



ISSN : 3108-2017(Online)
3108-1304(Print)

Vol.-2; Issue- (Jan.-March) 2026

Page No.- 15-37

©2026 IJSTE

<https://ijste.gyanvividha.com>

Author's :

1. Dushyant Kumar

Research Scholar, School of Applied Sciences, Suresh Gyan Vihar University, Jaipur, Rajasthan, India.

2. Aashi Thakur

IBDP Student At Genesis Global School, Noida.

3. Dr. Roshan Sharma

Assistant Professor, School of Applied Science, Suresh Gyan Vihar University Jaipur, Rajasthan India.

Corresponding Author :

Dr. Roshan Sharma

Assistant Professor, School of Applied Science, Suresh Gyan Vihar University Jaipur, Rajasthan India.

Effect of detergent-derived anionic cations on *Pheretima sp.* density, cast production, and vermicomposting efficiency

Abstract : Enhanced crop production among one of the most important worldwide needs in recent and in future. This relates to crop production and opens doors for improving the fertility of the soil. Vermicomposting is a method where using action of tiny worms it become possible to recycle the nutrients in the soil via sustainable manner. Various factors may impact on tiny worm's efficiency to make vermicompost. This review is inspired from such studies where detergents in household wastewater may affect the effectiveness of those tiny earthworms in their cast production and on their efficiency to make vermicompost. Not only biochemistry or physiology but ecological alteration may also be caused due to using household wastewater rich the lineal anionic and cationic detergents. Soil quality has also assessed. Impact of toxicity of detergents on earthworms has been included. Integration of bet, pit & heap methods used to culture earthworms. Novelty of this study is to fill the learning gaps in the study of impact of the toxicity of the detergents on earthworms and their vermicomposting efficiency.

Key words : Earthworms, Vermicomposting, Quadrate method, Sustainability, Waste water, Lineal anionic cations, Toxicity.

1. INTRODUCTION :

Vermicomposting is the solid-phase aerobic decomposition of organic residues that utilizes earth-worms and microorganisms. The ultimate product, vermicompost, is produced by oxidating and stabilizing organic waste. It is high in vitamins, growth hormones, enzymes, macro and micronutrients, and immobilized microorganisms^[1]. Earthworms are crucial to the process of breaking up and getting ready the substrate as well as altering biological activity. They are

mechanical mixers that break organic matter into small pieces, reducing its Carbon Nitrogen ratio, increasing the area of contact for micro-organisms to act upon, and making it more favorable for microbial activity and further decomposition^[2]. Vermicompost, the most beneficial by-product, has the best porosity, water-holding capacity, and plant-available nutrition supply. Consequently, this technique has versatility in processing numerous different types of wastes like sewage sludge, animal and food waste, and horticulture residues with urban refuse. By utilization of three consecutive phases or steps such as pre-composting, mesophilic, and maturing and stabilization vermicomposting effectively processes a vast spectrum of organic wastes into beneficial composts endowed with rich nutritional value(A. Singh, Karmegam, et al., 2020a). Numerous wastes have been successfully treated by the process, including sewage sludge and other solids obtained during the wastewater procedure, paper, brewery materials, urban residues, food and animal wastes, and horticultural residues from processed potatoes, dead plants, and mushroom industry residues^[4]. Figure 1 shows the vermicompost.

Vermicomposting is an organic process involving the effective decomposition of organic wastes by earthworms^[5]. By using this process, waste reduction is enhanced; soil fertility is improved, and environmental health is promoted^[6]. Earthworms decompose organic wastes like kitchen wastes and agricultural wastes, whereby they transform the materials into nutrient-rich humus that improve soil structure, water retention, and aeration^[7]. Rich in potassium (K), phosphate, and nitrogen (N), organic compost encourages healthy plant development without the need for artificial fertilizers. Vermicomposting lowers greenhouse gas emissions, trash disposal, and landfill waste. It is available to homes, farms, and businesses on small and big scales, and it speeds up the rates of decomposition^[8]. It not only enhances agricultural productivity but also supports the recycling of organic waste, thus playing a crucial role in promoting environmental sustainability and reducing pollution. Detergents are substances that are added to many household and industrial cleaning products. Once detergents are washed out, they enter into waste systems and finally end up in rivers, lakes, and oceans. Some detergents contain phosphates; once they leave the aquatic environment, they can create a problem for nutrient pollution. Overabsorption of phosphorus (P) in the water consequently enhances the high growth of algae, which forms algal blooms that use up oxygen within the water, leading to dead zones where aquatic life cannot be sustained^[9]. Besides this, other detergents carry surfactants and synthetic chemicals that are toxic to aquatic organisms, and they cause disruptions in the ecosystem and harm the fish and other wildlife in the area. The chemical composition and microbial balance in soil systems may change with the addition of detergents. Synthetic chemicals can thus restrict the growth of useful microorganisms that further have an important role in nutrient cycling and healthy soils. In addition, residues formed by detergents affect the structural properties of soil and somehow inhibit its plant-supporting ability^[10]. Soil fertility and functions may be hindered for considerable durations by certain parts of detergents that stay longer in soil. The impact is compounded by the fact that many of these traditional detergents are either non-biodegradable or partially biodegradable and thus result in the accumulation of harmful substances in the environment^[11]. Hence, there is an increased thrust towards developing and using environment-friendly and biodegradable detergents that will minimize damage to the environment and promote sustainability. Lineal anionic and cationic surfactants are mainly significant in detergents for cleaning efficiency. Lineal anionic surfactants like the

very commonly used alkylbenzene sulfonates often referred to as LAS, exhibit a powerful detergent character. They have a hydrophobic tail and a negatively charged hydrophilic head which facilitates the effective breaking of grease and oil, because, through surrounding and emulsifying it. On the other hand, cationic surfactants, such as quaternary ammonium compounds, carry a positive charge and are broadly applied in fabric softeners and disinfectants. The positive charge of its kind allows it to adhere to negatively charged surfaces; thus, cationic surfactants have a predisposition to act on negatively charged textiles and microbial cell walls with softening and antimicrobial effects. For example, though both surfactant types enhance cleaning ability, they should be employed cautiously, as they can affect the environment and human health. Persistence in the water system may harm aquatic life and soil health. This review focuses on the linear anionic cations in detergents. While there are some findings already conducted on the linear anionic and cationic surfactants that exist in detergents, its impact has not yet been well established on *Pheretima sp.*, which is one of the most common species of earthworms, and on the vermicomposting processes. The incidence of these surfactants may affect the populations of the microbes, highly responsible for composting operations. Therefore, the compost's nutritional availability and the components' pace of decomposition may differ. The cationic surfactants that consist of quaternary ammonium compounds are used in different cleaning agents and are known to possess antimicrobial properties^[12]. But it's unclear how they will affect earthworms, which are essential to the decomposition of organic materials. Toxic effects on behavioral changes, survival, and overall health might cause problems in the vermicomposting process of these surfactants on *Pheretima sp.* Novelty of this paper is to fill the learning gaps in the study of impact of the toxicity of the detergents on earthworms and their vermicomposting efficiency. This review overcome the knowledge gap, necessary to produce safer, more sustainable detergents and to protect the soil ecosystem and composting systems.

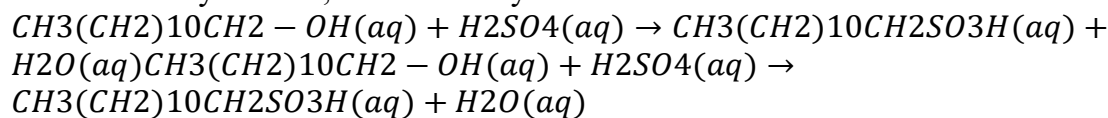
2. MATERIALS AND METHODS

1.1 Detergent and Their Chemical Compositions :

Combinations of artificial surface-active chemicals and other additives designed for cleaning are called detergents. A complex blend of surfactants, abrasives, chelating agents, oxidants, enzymes, colors, fragrances, optical brighteners, buffer materials, and other stabilizing elements, detergents are utilized in many household and laboratory applications. The term sometimes refers to soap or distinguishes it from some other cleaning agents. In molecular biology laboratories, people frequently use it as a synonym for surfactant. The first detergents were saponins and soap produced by hydrolyzing vegetable oils or animal fats with lye^[13]. Synthetic detergents were invented in Germany in World War I to replace soap in many applications in the home^[14]. Most detergent originally used in the laboratory was developed as part of laundry or industry detergent. Detergents are organic compounds whose structure is varied with an elongated hydrophobic hydrocarbon moiety and a polar or charged polar headgroup. The detergents grow more hydrophobic as the chain length rises, although the lipophilic group may also include steroid moieties, aromatic hydrocarbons, or unsaturated or branched- chain alkanes. Four primary headgroup types anionic, cationic, zwitterionic, and nonionic— are the foundation for the most fundamental categorization of detergent^[15]. Other classification systems have been introduced to understand the complexity of detergent structures and properties. Another type of classification of detergents is done by hydrophile- lipophile balance (HLB). HLB classifies

the solubility of the detergent in water. Nonionic detergents have a lower HLB and, therefore are not soluble in water. They act as defoamers and stabilizers. HLB is not a measured quantity but is calculated.

By dissolving the dirt and oil stains into tiny pieces and making them soluble, these chemical compounds efficiently remove them off surfaces. Products such as medications, shampoos, cosmetics, meals, cleaning supplies, antiseptics, petroleum recovery, toothpaste, vitamins, and tablets all include detergents. In hard water, they are less likely to generate calcium salts, and they usually have superior wetting, cleaning, and surfactant properties than soaps. There are several kinds of detergents, including powder, liquid, gel, sticks, sprays, sheets, pastes, and bars. The main factors influencing a detergent's composition are the objects to be cleaned, the kind of grime to be eliminated, and the cleaning technique either manual or mechanical. Laundry, dishwashing, and domestic detergents are among the several formulation types^[16]. Petroleum hydrocarbons and concentrated sulfuric acid react to produce sodium salt, which is then used to make synthetic detergents. For example, dodecyl alcohol and sulfuric acid combine to generate sodium dodecyl sulfate, a sodium alkyl sulfate^[17].



A reaction with sodium hydroxide converts the resultant dodecyl sulfate to the sodium salt.

$$CH_3(CH_2)_{10}CH_2SO_3H(aq) + NaOH(aq) \rightarrow CH_3(CH_2)_{10}CH_2SO_3Na(aq) + H_2O(aq)$$

1.2 Types of Detergents :

Detergents are versatile cleaning agents used across various sectors for removing dirt, grease, and impurities from surfaces, fabrics, and equipment. They are broadly classified based on their intended applications, such as household, industrial, laboratory, and specialty detergents (Table 1). Household detergents, like laundry and dishwashing products, are formulated for everyday cleaning tasks, while industrial detergents cater to heavy-duty needs in manufacturing, healthcare, and food processing. Laboratory detergents are specialized for delicate instruments and equipment in research environments. Each type contains a unique combination of surfactants and additives tailored to enhance cleaning performance in its specific context.

Table 1. Chemical Names Examples of Detergents

Chemical Name	Type	Examples	References
Sodium Lauryl sulphate	Anionic Detergent	Toothpaste	[18]
Quaternary ammonium salts	Cationic Detergents	Shampoos, Hair conditioners	[19]
Stearic acid and poly-ethylene glycol reactions	Non-ionic Detergents	Liquid dishwashing detergents	[20]

1.2.1 Household detergents :

Household detergents are necessary for maintaining hygiene, reducing germs, cleaning surfaces such as laundry and dishes, and prolonging the life of products. There are general-purpose cleansers available for different combinations of soil and surface, and these detergents are formulated taking into account the types of soil and surface. Materials such

as phosphates, enzymes, oxygen-based bleach, surfactants, anti-corrosion, anti-foaming, fragrance, and anti-caking chemicals are used in these cleansers. They come in several forms such as liquids, gels, powders, solids, sheets, pads, and sprays, and are safe for both users and the environment [21]. The two major types of household detergents are laundry detergents and dishwashing detergents. Laundry detergents, which are available in liquid, powder, gel, and bar forms, are necessary for cleaning garments. They function as fabric softeners by eliminating stains and grime from textiles and bleaching them. Important components include alcohols, builders, bleaches, optical brighteners, surfactants, additives, pH regulation, and anti-foaming agents. Additionally, some detergents include enzymes in them to remove biological stains [22]. The dishwashing detergents come in several varieties, such as solutions for hand and machine washing. Hand detergents create suds that remain for a long time, remove food soils, and keep dirt suspended. Automatic detergents dislodge organic deposits, break up dirt, bind minerals, and emulsify grease. Detergents that decompose naturally are better for the environment. Table 2 shows the different types of household detergents.

Table 2. Types of Household detergents

Category	Areas of application	Examples	References
General purpose	General-purpose cleaners for removing dirt, dust, and grime from household surfaces like floors, countertops, and tile	Flour cleaners, soaps, shampoos, etc	[24]
Laundry Detergents	Available in liquid, powder, and pod forms, designed to clean fabrics, often containing enzymes, surfactants, and optical brighteners.	Rin, Surf Excel, Tide, etc	[16]
Dishwashing Detergents	Available for manual dishwashing (hand soap) and automatic dishwashers, formulated to remove grease and food particles.	Vim Liquid	[25]
Disinfectants	Products that are both disinfectant and cleaning agents, such as powerful germicides or antimicrobial liquid sprays.	Detol, Hydrogen peroxide, Peracetic Acid, etc	[26]
Stain removers	Items designed to remove stains. This category does not contain bleachers. Several examples are stain sticks, cleaning solutions, and enzyme spot removers.	Vanish	[27]

1.2.2 Industrial detergents :

Industrial detergents are specialized cleaning agents formulated and designed specifically for all industrial uses, including manufacturing, food processing, and hospitality. Household detergent is contrasted with industrial formulation since the latter is more concentrated and formulated to handle all types of heavy-duty cleaning, such as grease, oils, or even difficult stains. Detergents can be either liquid, powder, or in solid forms and frequently contain a mixture of surfactants, solvents, and builders that increase their cleaning efficiency. Surfactants make the surface tension of water very low, hence quite easy for the detergent to penetrate and dislodge dirt and grime from surfaces [28]. Most industrial detergents also are made with material or process considerations in mind to prevent damage to the equipment they clean and must contain antimicrobial agents as an additive to maintain hygiene. Industrial detergent is, therefore important as both it impacts the cleaning performance and the environmental friendliness. More and more such biodegradable and eco-friendly options are being manufactured by many companies, which represents a huge increase in the quest to decrease the ecological footprint that industrial cleaning processes leave behind [29]. Thus, industrial detergents are crucial for maintaining hygienic conditions and cleanliness in each of these industries, as well as for enhancing productivity and quality.

1.2.3 Laboratory detergents :

Laboratory detergents fall within the general class of cleaning agents that have particularly been developed and compounded for use in scientific and research operations. Unlike conventional household detergents, such formulations have been engineered for the effective removal of biological contaminants, organic residues, and inorganic particles from laboratory equipment and surfaces [30]. They usually contain surfactants, which they utilize to reduce surface tension to enhance the penetration and emulsification capabilities. Most laboratory-grade detergents are biodegradable and compatible with many forms of cleaning operations, whether by hand or through automated processes, including those of ultrasonic cleaners [31]. Additionally, the detergents are designed to be solvent-free and chemical-free in terms of poisonous substances which may lower the chances of adverse reactions on sensitive materials or samples. Some laboratory cleaners are also designed to perform specific tasks, such as cleaning glassware with chemistry or microbiology experiments where residue needs to be eliminated to avoid cross-contamination and non-foaming formulations that are helpful in automated washing systems, where foam can interfere with the washing process [32]. Laboratory detergents are therefore very important in a laboratory setting in the sense that they help maintain the integrity of experiments and ensure the scientific work has a safe and clean working environment.

1.2.4 Common chemical constituents, with a focus on linear anionic cations :

A detergent's chemical composition consists of a wide range of substances that fall into three broad categories: surfactants, builders, additives, and miscellaneous. The detergent chemicals are shown in Figure 2. Surface-active substances called surfactants alter mass and energy transfer processes by changing the structure of inter-boundary layers. Their asymmetric structure, which contains of a hydrophobic and a hydrophilic component, allows them to concentrate at surfaces and lower surface tension. The hydrophilic group can be polypeptide, polyoxyethylene, quaternary ammonium, sucrose, carboxylate, sulfonate, or sulfate, whereas the hydrophobic group is a long aliphatic hydrocarbon

chain^[33]. Several names for surfactants include association colloids, colloidal electrolytes, tensides, paraffin chain salts, and amphipathic chemicals. Certain surface-active compounds have been synthesized containing fluorocarbon moieties, and not all of them are detergents. The surfactant molecule's hydrophobic and hydrophilic components have a balanced interaction with one another. Surfactants exhibit molecular structure-based subdivisions into many groupings. Only when anionic surfactants, such as linear alkyl benzene sulfonates (LAS) and alkyl benzene sulfonates (ABS), are neutralized with an alkaline or basic substance can complete deterrence be achieved. By producing cations, cationic surfactants such as mono- alkyl tri-methyl ammonium (MATMA) compounds and di-tallow dimethyl ammonium chloride (DTDMAC) neutralize. Several categories, such as amidoamine, amine oxides, imidazolines, fatty acid amides, nitriles, and polymeric surfactants, can be used to group these molecules^[34]. Phosphates, nitrates, and sulfates are anionic cations that are the most commonly used ingredients for detergents. Each has a distinct role in the preparation of formulas in cleaning products. Phosphates act as water softeners that remove dirt from surfaces and prevent their redissolution onto fabrics or surfaces by reacting with calcium and magnesium ions. Because of their function in allowing improved performance in detergent, however, they have undesirable impacts on the environment. When they are washed into waterways, they induce eutrophication wherein excessive algae growth robs the water bodies of oxygen and kills aquatic life^[35]. Nitrates are much less utilized, but there are a few cleaning agents that contain them as stabilizers or oxidizing agents. Like phosphates, however, if released in large quantities, nitrates can readily contribute to water pollution, contaminating drinking water supplies and inducing toxic algal blooms^[36]. The most commonly known surfactants in the sulfates are sodium lauryl sulfate (SLS) or sodium laureth sulfate (SLES). Although SLES is an effective foaming agent that enables the emulsification of grease and oils, making cleaning easier and more comfortable, sulfates tend to be harsh on skin and hair while not being biodegradable in specified proportions.

2.RESULT & DISCUSSION :

2.1 Environmental Impact of Detergents :

Detergents have been widely used both in households and industrial processes. However, they come with a significant environmental burden on the soil and water environment. Detergents carry a stream of chemicals into the environment when they are released through wastewater. These include surfactants, phosphate, and fragrances. Surfactants are excellent cleaning agents because they break up the surface tension of water. However, while doing that, they effectively tear up the water's surface layer, where most aquatic life feeds and breathes. Other surfactants break down so slowly that they persist in water throughout their lifecycle^[37]. Other substances commonly used in older detergent formulations are phosphates. These act by inducing eutrophication; that is, a lot of algae grows because the water system contains more nutrients. The algae suck up the oxygen in the water system, creating "dead zones" where there isn't enough oxygen to support aquatic life, thereby depressing entire ecosystems. Detergents generally alter the natural nutrient and microorganism balance in the soil system. When wastewater with detergents is applied for irrigation or percolates through the soil, it interferes with biological health in the soil. These chemicals add excess phosphates, which are desirable at low levels, but their excessive level leads to a shortage and surplus of nutrients-they equally impact plant development and soil fertility. Surfactants and other synthetic additives can harm favorable

microorganisms in the soil, which play a role in decomposition and nutrient cycling (Giagnorio *et al.*, 2017). However, because of their ubiquity, this could lead to low fertile soils and long-term degradation, hence reducing their use in farming. Surfactants may also alter the physical property of soil, thereby affecting the capacity of its water absorption and content; thus, an ecological functionality could be under threat. Some of the efforts that have been taken towards the reduction of damage detergents have caused to the environment include biodegradable and phosphate-free products. Modern detergents have been made more perishable in the environment, hence being less long-term detrimental. Wastewater treatment plants have also improved in terms of removing most of the harmful chemicals from effluents before they go into natural systems. However, many of these high-tech facilities are not accessible everywhere, and consequently, untreated or partially treated wastewater continues to threaten both soil and water systems the world over^[38]. Public consciousness coupled with tighter regulations in detergent formulations can further minimize the impacts of this washing agent on the environment, but the general use of detergents demands sustained scrutiny so that ecosystems are adequately protected against its destructive influence.

2.2 Biology and Ecology of *Pheretima sp* :

Pheretima is an earthworm genus from New Guinea and Southeast Asia. Hermaphroditic worms, having both male and female reproductive organs, enable the possibility of sexual and parthenogenetic reproduction. A peculiar characteristic of this species is that there is a glandular band called the clitellum, which is along the segments 14 to 16, essential for the reproduction process since mucus is secreted for cocoon formation. The female genital pore is also present ventrally on the 14th segment for easy egg release. Male genital pores are lateral on the 18th segment. In addition to genital papillae, they provide them with useful aid in copulation. The structure enables effective and diverse reproductive tactics. Like most earthworms, *Pheretima* is nocturnal, avoiding light and emerging only at night to feed and reproduce. They rely on a moist body surface for respiration and are often termed "farmer's friends" for their role in improving the porosity of soil and aiding irrigation. *Pheretima* worms represent a larger category of "pheretimoid" genera comprising roughly around 1,000 species distributed across the Oriental region, thus rendering them ecologically significant (Figure 3). Medically, *Pheretima* is used in China for the useful agents from the biology of this animal, especially in the treatment of stroke and epilepsy. *Pheretima* contains hypoxanthine, lumbrico-febrin, and lumbricin, with therapeutic application^[39]. Earthworms can be found in a variety of habitats, including manure, compost, litter, humus, and kitchen drainage, as well as woodland, grassland, agricultural land, and plant nurseries^[40]. Although omnivorous, they mostly consume dead organic stuff for nutrition. Earthworms are currently being examined as biological specimens and used in vermiculture, a subfield of biotechnology^[41]. Some earthworm species are chosen for waste utilization and vermicomposting due to their valuable function in organic matter decomposition and mineral recycling. Vermiculture and vermicomposting are gaining popularity in India and beyond.

Pheretima sp. plays a very important role in soil ecosystems by improving the structure, fertility, and nutrient cycling processes of soils. Due to their earthworm nature, they create holes in the soil, which improve aeration and water infiltration, hence making the soil pore and plant-friendly. The feeding behavior of such earthworms creates a breakdown of organic matter that is decomposed, forming nutrient-rich castings^[42]. In addition, these castings

contain nutrients such as N₂, P, and K that play a significant role in plant health and the overall fertility of the soil. *Pheretima* further decomposes organic matter into smaller bits that facilitate microbial decomposition. The entire ecosystem in the soil is better off by having *Pheretima* contribute to a healthier soil ecosystem that feeds onto growth in plants as well as better biodiversity^[43]. Their activities improve soil quality and are, therefore, essential to sustainable agricultural practices as well as natural ecosystems. *Pheretima sp.* is found in moist, tropical, and subtropical areas generally throughout Southeast Asia and New Guinea. They thrive on soils with a high organic content such as forests and grasslands as well as agricultural fields that do not dry out to an extent that would compromise the moistness levels sufficient to accommodate their respiration by skin. *Pheretima* prefers loose soil with good drainage properties; burrowing can occur easily because this is a precondition for feeding and reproduction. They often occur near decaying plant material, and this gives them a constant source of organic matter to feed on. They are often nocturnal or during wet seasons, given their sensitivity to desiccation^[44]. In agricultural areas, they are called farmer's friends for the good effects brought about by burrowing. It creates aeration in the soil and thus improves infiltration rates, which increases root growth. These earthworms indicate fertile soil, and they are important for natural or cultivated environments.

2.3 Sensitivity to Contaminants :

Earthworms are sensitive to many pollutants and contaminants in the soil, which may lead to damage affecting their health, behavior, and overall ecosystem functions^[45]. Heavy metals such as lead, mercury, and cadmium found in contaminated soils are absorbed by earthworm tissues and interfere with the metabolism processes. Such metals can cause damage to reproduction systems and slower growth rates; also, such metals increase mortality rates^[46]. Chemical pesticides and herbicides are another significant threat. Synthetic chemicals used in agriculture have been reported to be toxic to earthworms: disrupting their nervous system as well as decreasing their ability to digest organic matter. Such prolonged exposure may bring about immobilization and feeding activities, hence lower fertility of the soil (Bhat et al., 2016b). The microbial communities, on which earthworms rely for decomposition, also get disturbed. Earthworms also serve as bioindicators of healthy soil because their existence and activity normally reflect the quality of the soil environment^[48]. If exposed to pollutants, they can no longer burrow or aerate soils as well as typical earthworms and thus cause compaction, as well as decrease water infiltration into the soil, which is not a good scenario for plant growth^[49]. Organic pollutants, such as oil spills and industrial waste, can suffocate earthworms, affecting their breathing and affecting other organisms in the food chain^[17]. Earthworm populations must thus be protected not only for themselves but for their role in the maintenance of soil ecosystems, by regulating the use of harmful chemicals and the use of environmentally friendly agricultural techniques that decrease contamination. Factors determining earthworm population include soil, temperature, moisture, and pH as well as the availability of organic matter resulting from plant residues and human waste (Bahar, 2015; Hoeffner et al., 2018). The quantity of earthworms in a soil sample is a proxy for the health of the soil ecosystems and environmental stability. The qualities of soil, including cation exchange capacity, nutrient status, and moisture relationship, are influenced by the texture of the soil. Detergents are used in pesticide formulations, oil spill cleanup, and industrial and residential cleaning activities^[52]. The main corrosion inhibitor and detergent component, LAS, dissolves slowly in soil and rivers and can be harmful to soil organisms.

This can cause a reduction in biological production with unfavorable ecological and economic impacts if the detergents are freely discharged into water and arable soil [21]. Soil microorganisms may potentially alter their biodegradation and transform them into less harmful agents, or even into less critical sources of nutrients. Phosphate-free detergents might potentially lessen the overall negative environmental consequences of greywater from washing [53].

2.4 Effect of Lineal Anionic Cations on Pheretima Sp. :

Anionic cations that include nitrates, phosphates, and sulfates happen to be the most commonly used ions in detergents, fertilizers, and pollutants that find their way to the soil. Although these ions are necessary and found in demand for plant growth, they can disrupt the ecological balance in the soil, thus affecting the organisms living in it. Emerging research on anionic cations' effect on earthworm density and their health is growing in agricultural and environmental sciences [54]. The concentrations of these ions have been known to affect earthworm populations because they affect the pH of the soil and nutrient availability, changing earthworm behavior and ultimately causing a reduced survival rate. The effects of anionic cations on earthworm growth and reproduction are significant. The more nitrates and phosphates in water impede the growth of earthworms. These affect the digestive systems of earthworms and interfere with nutrient assimilation [55]. Their reproduction health has also been affected when particular species of earthworms have been exposed to such environments with increased levels of anionic cations that lowered cocoon production and hatchability. This reduction in breeding may translate to a decline in the earthworm population with time [56]. Since these animals aerate the soil, decompose organic matter, and encourage the cycling of nutrients, this decline may result in soil ecosystem imbalances. Apart from this, high concentrations of anionic cations also depress the global health of earthworms. Earthworms are very sensitive to changes in soil chemistry, and high concentrations of these ions cause physiological stress, reduce burrowing activities, and kill earthworms in extreme cases. Therefore, their health is essential for soil health since earthworms are an indicator of soil health (A. Singh, Kumar, et al., 2020b; Miškelytė & Žaltauskaitė, 2023). Thus, the knowledge of the effect of the anionic cation would be important to improvement in the applications of sustainable agriculture practices and environmental protection because this can potentially be critical in soil conservation principles and regulation of fertilizer application in terms of attaining healthy populations and ecosystems that can sustain for long times considering earthworms.

2.5 Mechanisms of Impact :

Anionic cations affect the earthworms through several chemical mechanisms that alter soil properties and their biological processes. The first, and most profound effect is the changing of the pH in the soil [59]. High concentrations of anionic cations, especially nitrates, and sulfates, increase the acidity of the soil; this will interfere with the earthworm's ability to regulate its internal pH, thus subjecting it to physiological stress, further interfering with the enzymatic functions needed for breaking down food and assimilating nutrients. Another mechanism includes direct toxicity. High concentrations of anionic cations, especially nitrates, can lead to oxidative stress in tissues surrounding earthworms. The cells will produce ROS that cause proteolysis, lipid peroxidation, and DNA structure damage. Such oxidative damage may impair growth, reproduction, and immune response in earthworms [60]. Furthermore, these ions may interfere with the earthworm's cuticle, that

external protective layer controlling water and ion exchange with soil. Altered ion balance because of high anionic cation concentrations can compromise the ability of the earthworm to maintain osmotic balance leading to dehydration or swelling, which further impacts health^[61]. Bioaccumulation refers to the gradual accumulation of substances in tissues of organisms over time. It happens in the case of earthworms by direct feeding on soil particles containing ions or absorption of these ions through the skin. As living organisms, earthworms are exposed intensely to these ions, which, when taken into their tissues, may provoke toxic effects over time^[62]. Toxicity problems arise when the concentration of anionic cations overpowers the detoxification capabilities of the organism and its modes of elimination. Nitrate toxicity results in oxidative damage as reactive N_2 species are generated within the body of the earthworms. Such compounds may damage proteins and lipids, DNA, and thus affect metabolism, reproduction, etc. Similarly, excessive concentrations of phosphate anions may lead to disruptions in the calcification process, while also bringing about muscle malfunctioning and stunted growths^[63]. For another aspect, earthworms are feeding crucial organisms; hence, the bio-accumulation of the toxic anions tied to them can have an impact on other organisms consuming them, for example, birds or small mammals. Recent research on *Pheretima* species has studied the effects of detergent-based anionic surfactants, including survival, behavior, and interaction with soil^[10] studied six dilutions of household detergent and found that *Pheretima guillelmi* and other *Eisenia andrei* had a 100% mortality rate from even the lowest concentration with long exposure. The lethal impacts were mostly from washing powder and shampoo, affecting the survival and escape behaviors of the worms in contaminated soils(B. Liu, 2022a). In addition, research indicated that detergent residue interferes with the vermicomposting process by affecting soil pH and earthworm activity. This study emphasizes the sensitivity of soil ecosystems to anthropogenic pollutants and underscores the pressing need for sustainable waste management in human-dominated landscapes. These results provide critical information to inform environmental conservation strategies.

2.6 Impact on Cast production and Soil Health :

2.6.1 Cast Production by Earthworms :

Earthworms are the megadrile annelids and are found in the class Oligochaeta. They constitute more than 80% of the invertebrate soil biomass and dwell in the ground. The food their diet consists of includes dirt along with other decomposing organic matter, which they excrete as wastes in the form of castings. Mineral soil and partially digested residues of plants comprise earthworm casts. They can bring large quantities of soil from the deeper layers to the surface and conduct organic matter downwards into deep layers of the soil. The earthworm casts are largely generated during rainy periods in tropical regions, with seasonal variations especially due to factors such as the physicochemical characteristics of the soils, changing land- use practices, feeding behaviors, and availability of food^[65]. Earthworm casts have higher moisture, pH, and levels of organic carbon and inorganic nutrients compared to the adjacent soil. Cast production by earthworms involves digestion and excretion, where earthworms digest organic matter and soil, effectively depositing the matter excreted as nutrient-rich casts^[66]. While burrowing in the soil, earthworms ingest decomposed plant material, microbes, and soil particles. The nutrients available during this process of digestion, such as N_2 , P, and K, are diluted and become readily available for use by plants^[67]. The resulting casts deposited on the surface or within the soil promote its structure, fertility, and aeration. The high concentration of organic

matter and useful microorganisms in the casts improves plant growth and retains more water. Earthworm cast production is very critical in nutrient cycling and soil health^[68]. The burrowing activity of earthworms enables channels with improved aeration of soil while facilitating good infiltration of water. On the other hand, their casts in the soil provide precious nutrients to it. Scientists have shown that earthworm casts offer greater amounts of plant- available nutrients than the adjacent substrate. This process enhances fertility in soils, especially in agricultural systems, where the earthworms are useful for practicing sustainability in farming^[69]. Earthworms cast, and through this process, improve the quality of soil naturally, therefore, they play a significant role in maintaining productive ecosystems and also contribute to the long-term conservation of soil. Long-chain organic compounds or specific nutrient ion-derived cations usually have some impact on the quantity and quality of earthworm casts. These ions influence earthworm activity and physiological activity in soils and thus play some role in variation in cast production. Higher concentrations of specific linear anionic cations may stimulate the availability of nutrients, hence increasing their increased consumption of organic matter by earthworms and leading to overall casts produced. Conversely, the specific cations at levels higher than what is permissible can be harmful. It makes earthworms reduce their activity or leads to health complications, which further affects the quantity of cast produced^[70]. The chemical composition of these casts also changes with the type and concentration of anionic cations present in the soil. Cations that enhance nutrient availability yielded high- quality casts that were highly nutritious and rich in beneficial microorganisms, which support plant growth while improving soil structure, whereas a toxic anionic cation at excessive levels will lower the quality of castings because it reduces the efficiency of digestive functions within the earthworm body and decreases nutrient contents^[71]. Therefore, understanding the linear anionic cation effect on earthworm cast production can help optimize health and fertility in several agricultural and ecological contexts.

2.6.2 Soil Health and Vermicomposting Efficiency :

Vermicompost is a nutrient-rich organic matter that improves soil health, crop productivity, and vitality. It perfects soil structure, aeration, and water retention and, through that, reduces emissions and allows for greater sustainability in agricultural production techniques^[72]. Vermicompost also promotes a healthy ecology of beneficial microbes-a great function that leads to increased soil biology, higher crop yields, and better plant health. Due to the higher microbial activity in vermicompost, the uptake of nutrients by the plants is enhanced along with vegetative growth, which makes the crops healthier and more productive. Agricultural techniques involving vermicompost will surely increase the sustainability aspects while addressing environmental concerns. The earthworm cast also increases the structure of the soil and the availability of nutrients in the soil; it greatly enhances the improvement of the overall health status of the soil. Being an invertebrate that ingests organic matter and soil, earthworms mix the soil into smaller, manageable particles to excrete afterward as nutrient-rich casts(Bhat et al., 2015a). In the practical sense, casts have a granular texture that increases soil aggregation; consequently, they enhance aeration and water infiltration^[74]. It is made healthier by the working of earthworms because this makes it a place where penetration by the root, as well as movement by microbes, happens, thus producing a very healthy ecosystem inside the soil^[75]. Earthworm casts also include large amounts of necessary nutrients like N₂, P, and K that are precursors of plant growth. The unique composition within these casts usually shows higher levels of available

nutrients than other soils around, making them extremely valuable for crops. The nutrient release happens in a slower and more bioavailability manner, thus the plants can absorb nutrients for a more extended period. In addition, the micro-activity by the microorganisms residing inside the cast itself increases the cycling of nutrients and contributes to the fertility of the soil as well^[76]. Through the improvement of both the physical structure and the nutrient availability of the soil, earthworm castings are indeed important in maintaining sustainable agriculture and ecosystem functionality that promotes healthy plant growth and yield crops^[77]. So much so, that earthworm activity is depressed to such an extent in vermicomposting that the efficiency of organic waste breakdown and nutrient cycling is seriously impaired. Earthworms are primarily responsible for the aeration of the compost, which aids in microbial activities that decompose organic matter. Where there are hardly any worms, the decomposition of compost is done at a much slower rate, meaning it takes longer to decompose and may result in incomplete decomposition of materials^[78]. This reduced activity also affects the quality of vermicompost produced since fewer nutrient-rich casts remain, which form the most significant contribution to improving the health of soils^[79]. Besides this, the low earthworm activities cause an imbalance in populations in the microorganisms of the composting condition, which ultimately leads to a reduction in nutrient release. This way, the general advantages of vermicomposting include an improved structure of soil, increased fertility, and improved crop yields. Thus, it is now a critical aspect of successful and sustainable composting techniques for maintaining healthy earthworm populations^[80].

2.7 Detergent Impact on Pheretima Sp. :

2.7.1 Geographical and Environmental Context :

The temperate regions exhibit immense climatic diversity and richness in biodiversity. It, therefore, forms a crucial area for ecological studies, as well as agriculture in India. Usually, these temperate regions lie between the subtropical lower zones and the alpine upper zones, with an elevation of generally 1,500-2,500 meters. The climate exhibits strong seasonal changes with warm summers and cold winters, which supports various deciduous and coniferous forests^[81]. Some common trees include oak, deodar, and pine. Providing habitat to many wildlife species, these temperate regions also experience heavy rainfall, mainly during monsoons, supporting good growth on fertile soils for agriculture to take place^[82]. Among them, apples, peaches, and cherries are some crops that grow well in this region; there is an essential area for horticulture in this region. The temperate climate allows for the realization of a cultural landscape through communities adapting their livelihoods to the natural resources available^[83]. Local soils differ with altitude and region within the provinces but are mainly sandy loam, clayey in texture, and slightly acidic to neutral pH. These are organic soils due to the decomposition of forest litter at the higher elevations but, mostly, in temperate and sub-alpine zones. Some areas have limitations in terms of soil fertility due to high rains and steep slopes, which result in erosion and nutrient loss. Organic means of soil fertility management are maintained by vermicomposting and green manure to prevent the draining away of nutrients^[84]. The agricultural practices are very diverse and varied according to the topography and climatic conditions. Crops grown at low altitudes include wheat, maize, and rice, while the temperate regions specialize mainly in horticulture, which comprises fruits such as apples, pears, and peaches. Terrace farming is the traditional method on a steep slope that helps reduce erosion due to the soil and uses land efficiently^[85]. The state is increasingly

pursuing organic farming and many farmers follow traditional, eco-friendly practices such as crop rotation and natural pest control to increase sustainability. Such practices further enhance productive agriculture that is combined with environmental balance ^[86].

3.7.2 Regional Impact of Detergents :

The quality of groundwater as well as surface water globally suffers from a serious risk from anionic detergents, according to the Executive Summary of the Environmental Impact Assessment. Anionic detergents primarily fall into the category of household and industrial cleaning products, characterized by long life in natural water systems as their rates of degradation are slow. Once these enter the groundwater, they can threaten its purity and render it unsafe for human consumption. Furthermore, residues of such detergents are said to affect surface water bodies, such as rivers and streams, for they contribute to pollution and disruption in such aquatic ecosystems; thus, the quality of such water is lowered, and biodiversity deteriorates while local communities, as well, are affected who depend on the same source of water ^[87]. Detergents, particularly those including phosphates and surfactants, are one of the emerging issues regarding contamination of local water bodies. Many rivers and streams that supply fresh water to people and wildlife are at risk from untreated wastewater containing detergent residues. The land nature of the different regions also aggravates the problem of runoff water from detergents flowing fast into the water bodies ^[88]. The spread of detergents has led to many harmful results, most of which have manifested in the eutrophication of water bodies, where phosphates present in detergents support excessive growth of algae. This causes a decrease in oxygen levels, thus killing the fish and other life-forming aquatic. Moreover, surfactants in detergents cause damage to aquatic organisms by disrupting the oils in the gills of the fish, thus affecting their respiration. Besides harming biodiversity, the pollution of freshwater ecosystems also threatens local livelihoods like fishing and tourism ^[89]. Some local programs promote biodegradable, phosphate-free detergents to less damage the ecological resources of both the aquatic and soil systems. Watershed cleanup, upgrading of wastewater treatment plants, and minimizing the diversion of rivers in direct untreated discharges are also proposed policies in the area ^[90]. Further studies and severe governance on detergent formulation must be enhanced to preserve the ecosystems and ensure proper development in the region.

3.7.2 Vermicomposting Practices :

Vermicomposting has rapidly gained as a waste management technique, especially in the rural areas and agricultural sectors of different states, using *Eisenia fetida* earthworms as the bio-destructor in organic matter, which is converted into nutrient-rich compost to supplement soil health and productivity ^[91]. More farmers in the state are adopting vermicomposting to step up the progressive reduction of dependency on chemical fertilizers and enhance sustainable crop productivity. Challenges still exist mainly regarding the appropriate care of vermicompost beds about regional climatic conditions. Cold temperatures, very damaging for earthworms, and low activity from earthworms at higher elevations due to the existence of cold winter stages prevent adequate potting activity under these situations because of the reliance on temperature control measures such as covering the compost bed with organic matter ^[92]. The unavailability of information and technical know-how on vermicomposting contributes to this wider restriction in its acceptance ^[93]. With these challenges, the government and training programs are promoting vermiculture as a feasible organic waste management and enhancement of soil fertility. The

local practices of vermicomposting have been enormously affected by the entry of environmental pollutants due to the increased use of detergents, chemical fertilizers, pesticides, and other pollutants through intensive agriculture^[83]. These pollutants can interfere with natural vermicomposting through injury to earthworms that are critical to the whole activity. Earthworms are vulnerable to harmful chemical residues found in organic waste, such as pesticide-containing agricultural residues or industrial pollutants, which might inhibit their activity, development, or ability to breed. This is not only damaging the efficiency of compost production but also degrading the quality of vermicompost at the end, which therefore narrows its scope on nutrient value and total benefits in terms of soil health^[94]. Moreover, the deposited heavy metals and other poisonous chemicals may cause harm to the targeted plants and the environment at large in case the contaminated vermicompost is released into open fields^[95].

3.8 Recommendations and Mitigation Strategies :

3.8.1 Best Practices for Detergent Use :

The development of sustainable agriculture practices or the decrease in synthetic fertilizers and pesticides in that specific place can be promoted. Organic farming allows for the use of compost and manure instead of chemical additives, without promoting contaminants in the soil. Another major requirement is the proper management of water waste from houses and industries. Advanced treatment systems should be installed to filter out harmful chemicals before they reach the soil or water bodies, which will prevent long-term environmental damage. Programs by the public for learning and observing how such wastes may be disposed of without any harm to the environment shall help further deal with this issue. Alternative products, such as phosphate-free, biodegradable detergents, and eco-friendly cleaning chemicals, are a great first step toward reducing soil contamination. These decompose faster in the environment and prove less damaging to both soil and water systems. In addition, natural methods through which contaminated soil may be detoxified include using plants, microorganisms, or fungi to try and suck and break pollutants inside them. While using vermiculture and organic composting, soil health would be good because these would feed the soil with nutrients without the usage of chemical treatments. With alternative options that adopt sustainable methods of use, soil ecosystems would be left intact for generations to enjoy.

3.8.2 Improving Vermicomposting Efficiency :

A specific strategy to improve vermicomposting in contaminated areas would be the pre-treatment of organic waste with reductions in toxic residues such as heavy metals or pesticide remnants before using it in vermicomposting systems. This might be through bio-remediation or by specific plants and microorganisms used to absorb or neutralize harmful substances. In addition, the choice of hardy earthworm species that are more tolerant of contaminants enhances the effectiveness of vermiculture if it is practiced in contaminated conditions. Regulated conditions of composting like the provision of coverings and adequate moisture and temperature levels reduce the impact of contaminants on the health and productivity of earthworms. Some other policy recommendations to promote sustainable vermicomposting include providing incentives and support for farmers and waste managers in the pursuit of green vermicomposting practices. Strengthening regulation laws against the use of chemical fertilizers and pesticides as deterrent measures would nudge people toward an organic farm. Expenditure on research and development has also to be made to discover new ways of detoxifying the contaminated soils as well as

improving the quality of composts. Public awareness programs may enhance training and sensitization of communities regarding the advantages of vermicomposting, its function in waste management, and ways to prevent contamination. It is, therefore, possible to upscale sustainable vermicomposting practices even in areas with major environmental pollutants by embedding these strategies into policy frameworks.

4 CONCLUSION :

This review discussed the environmental impacts of detergents; however, it pays particular emphasis on the effects of linear anionic and cationic surfactants on soil health and earthworm populations, particularly *Pheretima sp.* It identifies that common linear anionic and cationic surfactants of household detergents could replace the key microbial communities as required in vermicomposting. The review has highlighted the consideration gaps in knowledge about the specific effects of these chemicals on earthworm behavior, reproduction, and their function in soil aeration and nutrient cycling. It also underlines the relevance of knowing these impacts for temperate zones, where detergent contamination is posing a serious risk to soil biodiversity as well as efficiency in composting. It continued to call for more studies on the earthworm toxicity thresholds of these chemicals and went on to detail some of the possible solutions, which include the utilization of biodegradable detergents and pre-treating organic waste, to offer suggestions to make vermiculture and composting functions more sustainable in the detergent-polluted environment.

5 FUTURE PROSPECTIVES :

While it is well understood that ecological disturbances like anthropogenic activities, changes in land use, and habitat fragmentation strongly influence the variations of earthworm species, especially the anecic and epigeic types, the outlook of how these impacts affect earthworm functional diversity and their role in the provision of ecosystem service remains greatly unexplored. In addition, few studies exist on the behavioral alterations in detergents associated with earthworm activities, of which decreased burrowing and feeding could affect soil aeration and nutrient cycling. Furthermore, scant data exist on the long-term biochemical effects of detergent exposure to earthworms, more particularly enzyme inhibition and oxidative stress. It highlights lacunae in understanding the interactions involving earthworms, soil health, and environmental contaminants to be studied in detail, especially in such sensitive ecosystems. Further research should also be conducted to analyze the impacts of linear anionic cations in detergents on the density of *Pheretima sp.*, their casting productivity, and overall vermicomposting efficiency. Major study areas will include assessing the toxicity levels of various anionic cations against *Pheretima* and setting threshold levels where anionic cations severely decline the reproductive and digestive functioning of the worms. However, these detergents' influence on burrowing and organic material decomposition-which directly affects soil aeration and nutrient recycling activities of earthworms should also be studied. Also, the quality of vermicompost in terms of both nutrient content and microbial activity as affected by residues from these detergents over the long term should be determined. There, therefore is a research need in this area: detoxification or bioremediation techniques that will reduce the adverse impacts of such chemicals on earthworm populations can be effective in promoting sustainable vermicomposting practices in affected areas.

DECLARATION OF COMPETING INTEREST :

The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper. All authors

have read, understood, and have complied as applicable with the statement on “Ethical responsibilities of Authors” as found in the Instructions for Authors.

FUNDING SOURCES :

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

ACKNOWLEDGMENTS :

The author would like to acknowledge the research department of Suresh Gyan Vihar University for their support during study of this article.

DATA AVAILABILITY :

Author declares that data that support the findings of this study will be available from corresponding author upon asking.

REFERENCES :

- [1] Anuja, R.; Narayanan, S. P.; Sathrumithra, S.; Thomas, A. P.; Julka, J. M. First Record of Exotic Earthworm *Eukerria Kuekenthali* (Michaelsen, 1908) (Annelida: Oligochaeta) from Kerala, India. *Journal of the Bombay Natural History Society*. 2020. <https://doi.org/10.17087/jbnhs/2020/v117/131225>.
- [2] Thirunavukkarasu, A.; Sivashankar, R.; Nithya, R.; Sathya, A. B.; Priyadharshini, V.; Kumar, B. P.; Muthuveni, M.; Krishnamoorthy, S. Sustainable Organic Waste Management Using Vermicomposting: A Critical Review on the Prevailing Research Gaps and Opportunities. *Environmental Science: Processes and Impacts*. 2022. <https://doi.org/10.1039/d2em00324d>.
- [3] Singh, A.; Karmegam, N.; Singh, G. S.; Bhadauria, T.; Chang, S. W.; Awasthi, M. K.; Sudhakar, S.; Arunachalam, K. D.; Biruntha, M.; Ravindran, B. Earthworms and Vermicompost: An Eco-Friendly Approach for Repaying Nature’s Debt. *Environmental Geochemistry and Health*, **2020**, *42* (6). <https://doi.org/10.1007/s10653-019-00510-4>.
- [4] Butt, K. R.; Briones, M. J. I. Earthworms and Mesofauna from an Isolated, Alkaline Chemical Waste Site in Northwest England. *European Journal of Soil Biology*, **2017**, *78*. <https://doi.org/10.1016/j.ejsobi.2016.11.005>.
- [5] Sethi, S.; Gupta, P. Soil Contamination: A Menace to Life. In *Soil Contamination - Threats and Sustainable Solutions*; 2021. <https://doi.org/10.5772/intechopen.94280>.
- [6] Bennour, A.; Habes, D.; Soltani, N. Assessment of Soil Quality in Annaba Area (Northeast Algeria) Using the Earthworm *Lumbricus Terrestris*: Bioindicative Stress Responses and Heavy Metal Contamination. *Fresenius Environmental Bulletin*, **2020**, *29* (11).
- [7] Abbasi, S. A.; Nayeem-Shah, M.; Abbasi, T. Vermicomposting of Phytomass: Limitations of the Past Approaches and the Emerging Directions. *Journal of Cleaner Production*, **2015**, *93*. <https://doi.org/10.1016/j.jclepro.2015.01.024>.
- [8] Sinha, B.; Bhadauria, T.; Ramakrishnan, P. S.; Saxena, K. G.; Maikhuri, R. K. Impact of Landscape Modification on Earthworm Diversity and Abundance in the Hariyali Sacred Landscape, Garhwal Himalaya. *Pedobiologia*, **2003**, *47* (4). <https://doi.org/10.1078/0031-4056-00199>.
- [9] Giagnorio, M.; Amelio, A.; Grüttner, H.; Tiraferri, A. Environmental Impacts of Detergents and Benefits of Their Recovery in the Laundering Industry. *Journal of Cleaner Production*, **2017**, *154*. <https://doi.org/10.1016/j.jclepro.2017.04.012>.
- [10] Liu, B. Effects of Six Household Detergent Dilutions on the Behavior and Survival of *Eisenia Andrei* and *Pheretima Guillelmi* Earthworms. *Journal of Resources and Ecology*,

- 2023**, 14 (5). <https://doi.org/10.5814/j.issn.1674-764x.2023.05.019>.
- [11] Low, S. Y.; Tan, J. Y.; Ban, Z. H.; Siwayanan, P. Performance of Green Surfactants in the Formulation of Heavy-Duty Laundry Liquid Detergents (Hdld) with Special Emphasis on Palm Based Alpha Methyl Ester Sulfonates (α -Mes). *Journal of Oleo Science*. 2021. <https://doi.org/10.5650/jos.ess21078>.
- [12] Ahmed, S.; Marimuthu, N.; Tripathy, B.; Julka, J. M.; Chandra, K. Earthworm Community Structure and Diversity in Different Land-Use Systems along an Elevation Gradient in the Western Himalaya, India. *Applied Soil Ecology*, **2022**, 176. <https://doi.org/10.1016/j.apsoil.2022.104468>.
- [13] Zahran, H. A. From Fat to Foam: The Fascinating World of Soap Chemistry and Technology. *Egyptian Journal of Chemistry*. 2024. <https://doi.org/10.21608/EJCHEM.2023.195358.7627>.
- [14] Hajbabaie, M.; Reza Sabour, M.; Dezvareh, G.; Mostafa Hatami, A. Global Trends and Status in Detergents Research during the Years 2000-2020: A Systematic Analysis. *research Square*, **2022**.
- [15] Kogawa, A. C.; Cernic, B. G.; do Couto, L. G. D.; Salgado, H. R. N. Synthetic Detergents: 100 Years of History. *Saudi Pharmaceutical Journal*. 2017. <https://doi.org/10.1016/j.jsps.2017.02.006>.
- [16] Achaw, OW., Danso-Boateng, E. Soaps and Detergents. In: *Chemical and Process Industries*. In *Chemical and Process Industries*; Springer, Cham., 2021; pp 1–37.
- [17] Chen, X.; Wang, X.; Gu, X.; Jiang, Y.; Ji, R. Oxidative Stress Responses and Insights into the Sensitivity of the Earthworms *Metaphire Guillelmi* and *Eisenia Fetida* to Soil Cadmium. *Science of the Total Environment*, **2017**, 574. <https://doi.org/10.1016/j.scitotenv.2016.09.059>.
- [18] Paul, N. L.; Clark, H. J. Foaming at the Bit: Sodium Lauryl Sulphate (SLS)-Free Toothpastes. *New Zealand Dental Association News*, **2021**, 202 (March), 27–36.
- [19] Deka, S.; Sharma, A.; Kumar, P. Cationic Polymers and Their Self-Assembly for Antibacterial Applications. *Current Topics in Medicinal Chemistry*, **2015**, 15 (13), 1179–1195. <https://doi.org/10.2174/1568026615666150330110602>.
- [20] Kim, D. D. Structure and Property Correlations of Surface-Active Agents in the Control of Colloidal Behavior in Home/Personal Care and Biochemical Systems. **2021**.
- [21] Yin, S.; Yang, L.; Yin, B.; Mei, L. Nitrification and Denitrification Activities of Zinc-Treated Soils Worked by the Earthworm *Pheretima* Sp. *Biology and Fertility of Soils*, **2003**, 38 (3). <https://doi.org/10.1007/s00374-003-0643-0>.
- [22] Azizullah, A.; Richter, P.; Häder, D. P. Toxicity Assessment of a Common Laundry Detergent Using the Freshwater Flagellate *Euglena Gracilis*. *Chemosphere*, **2011**, 84 (10). <https://doi.org/10.1016/j.chemosphere.2011.04.068>.
- [23] Singh, J.; Singh, S.; Vig, A. P. Extraction of Earthworm from Soil by Different Sampling Methods: A Review. *Environment, Development and Sustainability*. 2016. <https://doi.org/10.1007/s10668-015-9703-5>.
- [24] Stanczak, A. Reactive Oxygen Species in Laundry Applications. **2018**.
- [25] Venkatesh, G. Dishwashers: Literature Review to Summarise the Multi-Dimensionality of Sustainable Production and Consumption. *Sustainability (Switzerland)*. 2022. <https://doi.org/10.3390/su141610302>.
- [26] McDonnell, G.; Russell, A. D. Antiseptics and Disinfectants: Activity, Action, and Resistance. *Clinical Microbiology Reviews*, **2001**, 14 (1). <https://doi.org/10.1128/cmr.1>

- 4.1.227-227.2001.
- [27] Removal, E. S. Quick ' n Easy Stain Removal.
- [28] Villota-Paz, J. M.; Osorio-Tejada, J. L.; Morales-Pinzón, T. Comparative Life Cycle Assessment for the Manufacture of Bio-Detergents. *Environmental Science and Pollution Research*, **2023**, *30* (12). <https://doi.org/10.1007/s11356-022-24439-x>.
- [29] YU, Y.; ZHAO, J.; Bayly, A. E. Development of Surfactants and Builders in Detergent Formulations. *Chinese Journal of Chemical Engineering*, **2008**, *16* (4). [https://doi.org/10.1016/S1004-9541\(08\)60115-9](https://doi.org/10.1016/S1004-9541(08)60115-9).
- [30] Khaerani, H.; Rohayati, Y.; Kusumayanti, I. N. Perancangan Perbaikan Positioning Produk Kemeja Schouten Berdasarkan Perceptual Mapping Dengan Metode Multidimensional Scaling. *Journal of Management and Bussines (JOMB)*, **2023**, *5* (1). <https://doi.org/10.31539/jomb.v5i1.5820>.
- [31] Chiplunkar, P. P.; Shinde, V. V.; Pratap, A. P. Synthesis and Application of Palm Fatty Acid Distillate Based Alkyd Resin in Liquid Detergent. *Journal of Surfactants and Detergents*, **2017**, *20* (1). <https://doi.org/10.1007/s11743-016-1905-9>.
- [32] Salih, H. S.; Ghazi, M.; Aljanabi, M. Implementing an Automated Inventory Management System for Small and Medium-Sized Enterprises. *Iraqi Journal for Computer Science and Mathematics*, **2023**, *4* (2). <https://doi.org/10.52866/ijcsm.2023.02.02.021>.
- [33] Abramson, J. J.; Shamoo, A. E. Anionic Detergents as Divalent Cation Ionophores across Black Lipid Membranes. *The Journal of Membrane Biology*, **1979**, *50* (3–4). <https://doi.org/10.1007/BF01868891>.
- [34] Aboul-Kassim, T. A.; Simoneit, B. R. T. Detergents: A Review of the Nature, Chemistry, and Behavior in the Aquatic Environment. Part I. Chemical Composition and Analytical Techniques. *Critical Reviews in Environmental Science and Technology*. 1993. <https://doi.org/10.1080/10643389309388456>.
- [35] G.E, O.; O.T, A.; R.O, A.; O.S, O.; P.O, A.; M.H, E. Assessment of the Toxicity and Biochemical Effects of Detergent Processed Cassava on Renal Function of Wistar Rats. *Toxicology Reports*, **2020**, *7*. <https://doi.org/10.1016/j.toxrep.2020.08.007>.
- [36] Bertrand, M.; Barot, S.; Blouin, M.; Whalen, J.; de Oliveira, T.; Roger-Estrade, J. Earthworm Services for Cropping Systems. A Review. *Agronomy for Sustainable Development*. 2015. <https://doi.org/10.1007/s13593-014-0269-7>.
- [37] Sachith, S. A Study on the Effect of Detergent on Megasculexkonkanensis. **2020**, No. May. <https://doi.org/10.15680/IJRSET.2019.0808015>.
- [38] Wu, J.; Zhang, C.; Xiao, L.; Motelica-Heino, M.; Ren, Z.; Deng, T.; Dai, J. Impacts of Earthworm Species on Soil Acidification, Al Fractions, and Base Cation Release in a Subtropical Soil from China. *Environmental Science and Pollution Research*, **2020**, *27* (27). <https://doi.org/10.1007/s11356-019-05055-8>.
- [39] Liu, C. H.; Lin, Y. W.; Tang, N. Y.; Liu, H. J.; Huang, C. Y.; Hsieh, C. L. Effect of Oral Administration of Pheretima Aspergillum (Earthworm) in Rats with Cerebral Infarction Induced by Middle-Cerebral Artery Occlusion. *African journal of traditional, complementary, and alternative medicines: AJTCAM / African Networks on Ethnomedicines*, **2012**, *10* (1). <https://doi.org/10.4314/ajtcam.v10i1.11>.
- [40] CUI, Y.; WANG, H. Introduction to the Monograph of Annelida: Oligochaeta: Haplotaxidae, Lumbriculidae, Naididae and Tubificidae in China. *Zoosymposia*, **2023**, *23*. <https://doi.org/10.11646/zoosymposia.23.1.11>.
- [41] Sinha, R. K.; Agarwal, S.; Chauhan, K.; Chandran, V.; Soni, B. K. Vermiculture

- Technology: Reviving the Dreams of Sir Charles Darwin for Scientific Use of Earthworms in Sustainable Development Programs. *Technology and Investment*, **2010**, 01 (03). <https://doi.org/10.4236/ti.2010.13019>.
- [42] Jiem, C.; Wong, M. H. Effect of Earthworm (Pheetmosp.) Density on Revegetation of Lead/Zinc Metal Mine Tailings Amended with Soil. *Chinese Journal of Population Resources and Environment*, **2008**, 6 (2). <https://doi.org/10.1080/10042857.2008.10684867>.
- [43] Singh, T. A.; Pal, N.; Sharma, P.; Passari, A. K. Spent Coffee Ground: Transformation from Environmental Burden into Valuable Bioactive Metabolites. *Reviews in Environmental Science and Biotechnology*. 2023. <https://doi.org/10.1007/s11157-023-09669-w>.
- [44] Waqar, A.; Shah, G. M.; Bakhat, H. F.; Shahid, M.; Aslam, M.; Ashraf, M. R.; Hafeez, R.; Murtaza, B.; Rashid, M. I. The Earthworm Species Pheretima Hawayana Influences Organic Wastes Decomposition, Nitrogen Mineralization and Maize N Recovery. *European Journal of Soil Biology*, **2019**, 90. <https://doi.org/10.1016/j.ejsobi.2018.11.003>.
- [45] Wu, J.; Ren, Z.; Zhang, C.; Motelica-Heino, M.; Deng, T.; Wang, H.; Dai, J. Effects of Soil Acid Stress on the Survival, Growth, Reproduction, Antioxidant Enzyme Activities, and Protein Contents in Earthworm (Eisenia Fetida). *Environmental Science and Pollution Research*, **2020**, 27 (27). <https://doi.org/10.1007/s11356-019-04643-y>.
- [46] Yadav, R.; Kumar, R.; Gupta, R. K.; Kaur, T.; Kiran, K.; Kour, A.; Kaur, S.; Rajput, A. Heavy Metal Toxicity in Earthworms and Its Environmental Implications: A Review. *Environmental Advances*. 2023. <https://doi.org/10.1016/j.envadv.2023.100374>.
- [47] Bhat, S. A.; Singh, J.; Vig, A. P. Effect on Growth of Earthworm and Chemical Parameters During Vermicomposting of Pressmud Sludge Mixed with Cattle Dung Mixture. *Procedia Environmental Sciences*, **2016**, 35. <https://doi.org/10.1016/j.proenv.2016.07.025>.
- [48] Beaula, B.; Queensly, and C. Effects of Sub Lethal Toxicity of Cypermethrin on Haematological Parameters Effects of Sub Lethal Toxicity of Cypermethrin on Haematological Parameters of Labeo Rohita (Hamilton). **2022**, No. October.
- [49] Badmus, S. O.; Amusa, H. K.; Oyehan, T. A.; Saleh, T. A. Environmental Risks and Toxicity of Surfactants: Overview of Analysis, Assessment, and Remediation Techniques. *Environmental Science and Pollution Research*. 2021. <https://doi.org/10.1007/s11356-021-16483-w>.
- [50] Bahar, I. Distribution of Earthworms at Different Habitats in Tangail, Bangladesh and Significantly Impacts on Soil PH, Organic Carbon and Nitrogen. *American Journal of Life Sciences*, **2015**, 3 (3). <https://doi.org/10.11648/j.ajls.20150303.26>.
- [51] Hoeffner, K.; Monard, C.; Santonja, M.; Cluzeau, D. Feeding Behaviour of Epi-Anecic Earthworm Species and Their Impacts on Soil Microbial Communities. *Soil Biology and Biochemistry*, **2018**, 125. <https://doi.org/10.1016/j.soilbio.2018.06.017>.
- [52] Ezemonye, L. I. N.; Ogeleka, D. F.; Okeimen, F. E. Toxicity of Neatex (Industrial Detergent) and Norust CR 486 (Corrosion Inhibitors) to Earthworms (Aporrectodea Longa) in Naturally Spiked Soil. *African Journal of Biotechnology*, **2006**, 5 (11).
- [53] Wang, W.; Zhang, J.; Wu, J.; Yu, R.; Zhang, Y.; Sun, L.; Gao, Y. Acute Toxicity and Ecotoxicological Risk Assessment of Three Volatile Pesticide Additives on the Earthworm—Eisenia Fetida. *International Journal of Environmental Research and Public Health*, **2021**, 18 (21). <https://doi.org/10.3390/ijerph182111232>.

- [54] Kumar, A.; Kamboj, N.; Kamboj, V.; Bisht, A.; Pandey, N.; Bharti, M. Efficient Management of Rice Straw Using Vermicomposting Technology: A Synergetic Approach of Agricultural Waste Management. In *Springer Proceedings in Earth and Environmental Sciences*; 2022. https://doi.org/10.1007/978-3-031-05335-1_9.
- [55] Gaupp-Berghausen, M.; Hofer, M.; Rewald, B.; Zaller, J. G. Glyphosate-Based Herbicides Reduce the Activity and Reproduction of Earthworms and Lead to Increased Soil Nutrient Concentrations. *Scientific Reports*, **2015**, *5*. <https://doi.org/10.1038/srep12886>.
- [56] Basha, P. M.; Latha, V. Evaluation of Sublethal Toxicity of Zinc and Chromium in *Eudrilus Eugeniae* Using Biochemical and Reproductive Parameters. *Ecotoxicology*, **2016**, *25* (4). <https://doi.org/10.1007/s10646-016-1637-7>.
- [57] Singh, A.; Kumar, V.; Verma, S.; Majumdar, M.; Sarkar, S. Significance of Vermicompost on Crop and Soil Productivity: A Review. *International Journal of Chemical Studies*, **2020**, *8* (5). <https://doi.org/10.22271/chemi.2020.v8.i5u.10517>.
- [58] Miškelytė, D.; Žaltauskaitė, J. Effects of Elevated Temperature and Decreased Soil Moisture Content on Triclosan Ecotoxicity to Earthworm *E. Fetida*. *Environmental Science and Pollution Research*, **2023**, *30* (17). <https://doi.org/10.1007/s11356-023-25951-4>.
- [59] Heggelund, L. R.; Diez-Ortiz, M.; Lofts, S.; Lahive, E.; Jurkschat, K.; Wojnarowicz, J.; Cedergreen, N.; Spurgeon, D.; Svendsen, C. Soil PH Effects on the Comparative Toxicity of Dissolved Zinc, Non-Nano and Nano ZnO to the Earthworm *Eisenia Fetida*. *Nanotoxicology*, **2014**, *8* (5). <https://doi.org/10.3109/17435390.2013.809808>.
- [60] Ray, S.; Gautam, A.; Ray, A.; Das, S.; Ray, M. Analysis of Oxidative Stress and Cellular Aggregation in the Coelomocytes of Earthworms Collected from Metal Contaminated Sites of Industrial and Agricultural Soils of West Bengal, India. *Environmental Science and Pollution Research*, **2019**, *26* (22). <https://doi.org/10.1007/s11356-019-05438-x>.
- [61] Zeb, A.; Li, S.; Wu, J.; Lian, J.; Liu, W.; Sun, Y. Insights into the Mechanisms Underlying the Remediation Potential of Earthworms in Contaminated Soil: A Critical Review of Research Progress and Prospects. *Science of the Total Environment*. 2020. <https://doi.org/10.1016/j.scitotenv.2020.140145>.
- [62] Zhao, W.; Teng, M.; Zhang, J.; Wang, K.; Zhang, J.; Xu, Y.; Wang, C. Insights into the Mechanisms of Organic Pollutant Toxicity to Earthworms: Advances and Perspectives. *Environmental Pollution*. 2022. <https://doi.org/10.1016/j.envpol.2022.119120>.
- [63] Adeel, M.; Shakoor, N.; Shafiq, M.; Pavlicek, A.; Part, F.; Zafiu, C.; Raza, A.; Ahmad, M. A.; Jilani, G.; White, J. C.; et al. A Critical Review of the Environmental Impacts of Manufactured Nano-Objects on Earthworm Species. *Environmental Pollution*. 2021. <https://doi.org/10.1016/j.envpol.2021.118041>.
- [64] Liu, B. Dilutions of Household Detergents Kill *Eisenia Andrei* and *Pheretima Guillelmi* Earthworms. **2022**, 1–12.
- [65] Hmar, L.; Ramanujam, S. N. Earthworm Cast Production and Physico-Chemical Properties in Two Agroforestry Systems of Mizoram (India). *Tropical Ecology*, **2014**, *55* (1).
- [66] Le Bayon, R. C.; Binet, F. Earthworms Change the Distribution and Availability of Phosphorous in Organic Substrates. *Soil Biology and Biochemistry*, **2006**, *38* (2), 235–246. <https://doi.org/10.1016/j.soilbio.2005.05.013>.
- [67] Clause, J.; Barot, S.; Richard, B.; Decaëns, T.; Forey, E. The Interactions between Soil Type and Earthworm Species Determine the Properties of Earthworm Casts. *Applied Soil*

- Ecology*, **2014**, 83. <https://doi.org/10.1016/j.apsoil.2013.12.006>.
- [68] Dey, A.; Chaudhuri, P. S. Earthworm Community Structure of Pineapple (Ananas Comosus) Plantations under Monoculture and Mixed Culture in West Tripura, India. *Tropical Ecology*, **2014**, 55 (1).
- [69] Boonchamni, C.; Boonthai Iwai, C.; Ta-Oun, M. *Physical-Chemical Properties of Earthworm Casts in Different Earthworm Species*; 2019.
- [70] Chaudhuri, P. S.; Pal, T. K.; Nath, S.; Dey, S. K. Effects of Five Earthworm Species on Some Physico-Chemical Properties of Soil. *Journal of Environmental Biology*, **2012**, 33 (4).
- [71] Iordache, M. Chemical Composition of Earthworm Casts as a Tool in Understanding the Earthworm Contribution to Ecosystem Sustainability – a Review. *Plant, Soil and Environment*. 2023. <https://doi.org/10.17221/461/2022-PSE>.
- [72] Vuković, A.; Velki, M.; Ečimović, S.; Vuković, R.; Čamagajevac, I. Š.; Lončarić, Z. Vermicomposting—Facts, Benefits and Knowledge Gaps. *Agronomy*. 2021. <https://doi.org/10.3390/agronomy11101952>.
- [73] Bhat, S. A.; Singh, J.; Vig, A. P. Potential Utilization of Bagasse as Feed Material for Earthworm Eisenia Fetida and Production of Vermicompost. *SpringerPlus*, **2015**, 4 (1). <https://doi.org/10.1186/s40064-014-0780-y>.
- [74] Liu, P.; Song, Y.; Wei, J.; Mao, W.; Ju, J.; Zheng, S.; Zhao, H. Synergistic Effects of Earthworms and Plants on Chromium Removal from Acidic and Alkaline Soils: Biological Responses and Implications. *Biology*, **2023**, 12 (6). <https://doi.org/10.3390/biology12060831>.
- [75] Rathore, S.; Kumar, R. Vermicompost Fertilization and Pinching Improves the Growth, Yield, and Quality of Super Food (Chenopodium Quinoa Willd.) in the Western Himalaya. *Acta Physiologiae Plantarum*, **2021**, 43 (2). <https://doi.org/10.1007/s11738-020-03184-z>.
- [76] Ali, U.; Sajid, N.; Khalid, A.; Riaz, L.; Rabbani, M. M.; Syed, J. H.; Malik, R. N. A Review on Vermicomposting of Organic Wastes. *Environmental Progress and Sustainable Energy*. 2015. <https://doi.org/10.1002/ep.12100>.
- [77] Enebe, M. C.; Erasmus, M. Mediators of Biomass Transformation – A Focus on the Enzyme Composition of the Vermicomposting Process. *Environmental Challenges*. 2023. <https://doi.org/10.1016/j.envc.2023.100732>.
- [78] Picchioni, G. A. Seashore Paspalum: The Environmental Turfgrass. *HortTechnology*, **2018**, 11 (1). <https://doi.org/10.21273/horttech.11.1.144>.
- [79] Singh, J.; Singh, S.; Vig, A. P.; Kaur, A. Environmental Influence of Soil toward Effective Vermicomposting. In *Earthworms - The Ecological Engineers of Soil*; 2018. <https://doi.org/10.5772/intechopen.75127>.
- [80] Medina-Sauza, R. M.; Álvarez-Jiménez, M.; Delhal, A.; Reverchon, F.; Blouin, M.; Guerrero-Analco, J. A.; Cerdán, C. R.; Guevara, R.; Villain, L.; Barois, I. Earthworms Building up Soil Microbiota, a Review. *Frontiers in Environmental Science*. 2019. <https://doi.org/10.3389/fenvs.2019.00081>.
- [81] Wani, S. A.; Mugal, M. A.; Dar, F. A.; Sudhakar Reddy, C.; Rashid, I.; Khuroo, A. A. Biodiversity Data Synthesis on Trees of Indian Himalayan Region: Policy and Management Implications. *Global Ecology and Conservation*, **2023**, 48. <https://doi.org/10.1016/j.gecco.2023.e02698>.
- [82] Pandey, R.; Rawat, M.; Pathak, A.; Mehta, D.; Bala, N.; Bhatt, I. D.; Chaturvedi, R. K.

- Identification of Functional Traits Responsible for Environmental Vulnerability of Cedrus Deodara in Temperate Forests of Western Himalaya. *Ecological Indicators*, **2023**, 157. <https://doi.org/10.1016/j.ecolind.2023.111302>.
- [83] Access, O. Taxa. **2024**, 2024 (June).
- [84] Arora, S.; Bhatt, R.; Sharma, V.; Hadda, M. S. Indigenous Practices of Soil and Water Conservation for Sustainable Hill Agriculture and Improving Livelihood Security. *Environmental Management*, **2023**, 72 (2). <https://doi.org/10.1007/s00267-022-01602-1>.
- [85] Sud, A.; Kanga, R.; Singh, S. K.; Meraj, G.; Kanga, S.; Kumar, P.; Ramanathan, A. L.; Sudhanshu; Bhardwaj, V. Simulating Groundwater Potential Zones in Mountainous Indian Himalayas—A Case Study of Himachal Pradesh. *Hydrology*, **2023**, 10 (3). <https://doi.org/10.3390/hydrology10030065>.
- [86] Thakur, A.; Kumar, A.; Kumar, C. V.; Kiran, B. S.; Kumar, S.; Athokpam, V. A Review on Vermicomposting: By-Products and Its Importance. *Plant Cell Biotechnology and Molecular Biology*, **2021**, 22 (11–12).
- [87] Chen, C.; Habert, G.; Bouzidi, Y.; Jullien, A. Environmental Impact of Cement Production: Detail of the Different Processes and Cement Plant Variability Evaluation. *Journal of Cleaner Production*, **2010**, 18 (5). <https://doi.org/10.1016/j.jclepro.2009.12.014>.
- [88] Amrita, A.; Yadav, M.; Yadav, E. The Pollution Status of Some North Indian Rivers : A Review. *JOURNAL OF EXPERIMENTAL ZOOLOGY INDIA*, **2024**, 27 (01). <https://doi.org/10.51470/jez.2024.27.1.1>.
- [89] Ukaogo, P. O.; Ewuzie, U.; Onwuka, C. V. Environmental Pollution: Causes, Effects, and the Remedies. In *Microorganisms for Sustainable Environment and Health*; 2020. <https://doi.org/10.1016/B978-0-12-819001-2.00021-8>.
- [90] Rätty, M.; Huhta, V. Earthworms and PH Affect Communities of Nematodes and Enchytraeids in Forest Soil. *Biology and Fertility of Soils*, **2003**, 38 (1). <https://doi.org/10.1007/s00374-003-0614-5>.
- [91] Julka, A. S. J.; Ahmed, S. Earthworm Diversity and Distribution in District Mandi, Himachal Pradesh of Northwest Himalaya, India. *Journal of Entomology and Zoology Studies*, **2022**, 10 (5). <https://doi.org/10.22271/j.ento.2022.v10.i5b.9050>.
- [92] Rajwar, N.; Singh, V.; Bhatt, S.; Bisht, S. S. Earthworm Population Dynamics in Three Different Land Use Systems along an Altitudinal Gradient (208–2609 m Asl) in Kumaun Himalayas, India. *Tropical Ecology*, **2022**, 63 (1). <https://doi.org/10.1007/s42965-021-00178-x>.
- [93] Singh, S.; Singh, J.; Vig, A. P. Diversity and Abundance of Earthworms in Different Landuse Patterns: Relation with Soil Properties. *Asian Journal of Biological and Life Sciences*, **2020**, 9 (2). <https://doi.org/10.5530/ajbls.2020.9.18>.
- [94] Ahmed, S.; Julka, J. M.; Kumar, H. Earthworms (Annelida: Clitellata: Megadrili) of Solan, a Constituent of Himalayan Biodiversity Hotspot, India. *Travaux du Muséum National d'Histoire Naturelle "Grigore Antipa"*, **2020**, 63 (1). <https://doi.org/10.3897/travaux.63.e49099>.
- [95] Rashid, A.; Schutte, B. J.; Ulery, A.; Deyholos, M. K.; Sanogo, S.; Lehnhoff, E. A.; Beck, L. Heavy Metal Contamination in Agricultural Soil: Environmental Pollutants Affecting Crop Health. *Agronomy*. 2023. <https://doi.org/10.3390/agronomy13061521>.

•