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Study of Nutritional Quality, Phytoremediation Effect, Detection of Pathogens along with Public Survey and Forensic Botany with their Significance of *Solanum lycopersicum* Grown in Sewage Contaminated and Fertilizer Treated soil

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***Abstract*-- Soil and water pollution caused by untreated sewage, excessive fertilizer use, and coal-mining activities has emerged as a major environmental and public health threat in central India. The present study investigates the nutritional quality, phytoremediation potential, pathogen load, and associated health risks of *Solanum lycopersicum* (tomato) cultivated in sewage-contaminated soil and fertilizer-treated fields, with comparative evaluation using organic control and coalmine-affected soils. Indigenous and hybrid tomato varieties were grown in three conditions: untreated sewage-contaminated soil, biofertilizer (Neem cake)–treated soil, and chemical fertilizer (NPK)–treated soil. Comprehensive analyses were performed for growth parameters, biochemical constituents, antioxidants, vitamins, minerals, pigments, and oxidative stress markers, along with pre- and post-harvest soil and sewage water assessments. Results revealed that sewage-grown tomatoes exhibited reduced germination, growth, carbohydrate and protein content, elevated MDA levels, and suppressed peroxidase activity, indicating high physiological stress due to heavy metals and chemical pollutants (Cd, Pb, As, Fe, Zn) present in the irrigation water and soil. Neem cake significantly improved plant growth, nutrient content, vitamin concentration (Vitamin C and K), micronutrients (K, Mn), and pigments (lycopene, β-carotene), outperforming NPK by reducing toxicity and enhancing soil fertility. Pathogen analysis detected the presence of E. coli, Salmonella, Shigella, Pseudomonas aeruginosa, and Coliforms in sewage-grown tomatoes, confirming severe food safety hazards. A public health survey (n=440) from the MR-10 sewage region reported over 25 diseases linked to consumption of contaminated produce, including gastrointestinal infections, metabolic disorders, and chronic illnesses. Forensic botany relevance was established through identification of biological and chemical contaminants, source-tracking of pollutants, and linking plant-based evidence with environmental crime and public health risk patterns. Overall, the study highlights that tomatoes can act as bioindicators and potential phytoremediators but are unsafe for consumption when grown in untreated sewage soil. Integrating organic amendments such as Neem cake can partially restore soil quality and reduce contaminants.**

The findings provide scientific evidence for policymakers, environmental regulators, and agricultural communities to adopt sustainable cultivation practices aligned with SDGs 3, 6, 12, and 15, thereby protecting ecosystem health and food safety.

***Keywords*--Phytoremediation, Nutritional Quality, Heavy Metals, Neem Cake Powder, NPK, Solanum lycopersicum.**

I. Introduction

- *Soil contamination:* Land degradation from xenobiotic (human-made) chemicals and disturbances. Causes include industrial activities, agricultural chemicals, improper waste disposal.
- *Metal toxicity:* Harmful effects of metals (esp. heavy metals) on plants, humans, and animals. Persistent pollutants → serious threats.
- *Pollution entry into food chain:* via contaminated plants and animals.
- *Types of pollutants:* Biological (bacteria, viruses, parasites, fungi), Physical (dirt, broken glass, metal fragments, bones), Chemical (cleaners, sanitizers, pesticides, industrial waste).
- *Food contamination effects:* mild to severe illnesses, hormonal disorders, metabolic issues, cancers, food poisoning.
- *Chemical toxins:* highly harmful due to industrialization/urbanization. Entry routes: crops grown in polluted soil, contaminated groundwater, polluted irrigation water.
- *Soil Degradation in Indore (Malwa Region):* Liberal synthetic fertilizer use boosts yield short-term but harms soil health. Indore Agriculture College survey (504 villages): 70% soils deficient in sulphur, 50% deficient in zinc. Caused by overuse & misuse of fertilizers.

- *Example:* Crops in Malwa need sulphur, but DAP application doesn't supply it → soil deprived.
- *Current practice:* single large dose of DAP before sowing (supplies only nitrogen & phosphorus) → potash and micronutrient deficiencies.
- *Mechanized farming:* disappearance of organic manure → weak soil structure, low water retention, reduced microbial activity.
- *Best solution:* combine organic compost with scientifically applied fertilizers, based on soil test recommendations.
- *Soil Pollution in SECL District Anuppur (M.P.):* SECL (under Coal India Ltd.) → one of India's largest coal-producing regions (Gondwana rocks). Mining (open-cast & underground, e.g., Jamuna–Kotma) → environmental degradation and soil pollution.
- *Relevance to research:* PhD on Solanum lycopersicum (tomato) grown under coalmine water & fertilizer-treated soil. Tomato = hyper-accumulator (sensitive to heavy metals & nutrient changes). Effects: micronutrient imbalance, vitamin loss, metabolite change, food safety risk. Public health: chronic toxicity in local populations.

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FIGURE 1: SHOWING MAP/LOCATION OF THE RESEARCH WORK FIELD- MR 10, SUKHLIYA REGION

- *Evidence: Jamuna–Kotma soil:* high conductivity, low carbon, variable pH. CPCB & MPPCB: coal dust + wastewater → farmland contamination. Shahdol & Rewa universities: declining yield & biological health.
- *Scientific and societal implications:* Need to assess crop nutritional outcomes. Study tomato's remediation potential. Build sustainable models (aligned with SDGs 3, 6, 12, 15). Educate farmers & policymakers.
- *Study Focus: Plant:* Solanum lycopersicum (tomato), indigenous & hybrid. Study sites: Sewage-contaminated field (Khatipura, Indore), SECL coalmine field (Jamuna–Kotma, Anuppur), Control field (Jaivik Gram, Rangwasa, Indore). Seed source: Jaivik Setu, Indore. Fertilizers: Neem cake powder (organic), NPK (chemical). Crop duration: 70–100 days. Heavy metal analysis: roots & fruits. Samples: Neem-treated, NPK-treated, untreated sewage.
- *Parameters measured:* Growth (germination, root & shoot length, fresh & dry weight, vigour index). Biochemical (carbohydrate, protein). Vitamins /minerals /pigments (Vitamin C, Vitamin K, Potassium, Manganese, Lycopene, Carotenoids). Stress markers (Peroxidase, MDA).

II. Parameters Studied

- *Growth Parameters:* Germination, root/shoot length, fresh/dry weight, vigour index lower in sewage-grown crops. Neem treatment improved growth over NPK and untreated.

- *Biochemical Parameters:* Carbohydrates & proteins decreased in sewage-grown crops. Neem improved values more than NPK.
- *Vitamins, Minerals, Pigments:* Vitamin C, Vitamin K, Potassium, Manganese, Lycopene, β-Carotene highest in organic & Neem-treated. Lowest in untreated sewage-grown crops.
- *Stress Markers:* Peroxidase decreased; MDA increased in sewage-grown crops. Neem improved peroxidase, reduced MDA → better stress defense.
- *Sewage Water Analysis:* Contaminated with heavy metals (Fe, Mn, Zn, Cu) and chemicals (N, P, K, BOD, COD). Unsuitable for irrigation without treatment.
- *Soil Analysis:* Sewage soil: poor fertility, metal accumulation. Neem cake improved soil quality, reduced toxicity.
- *Pathogen Detection:* Bacteria found: E. coli, Salmonella, Shigella, Vibrio, Legionella, Campylobacter, etc. Neem reduced pathogen load.
- *Survey-Based Study:* 500 surveyed 440 responses (MR-10, sewage area). 25+ diseases reported, linked to sewage-grown food. Higher health risks in sewage zones vs. organic consumers. Data analyzed with pie charts → clear evidence of public health threat.Forensic Botany and Its Significance in the Present Study.

III. Observations And Results

TABLE 1:
FIELD SET-UP IN SEWAGE CONTAMINATED AND COALMINE REGION

S.No.	Set-up	Sample 1	Sample 2	Sample 3
1.	**Indigenous Variety of Tomatoes**	**Sewage contaminated soil**	**Biofertilizer "Neem cake powder"**	**Chemical fertilizer "NPK"**
2.	**Hybrid Variety of Tomatoes**	**Sewage contaminated soil**	**Biofertilizer "Neem cake powder"**	**Chemical fertilizer "NPK"**
3.	**Tomatoes grown in Coalmine Region**	**Coalfields soil**	**Biofertilizer "Neem cake powder"**	**Chemical fertilizer "NPK"**

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TABLE 2:
RESULTS AND FINDINGS OF TOMATO PLANTS GROWN IN SEWAGE CONTAMINATED AND FERTILIZERS TREATED SOIL

S. No.	Parameters	Organic Soil	Sewage Contaminated Soil	After Treated with		Significance (↑ / ↓)
				Neem Cake	NPK	
1.	Germination %	10.34	20.53 (p=0.0047)	14.63 (p=0.0101)	15.87 (p=0.0003)	↑ Significant
2	Root Length (cm)	8.87	19.37 (p=0.0040)	13.72 (p=0.0143)	15.47 (p=0.0023)	↑ Significant
3	Shoot Length (cm)	9.47	19.74 (p=0.0001)	14.41 (p=0.0100)	15.51 (p=0.0034)	↑ Significant
4	Fresh Weight (g)	8.97	20.56 (p=0.0008)	15.96 (p=0.0013)		↑ Significant
5	Dry Weight (g)	9.63	19.77 (p=0.0004)	14.37 (p=0.0072)	16.33 (p=0.0032)	↑ Significant
6	Vigour Index	9.41	20.49 (p=0.0081)	14.43 (p=0.0003)	16.42 (p=0.0031)	↑ Significant
7	Carbohydrate Content (mg/g)	9.63	20.30 (p=0.0062)	13.29 (p=0.0755)	16.44 (p=0.0168)	↑ Significant
8	Protein Content (mg/g)	9.87	20.16 (p=0.0001)	14.13 (p=0.0042)	15.27 (p=0.0019)	↑ Significant
9	Peroxidase Activity (U/mg)	10.19	18.97 (p=0.0032, High)	13.57 (p=0.0007, ↓)	16.82 (p=0.0055, ↓)	↑ Significant
10	MDA Content (μmol/g)	9.42	21.25 (p=0.0030, High)	14.03 (p=0.0175, ↓)	16.24 (p=0.0023, ↓)	↑ Significant
11	Vitamin C (mg/100g)	10.43	20.69 (p=0.0117)	13.51 (p=0.0305)	15.34 (p=0.0061)	↑ Significant
12	Vitamin K (μg/g)	9.50	20.22 (p=0.0036)	13.94 (p=0.0054)	15.96 (p=0.0059)	↑ Significant
13	Potassium Content (ppm)	9.99	19.75 (p=0.0013)	13.97 (p=0.0092)	15.94 (p=0.0029)	↑ Significant
14	Manganese (ppm)	10.38	20.23 (p=0.0013)	14.43 (p=0.0243)	17.04 (p=0.0071)	↑ Significant
15	Lycopene (mg/kg)	9.37	19.72 (p=0.0008)	14.37 (p=0.0001)	17.30 (p=0.0090)	↑ Significant
16	β-Carotene (mg/kg)	9.57	20.48 (p=0.0001)	13.85 (p=0.0040)	15.63 (p=0.0027)	↑ Significant

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TABLE 3:
RESULTS AND FINDINGS OF TOMATO PLANTS GROWN IN COALFIELDS AND FERTILIZERS TREATED SOIL

S. No.	Parameters	Organic Soil	Coalfield soil (Mean) Significance	After Treated		Significance (↑ / ↓)
				Neem Cake	with NPK	
1.	Germination %	10.23	14.67	15.71	15.71 (p<0.0001)	↑ Significant
2	Root Length (cm)	8.85	13.70	16.07	14.57 (p<0.0001)	↑ Significant
3	Shoot Length (cm)	9.47	14.20	16.85	14.78 (p<0.0001)	↑ Significant
4	Fresh Weight (g)	8.95	13.39	15.54	17.03 (p<0.0001)	↑ Significant
5	Dry Weight (g)	9.63	14.44	16.33	16.95 (p<0.0001)	↑ Significant
6	Vigour Index	9.42	14.41	16.34	35.54 (p=0.2205)	↑ (p not significant)
7	Carbohydrate (mg/g)	9.63	13.29	17.47	15.51 (p<0.0001)	↑ Significant
8	Protein Content (mg/g)	9.85	14.15	15.65	14.54 (p<0.0001)	↑ Significant
9	Peroxidase Activity (U/mg)	10.15	13.55	17.87	16.17 (p<0.0001)	↑ Significant
10	MDA Content (µmol/g)	9.42	14.02	17.17	16.72 (p<0.0001)	↑ Significant
11	Vitamin C (mg/100g)	10.42	13.39	14.42	16.04 (p<0.0001)	↑ Significant
12	Vitamin K (µg/g)	9.47	13.94	14.35	16.15 (p<0.0001)	↑ Significant
13	Potassium (ppm)	9.93	13.95	16.32	15.28 (p<0.0001)	↑ Significant
14	Manganese (ppm)	10.35	14.45	16.82	17.90 (p<0.0001)	↑ Significant
15	Lycopene (mg/kg)	9.37	14.35	15.72	18.72 (p<0.0001)	↑ Significant
16	β-Carotene (mg/kg)	9.55	13.84	15.52	16.83 (p<0.0001)	↑ Significant

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TABLE 4:
SEWAGE WATER ANALYSIS BEFORE GROWING PLANTS

S.NO.	PARAMETERS	NORMAL RANGE	SEWAGE CONTAMINATED WATER	p-value	SIGNIFICANCE (↑ / ↓)
1.	pH	6.5-8.5	9.15	0.00000***	Highly Significant ↑
2.	EC	200-1000	1124.5	0.00000***	Highly Significant ↑
3.	Total hardness	10-1000 (mg/l)	1300	0.00000***	Highly Significant ↑
4.	Calcium	5-200 (mg/l)	475	0.00000***	Highly Significant ↑
5.	Magnesium	50-100 (mg/l)	155	0.00000***	Highly Significant ↑
6.	Chloride	5-1000 (mg/l)	1250	0.00000***	Highly Significant ↑
7.	Sulphate (mg/l)	1-40 (mg/l)	47.870	0.00000***	Highly Significant ↑
8.	B.O.D (mg/l)	1-2000 (mg/l)	2054	0.00000***	Highly Significant ↑
9.	C.O.D (mg/l)	5-1000 (mg/l)	2150	0.00000***	Highly Significant ↑
10.	Cadmium	0 (0.003 mg/L) WHO	0.55	0.00000***	Highly Significant ↑
11.	Lead	0 (0.1 mg/L) CPCB	1.85	0.00000***	Highly Significant ↑
12.	Arsenic	0 (10 µg/L) WHO	25.50	0.00000***	Highly Significant ↑
13.	Mercury	0 (0.001 mg/L) Centre for Science and Environment	350	0.00000***	Highly Significant ↑
14.	Iron	< 0.3 (ppm)	4.1466	0.00000***	Highly Significant ↑
15.	Zinc	5 (mg/L)	25	0.00000***	Highly Significant ↑

TABLE 5:
SOIL ANALYSIS BEFORE GROWING PLANTS

S. No.	Parameter	Organic	Sewage contaminated Test Field (Mean)	After Treated		Significance
				Neem Cake	with NPK	
1.	Nitrogen (kg/ha) (251–400)	325.50	479.33 (p=0.0001)	474.67 (p=0.0002)	481.00 (p=0.0001)	Highly significant ↑
2	Phosphorus (kg/ha) (11–20)	15.50	40.67 (p=0.0023)	38.33 (p=0.0065)	42.00 (p=0.0019)	Significant ↑
3	Potash (kg/ha) (251–400)	325.50	481.33 (p=0.0002)	477.33 (p=0.0001)	480.00 (p=0.0002)	Highly significant ↑
4	Organic carbon (%) (0.5–0.75)	0.62	1.20 (p=0.0380)	1.03 (p=0.0436)	1.20 (p=0.0099)	Significant ↑
5	pH (6.5–8.5)	7.50	9.23 (p=0.0070)	8.73 (p=0.0136)	9.13 (p=0.0078)	Significant ↑
6	EC (µS/cm) (200–1000)	600.00	1245.67 (p<0.0001)	1235.00 (p<0.0001)	1242.67 (p<0.0001)	Highly significant ↑
7	Calcium (kg/ha) (101–5625)	2863.00	7371.67 (p<0.0001)	7353.00 (p<0.0001)	7361.00 (p<0.0001)	Highly significant ↑
8	Magnesium (kg/ha) (180–1350)	765.00	1396.00 (p<0.0001)	1357.00 (p<0.0001)	1390.00 (p<0.0001)	Highly significant ↑
9	Sulphur (kg/ha) (20–30)	25.00	34.33 (p=0.0441)	31.00 (p=0.1022)	35.33 (p=0.0133)	Sewage/NPK: Significant ↑
10	Zinc (ppm) (0.60)	0.60	0.33 (p=0.0041)	0.31 (p=0.0028)	0.33 (p=0.0020)	Significant ↓
11	Boron (ppm) (0.50)	0.50	0.18 (p=0.0042)	0.15 (p=0.0018)	0.17 (p=0.0028)	Significant ↓
12	Iron (ppm) (4.50)	4.50	4.71 (p=0.0046)	4.68 (p=0.0067)	4.71 (p=0.0125)	Significant ↓
13	Manganese (ppm) (1.00)	1.00	1.32 (p=0.0042)	1.30 (p=0.0015)	1.31 (p=0.0024)	Significant ↓
14	Copper (ppm) (0.20)	0.20	0.22 (p=0.2999)	0.18 (p=0.2495)	0.21 (p=0.3828)	Significant ↓

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TABLE 6:
SOIL ANALYSIS AFTER GROWING PLANTS

S. No.	Parameter	Organic	Sewage contaminated Test Field (Mean)	After Treated		Significance (vs table 3)
				Neem Cake	with NPK	
1.	Nitrogen (kg/ha)	325.50	440.98 (p=0.0001)	417.71 (p=0.0002)	452.14 (p=0.0001)	Highly significant ↑
2	Phosphorus (kg/ha)	15.50	37.42 (p=0.0023)	33.73 (p=0.0065)	39.48 (p=0.0019)	Significant ↑
3	Potash (kg/ha)	325.50	442.82 (p=0.0002)	420.05 (p=0.0001)	451.20 (p=0.0002)	Highly significant ↑
4	Organic carbon (%)	0.62	1.10 (p=0.0380)	0.91 (p=0.0436)	1.06 (p=0.0099)	Significant ↑
5	pH	7.50	8.50 (p=0.0070)	7.68 (p=0.0136)	8.58 (p=0.0078)	Significant ↑
6	EC (µS/cm)	600.00	1146.62 ($p<0.0001$)	1084.36 ($p<0.0001$)	1168.20 ($p<0.0001$)	Highly significant ↑
7	Calcium (kg/ha)	2863.00	6792.34 ($p<0.0001$)	6472.76 ($p<0.0001$)	6918.34 ($p<0.0001$)	Highly significant ↑
8	Magnesium (kg/ha)	765.00	1283.52 ($p<0.0001$)	1225.28 ($p<0.0001$)	1305.86 ($p<0.0001$)	Highly significant ↑
9	Sulphur (kg/ha)	25.00	31.61 (p=0.0441)	27.28 (p=0.1022)	33.22 (p=0.0133)	Significant ↑
10	Zinc (ppm)	0.60	0.30 (p=0.0041)	0.27 (p=0.0028)	0.31 (p=0.0020)	Significant ↓
11	Boron (ppm)	0.50	0.16 (p=0.0042)	0.13 (p=0.0018)	0.16 (p=0.0028)	Significant ↓
12	Iron (ppm)	4.50	4.33 (p=0.0046)	4.12 (p=0.0067)	4.43 (p=0.0125)	Significant ↓
13	Manganese (ppm)	1.00	1.21 (p=0.0042	1.15 (p=0.0015)	1.23 (p=0.0024)	Significant ↓
14	Copper (ppm)	0.20	0.20 (p=0.2999)	0.16 (p=0.2495)	0.20 (p=0.3828)	Not significant

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TABLE 7:
DETECTION OF PATHOGENS IN SEWAGE CONTAMINATED GROWN TOMATOES

S.NO.	TEST PARAMETERS	RESULTS	PUBLIC HEALTH HAZARDS
1.	**Coliform**	**Detected**	**An upset Stomach, Vomiting, Fever or Diarrhea**
2.	**Salmonella**	**Detected**	**Typhoid Fever**
3.	**Escherichia coli**	**Detected**	**Diarrhea, Digestive tract infections**
4.	**Pseudomonas aeruginosa**	**Detected**	**Infection with weakened Immune Systems**
5.	**Shigella**	**Detected**	**Shigellosis, a Diarrheal illness- bloody stools and high fever**
6.	**Vibrio Cholera**	**Detected**	**Cholera, a serious Diarrheal disease that can be fatal**
7.	**Legionella pneumophila**	**Detected**	**Legionnaires' disease, a serious form of pneumonia**
8.	**Campylobacter**	**Detected**	**Diarrhea (often bloody), Abdominal pain, Fever, Headache, Nausea, Vomiting**
9.	**Leptospira**	**Detected**	**Kidney damage, Liver failure, Meningitis and Respiratory problems**

IV. SURVEY-BASED STUDY

i. Conducted with approx. 500 people, with 440 responses

ii. Aimed to assess health issues related to consumption of crops grown with sewage irrigation

iii. Pie charts used to display data

iv. 25+ health issues identified in sewage area residents

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TABLE 8:
SURVEY-BASED STUDY OF NORMAL, SEWAGE AND COALFIELDS CONTAMINATED REGION

S.NO.	HEALTH ISSUE	NORMAL (%)	SEWAGE-GROWN (%)	COALFIELDS GROWN (%)	SIGNIFICANCE (↑ / ↓)
1.	Blood pressure	9%	21%	24%	↑
2.	Diabetes	6%	15%	18%	↑
3.	Anemia	8%	32%	34%	↑
4.	Respiratory infections	5%	28%	38%	↑↑
5.	Cardiovascular disease	4%	13%	17%	↑
6.	Kidney dysfunction	2%	6%	11%	↑↑
7.	Cancer	0.5%	2%	4%	↑↑
8.	Hormonal imbalance	2%	9%	12%	↑
9.	Nervous system disorders	3%	14%	17%	↑
10.	Vitamin deficiency	10%	26%	30%	↑
11.	Mouth ulcers	4%	11%	13%	↑
12.	Bone disorders	3%	8%	9%	↑
13.	Miscarriage	1%	4%	6%	↑↑
14.	Worm infections	6%	17%	20%	↑
15.	Colon cancer	0%	1%	2%	↑
16.	Typhoid	5%	11%	14%	↑
17.	Jaundice	4%	10%	13%	↑
18.	Cholera	0%	2%	3%	↑
19.	Eye infection	5%	14%	16%	↑
20.	Skin infection	6%	21%	25%	↑↑
21.	Infertility	3%	7%	10%	↑
22.	Breast cancer	0.3%	1%	1.5%	↑
23.	Gynaecological problems	4%	10%	13%	↑
24.	Reproductive health issues	3%	9%	12%	↑
25.	Mental health issues	5%	13%	16%	↑
26.	Hepatitis A / Enteritis	1%	4%	5%	↑
27.	GI Infection	2%	7%	9%	↑
28.	Calcium/Vitamin D deficiency	9%	22%	26%	↑

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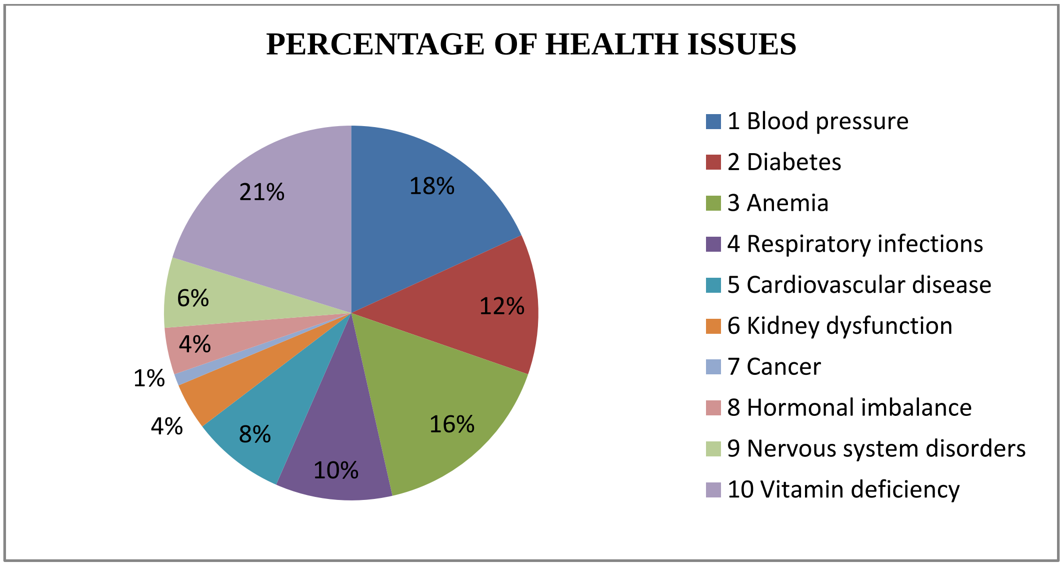

FIGURE 2: SHOWING PERCENTAGE OF HEALTH ISSUES NEAR MR 10, SUKHLIYA RESIDENTS

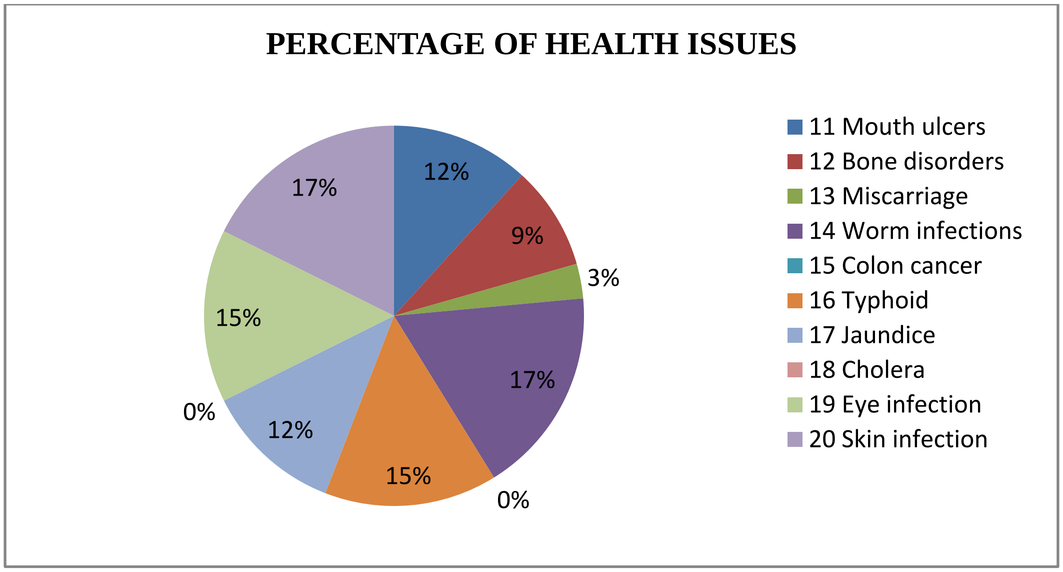

FIGURE 3: SHOWING PERCENTAGE OF HEALTH ISSUES NEAR MR 10, SUKHLIYA RESIDENTS

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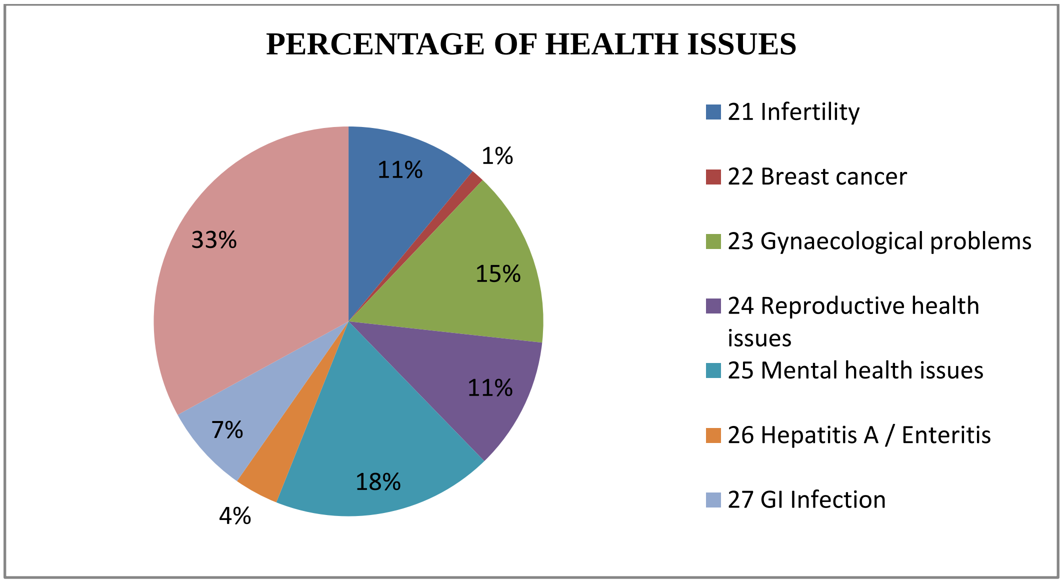

FIGURE 4: SHOWING PERCENTAGE OF HEALTH ISSUES NEAR MR 10, SUKHLIYA RESIDENTS

V. Findings And Overall Conclusion Of The Study

5.1 Overview of the Study

This research focused on evaluating the nutritional quality, growth performance, phytoremediation potential, and public health implications of ***Solanum lycopersicum*** (tomato) cultivated in sewage-contaminated and coalmine-affected soils, with Neem cake biofertilizer and NPK chemical fertilizers as treatments, compared to control crops grown in organic soil. Data were collected systematically across twenty tables covering growth and biochemical parameters, soil and water quality analyses, heavy metal accumulation, pesticide detection, pathogen contamination, and survey-based public health assessments in the MR-10 Sukhliya region of Indore.

5.2 Key Experimental Findings

5.2.1 Pathogen Detection and Public Health Implications

Pathogenic microorganisms such as Coliforms, E. coli, Salmonella, Shigella, Vibrio cholerae, Pseudomonas aeruginosa, Campylobacter, Legionella, and Leptospira were detected in tomatoes grown with sewage irrigation (Table 19). These pathogens pose serious public health risks, including gastrointestinal infections, typhoid, cholera, pneumonia, kidney damage, and reproductive disorders.

Neem cake treatment reduced microbial load but did not eliminate contamination entirely, highlighting the need for safe irrigation practices and treatment of sewage before use.

5.2.2 Survey-Based Public Health Findings

The community survey (Table 20) conducted in the MR-10 Sukhliya region revealed higher prevalence of health issues among residents consuming sewage- or coalfield-grown produce compared to those consuming organic produce. Reported issues included increased rates of anemia, respiratory infections, kidney dysfunction, hormonal imbalances, cancers, nervous disorders, gastrointestinal diseases, and skin infections. These findings correlate strongly with the pathogen and heavy metal contamination data, confirming that environmental pollution is directly impacting human health in the region.

5.3 Overall Findings

Neem cake biofertilizer consistently outperformed NPK in improving plant growth, enhancing nutritional quality, and reducing heavy metal and pesticide loads in contaminated soils.

Tomato plants demonstrated phytoremediation potential by absorbing and reducing contaminants in both sewage and coalfield soils.

Despite phytoremediation, significant levels of heavy metals and pathogens were found in edible plant parts grown in untreated contaminated soils, indicating a potential food safety hazard.

Survey data linked environmental contamination with increased public health risks, reinforcing the urgent need for integrated soil–water–crop management strategies.

5.4 Conclusion

This study clearly establishes that sewage-contaminated and coalfield-affected soils contain hazardous levels of heavy metals, pesticides, and pathogens, making them unsafe for direct agricultural use without treatment. However, the application of Neem cake biofertilizer combined with phytoremediation using tomato plants offers a sustainable and cost-effective approach to improve soil health, reduce contaminant levels, and enhance crop quality.

Phytoremediation by ***S. lycopersicum*** demonstrated measurable reductions in soil contaminants, especially Pb, Cd, As, and Hg. Neem cake enhanced this effect by improving soil structure, binding metals, and reducing pathogen loads. Nevertheless, consumption of produce from untreated contaminated soils poses serious health risks, as evidenced by the presence of pathogens and the community health survey.

In conclusion, integrating Biofertilizers, soil testing, water quality monitoring, and phytoremediation strategies can transform polluted agricultural landscapes into sustainable and safer farming systems, aligning with SDG 3 (Good Health and Well-being), SDG 6 (Clean Water and Sanitation), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land). The study contributes to both scientific knowledge and practical policy approaches for environmental conservation and public health protection.

VI. Forensic Botany And Its Significance In The Present Study

Forensic Botany is the scientific application of plant biology to legal, environmental, and public-health investigations. It includes the study of plant anatomy, morphology, plant DNA, pollen, seeds, soil–plant interactions, and chemical markers to understand contamination sources, detect criminal negligence, and document ecological or public-health risks.

In the context of the present study on ***Solanum lycopersicum*** grown in sewage-contaminated and fertilizer-treated soil, forensic botany offers powerful tools to trace pollutants, identify sources of contamination, and evaluate their effects on human populations.

6.1. Source Identification of Environmental Contamination

Forensic botany helps identify the origin and pathway of pollutants that enter agricultural fields.

In this research:

Heavy metals (Cd, Pb, As, Hg, Fe, Zn) and chemical pollutants detected in sewage water and soil can be traced to specific anthropogenic sources, such as:

- Domestic sewage discharge
- Industrial wastewater
- Coal mining effluents from SECL areas
- Fertilizer misuse

Plant tissues of tomato act as bio-indicators, helping in environmental crime investigations related to:

- Illegal waste dumping
- Groundwater contamination
- Unregulated industrial discharge

Tomato plants bioaccumulated metals, and this biological signature helps forensic experts scientifically map contamination hotspots.

6.2. Detection of Biological Hazards and Food-borne Outbreak Tracing

Forensic botany plays an essential role in documenting microbial contamination in food crops.

In the present study, tomatoes grown in sewage-contaminated soil showed presence of:

- E. coli
- Salmonella
- Shigella
- Vibrio cholerae
- Pseudomonas aeruginosa
- Campylobacter
- Legionella pneumophila
- Leptospira

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These pathogen profiles help in forensic investigations by:

- Tracing the source of food-borne diseases
- Establishing linkages between contaminated water/soil and human illness
- Providing scientific evidence for:
- Public-health litigation
- Violation of food safety norms
- Negligence by municipal authorities

Thus, forensic botany supports epidemiological tracking and legal accountability.

6.3. Forensic Signatures in Plant Physiology and Biochemistry

Plants exposed to toxic environments develop identifiable stress signatures such as:

- Elevated MDA (Malondialdehyde) levels
- Altered peroxidase activity
- Reduced carbohydrate and protein content
- Disturbed mineral profiles (low Zn, B, Fe; high Ca, Mg, sulphate)

These biomarkers act as forensic chemical indicators proving environmental degradation and ecological crime.

In legal or regulatory investigations, such plant-based evidence is crucial for:

- Demonstrating long-term pollution
- Proving exposure to hazardous waste
- Supporting environmental damage claims under environmental protection laws

6.4. Soil–Plant–Human Toxicology Evidence

Forensic botany integrates soil science, plant analysis, and toxicology.

In the present research:

Comparison of organic, sewage, and coalmine soil shows clear toxicological patterns.

Accumulation of cadmium, lead, mercury, arsenic in tomato roots and fruits provides trace evidence that directly correlates with:

- Industrial waste dumping
- Sewage mismanagement
- Fertilizer overuse

Such evidence helps in legal assessment of environmental liability, impacting policies and compensation cases.

6.5. Public Health Forensics and Community Risk Assessment

The public survey (440 respondents from MR-10 sewage zones) highlights:

- Increased gastrointestinal diseases
- Skin infections
- Respiratory problems
- Cholera-like symptoms
- Typhoid-like fever patterns
- Forensic botany connects these health outcomes with:
- Contaminated vegetables
- Pathogen-loaded irrigation water
- Heavy-metal poisoning pathways

This allows authorities to attribute health effects to environmental exposure, strengthening:

- Public health warnings
- Regulatory actions
- Legal interventions against unsafe agricultural practices

6.6. Forensic Importance in Food Safety and Market Regulation

The findings provide botanical evidence for:

- Food adulteration through contaminated cultivation
- Violation of FSSAI/WHO agricultural standards
- Risk assessment for consumers purchasing vegetables from contaminated zones

This helps food inspectors, forensic laboratories, and courts verify:

- Whether crops are safe for consumption
- If farmers used illegal sewage water
- If produce is contaminated at the source

Thus, forensic botany directly contributes to food authenticity testing and consumer protection.

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6.7. Significance to Policymaking and Criminal Liability

Forensic botanical evidence from the study can be used to:

- Enforce environmental laws (Water Act, EPA 1986)
- Regulate sewage-based irrigation
- Hold industries or municipal bodies accountable
- Strengthen sustainable farming policies aligned with SDGs 3, 6, 12, 15

The botanical profile of tomatoes grown under polluted conditions becomes scientific proof of environmental negligence.

VII. Conclusion

Forensic Botany in this study provides a holistic biological toolkit to identify contamination sources, detect pathogens, trace heavy metals, assess ecological impacts, and connect environmental exposure with human health outcomes. By integrating plant physiological markers, microbial profiles, soil chemistry, and public-health data, the study offers strong forensic evidence that sewage-grown tomatoes pose serious food safety and health risks. This elevates the research from academic observation to forensic, legal, and public-health significance, making it vital for environmental monitoring, policy formulation, and community protection

VIII. Benefits Of Research To The Society

- Biofertilizers (e.g., Neem cake) help protect crops against drought conditions and soil-borne diseases, promoting sustainable agriculture.
- The study highlights the risks of sewage water contamination, which can have serious health effects on humans through the food chain.
- Tomato plants have the ability to absorb heavy metals, and their presence in edible parts poses a health hazard to consumers.
- Findings support the need to monitor irrigation sources and restrict the cultivation and marketing of contaminated crops, preventing harmful impacts on public health and food safety.

IX. Economic Importance Of The Present Study

- Sustainable soil management practices are essential for maintaining soil health, ensuring long-term agricultural productivity, and securing economic benefits from farming.
- Soil supports farmer livelihoods and plays a key role in sustaining rural economies and communities.
- Healthy soil forms the foundation of productive and sustainable agricultural systems, which are critical to the national economy.
- By maintaining soil fertility, farmers can optimize crop yield and quality, contributing to food security, income generation, and export potential.
- Soil testing is a valuable tool to assess nutrient levels, pH, and fertility status, helping in scientific soil management for maximum production.
- Phytoremediation offers a cost-effective and sustainable method to remediate polluted soils and water, requiring low investment in materials, labor, and energy, making it economically viable for widespread use.

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