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# SOIL CHEMICAL DEGRADATION DUE TO LONG-TERM IRRIGATION WITH CARPET INDUSTRY WASTEWATER: A CASE STUDY OF BHADOHI DISTRICT, UTTAR PRADESH

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**Abstract**

Carpet manufacturing in Bhadohi (India's "Carpet City") generates significant quantities of wastewater rich in salts, organic matter, synthetic dyes, and heavy metals. In many local agricultural areas, untreated or partially treated effluent is used for irrigation due to water scarcity and economic constraints. This study evaluates the effects of long-term irrigation with carpet industry wastewater on soil chemical properties and assesses the potential consequences for soil health, crop productivity, and environmental sustainability. Soil samples were collected from irrigated fields at different distances from discharge points and compared with reference (non-irrigated) soils. Results indicate substantial increases in salinity, pH, heavy metal accumulation and nutrient imbalance. The findings call for urgent policy intervention and adoption of safer irrigation practices.

**Keywords-** Chemical degradation, Soil, Carpet industry, Heavy metal, Irrigation, Bhadohi.

## Introduction:

The carpet industry in Bhadohi and its periphery is one of the most important export hubs in India. The production process involves dyeing, washing, and finishing operations that generate wastewater containing synthetic dyes, salts (e.g., NaCl, $Na_2SO_4$), surfactants, organic load, and trace metals. Due to insufficient wastewater treatment infrastructure and high freshwater demand, local farmers often use untreated effluent for irrigation. Over time, this practice alters soil chemistry, risking land degradation and reduced agricultural productivity. Soil chemical properties — including pH, electrical conductivity (EC), exchangeable sodium percentage (ESP), cation exchange capacity (CEC), organic carbon, and bioavailable metals — determine soil fertility and crop yield. Long-term application of industrial effluent may cause salinization, sodification, metal toxicity, and nutrient imbalance, impairing soil function and posing ecological and health risks[1,2].

Water, a vital natural resource is an essential component of the environment for sustaining life on earth. It is investigated that 2.4 billion people in the world are unable to assess clean water, while 946 million people are left with limited alternative options due to SES (i.e., socio-economic status) factors[3,4]. Population growth, urbanization, climate change, rising food demand, etc., are the significant factors that will widen the gap between availability and demand of water worldwide.

The requirement for irrigation water rises as a result of rising food demand, and wastewater is used to fulfil this need due to the scarcity of groundwater. Long-term wastewater irrigation of the agricultural fields causes the accumulation of heavy metals in soil and their transfer to food crops and thus rises over the safe level, resulting the area to be considered as a contaminated area. Treated and untreated wastewaters are used in agriculture to meet the rising demand for irrigation water [5,6]. Around 11% of the total cultivated area is irrigated by untreated wastewater globally reported[7]. Likewise, about 10% of the global population consumes crops and vegetables irrigated with wastewater[8]. Wastewater is rich in organic matters and nutrients, therefore its use in the agriculture is recognized as one of the ways of wastewater management[9]. The occurrence of heavy metals in wastewater is low generally below the permissible limit but long-term irrigation with wastewater effluents has elevated heavy metals in soil[10,11]. The transfer of heavy metals from soil to plants is primarily influenced by kinds of sources, seasons, loading rates, soil pH, redox potential, texture, organic matters, different types of available metal fractions and total metal concentrations, etc. [12].

Heavy metals cause several health hazards in human beings (e.g., cancer, neurological damage, lower intelligence quotient, kidney damage, skeletal and bone disorder)[13]. In recent years, research on health risks associated with the consumption of food contaminated by pesticides, heavy metals, or other toxicants has been motivated due to growing food safety concerns [14]. International agencies such as World Health Organization (WHO), Food and Agricultural Organization (FAO), United States of Environmental Protection Agency (USEPA) etc., have set the maximum allowable limits for the contents of heavy metals in water, crops, and soil to protect the public and environmental health resulting from the mobility of heavy metals in the environment and their bioaccumulation [15]. There is a high need to build accurate predictive models that can provide early

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information on the toxicity of heavy metals in growing crops in a contaminated region. The toxicity of heavy metals depends on characteristics of the growing medium, exposure types and paths, nutritional imbalance, intracellular homeostasis interruption and oxidative degradation of biological macromolecules (e.g., enzymes, DNA, lipids and proteins, etc.) by free radicals' generation.

**Materials and Methods:**

**Study Area**

Bhadohi district is located in southeastern Uttar Pradesh, India. The area has alluvial soils with moderate fertility and supports paddy, wheat, pulses, and oilseed cultivation. Several dyeing and carpet finishing units discharge wastewater into open drains used for irrigation.

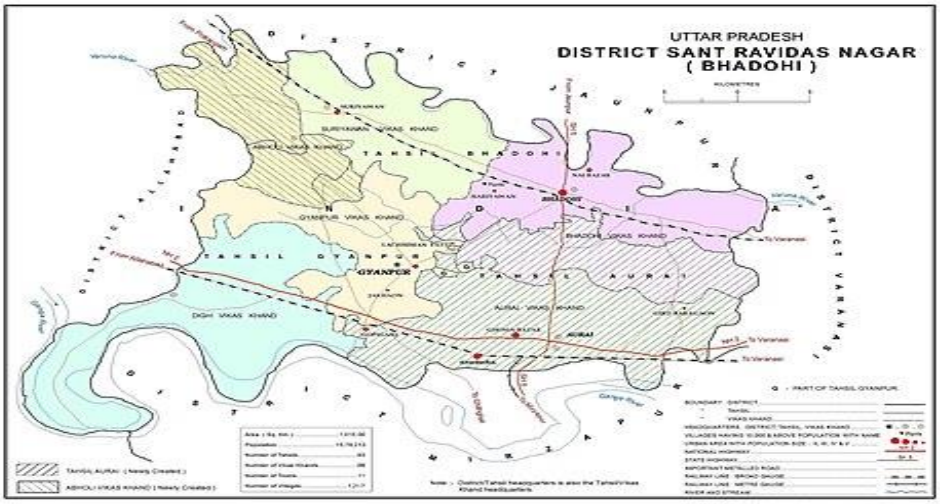


**Fig-1** Bhadohi Map

**Sampling Strategy**

- **Sites**: Five effluent-irrigated fields located near industrial discharge points; three control sites with no history of effluent irrigation (located >10 km away).
- **Samples**: Composite surface soil (0–15 cm) and sub-surface soil (15–30 cm) collected during the post-monsoon season.
- **Replication**: Three replicates per site.

### Analytical Methods

### Physicochemical Analysis

| Parameter | Method |
|---|---|
| pH | pH meter (1:2.5 soil: water) |
| Electrical Conductivity (EC) | Conductivity meter |
| Organic Carbon | Walkley-Black method |
| Cation Exchange Capacity (CEC) | Ammonium acetate method |
| Exchangeable Sodium Percentage (ESP) | Calculation from exchangeable cations |
| Available Nitrogen (N) | Kjeldahl distillation |
| Available Phosphorus (P) | Olsen's method |
| Available Potassium (K) | Flame photometry |

### Heavy Metals

Cr, Zn, Ni, Pb, Cu were extracted using di-acid digest and quantified by Atomic Absorption Spectrophotometry (AAS).

### Statistical Analysis

Data were analyzed using ANOVA to detect differences between effluent-irrigated and control soils. Correlation matrices were used to evaluate relationships among soil parameters.

## Results

### Soil pH and Electrical Conductivity

Effluent-irrigated soils exhibited significantly higher pH and EC compared to control soils:

| Parameter | Control Mean | Effluent-Irrigated Mean |
|---|---|---|
| pH (0–15 cm) | 7.4 ± 0.2 | 8.3 ± 0.3* |
| EC (dS/m) | 0.45 ± 0.1 | 3.2 ± 0.5* |

*Significant at $p < 0.05$

**Salinity and Sodicity**

- EC values in effluent-irrigated sites exceeded 2 dS/m, indicating moderate to high salinity.
- ESP values rose above 15% in irrigated plots, suggesting early sodic soil development.

**Organic Carbon and Cation Exchange Capacity**

Organic carbon showed slight increases but lacked statistical significance. However, CEC tended to rise in effluent-irrigated soils due to increased clay dispersion.

**Table-1** Macronutrients

| Nutrient | Control | Effluent Irrigated |
|---|---|---|
| N (kg/ha) | 210 ± 15 | 210 ± 18 |
| P (kg/ha) | 18 ± 5 | 22 ± 3* |
| K (kg/ha) | 250 ± 20 | 240 ± 25 |

Phosphorus showed slight enrichment, possibly due to detergents used in the carpet process.

**Heavy Metals:**

**Table-2** Effluent-irrigated soils had markedly elevated heavy metal concentrations:

| Metal | Control (mg/kg) | Irrigated (mg/kg) | Permissible Limit (India) |
|---|---|---|---|
| Cr | 22 ± 3 | 78 ± 11* | 50 |
| Zn | 45 ± 5 | 160 ± 14* | 150 |
| Ni | 18 ± 2 | 60 ± 8* | 30 |
| Pb | 12 ± 2 | 38 ± 5* | 20 |
| Cu | 19 ± 1 | 62 ± 7* | 50 |

*Significant at $p < 0.01$

Correlation analysis showed strong positive associations between EC, ESP, and heavy metal concentrations.

**Table-3** Physicochemical Profile

| Parameter | Observed Range | CPCB Limit |
|---|---|---|
| pH | 7.5-11.2 | 5.5-9.0 |
| EC (µS/cm) | 1800-3500 | 2000 |
| TDS (mg/L) | 1200-2800 | 2100 |
| DO (mg/L) | 0.5-3.2 | 5.0 |
| $BOD_5$(mg/L) | 400-950 | 30 |
| COD (mg/L) | 1500-3800 | 250 |
| Chlorides (mg/L) | 800-2200 | 1000 |
| Sulphates (mg/L) | 400-1100 | 1000 |

**Discussion:**

**Alkalinity and Salinity Build-Up**

Continuous application of saline effluent increased soil pH and EC. Elevated salinity adversely affects soil structure by dispersing clay particles, reducing porosity and water infiltration. Field conditions may exhibit crust formation and reduced seedling emergence.

**Sodicity Trends**

High ESP (>15%) suggests sodic soil development. Sodicity affects soil permeability and causes poor aeration, which harms root growth and nutrient uptake. Gypsum amendment may be required to reclaim such soils.

**Nutrient Imbalance**

While N and K levels remained comparable, slight P enrichment may reflect phosphate additives in detergents or dyes. Excess P can cause nutrient imbalances, leading to luxury uptake or antagonism with micronutrients like Zn.

**Heavy Metal Accumulation**

The significant increase in Cr, Ni, Pb, and Zn is concerning:

- **Chromium (Cr)** is frequently used as a mordant and may form stable complexes with dyes.
- **Nickel and Lead** contribute to phytotoxicity, inhibiting photosynthesis and enzyme activity.
- Heavy metals accumulate in plant tissues, posing food safety risks.

The elevated concentrations above permissible soil limits indicate potential long-term ecological and health hazards.

**Soil Organic Carbon**

No significant rise in organic carbon suggests that effluent organic load may be rapidly mineralized, or soil microbial activity is constrained due to salinity and metals.

**Implications for Agriculture**

Soil degradation due to industrial effluent use can:

- Reduce crop yields over time.
- Promote micronutrient deficiencies or toxicities.
- Increase soil reclamation costs.
- Threaten groundwater quality through leaching.

**Conclusion**

This study demonstrates that long-term irrigation with untreated carpet industry wastewater in Bhadohi has significantly altered soil chemical properties. There is a clear trend of increased salinity, sodicity, and heavy metal accumulation, with potential negative effects on soil health and agriculture. Immediate mitigation strategies, policy reforms, and community awareness are crucial to prevent irreversible land degradation and safeguard environmental and human health.

**Recommendations**

- Strict enforcement of effluent discharge standards.
- Regular monitoring of irrigation water quality.
- Ban or restrict use of untreated industrial effluent for irrigation.
- Gypsum application to reduce sodicity.
- Organic amendments (farmyard manure, compost) to improve structure and microbial activity.
- Leaching practices using high-quality irrigation water during monsoons to flush salts.

**Treatment and Water Reuse**

- Establish Central Effluent Treatment Plants (CETPs) for carpet clusters.
- Promote constructed wetlands and bioremediation units.
- Encourage recycling of treated water for washing and cooling processes.

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