

Pesticide Usage Patterns in Tomato Cultivation: A Field-Based Assessment in Chamarajanagara District, Karnataka

Arun K S¹, Nagalambika Prasad², Harsha T. S³, and Lingaraju H G*¹

¹Department of Environmental Sciences, JSSAHER, Mysuru, India

²Department of Microbiology, JSSAHER, Mysuru, India

³Department of Environmental Sciences, KSOU, Mysuru, India

Citation: Arun K S, Nagalambika Prasad, Harsha T. S, and Lingaraju H G (2026). Pesticide Usage Patterns in Tomato Cultivation: A Field-Based Assessment in Chamarajanagara District, Karnataka. *Environmental Reports; an International Journal*.

DOI: <https://doi.org/10.51470/ER.2026.8.2.66>

Corresponding Author: Lingaraju H G | E-Mail: (lingarajuhg@jssuni.edu.in)

Received 25 April 2026 | Revised 22 May 2026 | Accepted 23 June 2026 | Available Online July 26 2026

ABSTRACT

Tomato (*Solanum lycopersicum* L.) is an economically important vegetable crop in Karnataka and is highly susceptible to a range of insect pests and diseases. Consequently, chemical pesticides are frequently used to protect tomato crops and maintain productivity. However, repeated and inappropriate pesticide application may contribute to pesticide residues, soil-quality deterioration, disruption of beneficial microorganisms, development of pest resistance and occupational exposure. The present study was undertaken to assess pesticide-use practices in tomato cultivation in Chamarajanagara District, Karnataka, with particular emphasis on the physicochemical and microbiological characteristics of agricultural soils from the district. Soil samples representing five taluks Gundlupete, Chamarajanagar, Kollegala, Hanur and Yelandur were analysed for pH, nitrogen, potassium, organic carbon, phosphorus, magnesium, electrical conductivity, total bacterial count, yeast and mould count, and actinomycete count. The laboratory analyses were conducted in December 2025 using procedures referenced to the Soil Testing Manual of the Department of Agriculture and Co-operation, Government of India, and FAO methodology. The observed soil pH ranged from 7.52 to 8.38, indicating neutral to moderately alkaline conditions. Electrical conductivity varied substantially from 158 to 4200 $\mu\text{S}/\text{cm}$, while total organic carbon ranged from 0.10 to 1.92%. Nitrogen ranged from 112 to 261.07 mg kg^{-1} , potassium from 65 to 255 mg kg^{-1} and phosphorus from 222.13 to 632.04 mg kg^{-1} . Considerable variation was also observed in microbial populations, with total bacterial counts ranging from 5×10^6 to 1.1×10^8 , yeast and mould counts from 3×10^5 to 8.8×10^6 , and actinomycete counts from 2×10^5 to 5×10^5 . These findings demonstrate substantial spatial variation in soil characteristics among the selected taluks. However, the present laboratory dataset alone does not establish that the observed differences were caused by pesticide application. Farmer-level pesticide-use information, including active ingredients, formulation, dose, number of applications, application intervals and field history, is required to establish such relationships. The study provides a useful baseline for integrating pesticide-use surveys with soil quality and microbial assessment and for developing integrated pest management strategies for tomato cultivation in Chamarajanagara District.

Keywords: Tomato, pesticide, soil quality, soil microorganisms, integrated pest management, Chamarajanagara.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the major vegetable crops cultivated in India and is an important component of commercial horticulture and smallholder farming systems. Tomato production is affected by a wide range of insect pests and diseases, and the intensity of pest incidence varies with season, crop growth stage, climatic conditions, cultivar and crop-management practices. Consequently, chemical pesticides continue to be an important component of pest-management programmes in many tomato-growing regions. Recent studies from India have also identified high pest and disease incidence and expenditure on plant-protection chemicals among the important production constraints perceived by tomato growers, emphasising the continuing dependence on chemical crop protection in intensive tomato production systems [18]. The intensive use of pesticides has attracted considerable attention because of potential occupational, environmental and food-safety implications.

The Food and Agriculture Organisation (FAO) recognises that inappropriate pesticide use can harm farmers, consumers, non-target organisms and ecosystems, while excessive reliance on pesticides may contribute to pest resistance and disruption of natural enemies. FAO therefore promotes integrated pest management (IPM) and rational pesticide use as components of sustainable crop production. The FAO/WHO International Code of Conduct on Pesticide Management further emphasises responsible management throughout the pesticide life cycle, including selection, distribution, storage, application and disposal [9,10].

The dependence of vegetable growers on chemical pesticides is influenced by pest pressure, farmers' perceptions of pesticide effectiveness, accessibility of agricultural inputs and sources of technical information. De Costa et al. [8], in a study of small-scale chilli and tomato farmers, reported substantial dependence on pesticides and limited adoption of IPM, highlighting the importance of farmer awareness, training and improved pest-management practices.

Such findings demonstrate that pesticide-use behaviour is not determined solely by the occurrence of pests but is also associated with farmers' knowledge, perceptions and access to appropriate technical advice.

Evidence from Karnataka provides important location-specific information. Keshavareddy et al. [11], in a survey of 129 tomato growers in Ramanagara District, documented the use of numerous pesticides in tomato production. Pesticide dealers were reported as an important source of pesticide-related information, while many farmers used knapsack sprayers and did not consistently adopt recommended personal-protection measures. The study emphasized farmer education, safe pesticide handling and integrated pest and disease management. More recent research on tomato production in Karnataka has continued to identify high expenditure on plant-protection chemicals and severe pest and disease incidence as important production constraints, indicating that pesticide-dependent crop protection remains relevant to tomato-growing systems in the state [18].

The environmental significance of pesticide use extends beyond the target pest. Following application, pesticides can undergo adsorption, degradation, volatilisation, runoff and leaching, depending on their physicochemical characteristics and environmental conditions. Agricultural soils can consequently act as important sinks for pesticide residues and may also facilitate their subsequent movement into surface water and groundwater. A comprehensive review of pesticide contamination in India by Rajan et al. [15] documented pesticide occurrence in different components of the hydrogeo-environment and emphasised the importance of agricultural activities as sources of pesticide contamination and subsequent environmental transport.

Pesticide residues are also relevant to food safety because repeated applications during crop production can result in detectable residues in harvested commodities. Monitoring studies conducted in India have demonstrated the occurrence of multiple pesticide residues in fruiting vegetables. Sharma et al. [17], for example, evaluated 2,319 samples of tomato, capsicum, brinjal and cucurbits collected from northern and western regions of India and detected 56 pesticides among 155 analytes investigated. Frequently detected compounds included acetamiprid, profenofos, imidacloprid and chlorpyrifos. Similarly, Khetagoudar et al. [13] developed and validated a multiresidue GC-MS/MS method for determination of pesticides in tomato, demonstrating the importance of sensitive analytical approaches for monitoring pesticide residues in tomato production systems.

Importantly, pesticide residues may occur not only in harvested tomato fruits but also in the soil in which the crop is cultivated. Akoijam et al. [1] investigated the residual behaviour of chlorantraniliprole, thiamethoxam, flubendiamide and deltamethrin in tomato and soil under field conditions, demonstrating the relevance of soil as a compartment for assessing pesticide persistence following crop protection treatments. Kumar et al. [14] similarly investigated the dissipation and persistence of chlorantraniliprole in tomato under open-field conditions and reported measurable initial residues followed by decline over time, illustrating the importance of application rate, environmental conditions and pre-harvest intervals in pesticide-residue dynamics.

Soil is particularly important because it functions not only as the physical medium for crop production but also as a complex biological system.

Soil microorganisms, including bacteria, fungi and actinomycetes, perform essential ecosystem functions associated with decomposition, organic-matter transformation, nutrient mineralisation, carbon cycling, nitrogen transformation and maintenance of soil fertility. Consequently, changes in soil physicochemical and microbiological characteristics can provide useful indicators of soil quality and ecosystem functioning. Parameters such as soil pH, electrical conductivity, organic carbon, available nitrogen, phosphorus, potassium and microbial abundance are therefore valuable for characterizing agricultural soils.

A growing body of research indicates that pesticide exposure can influence soil microbial communities, although the magnitude and direction of these effects depend on pesticide type, concentration, application frequency, soil characteristics and the sensitivity of individual microbial groups. Akter et al. [2], in a systematic review of the effects of neonicotinoids on soil microbiology, found that the available studies reported variable responses; nevertheless, approximately 45% of the reviewed studies reported adverse effects on microbial community structure, diversity, functioning, enzymatic activity or nitrogen transformation. The authors also highlighted the limited number of field-based investigations and the need to consider interactions between pesticide exposure and soil physicochemical properties.

Similarly, recent reviews have emphasized that pesticide exposure can alter soil microbial diversity, composition and functional processes. A review by Dangi [7] summarized evidence that herbicides and insecticides can influence soil microbial communities and emphasized the importance of understanding pesticide-microbiome interactions under intensive agricultural systems. Residual pesticides may also affect beneficial soil bacteria through physiological and enzymatic mechanisms, potentially influencing microbial functions associated with nutrient cycling and soil fertility. These observations are particularly relevant to vegetable production systems where repeated pesticide application may result in recurring exposure of soil microbial communities.

At the same time, soil microorganisms constitute an important biological mechanism for pesticide transformation and degradation. Microbial degradation can involve processes such as hydrolysis, oxidation, reduction and other enzymatically mediated transformations. The efficiency of biodegradation depends on pesticide chemistry, soil pH, temperature, moisture, organic matter, nutrient availability and the composition and metabolic capacity of indigenous microbial communities. Aldas-Vargas et al. [3] emphasized that pesticides applied to agricultural fields can enter soil and subsequently reach surface water and groundwater, while monitoring their biodegradation at environmentally relevant concentrations remains technically challenging. More recent research has highlighted the potential of pesticide-tolerant microbial consortia and plant-growth-promoting rhizobacteria for transforming pesticide compounds and supporting remediation of contaminated agricultural soils. Microbial enzymes involved in pesticide degradation have also received increasing attention as potential tools for the bioremediation of pesticide-contaminated soils [6].

The relationship between pesticide application and soil health is therefore complex. Pesticides may exert selective or inhibitory effects on particular microbial groups, whereas pesticide-degrading microorganisms may become enriched under repeated exposure.

The response may further depend on soil physicochemical conditions and the characteristics of the pesticide applied. Recent work has consequently emphasized the need to examine pesticide persistence together with microbial dynamics rather than treating pesticide contamination and soil microbiology as independent components [16].

From an agricultural sustainability perspective, assessment of pesticide use should therefore extend beyond simply recording whether pesticides are applied. Information on the type and number of pesticides, active ingredients, frequency and dosage of application, target pests, application methods, sources of pesticide-related information and adoption of protective measures provides a more meaningful description of pesticide-use behaviour. When combined with assessment of soil physicochemical and microbiological characteristics, such information can provide an integrated baseline for understanding the environmental implications of pesticide-dependent tomato production.

Chamarajanagara District is an important agricultural region of southern Karnataka, where vegetable cultivation contributes substantially to local agricultural activity and rural livelihoods. However, compared with other tomato-producing areas of Karnataka, location-specific information linking pesticide-use practices with soil physicochemical and microbiological characteristics in Chamarajanagara District remains limited. In particular, systematic information on the types and frequency of pesticides used by tomato growers and the associated condition of agricultural soils is required to establish a regional baseline.

Therefore, the present study was undertaken to (i) document pesticide-use patterns and practices among tomato growers in the major tomato-growing areas of Chamarajanagara District, Karnataka; (ii) assess selected physicochemical characteristics of soils under tomato cultivation; and (iii) evaluate selected microbiological characteristics of these soils to establish a baseline for understanding the relationship between pesticide-dependent crop management and soil quality. The study is intended to generate location-specific information that can support safer pesticide-use practices, farmer awareness, integrated pest management and sustainable management of agricultural soils in tomato-growing systems.

2. Materials and Methods

2.1 Study area

The study was conducted in Chamarajanagara District, Karnataka, India. Soil samples were represented by five taluks of the district: Gundlupete, Chamarajanagar, Kollegala, Hanur, Yelandur.

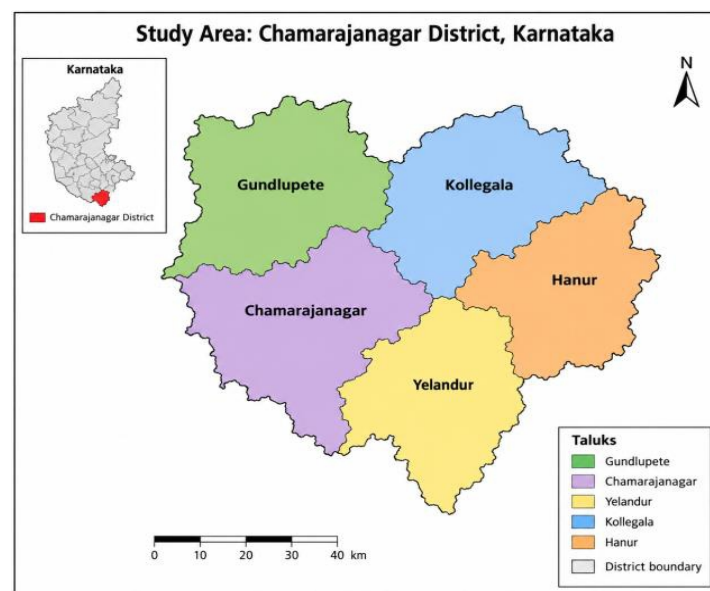
The study incorporated laboratory analysis of soil samples collected from the selected locations.

2.2 Soil sampling and laboratory analysis

According to the laboratory report, the soil samples were submitted for testing on 09 December 2025, analysed between 10 and 17 December 2025, and the reports were issued on 18 December 2025. The samples were supplied by the researcher and were reported to be in satisfactory condition on receipt.

The laboratory report identifies the following parameters:

Sl. No	Parameter
1	pH at 25°C
2	Electrical conductivity
3	Potassium as K
4	Oxygen carbon
5	Total organic carbon
6	Phosphorus
7	Magnesium
8	Nitrogen as N
9	Total bacterial count
10	Yeast and mould count
11	Actinomycete count



The physicochemical analyses were reported with reference to the Soil Testing Manual of the Department of Agriculture and Co-operation, Ministry of Agriculture, Government of India (January 2011) and FAO-2007.

Microbiological parameters were reported as counts obtained through laboratory microbiological procedures. The laboratory report also states that calibrated instruments were used for sampling and testing and that the reported results apply only to the tested samples and parameters.

2.3 Farmer survey for pesticide-use assessment

For the pesticide-use component, a structured questionnaire should be administered to selected tomato growers in each taluk. The questionnaire should record:

- farmer age and education;
- farm size;
- area under tomato cultivation;
- tomato variety/hybrid;
- cropping season;
- major insect pests and diseases;
- pesticide trade name;
- active ingredient;
- pesticide category;
- formulation;
- quantity purchased;
- quantity applied per acre/hectare;
- number of applications;

- interval between applications;
- mixing of pesticides;
- use of adjuvants;
- spraying equipment;
- source of pesticide recommendation;
- use of personal protective equipment;
- pre-harvest interval;
- storage practices;
- disposal of empty containers;
- awareness of pesticide labels;
- awareness of IPM practices.

Important methodological note: these farmer-level pesticide-use variables were not included in the uploaded laboratory report. Consequently, no numerical pesticide-use values have been assigned in the present manuscript.

2.4 Microbiological assessment

The available laboratory data included total bacterial count, yeast and mould count, and actinomycete count.

These measurements were considered indicators of the culturable microbial component of the analysed soils.

2.5 Data analysis

Descriptive statistics including minimum, maximum, mean and standard deviation can be used for the soil parameters. Pesticide-use data, once collected, can be analysed using frequency distributions, percentages, mean application frequency and quantity of active ingredient applied per unit area. For evaluating relationships between pesticide use and soil characteristics, Pearson or Spearman correlation analysis may be employed depending on data distribution. Analysis of variance (ANOVA) may be used to compare soil parameters among taluks if assumptions of the statistical test are satisfied.

3.0 Results

3.1 Physicochemical characteristics of soil

The laboratory results showed considerable variation among the five sampled taluks.

Table 1: Physicochemical characteristics of soil samples from different taluks of Chamarajanagara District

Parameter	Gundlupete	Chamarajanagar	Kollegala	Hanur	Yelandur
pH	7.52	8.38	7.92	7.96	8.15
Nitrogen (mg/kg)	112.00	229.60	168.00	261.07	233.00
Potassium (mg/kg)	65.00	190.00	180.00	200.00	255.00
Oxygen carbon (%)	0.21	3.31	0.17	1.84	1.10
Total organic carbon (%)	0.21	1.92	0.10	1.07	0.64
Phosphorus (mg/kg)	222.13	293.12	352.66	261.06	632.04
Magnesium (mg/kg)	264.00	312.00	324.00	48.00	84.00
EC ($\mu\text{S}/\text{cm}$)	158	4200	2500	276	1120

The soil pH ranged from 7.52 in Gundlupete to 8.38 in Chamarajanagar. The overall mean pH of the five samples was approximately 7.99. Nitrogen concentrations ranged from 112 mg/kg in Gundlupete to 261.07 mg/kg in Hanur. Potassium varied from 65 mg/kg in Gundlupete to 255 mg/kg in Yelandur. Phosphorus exhibited substantial variation, with the lowest concentration of 222.13 mg/kg in Gundlupete and the highest concentration of 632.04 mg/kg in Yelandur. Total organic carbon varied markedly among the samples. The lowest value was 0.10% in Kollegala, whereas the highest was 1.92% in Chamarajanagar. Electrical conductivity showed the greatest apparent spatial variation among the measured physicochemical parameters. Values ranged from 158 $\mu\text{S}/\text{cm}$ in Gundlupete to 4200 $\mu\text{S}/\text{cm}$ in Chamarajanagar, with intermediate values of 2500 $\mu\text{S}/\text{cm}$ in Kollegala, 276 $\mu\text{S}/\text{cm}$ in Hanur and 1120 $\mu\text{S}/\text{cm}$ in Yelandur.

3.2 Soil microbial characteristics

Table 2: Microbial characteristics of soil samples

Parameter	Gundlupete	Chamarajanagar	Kollegala	Hanur	Yelandur
Total bacterial count	5.6×10^7	10.1×10^7	5×10^6	11×10^7	5.7×10^7
Yeast& mould count	3×10^5	4×10^5	5×10^5	8.8×10^6	1.6×10^6
Actinomycete count	5×10^5	2×10^5	2×10^5	3×10^5	5×10^5

Total bacterial counts ranged from 5×10^6 in Kollegala to 11×10^7 in Hanur. The highest yeast and mould count was observed in Hanur (8.8×10^6), whereas the lowest was observed in Gundlupete (3×10^5). Actinomycete counts varied between 2×10^5 and 5×10^5 .

The variation indicates that the microbial characteristics of the sampled agricultural soils were not uniform across the district.

4. Discussion

4.1 Spatial variation in soil physicochemical characteristics

The present study revealed appreciable spatial variation in the physicochemical characteristics of soils collected from the five selected taluks of Chamarajanagara District. Soil pH ranged from 7.52 to 8.38, indicating predominantly neutral to moderately alkaline conditions.

The highest pH was recorded in Chamarajanagar. Soil pH is an important determinant of nutrient availability, microbial processes, mineral solubility and the environmental behaviour of agrochemicals. The relationship between pH and nutrient availability is complex and depends on both soil properties and plant nutrient uptake processes [4]. Therefore, the observed variation in pH may contribute to differences in nutrient dynamics and microbial activity among the study locations. The most pronounced spatial variation was observed for electrical conductivity (EC), which ranged from 158 $\mu\text{S}/\text{cm}$ in Gundlupete to 4200 $\mu\text{S}/\text{cm}$ in Chamarajanagar, while Kollegala also showed a comparatively high value of 2500 $\mu\text{S}/\text{cm}$. Soil EC provides an indirect measure of the concentration of soluble ionic constituents and is widely used as an indicator of soil salinity or soluble-salt status.

However, EC is influenced by several factors, including soil moisture, ionic concentration, soil texture and the composition of the soil solution; consequently, EC alone should not be interpreted as evidence of a specific salt or source of salinity.

The comparatively high EC observed in Chamarajanagar and Kollegala may therefore reflect differences in soluble-ion concentration, irrigation practices, fertilizer inputs, soil characteristics or other site-specific management conditions. The present dataset, however, does not contain information on irrigation-water chemistry, fertilizer application, manure use, soil texture or historical management. Hence, a specific agricultural source cannot be assigned to the observed EC variation. Further investigation involving sodium, calcium, magnesium, chloride, sulphate, bicarbonate and other major ions, together with irrigation-water quality, would be required to determine the underlying cause of the elevated EC values.

Available macronutrients also showed substantial spatial variation. Particularly high available phosphorus was recorded in Yelandur (632.04 mg/kg), whereas nitrogen and potassium also varied among the sampling locations. Such spatial heterogeneity may arise from differences in fertilizer and organic-matter inputs, crop removal, soil mineralogy, pH, moisture regime and previous land-use history. Because these management and soil variables were not simultaneously measured, the observed nutrient concentrations should be regarded as site-specific baseline observations rather than evidence of a particular nutrient-management practice.

The spatial heterogeneity observed in the present investigation is therefore important from a soil-quality perspective. However, the available dataset represents one soil sample from each selected taluk, and the results should consequently be interpreted as preliminary spatial observations rather than statistically representative estimates of the entire taluk. Replicated sampling across several tomato fields within each taluk would be necessary to distinguish genuine spatial patterns from field-level variability.

4.2 Soil organic carbon and implications for soil biological functioning

Total organic carbon (TOC) ranged from 0.10 to 1.92% across the study locations, demonstrating considerable variation in the organic status of the sampled agricultural soils. Soil organic carbon is a fundamental component of soil functioning because it provides substrates and energy for microorganisms and contributes to aggregation, nutrient retention and carbon cycling. Soil microorganisms are directly involved in the decomposition and transformation of organic matter and therefore play an important role in soil carbon turnover and stabilization [20].

The relatively low organic carbon concentration observed in Kollegala is noteworthy because reduced organic-carbon availability may influence microbial substrate supply and nutrient-cycling processes. However, the relationship between organic carbon and microbial abundance is not necessarily linear because microbial communities are simultaneously regulated by pH, nutrient availability, soil texture, moisture, crop type and management practices. A global meta-analysis demonstrated that soil organic carbon and microbial community characteristics can respond jointly to management practices and that pH, soil texture, crop type and climatic conditions may modify microbial responses [5].

Accordingly, the differences in microbial counts observed among the present sampling locations should not be attributed solely to variation in organic carbon. Instead, organic carbon should be considered one component of a broader soil ecological system involving nutrient availability, physicochemical conditions and agricultural management. Future investigations should therefore incorporate information on organic amendments, crop residues, fertilizer application, irrigation, cropping history and pesticide-use intensity to determine their relative contribution to variation in soil biological properties.

4.3 Variation in soil microbial populations

The observed differences in total bacterial, yeast and mould, and actinomycete counts among the five taluks provide a useful preliminary baseline for evaluating biological variation in tomato-cultivated soils. Soil microorganisms are central to decomposition, nutrient transformation, carbon cycling and several processes that contribute to soil fertility. Microbial indicators can therefore complement conventional physicochemical measurements when assessing agricultural soil quality. Recent research has emphasized that integrating microbiological indicators with physicochemical parameters can improve the diagnosis of soil-management effects and provide information on nutrient cycling and organic-matter transformation. Nevertheless, the observed differences in microbial counts cannot be interpreted as direct evidence of pesticide effects. Pesticides can influence soil microbial communities, but their effects are highly dependent on active ingredient, concentration, exposure duration, application frequency, soil properties and environmental conditions. A recent review reported that pesticides and insecticides may influence microbial structure, diversity, cellular processes and biochemical functions, although responses vary considerably among pesticides and environmental conditions [7].

A systematic review of neonicotinoid effects on soil microorganisms similarly found that approximately 45% of the reviewed studies reported adverse effects on microbial community structure, composition, diversity, functioning, enzymatic activity or nitrogen transformation. Importantly, the review identified a shortage of field-based studies and highlighted the need to evaluate pesticide effects together with soil physicochemical characteristics. This observation is directly relevant to the present study because the current dataset provides microbial counts but does not include pesticide-residue concentrations or temporal measurements before and after pesticide application.

Therefore, the differences in bacterial, yeast and mould, and actinomycete populations observed among the taluks should be interpreted as spatial differences in soil microbial abundance, rather than pesticide-induced changes. Establishing a causal relationship would require repeated sampling before pesticide application, during the crop cycle and after harvest, together with quantitative information on pesticide active ingredients and application intensity.

4.4 Relationship between pesticide use and soil characteristics

The present study was undertaken in the context of pesticide-dependent tomato production; however, the available laboratory dataset does not permit a direct statistical assessment of the relationship between pesticide application and soil properties.

In particular, pesticide active ingredients and residues were not chemically quantified, and farmer-level information on dosage, number of applications, formulation and application frequency was not incorporated into the laboratory dataset. Consequently, the observed variation in pH, EC, nutrients, organic carbon and microbial abundance should not be interpreted as being caused by pesticide application. This distinction is important because pesticide behaviour in soil is controlled by multiple interacting processes. Adsorption, degradation, transformation, volatilization and leaching determine pesticide persistence and environmental mobility. Moreover, soil pH, organic carbon, texture, moisture and microbial activity can influence pesticide fate. Recent reviews emphasize that pesticide effects on soil microbial functions depend strongly on chemical structure, mode of action, dose and soil environmental conditions [16].

At the same time, pesticide exposure can potentially modify microbial populations and functions. A recent review concluded that pesticide application may alter microbial metabolism and soil biological functions, including processes associated with carbon and nitrogen cycling [19]. Thus, the microbial observations generated in the present study are valuable as baseline measurements, but stronger inference regarding pesticide effects requires integration with pesticide-use records and residue measurements.

An appropriate future design would compare soils under different pesticide-use intensities, including low-input, moderate-input and intensive pesticide-management systems, together with fields managed under IPM and minimally exposed reference soils. Repeated seasonal measurements would further allow temporal changes in microbial populations and soil properties to be distinguished from inherent spatial variability.

4.5 Pesticide-use practices among tomato growers

Assessment of pesticide use should distinguish between the number of applications, quantity of commercial formulation and quantity of active ingredient applied. The number of sprays alone may provide an incomplete measure of pesticide intensity because commercial products differ substantially in active-ingredient concentration and formulation. Consequently, active ingredient should preferably be calculated as:

Active ingredient applied (kg) = Quantity of formulation applied (kg or L) × Active ingredient concentration (%) / 100

Pesticide-use intensity can subsequently be expressed relative to cultivated area:

Pesticide-use intensity = Total active ingredient applied / cultivated area

This approach would facilitate quantitative comparison among farmers and between taluks and would provide a stronger basis for examining associations between pesticide intensity and soil biological characteristics. The findings can be contextualized with previous research from Karnataka. Keshavareddy [12], based on a survey of 129 tomato growers in Ramanagara District, documented the use of numerous pesticides and found that pesticide dealers were the most frequently reported source of pesticide information, followed by Krishi Vigyan Kendras. The study also reported extensive use of knapsack sprayers and inadequate personal protective measures among many respondents.

The Ramanagara study provides a useful regional comparison but should not be assumed to represent current pesticide-use practices in Chamarajanagara District. Differences in pest pressure, cropping systems, market conditions, farmer knowledge, extension services and pesticide availability may produce different patterns of pesticide use. Consequently, farmer-level data collected directly from the five taluks in the present study would be necessary to establish the local pesticide-use profile.

4.6 Implications for integrated pest management

The findings support the need to evaluate tomato pest management as an integrated crop-protection system rather than considering pesticide application in isolation. FAO defines integrated pest management as an ecosystem-based approach that combines biological, chemical, physical and cultural measures while seeking to minimize pesticide use and associated risks.

For tomato production, an IPM-oriented strategy can incorporate regular pest surveillance, identification of pest and disease incidence, economic-threshold-based interventions, resistant or tolerant cultivars where available, crop sanitation, cultural and mechanical practices, biological control and appropriate botanical or microbial biopesticides. Chemical pesticides remain one component of IPM, but their selection and application should be based on the target pest, recommended dose, registered use, appropriate mode-of-action rotation and adherence to label directions. Evidence from Ramanagara District also demonstrates the potential value of improved crop-management practices. Keshavareddy et al. [11,12] reported higher productivity under demonstrated integrated crop-management practices compared with conventional farmer practices in their field demonstrations. Although those findings cannot be directly extrapolated to Chamarajanagara, they indicate the relevance of locally adapted extension and demonstration programmes for improving crop-management practices.

FAO further emphasizes that inappropriate pesticide use can harm non-target organisms and ecosystems and that over-reliance on pesticides can contribute to pest resistance and disruption of natural enemies. Therefore, farmer education should encompass not only pesticide selection and dosage but also pest monitoring, biological control, resistance management, personal protection, pre-harvest intervals and appropriate disposal of pesticide containers.

4.7 Environmental significance of the observed soil characteristics

The observed differences in soil EC, nutrients, organic carbon and microbial abundance have environmental significance because these parameters collectively characterize important aspects of agricultural soil functioning. In particular, the high EC values observed in Chamarajanagar and Kollegala warrant further investigation because sustained accumulation of soluble salts can influence plant water relations and nutrient balance. However, EC should be interpreted together with soil texture, moisture status, ionic composition and irrigation-water quality rather than being treated as an independent diagnostic of soil degradation. Similarly, differences in organic carbon and microbial populations may reflect differences in soil management and substrate availability.

Because microorganisms participate directly in organic-matter decomposition and nutrient cycling, changes in microbial abundance or activity can provide additional information about soil biological functioning.

The environmental interpretation becomes particularly important in the context of pesticide use. Pesticides that reach the soil may affect non-target microbial communities, while soil microorganisms can simultaneously participate in pesticide transformation and degradation. Recent research emphasizes that pesticide persistence and microbial dynamics are interconnected processes and that microbial responses depend on pesticide chemistry and environmental conditions. Therefore, the present results should be considered a baseline assessment of soil physicochemical and microbiological status, rather than direct evidence of pesticide contamination or pesticide-induced soil degradation.

4.8 Limitations and implications for future research

Several limitations should be considered when interpreting the present findings. First, the available laboratory dataset comprises only five soil samples, with one sample representing each selected taluk. Consequently, the results describe the sampled locations but cannot be considered statistically representative of all tomato-growing fields within the respective taluks. Second, farmer-level information on pesticide quantity, active ingredients, application frequency and application history was not available in the laboratory dataset [20].

Third, pesticide residues were not chemically analysed in either soil or tomato fruits. Therefore, the present results cannot establish the presence, concentration or persistence of pesticide residues. Fourth, pre-treatment and post-treatment soil samples were unavailable, preventing assessment of temporal changes in microbial populations associated with pesticide application. Fifth, information concerning fertilizer application, irrigation-water quality, crop variety, organic amendments and previous land use was not available.

Finally, microbial assessment was restricted to total bacterial, yeast and mould, and actinomycete counts and did not provide information on microbial community composition or functional diversity. These limitations are important because pesticide responses can be highly specific to microbial taxa and functional groups. Recent studies have therefore advocated the use of more sensitive microbiological and molecular indicators for evaluating pesticide effects on soil microbial communities.

Future research should consequently integrate structured farmer surveys, quantitative pesticide-use assessment, pesticide-residue analysis, replicated soil sampling and microbial community characterization. Measurements of microbial biomass carbon, soil respiration, dehydrogenase activity, phosphatase activity and molecular markers of bacterial and fungal diversity would provide a more comprehensive assessment of soil biological functioning.

5.0 Conclusion

Overall, the present investigation demonstrates substantial spatial heterogeneity in the physicochemical and microbiological characteristics of soils sampled from the five taluks of ChamaraJanagara District. The variation in pH, EC, organic carbon, nitrogen, phosphorus and potassium indicates that tomato-cultivated soils within the district are not environmentally homogeneous.

The corresponding variation in bacterial, yeast and mould, and actinomycete populations further indicates differences in the biological characteristics of the sampled soils.

However, these observations should not be interpreted as evidence that pesticide application is responsible for the observed spatial differences. Rather, they establish a baseline against which future pesticide-residue and soil-health studies can be compared. A stronger assessment of pesticide impacts would require replicated field sampling, quantitative pesticide-use histories, active-ingredient measurements, residue analysis and repeated microbiological assessment. Such an integrated approach would provide a scientifically stronger basis for evaluating pesticide-use intensity, soil biological responses and environmental risks associated with tomato production in ChamaraJanagara District. It would also support development of locally relevant IPM and sustainable soil-management strategies consistent with the FAO/WHO framework for rational pesticide management.

References

1. Akoijam, R., Ningombam, A., and Beemrote, A., (2023). Residual Pattern of Chlorantraniliprole, Thiamethoxam, Flubendiamide and Deltamethrin in Tomato Fruit and Soil. *Bulletin of Environmental Contamination and Toxicology*, 111, 69. <https://doi.org/10.1007/s00128-023-03799-1>.
2. Akter, S., Hulugalle, N.R., & Jasonsmith, J. (2023). Changes in soil microbial communities after exposure to neonicotinoids: A systematic review. *Environmental Microbiology Reports*, 15, 431–444. <https://doi.org/10.1111/1758-2229.13193>.
3. Aldas-Vargas, A., Poursat, B.A.J., & Sutton, N.B. (2022). Potential and limitations for monitoring of pesticide biodegradation at trace concentrations in water and soil. *World Journal of Microbiology and Biotechnology*, 38, 240.
4. Barrow, N.J. & Hartemink, A.E. (2023). The effects of pH on nutrient availability depend on both soils and plants. *Plant and Soil*, 487, 21–37.
5. Cui, J. et al. (2023). Investigating the effects of organic amendments on soil microbial composition and its linkage to soil organic carbon: A global meta-analysis. *Science of the Total Environment*, 894, 164899. DOI: 10.1016/j.scitotenv.2023.164899.
6. Chia, X.K., Hadibarata, T., Kristanti, R.A., (2024). The function of microbial enzymes in breaking down soil contaminated with pesticides: a review. *Applied Microbiology and Biotechnology*, 47, 597–620. <https://doi.org/10.1007/s00449-024-02978-6>.
7. Dangi (2024). A review of the impact of herbicides and insecticides on the microbial communities. *Environmental Research*, 245, 118020. DOI: 10.1016/j.envres.2023.118020.
8. De Costa, D.M., De Costa, J.M., Weerathunga, M.T., Prasannath, K., & Bulathsinghalage, V.N. (2021). Assessment of management practices, awareness on safe use of pesticides and perception on integrated management of pests and diseases of chilli and tomato grown by small-scale farmers in selected districts of Sri Lanka. *Pest Management Science*, 77, 5001–5020. <https://doi.org/10.1002/ps.6542>.
9. FAO (2014). *International Code of Conduct on Pesticide Management*. Food and Agriculture Organization of the United Nations.
10. FAO/WHO (2021). *Managing pesticides in agriculture and public health: A compendium of FAO and WHO guidelines and other resources*, 2nd ed. WHO.
11. Keshavareddy, G., Nagaraj, K.H., Kamala Bai, S., & Kulkarni, L.R. (2018). Pesticides Usage and Handling by the Tomato Growers in Ramanagara District of Karnataka, India – An Analysis. *International Journal of Current Microbiology and Applied Sciences*, 7(4), 3312–3321. <https://doi.org/10.20546/ijcmas.2018.704.375>.

12. Keshavareddy, G. et al. (2018). Integrated crop management – A way for doubling the income of tomato growers in Ramanagara District of Karnataka, India. *International Journal of Current Microbiology and Applied Sciences*, 7(6), 2161–2168. DOI: 10.20546/ijcmas.2018.706.256.
13. Khetagoudar, M.C., (2022). Multiresidue pesticide analysis in tomato using GC-MS/MS using modified QuEChERS method with titanium-coated graphite with CNT-ABS nanocomposite as dispersive solid-phase extraction materials. *Food Quality and Safety*, 6, fyac004. <https://doi.org/10.1093/fqsafe/fyac004>.
14. Kumar, V., Sahoo, S. K., & Sujatha, B. (2022). Dissipation and persistence pattern of chlorantraniliprole residues in tomato under open field conditions and its estimation through UHPLC-PDA. *Pest Management in Horticultural Ecosystems*, 28(1), 140–146
15. Rajan, S., Parween, M., & Janardhana Raju, N. (2023). Pesticides in the hydrogeo-environment: a review of contaminant prevalence, source and mobilisation in India. *Environmental Geochemistry and Health*, 45, 5481–5513. <https://doi.org/10.1007/s10653-023-01608-6>.
16. Ray, S.S., Parihar, K., Goyal, N. & Mahapatra, D.M. (2024). Synergistic insights into pesticide persistence and microbial dynamics for bioremediation. *Environmental Research*, 257, 119290. DOI: 10.1016/j.envres.2024.119290.
17. Sharma et al. (2022). Monitoring and dietary risk assessment of pesticide residues in brinjal, capsicum, tomato, and cucurbits grown in Northern and Western regions of India. *Journal of Food Composition and Analysis*, 110, 104543. <https://doi.org/10.1016/j.jfca.2022.104543>.
18. Vijayakumar, J., Jamakhandi, B., Kulkarni, G., & Patil, V. (2023). Comparative analysis of production and marketing constraints of tomato growers in Karnataka—with special reference to Kolar and Belagavi districts. *Journal of Farm Sciences*, 36(1), 98–100. <https://doi.org/10.61475/jfm.v36i01.324>.
19. Virk, A.L. (2024). Pesticide effects on crop physiology, production and soil biological functions. *Advances in Agronomy*, 187, 171–212. DOI: 10.1016/bs.agron.2024.05.003.
20. Wu, H. (2024). Unveiling the crucial role of soil microorganisms in carbon cycling: A review. *Science of the Total Environment*, 909, 168627. DOI: 10.1016/j.scitotenv.2023.168627.