Breaking of cathode ray tubes, fluorescent tubes and de-soldering of printed circuit boards causes an exceptionally high release of toxic chemicals such as mercury, lead, barium, yttrium, cadmium, nickel, zinc, copper, antimony and sliver etc. (Bi et al., 2010; Lecler et al., 2015; Aucott et al., 2003; Zimmermann et al., 2014). High concentration of zinc, copper, arsenic, lead, cadmium and selenium is reported in surface soil and ground water near electronic recycling units (Pradhan and Kumar, 2014). Shredding of plastic materials of electronics causes ambient aerial emission of brominated flame retardants (Ceballos and Dong, 2016). Large particles released during crushing and shredding gets deposited on surface soil affecting soil aeration and functions (Zhang et al., 2012).

### d. Metallurgical Operations:

Metallurgical operations focuses on purification and refining of recovered metallic elements. Pyrometallurgical techniques employs incineration and smelting for obtaining target metals and results in emission of metal fumes, dioxins and other pollutants (Zhang et al., 2012; Priya and Hait, 2017). Hydrometallurgy involves dissolution and recovery of target metals by employing various acids, bases, halides, cyanides and thiosulphates and results in contamination of soil and water with used additives and heavy metals. (Zhang et al., 2012; Iannicelli-Zubiani etal., 2017). Acid leaching is the most common form of hydrometallurgy causes generation of acid waste and waste water which is normally discharged in open areas or in nearby streams causing contamination of soil, water and deep sediments. Lower pH causes increased solubility and phytoavailability of heavy metals which further intensifies the contamination risk (Quan et al., 2014).

## 2.4 Consequences of Soil Contamination:

Although soil has a natural capacity to store, degrade and detoxify a number of chemicals but extensive and unjudicial use of electronics and their subsequent treatment and disposal causes soil contamination, soil burdens, transportation of soil pollutants to different biological systems including human beings and numerous acute to chronic health hazards.

#### a. Altered Soil Composition:

The contamination of soil by e-waste alters its original composition and physical, chemical and biological properties which results in acidification, loss of soil organic matter, nutrient deficiency, desertification, salinization, loss of soil biodiversity and habitats (Cachada et al., 2018). A significantly lower pH and total organic count (TOM) is reported is soils contaminated due to e-waste recycling operations (Wu et al., 2015). The bio toxicity of a pollutant in the soil does not merely depend upon its concentration, in fact the physiochemical properties of soil greatly influence the bioavailability and potential mobility of pollutants (Tang et al., 2010).

Complex association of numerous microorganism in soil is associated with several key functions such as breakdown of organic matter, nutrient recycling, soil formation, and degradation of some pollutants. Significant alternation in variety, composition and function of soil microorganisms is reported in the highly polluted soils due to e-waste recycling (Liu et al., 2015).

## b. Soil Burdens:

Contamination of agricultural lands and vegetables with toxic metals is observed in vicinity of e-waste treatment sites (Lou et al., 2011). Critical level of heavy metals such as Pb, Cd, Ni, Cr and organic pollutants such as polychlorinated biphenyls and persistent aromatic hydrocarbons is reported in agricultural soils near e-waste recycling sites (Tang et al., 2010). Prersence of toxic polychlorinated dibenzo-p-dioxins and dibenzofurans is reported in contaminated soils of e-waste (Ma et al., 2008).

Relatively high concentration of brominated flame retardants (BFRs) such as polybrominated biphenyl ethers (PBDEs) and tetrabromobisphenol-A (TBBPA) and heavy metals like Hg, As, Pb, Cu, Zn, Ni, Cd is reported in sediments, soil and herb plants near e-waste dismantling sites (Wang et al., 2015).

## c. Transport Pathway of Soil Pollutants to Biological Systems:

Pollutant present in the soil can follow different routes such as leaching to the ground water, volatilization to atmosphere, degradation by chemical and microbial reactions within soil, conversion into less toxic form i.e. sequestration or assimilation in biological systems and food chains. Thus potential bio toxicity of a soil pollutant depends on many factors such as its bioavailability, uptake by living organisms and its metabolism, detoxification, excretion or accumulation in their bodies. (Cachada et al., 2018).

Plants grown in contaminated soil absorb toxic chemicals by their roots and transport and accumulate them in different tissues. Another plausible mechanism of toxin uptake by plants is direct foliar absorption from polluted atmosphere (Lou et al., 2011). Generally most of the toxic pollutants enters in different food chains through plants and shows bioaccumulation, bio amplification and enhanced bio toxicity at different tropic levels.

### d. Routes of Exposure in Human Beings:

The toxic chemicals from e-waste causes several health complications in human being through contaminated air, water and soil. Human exposure to the hazardous chemicals occur through inhalation, skin contact or dermal absorption and oral intake of contaminated water and food (Perkins et al., 2014).

Massive and critical exposure of populations mainly takes place through intake of contaminated plant products grown in polluted soil and water. Another potential route of indirect exposure is intake of contaminated animal food such as dairy products, poultry products and fishes (Lou et al., 2011; Moeckel et al., 2020).

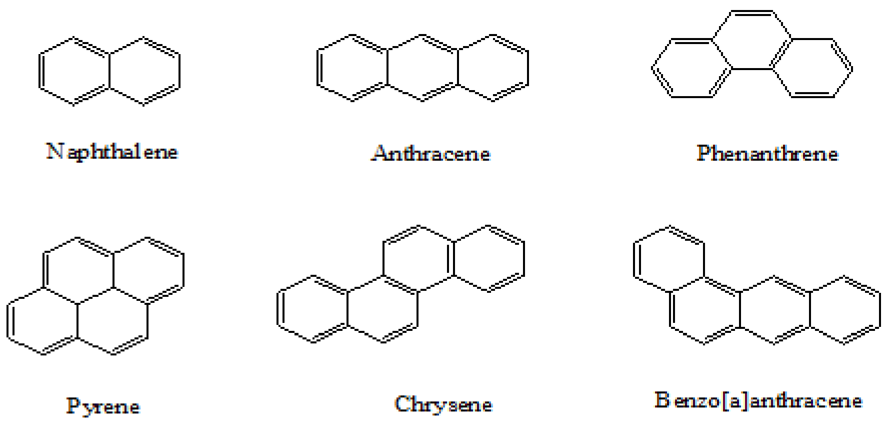
## 2.5 Chemical Toxicology of Dangerous Pollutants:

Chemical toxins of e-waste causes numerous health complications through genetic mutations, immune disorders, cellular malfunctioning's, enzyme inhibition, hormonal imbalance, damage to vital organs and systems, neonatal outcomes (Grant et al., 2013). Toxicology of some potentially hazardous pollutants from e-waste is discussed in this section in order to get a comprehensive idea about chemical hazards of e-waste.

### a. Polyaromatic Hydrocarbons:

Polyaromatic hydrocarbons (PAHs) represents a group of highly lipophilic aromatic compounds with longer half-lives, and are known to resist degradation. PAHs shows tendency to persist, bio accumulate and bio amplify in food chains and shows carcinogenic, mutagenic and teratogenic potential (Cachada et al., 2018). PAHs are known to cause a number of health hazards such as nausea, vomiting, breathing problems, skin allergies, diarrhoea, kidney damage, immune disorders and liver problems. (Abdel-Shafy and Mansour, 2016).

**Figure 2.2: Hazardous polyaromatic hydrocarbons**



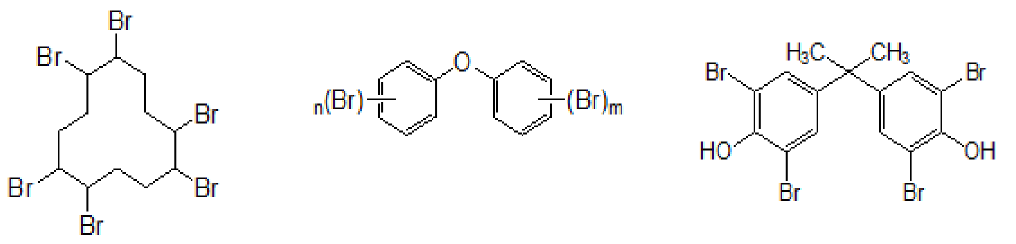

### b. Brominated Flame Retardants:

Brominated flame retardants (BFRs) are the bromoorganic compounds invariably added to plastic components of electronic and electric items to reduce their flammability. BFRs belongs to the group of persistent organic compounds and shows toxicity through bioaccumulation and bio persistence.

A number of different BFRs are present in e-waste such as hexabromocyclododecane (HBCD), polybrominated diphenyl ethers (PBDE), polybrominated biphenyls (PBBs), bisphenol-A ethers, and tetrabromobisphenol-A (TBBP-A) etc. (Wang et al., 2015).

BFRs can causes cancer, diabetes, malfunctioning of thyroid and estrogen, impaired memory and learning, reproductive disorders and abortions (Kim et al., 2014).

**Figure 2.3: Brominated flame retardants**



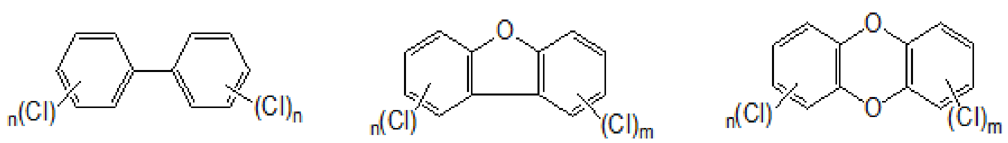

HBCD PBDEs TBBPA

**c. Polychlorinated Biphenyls and Dioxins:**

Polychlorinated biphenyls (PCBs), polychlorinated dibenzo dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) are extremely dangerous highly lipophilic group of chlorine containing organic compounds with marked tendency of persistence and bioaccumulation across food chains.

These polychlorinated pollutants are carcinogenic in nature and can cause mental retardation, neurobehavioral disorders, thyroid dysfunction, diabetes, immune disorders, endometriosis and developmental disorders (Arisawa et al., 2005).

**Figure 2.4: Polychlorinated biphenyls, dioxins and dibenzofurans**




PCBs PCDFs PCDDs

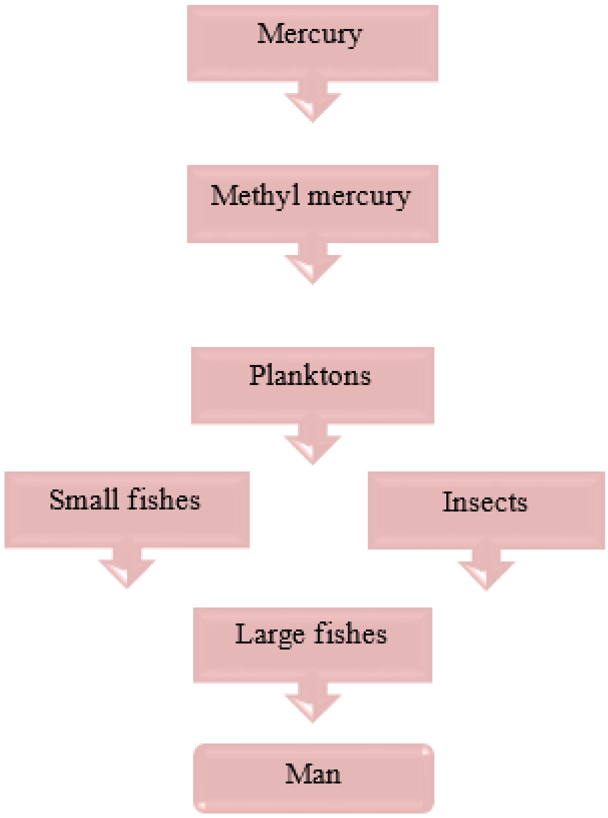
## d. Lead:

Lead shows several adverse health effects such as nervous disorders, anaemia, birth defects, sterility, cancer, high blood pressure, interference in metabolism of calcium and vitamin D, abortions and kidney malfunction. (Pinto, 2008; Goyer, 1993).

## e. Mercury:

Mercury is extremely toxic in nature and can cause convolutions, tremors, headaches, speech and visual impairments, cognitive and motor dysfunction, memory loss, insomnia, neuromuscular effects, mental retardation, behavioural disorders, genetic disorders and kidney damage (Rice et al., 2014). Extreme toxicity of mercury is reported in Japan as Minimata disease affecting thousands of people. Main cause of massive contamination was the bioaccumulation and bio amplification of toxic methyl mercury through food chains. Dietary intake of fishes contaminated with methyl mercury causes nervous and brain disorders, permanent paralysis, metabolic malfunctioning and genetic disorders (Kudo et al., 1991).

**Figure 2.5: Propagation of hazardous mercury in a food chain**




## f. Arsenic

Arsenic shows potent toxicity in humans and affects vital metabolic pathways. Pentavalent arsenic called arsenate shows resemblance with phosphate and interfere in ATP generation and energy production through citric acid cycle. Trivalent arsenic called arsenite is more toxic form of arsenic as it reacts with thiol and sulfhydryl group present in enzymes and proteins resulting in enzyme inhibition and metabolic disorders (Hughes, 2002). Arsenic can also cause nervous disorders, skin cancer, renal malfunction, diabetes mellitus, cardiovascular problems and liver damage (Singh et al., 2011).

### g. Cadmium:

Cadmium shows bioaccumulation in kidney, liver and bones and causes metabolic disorders, enzyme inhibition, DNA damage, birth defects, cancer, kidney, liver and bone deteriorations, lungs dysfunction and nervous disorders. (Rani et al., 2014; Perkins et al., 2014). Most severe cadmium poisoning is reported in Japan as itai-itai or brittle bone disease and is associated with painful symptoms of extremely fragile bones, joints weakening, kidney failure and skeletal deformations (Aoshima, 2016).

### h. Chromium:

Hexavalent chromium compounds shows high bio toxic potentials and can cause inhibition of respiratory enzymes, dermatitis, allergies, ulceration, perforation of nasal septum, kidney damage, lung cancer, bronchial asthma, liver and stomach disorders (Costa and Klein, 2006).

### i. Beryllium:

Toxic effects of beryllium are skin allergies, damage to mucous membrane, conjunctivitis, respiratory disorders, cancer, heart problems and fatal lung disease. Acute beryllium disorder caused by short term exposure results in severe cough, sore throat and pneumonia like symptoms. Berylliosis or chronic beryllium disease caused by prolonged exposure results in shortness of breath, inflammation of lungs, chest pain, heart disease and weight loss (Wambach and Laul, 2008).

### j. Antimony:

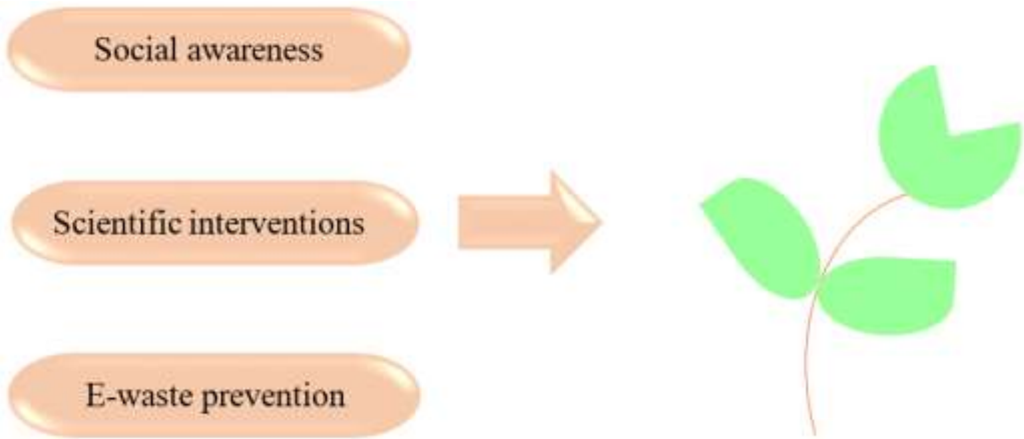
Antimony shows district toxicological profile and causes dermatitis in the form of pustules and eruptions called ‘antimony spots’. Antimony also causes diarrhoea, loss of appetite, muscle weakness, vomiting, chronic bronchitis, genetic defects, respiratory irritations, kidney damage, pneumoconiosis and myocardial degeneration (Sundar and Chakravarty, 2010).

## 2.6 Conclusion:

Generation of e-waste, its improper recycling and disposal has become an emerging environmental problem in today’s world endangering our natural resources, delicate ecological associations, biodiversity and human health.

Comprehensive and dedicated planning, monitoring and regulation of e-waste is urgently required particularly in poor and developing economies. In order to reduce the rate of e-waste generation, the prime focus should be on pollution prevention by enlightening social awareness against detrimental effects of e-waste on both abiotic and biotic systems. In parallel combination, high-tech and environmentally benign methods should be developed both for e-waste treatment as well as for environmental protection and remediation in order to protect our mother nature.

**Figure 2.6: Prevention of E-Waste for a Better Tomorrow**

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# 3. A Review on the Effects of Pernicious Arsenic Element and Its Phytoremediation

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**Abstracts:**

Arsenic (As), a group 15 elements of periodic table, is a heavy metal that becomes worldwide thread for the great arsenic pollution both in agricultural land and drinking water. The arsenic salts accumulates the soil particles that cause soil pollution and by heavy rain fall arsenic enter into ground water and contaminates it that ultimately cause a huge agricultural pollution by irrigating this contaminated ground water. This arsenic causes a lot of agricultural damage which can cause economic loss.

For the presence of arsenic plant growth and crop production are redacted and its main causes are uncontrolled industrialization, excess amount of coal burning and also some natural cause as volcano.

In this review it is trying to discuss the removal of arsenic by phytoremediation and it is processed by some plants as sunflower, date, palm, willow, poplar and a grass named vertiver. These plants can absorb both organic and inorganic form of arsenic by their roots and convert the toxic arsenic to non-toxic arsenic that is used their metabolism.

**Keywords:** Arsenic, Heavy metal, Microbiology, Botany, Soil biology, Pollution.

## 3.1 Introduction:

Arsenic is one of the most effective and pollution causing heavy metals that has become a matter of great concern to the people in mainly agricultural field because of its fatality to both crops and human health. Arsenic is a natural contaminant and it can enter in the agricultural fields by irrigating ground water that in many cases acts as a natural source of arsenic. In the ground water arsenic is present as a dissolved salt form. The presence of high concentration arsenic in the ground water is normally connected with the geothermal environment of volcanic deposits, geothermal systems and basin fill deposits alluvial lacustrine origin.

In ground water arsenic comes from the oxidative or reductive products of iron oxides or sulphides and organic matters and present as dissolved form as arsenates or arsenites. Another source of arsenic in agricultural fields is pesticides because in pesticides arsenic is used to protect plant from rotten and decay and also as weed killer. But now the arsenic became a great concern for the cause of effective in crop production and death of plants.

**Fig 3.1: Arsenic (As)**

**Fig 3.2: Arsenic affected rice**

## 3.2 Sources:

There are many sources of arsenic in nature that’s why it is abundantly found in agricultural lands. Many natural incidences can produces arsenic volcanoes, weathering of rocks, natural oxidation, reduction of metal ions and etc.

But uncontrolled industrialization and use of huge amount of chemical fertilizers and pesticides play the major role in arsenic consumption in land. Besides this huge amount of coal burning, mining can produces a lots of arsenic as their byproduct primarily in the atmosphere arsenic spread out as arsenic trioxide, then it binds onto the surface of any particles which are scattered into the ground water level by rain fall and the ground water became arsenic contaminated.

The three most effective arsenic bio-transformative ways are redox transformation between arsenic and arsenate, the reduction and methylation of arsenic and bio-synthesis of organo arsenic compounds. Both natural and artificial sources of arsenic high up the arsenic level in soil from normal to extreme level that causes severe plant damages and degradation in crop production.

## 3.3 Characteristics of Arsenic:

Arsenic is one of the 20th most plentiful minerals in the Earth's count and it also the position holder among the 12th most abundant minerals in human body. In all of the natural media it is found in low concentration.

### a. Physical Characteristics:

The three allotropes of arsenic those are most common are grey, yellow and black arsenic among which grey is the most common. Normally arsenic is formed in two oxidation states the trivalent state arsenic (III) and the pentavalent state arsenic (v). Besides this arsenic is also present in 3 states in arsenides which are alloy like intermettalic compounds. Grey arsenic is a semimetal but can be converted into semiconductor. The density of gray arsenic is 5.73g/cm3.

### b. Chemical Characteristics:

Arsenic can for content molecules by binding with non-meals. Arsenic is stable in dry air but it can produce a golden-bronze tarnish upon exposure to humidity that in the end becomes a black surface layer, and arsenic get heated in atmosphere, oxidation occurs and produced arsenic trioxide. Arsenic react with metals to form arsenides and however it does not react with water, alkalis and non-oxidizing acids.

### c. Toxicity:

The toxic effect of various forms of arsenic depends on their oxidative states and chemical structures. When the inorganic forms of arsenic, presenting in soil is taken up and transported through the food chain it turned out to be toxic. The oxidation state as (v) is less toxic than As (III) and mostly present in immobile mineral forms, where As (III) form gets mobilized into water and enter living cells. Normally plants contains low level of As ($<$3.6mg/kg). High concentration of arsenic can cause toxic effect in plant and results inhibition of seed germination, decrease in plant growth, decrease in crop productivity and etc. For its high toxic effect arsenic is also called 'The King of Poison'.

## 3.4 Forms of Arsenic in Soil:

In the soil arsenic is found in both organic and inorganic forms where in it inorganic forms are present as mineral. Arsenic posses about 300 inorganic minerals including arsenates, sulphides, sulfosalts, arsenates etc.

These inorganic forms of arsenic gets methylated at the time of entering into food chain and produce less toxic organic forms as mono-methylarsine (MMA), dimethylearsine (DMA) and trymethylarsine (TMA).

## 3.5 Effects on Plant and Crops:

### a. Effect on Plant Growth:

Presence of Arsenic in agricultural fields can make many disturbances in plant metabolism, plant growth and crop productivity. Presence of high conc. of arsenic reduces the root length, sooth length, and number of leaves, leaf area and dry mass of plant. It hampers the bio-chemical and metabolic process of plant which ultimately causes death of plant.

### b. Effect or Photosynthesis:

Arsenic causes negative effect or photosynthetic apparatus. It occurs severe injuries in membrane of chloroplast and destroys the fundamental photosynthetic process. Besides this arsenic can retreat the fixation of CO2 and Ps-II functions.

Besides this contamination of arsenic results in interaction of functional groups of enzymes, plants water status, replacements of essential ions, reduction of the level of essential amino acids those ultimately cause in lower fruit production, wilting, curling and necrosis of leaf blades.

### c. Phytoremediation:

Heavy metals as arsenic cannot be destroyed but can be transformed from their one oxidation state to another. These are various plants that can act as hyper accumulator of arsenic such as alfalfa, sunflower, willows, poplars and several types of grasses.

It is reported that the mine soil which is an abundantly accumulator of arsenic, can also be cleaned up by phyremediation. These plants take up arsenic through their roots by active and passive transport and converted it to nontoxic organic matter that is used in their metabolism. These plants are low in cost and also available. So they can be easily used for phytoremediation.

Besides this there are also some microorganisms such as Pseudomonas putida, Methylibiumpetroleiphilum can synthesize siderophores that act as washing agent of arsenic. These microbes able to remove upto 92.8% of arsenic from contaminated soil after five washes.

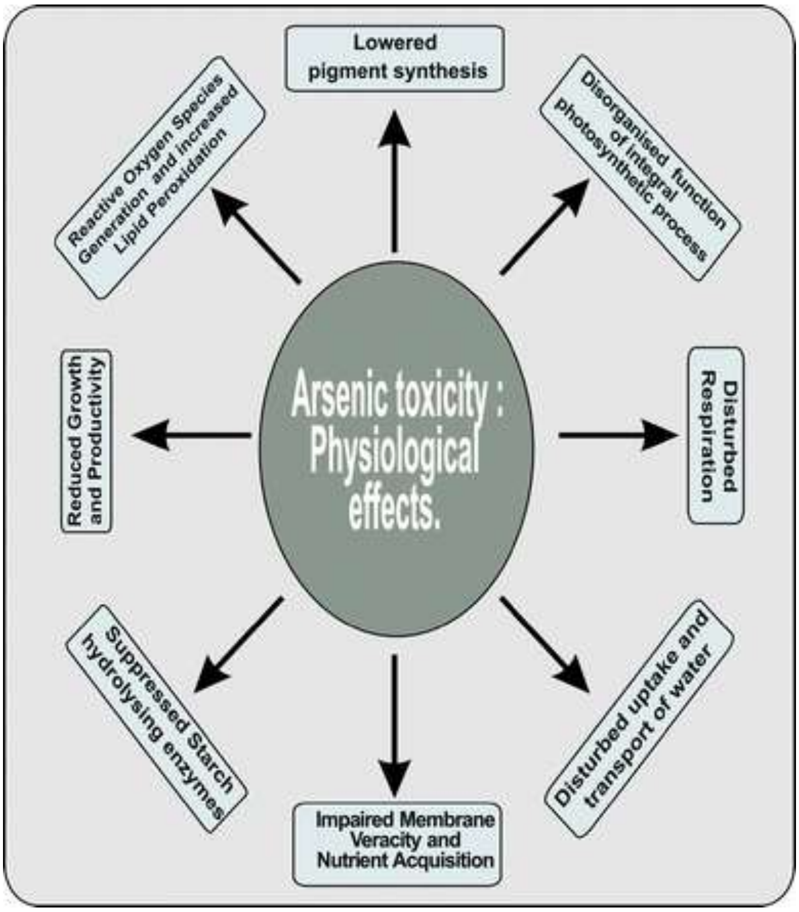


**Fig 3.3: Effect of arsenic on plants**

**Fig 3.4: Effect of arsenic poisoning in the rice**

**Fig 3.5: Arsenic affected decay in rice plants**

## 3.6 Conclusion:

Arsenic is one of the toxic chemical elements present in soil in both inorganic and organic form. It is worstly impact of environment, causes soil pollution, effect on human health. Arsenic is reacts with other soil element, result poor growth of agricultural crop. It is a heavy metal has high risk to contaminate groundwater. The toxicity of arsenic is depends on its oxidative state and chemical structure. There are few eco-friendly and easy approaches to detoxify arsenic contaminated soil and water. Phytoremediation, a process in which several plants like willow, poplar, alfalfa, sunflower, corn, date and several grasses can detoxify arsenic. These plants can accumulate arsenic like heavy metal and absorb it from environment. So, we can this simple and easily affordable process to improve soil quality and cleaning up our environment. Pollution free life is healthy and wealthy life.

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In the areas with long history of use of arsenic elevated groundwater for irrigation in winter, the Agricultural lands have been affected severely with arsenic, up to 54 mg/kg.
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# 4. Present Scenario of Bio fertilizer Use in Agriculture and Aquaculture

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## 4.1 Introduction:

India is regarded as one of the world's 12 mega-biodiversity countries. The population in India and the World is increasing day by day. It puts pressure on the agricultural lands and other resources to fulfil the need for food of this enormous population. In the case of Asia, it has been estimated that each 1% increment in crop productivity leads to a 0.48% reduction in the number of poor people (Thirtle *et al*., 2003); while, in India, 1% rise in agricultural value-added per hectare Poverty decreases by 0.4 percent in the short run and by 1.9 percent in the long run as a result of the indirect effects of lower food prices and higher wages. (Ravallion and Datt, 1996). Soils are losing calcium contents, and hence its biodiversity is critically affected.

As a result, the most difficult issue at the moment is increasing food production from rapidly shrinking per-capita agricultural land. (Bhattacharyya, 2009; Mazid and Khan, 2014). Despite the fact that India's production was remarkably high during the Green Revolution, poverty persists because it was concentrated primarily in favorable areas. To make agriculture sustainable, a well-balanced and reasonable use of nutrients that is both cost-effective and environmentally friendly must be implemented. Venkataraman and Shanmugasundaram, 1992; Mahdi et al., 2010); in that case, bio fertilizer could be a better option (Pindi and Satya Narayana, 2012; Borkar, 2015). Now, the Government of India has also taken a stride to harness the full potential of the available bio fertilizers by introducing them along with chemical fertilizers to the farmers (Ghosh, 2004).

Visualizing the economic burden and environmental cost of applying this considerable quantity of additional fertilizers, which can be met from biological sources like bio fertilizers, will significantly impact.

## 4.2 Bio fertilizer:

The term 'bio fertilizer,' also known as ‘micro inoculants' (Arora et al., 2010), was derived from a contraction of the term 'biological fertilizer,' with biological denoting the use of living organisms, that colonize in the rhizosphere, accompanying the interior of the plant and stimulating growth and enhance mineral nutrient accessibility and uptake by the host plant. (Vessey, 2003; Malusa *et al*., 2012; Malusa and Vassilev, 2014). It denotes all nutrient inputs and plant growth that are of biological origin that can improve soil fertility and crop productivity. They are known to not only improve yields and produce quality but also improve nutrient use efficiency. The use of cheap and eco-friendly inputs like bio fertilizers is vital for India, where most of the farming will continue to be in the hands of small farmers.

Nobbe and Hiltner performed the first trials on bio fertilizers on Rhizobia in 1895 and cultured 'Nitragin' in the laboratory. In India, N.V.Joshi, 1956 was the first to study legume 'Rhizobium'. Under the Ninth Year Plan, the Ministry of Agriculture initiated the actual effort to popularize and promote the input by setting up the National Project on Development and Use of Bio fertilizers (NPDB).

## 4.3 Nutrient Deficiency in Soil:

Roots primarily absorb the nutrients present in the aqueous environment. Besides Nitrogen, Phosphorus, Potassium (NPK); Sulphur, Zinc and Calcium are also required in reasonable quantities. Whereas other nutrients such as Iron, Boron etc. though needed in small amounts, their deficiency significantly impacts plant growth and life. Micronutrient deficiency due to Zn, Boron, Iron and Sulphur in soils is increasing day by day in India. Hence by application of secondary and micronutrients along with NPK nutrients can increase significant yields of production.

Role of Bio fertilizers:

a. Increase crop yield by 20-30%.
b. Replace chemicals nitrogen and phosphorus by 25 %.
c. Stimulate plant growth.
d. Activate soil biologically.
e. Restore natural fertility.
f. Provide protection against drought and some soil-borne diseases.

Method of Application of Bio fertilizers:

**1. Seed treatment:** Take both 200 gm of N bio fertilizer and Phosphoric in 300-400 ml of water and wait until mixed thoroughly. Finally, Mix this paste with 10 kg seeds & dry it in the shade. Sow immediately.

**2. Seedling root dip:** For vegetables, 1 kg each of two bio fertilizers mixed in water. Dip the roots of desired seedlings in this suspension for 30-40 min before transplanting. Whereas For paddy, make a bed in the field and fill it with water. Mix biofertilisers in water and dip the roots of seedlings for 8-10 hrs.

**3. Soil treatment:** Mix 4 kg each of biofertilisers in 200 kg of compost and leave it overnight. Apply this mixture to the soil at the time of sowing or planting. In plantation crops, apply this mixture near the root zone and cover it with soil.

Precautions while usage:

- Store bio fertilizer packets in a cool and dry place away from direct sunlight and heat.
- Use the right combination of biofertilisers.
- Rhizobium is crop-specific, so used in the specified crop.
- Do not mix with chemicals.
- While purchasing, ensure that each packet is provided with necessary information like name of the product, name of the crop for which intended, name and address of the manufacturer, date of manufacture, date of expiry, batch No and instructions for use.
- Use the packet before expiry, only on the specified crop, by the recommended method.

## 4.4 Bio Fertilizers Consumption in India:

Till 1997-98 strong correlation was found between fertilizer consumption and food grains production, which distorted this relationship. Most states are experiencing an increase in fertilizer consumption with a slower pace of crop productivity. Some states witness consumption of fertilizer picking up without any conspicuous gain on agricultural crop productivity.

The following types of microorganisms as bio fertilizers are available to the farmers in India:

- Nitrogen fixer, e.g. Rhizobium, Brady rhizobium, Azospirillum, Azotobacter, Acetobacter, Azolla and BGA.
- Phosphorus solubilizer, e.g. Bacillus, Pseudomonas and Aspergillus.
- Phosphate mobilizer, e.g. VA-mycorrhiza (VAM) like Glomus.
- K-solubilizer, e.g. Frateuria aurantia.
- Silicate solubilizer, e.g. Thiobacillus thiooxidans.
- Plant growth-promoting bio fertilizers, e.g. Pseudomonas sp. (Muraleedharan, 2010; Mishra and Arora, 2016).

Negative Impacts of Fertilizers:

**a. Availability and cost:**

- Demand is much higher than availability. It is estimated that by 2020, to achieve the targeted production of 321 million tonnes of food grain, the nutrient requirement will be 28.8 million tonnes, while their availability will be only 21.6 million tonnes being a deficit of about 7.2 million tones.

- Increasing costs are getting unaffordable for both small and marginal farmers.

**b. Effect of Chemical fertilizers in soil and environment:**

- Excessive and imbalanced use of inorganic fertilizers harms the soil causing a decrease in organic carbon, reduction in the microbial flora of soil, increasing acidity and alkalinity and hardening of soil, and reduction in species diversity.
- Excessive use of N-fertilizer is contaminating water bodies, thus affecting fish fauna and causing health hazards for human beings and animals.
- The production of chemical fertilizers adds to the pollution.

## 4.5 Present Scenario of Bio Fertilizers in India:

Despite the multiple advantages of bio fertilizers in agricultural production, several constraints at different levels, i.e. from the production unit to farmers' field, make it less prevalent in India. Now, the government of India is boosting the bio fertilizer industries by providing subsidies to a maximum of 20 lakh rupees and awarding a national productivity award to the efficient bio fertilizer production unit (Borkar, 2015). Agro Industries Corporation has the maximum production capacity, followed by State Agriculture Departments, National Bio fertilizers Development Centers, State Agricultural universities and private sectors (Pindi and Satya Narayana, 2012).

Generally, the activity of microorganisms are location and crop-specific so, strains selected for particular areas as well as crops should have good adaptability for this specific location and some qualities like competitive ability over other strains for nodulation of the host, N-fixing ability, potentiality to colonize and survive in adverse physical conditions (Panda, 2013). Some bio fertilizer production units do not have sufficient technically well-qualified microbiologists or skilled persons who can make available high-quality biofertilisers rather depend on more non-skilled labors working on a contract basis that leads to substandard bio fertilizers (Mahdi et al., 2010; Mathur et al., 2010; Motghare and Gauraha, 2012). In addition, the non-availability of good quality peat in India has also headed to the development of alternative carriers like lignite, charcoal, etc., which are mainly used unsterilized (Borkar, 2015; Panda, 2013). Most studies suggest that biofertilizers sold in markets are contaminated and have a low count of microorganisms. Generally, producers do not pay attention to the host-specific strains, and as a result, biofertilizers cannot express their potentiality (Mazid and Khan, 2014; Motghare and Gauraha, 2012).

Indian Standard Institute (ISI) specifications are recently available only for Rhizobium and Azotobacter; Azospirillum and phosphobacteria have been formulated. There is no regulatory action for the production of biofertilizers (Mazid and Khan, 2014).

## 4.6 Biofertilizers in Agriculture Vs Aquaculture:

Along with the increase in productivity, an eco-friendly, sustainable approach to agricultural practices is becoming increasingly necessary.

Excessive use of inorganic fertilizers is unsustainable or harmful for any farming practice from economic and ecological points of view has led to the use of various kinds of manure and, till recently, biofertilizers for fixing nitrogen solubilizing phosphates and decomposing/recycling carbon. Biofertilizers are live microbial cells such as cyanobacteria, nitrogen-fixing bacteria (such as Rhizobium, Azotobacter, and Azospirillum etc.) and phosphate-solubilizing bacteria (such as Bacillus etc.). These are positively active in enriching the ecological niche in which they are found with macro-nutrients like nitrogen and phosphorus, reorienting the in situ microbial ecology for human economic benefit. However, unlike agriculture, aquaculture practices call for a bio fertilizer with a conceptual difference.

Agriculture and the production of food by a man during civilization were probably the first human interventions that resulted in various specialized branches of food production. Aquaculture has emerged as one of the essential branches of food production. Sustained and enhanced productivity are the primary goals of aquaculture. Diseases have become an integral part of intensive aquaculture necessitating the use of chemicals, drugs, and antibiotics in health management. Although these measures produced enhanced productivity, continual use of chemicals and fertilizers are known to have deleterious effects on the environment and sustained productivity (World Health Organization antimicrobial resistance fact sheet 194, http://www.who.int/inf-fs/en/fact194.html). Biofertilizers (microbial interventions) were initiated to make aquatic production more sustainable and disease management measures more environmentally friendly. In aquaculture, this may be achieved by maintaining balanced populations of bacteria and using defined probiotics in several ways, such as enrichment of larval food, inclusion in the diet, or addition to the water, as a remediation agent. The use of antibiotics disturbs the microbiological balance of gut flora, eliminating most of the beneficial flora. The use of antibiotics is discouraged as it has led to drug-resistant bacteria, immune suppression in animals, harmful effects on the environment and concerns on food safety.

Moreover, aqua cultural products are sometimes banned due to the rejection of export consignments. Hence, the usage of probiotics is propagated to counter the effect of viral and bacterial infections in commercial aquaculture. It is reported that fish ingest only 20–30% antibiotics, and the remaining reaches the environment. Even the antibiotics ingested by aquatic animals may be excreted as such or as metabolites, harming animals and human consumers. Pathogens such as Vibrio's and Aeromonads can develop resistance to antibiotics very quickly. So there is a need for an alternative health management strategy, which biofertilizers can accomplish. Charcoal-immobilized Azotobacter is recommendable as an aqua-bio fertilizer of better performance in low cost, eco-friendly, and sustainable aquaculture practice. However, the concept of biofertilizers in an aquatic system must be broad-based to ensure a tangible result/success.

It must be delivered for practice not simply as a technology but as a technology package. The organisms must serve as biofertilizers, detritus processors, fish food organisms, etc., ensuring a more substantial trophic base.

Such microorganisms, upon extended efforts, could also be supplementing as bioremediation/ bioaugmentors/bio ameliorators, bio filters, which is a single term that could be defined as probiotics.

## 4.7 Conclusion:

Biofertilizers, essential components of organic farming, play a vital role in maintaining long-term soil fertility and sustainability by fixing atmospheric di-nitrogen and mobilizing fixed macro and micronutrients in the soil into forms available to plants. Currently, there is a gap of ten million tons of plant nutrients between the removal of crops and supply through chemical fertilizers. In the context of both the cost and environmental impact of chemical fertilizers, excessive reliance on chemical fertilizers is not practicable in the long run because of the cost, both in domestic resources and foreign exchange involved in setting up fertilizer plants and sustaining the production. In this context, biofertilizers would be the viable option for farmers to increase productivity per unit area.

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# 5. Application of Vermitechnology in Agriculture and Aquaculture

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## 5.1 Introduction:

Now a day's agriculture is distinguished by excessive use of inorganic fertilisers, herbicides and pesticides, and insufficient use of organic fertilisers (Li et al. 2007; Gill and Garg. 2014).

As well as to increase crop production, excessive use of inorganic fertilisers was practised widely worldwide. This chemical farming will affect both terrestrial and aquatic compartments. To address such issues, urgent action is required to maintain agriculture production to feed the human should be produced sustainably.

Animal manure is a beneficial soil fertiliser because it contains a high concentration of macro-and micronutrients for crop growth and is a low-cost, ecologically acceptable alternative to mineral fertilisers. The non-thermophilic biodegradation of organic materials accomplishes vermicomposting by earthworms and microorganisms.

Earthworm plays a primary role in the process of vermicomposting. But actual decomposition of organic matter accomplishes by the microorganisms. Firstly, earthworms act on the organic matter; it consumes organic waste it generates fragmented matter, by the action of beneficial microorganisms, numerous enzymes such as cellulase, amylase, lipase, protease, urease and chitinase and finally excreted in the form of “casts” (Munnoli et al. 2010; Dominguez and Edwards 2004), next step is maturation like a phase in which microbes degrade earthworm-processed materials.

Earthworm secretes the substance known as a coelomic fluid into the organic waste, which is helpful to destroy the pathogenic microorganisms such as Salmonella, Serratia marcesens and Escherichia coli and enhance the growth of plants (Prabha 2009).

Nutrients move from one system component to another system by the typical process called biodegradation. It is enhanced by the earthworm, releases macronutrients, and available phosphorus is more accessible to plants.

Vermicompost has been shown to have a positive effect on a wide variety of crops such as ornamental plants; a medicinal plant, forestry species promoted seed germination, helps in root growth, and stimulates flowering and fruit yield. In addition to this, several studies of previous research stated that vermicompost had a positive role in aquaculture.

## 5.2 Earthworm Distribution:

Earthworms have a significant role in soil health profile both in temperate and tropical countries, and this is commonly regarded as intestine of earth, farmer’s friends and natural ploughmen, by this way it impacts on the physical (soil texture, porosity and resistivity), chemical (Cation exchange capacity and buffering capacity) and biological properties of soil (Singh et al., 2016a).

Abiotic factor (pH, moisture, soil texture and organic carbon) affects the distribution of earthworm species in different region of habitat in the soil. It showed a positive correlation between abiotic factors *vs* earthworm distribution, mostly this prefer to show higher diversity near to both gardens and nurseries (consists of high organic matter) compared to the chemical farming area (Singh et al., 2016b), besides it also depends on the different array of food source available and reproduction potential of species.

Earthworms are classified into three types based on ecological life form a)epigeics, b)anecics, c)endogeics

Epigeics exhibit higher respiration capacity, maturation, fecundity, mobility, and a smaller body than other earthworms (anecics and endogeics).

Endogeics are larger than epigeics, pigmentation usually absent, higher burrowing capacity; they show strong sensitivity to light, and primarily they are associated with organic matter.

Aneceics are anterior- dorsally pigmented, medium reproductive rate, hooked chetae. They are phytogeophagous worms, live in strongly developed vertical burrows.

**Table: 1 Classification of Earthworms**

| **Epigeics** | **Endogeics** | **Aneceics** |
|---|---|---|
| *Eisenia foetida* | *Aporrectodea caliginosa* | *Lumbricus terrestris* |
| *Lumbricus rubellus,* | *A. trapezoids* | *L. polyphemus* |
| *L. castaneus* | *A. rosea* | *Aporrectodea longa* |
| *L. festivus* | *Millsonia anomala* | *L.mauritii* |
| *Eiseniella tetraedra* | *Octolasion cyaneum* | *D. willsi* |
| *Dendrodrilus rubidus* | *O. lacteum* | |
| *D. octaedra* | *Pontoscolex corethrurus* | |

**Table: 2 Raw Materials and Earthworm Species Used in Vermicomposting (From Gupta et al., 2019)**

| Bagasse | *Eisenia foetida* |
|---|---|
| Banana | *Eudrilus eugeniae,* |
| wastewater of a palm oil mill | *Eudrilus eugeniae* |
| Domestic waste + cow-dung | *Perionyx excavates, Perionyx sansibaricus* |
| Cattle manure | *Eudrilus eugeniae* |
| Wooden or plastic | *Eisenia foetida, Eudrilus eugeniae, Perionyx excavates* |
| Vegetable waste + floral waste | *Eudrilus eugeniae, Eisenia foetida, Perionyx excavates* |

## 5.2.1 Benefit of Vermicompost in Agriculture:

Dominant crops such as cereals and root vegetables are considered leading crops, routinely taken as higher amounts beside it supply good fraction nutrients, high-calorie content, and energy. Wheat, Rice (*Oryza sativa L.*) and maize are the chief cultivated crops (staple crops), combined supply nearly 42% of calories to human population consumption.

Split treatment of vermicompost prepared from six mixed organic waste inoculated with earthworms (*Eisenia fetida*) and applied to rice at a different stage of crop growth resulted in higher yield characteristics such as panicles (294 m2), full grains per panicle (138), total spikelets per panicle (142) and grain yield (3.91 t ha-1) ( Bejbaruah et al., 2013).

Bread wheat (*Triticum aestivum L.*) contributes to nearly 30% of overall cereal production and more than 50% of total human calorie consumption (FAOSTAT, 2015). In another experiment, a combination of deep tillage system and vermicompost made up of various crop organic waste (rice, cotton and maize straw) biodegraded by using the worms (*Eisenia fetida* and *Dendrobaena veneta*) applied to wheat crop in both seasons showed higher grain yield (kg ha− 1) Biomass yield (kg ha-1) compared to chemical amendment (sulfuric acid and gypsum) and control (Ding et al., 2021).

A research carried out in eastern China, an area mainly undergoes temperate, and monsoon climate, two different types of compost were taken to know the efficiency of vermicompost. Organic matter and nitrogen, available phosphorous, and potassium quantity showed higher in the cattle manure-vermicompost (added with Eisenia fetida)-maize system (VC system) than the traditional type of compost made of cow dung. During the breakdown of the organic compounds, pH significantly decreased, especially vermicomposting compost. In this system, maize absorbed a greater nutrient, ultimately increasing the yield in dry matter of total above-ground biomass and maize grain by 7.7% and 18.3%, respectively (L. Guo et al., 2015). Similarly, waste generated in aquaculture is mainly of aquaculture sludge or soil waste generated from aquaculture. It comprises uneaten feed settle on the bottom of the pond and becomes sludge, harming aquatic species. This nitrogenous organic waste is converted into valuable fertiliser by the vermitechnology process. This vermicompost is used in the agriculture field as fertiliser, which promotes the growth of crops (Birch et al., 2010).

### 5.2.2 Benefit of Vermicompost in Aquaculture:

Several studies reported that vermicompost could be utilised in an aquaculture farm differently.

Application of vermicompost to aquaculture pond as fertiliser showed the higher population of both Phytoplankton (3,034 L-1), Zooplankton (780 L-1) production compared to other inorganic fertiliser (Single superphosphate and Mixed fertiliser). Vermicompost may contribute higher nutrient content, enhance the plankton production, which eventually increases the fish yield of *Oreochromis mossambicus* (Cichlidae) (4,000.00 kg ha-1 90 days) as well as increases the overall productivity of the pond (Chakrabarty et al., 2010). Similar to that seen by (Chakrabarty et al., 2009), who noticed that the application of vermicompost might be contributed to increasing the phytoplankton population (2,759 nos l-1) and fish yield (3,970.56 kg ha-190 day-1) than diammonium phosphate and compost without earthworm. Vermicompost (prepared from cow dung) applied to fish pond as manure at the rate of 15,000 kg/ha/year contributed the better water quality parameters (mainly, Dissolved oxygen), Zooplankton population, enhanced fish yield/tank and Specific growth rate of Common carp, *Cyprinus carpio* compared to semi-digested cow dung (Kaur, V. I. and Ansal, M. D. (2010). The pond fertilised using vermicompost @10000kg/ha/yr revealed the most growth of *Catla catla* in weight gain, length gain, and growth increment (Kaur J and Gupta, 2016).

Organic acids, such as liquid vermicompost can assist shrimp farming by improving growth, feed utilisation, gastrointestinal health, and disease resistance in aquatic animals (Ng WK and Koh CB YC, 2017).

Notably, application of vermicompost @ 10,000 kg/ha/yr and 15,000 kg/ha/yr in fish rearing pond of two different treatments revealed that the absence of bacteria such as *E. aerogens, P. fluorescens, P. aeruginosa, Shigella sp., K. oxytoca,* and *Streptococcus sp*. were all found to be negative, both treatments showed a higher growth rate of Indian major carps in rearing ponds (Kumar, S., and Godara, S., 2019). Vermicomposting is recommended as a safe and long-term method of converting sludge from aquaculture into extremely valuable vermicompost and earthworm biomass. Stabilized vermicompost produced from sludge can be utilised in agriculture farming systems. Earthworms, high in protein, have been advocated as a feed for livestock, including fish (A. Kouba et al.,2017).

## 5.3 Conclusion:

Inorganic farming harms the ecosystem; it has altered microbial communities in the soil and decreased soil fertility. Alternatively, organic farming leads to less stress on the soil and water compartment. Vermicompost increased soil fertility, supported plant growth, a significant role in pest control, arthropod suppression, nematode control, and it has better management in medical waste and sewage water treatment. In addition, vermicompost plays a significant role in aquaculture; directly (Fish feed) or indirectly improves phytoplankton production, ultimately increasing the fish yield.

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