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Study on Crop Changes in Form and Biochemistry in Response to Industry Effluents

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ABSTRACT

Industrialization has been one of the cornerstones of modern economic progress. India's rapid industrial growth, particularly in textile, leather, pulp and paper, fertilizer, sugar, distillery, metal plating, and pharmaceutical sectors, has contributed significantly to employment generation and economic development. The release of this waste in the environment untreated or inadequately treated into open lands, rivers, or irrigation canals, they infiltrate agricultural soils and affect crop health, soil fertility, and food safety. The composition of industrial wastewater is complex and typically contains suspended solids, organics, salts, dyes, surface active compounds, phenols, and heavy metals. Their toxic effects are multifaceted, disturbing plant metabolism, photosynthesis, and enzymatic activities, thereby affecting both the form (morphology) and biochemistry of plants. For this reason, it is necessary to analyze the effects of the effluents on crops both morphologically and biochemically

KEYWORDS
Industrialization; Industrial effluents; Industrial wastewater; Crop health; Soil fertility; Food safety; Heavy metals; Plant metabolism; Photosynthesis; Enzymatic activities; Plant morphology; Plant biochemistry; Effluent effects; Toxic environments.

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1. Introduction

It can be noted from the figures that the 392 sugar mills in India in the period 1991-92 had produced 134 million tons of sugar from the total availability The cane production during this time amounted to 239 million tons on land covering 3.8 million hectares (Anonymous, 1993). During this period, the sugar production resulted in the generation of more than 4.02 million tons of press mud (Jambhekar, 1992). The amount of press mud generated per year is roughly five million tons, which is growing at a fast pace. Sugar industries produce vast amounts of polluting effluent which is disposed of either on land or into water bodies. Therefore, surface water serves as the main recipient of these industrial wastes.

At the present moment, various industries continue to discharge huge amounts of effluents loaded with nutrients, metals, and other toxins into cultivable areas Several types of wastes arise from industries, and these wastes are often disposed of in the neighboring land and water sources, thus contributing to environmental pollution (Chandra et al., 2009; Maliwal et al., 2004).Though certain categories of wastes are known to be hazardous to the health of humans and animals, others are potentially harmful to their health.

Fresh and dry weight of seedlings increase with low concentration of the effluents but decrease with high concentrations.A certain level of nutrients and minerals is essential for the growth of seeds, and in a similar way, effluents also contain certain nutrients which are essential for the growth of the plant. In such a case, nutrients present in the effluents generated by this particular industry in adequate amounts can be useful in the promotion of seedling growth, resulting in increase in matter's weight whether it is in wet or dry state.

Earlier research studies have revealed that the pollution of river called 'Gundur' resulted from the effluents of the paper mill in Rajahmundry. Similarly, Motwani et al. (1956) found that the effluents discharged from Rohtas Industries factory in Dalmianagar polluted the Sone River.This gave rise to an increase in the concentrations of organic matter along with other pollutants such as nitrate and phosphate that exceeded their permissible limits. These nutrients result in the process of eutrophication in the river, and they get absorbed with time.

Physicochemical characteristics of soil have been determined by Ajmal & Khan (1983) by making use of sugar mill effluent for the purpose of irrigation. In this case, it is evident that Somasekhar et al., in 1984, mentioned that nitrogen, phosphorus, and potassium content were found in higher amount in effluent sample as compared to control sample. This situation is due to pollution of soil due to the presence of pollutants in the form of waste products from industries. Such wastes not only provide nutrition to plants but also have contaminants in the form of poisonous elements.

In yet another experiment conducted by Karunyal et al. (1994), it has been observed that the lower concentration of tannery effluent enhances the protein content in Oryza sativa, Gossypium hirsutum, Vigna mungo and Vigna unguiculata. In one more study, Pujar (1995) discovered that irrigation of industrial effluent along with water results in absorption of zinc, copper, iron and manganese in maize and wheat. In yet another experiment conducted by Singaram (1995), it has been discovered that soils irrigated with industrial effluents had lower water holding capacity but higher porosity than control soils.

Srinivasachary et al. (1998), there have been various tests that were conducted to examine the effects of industrial wastewater on the germination and growth of peas. From their research, it was observed that the soils that had been treated with paper mill waste had more NPK and organic carbon than soils that had not been treated. Meanwhile, according to Misra and Sahoo (1999), there were many industrial effluents that had high content of elements like calcium, iron, magnesium, sodium, potassium, and chromium that could negatively influence the metabolism of plants. While on one hand, such effluents can enrich the soil with nutrients; on the other hand, they can be toxic for plants.

According to Kaushik et al. (2004), it was discovered that the results of the experiment conducted on the effect of textile effluents on the growth of various types of wheat showed that textile effluents are of brown-black color, and there was no presence of dissolved oxygen in the effluents. Further, there is a presence of higher levels of total solids, total alkalinity, BOD, and COD in the effluents. In terms of the chemical components, textile effluents have high quantities of total nitrogen, phosphates, chlorides, sulphates, sodium, and calcium.

Ayyasamy et al. (2008), the effluents from sugar factories have played a significant role in determining the growth and biochemistry of plants. The effluents from sugar factories contain various important components, such as nitrogen, chloride, sulphate, calcium, and magnesium. The discharge of the effluents may lead to changes in soil and water quality in terms of their pH, EC, BOD, COD, TDS, total nitrogen, phosphate, and sulphate. These factors can play an influential role in plant growth. The use of increased concentrations of the effluents in irrigation has affected shoot length, free amino acids, protein, and total chlorophyll content.

The toxic effects of effluents from sugar factories on seed germination of paddy, vigour index, and chlorophyll content have been explored by Krishna and Leelavathi (2002). They revealed that low concentration of effluent led to higher vigour index value, and higher concentration inhibited plant development. In the same vein, the effects of distillery effluent and industrial sludge leachate on germination of black gram have been studied by Mishra and Pandey (2002), and higher concentration of industrial effluents was shown to inhibit the growth of crops by reducing shoot and root lengths.

A study was carried out by Raju et al. (2015) on the impact of industrial effluents on seed germination and growth of Oryza sativa L. and Triticum vulgare L. It was established that an increase in effluent concentration led to a decrease in seed germination and seedling growth, indicating the negative impact of industrial waste water.

A field experiment was conducted by Srivastava et al. (2015) to evaluate the effect of sugar mill effluent (SME) in various concentrations (10%, 25%, 50%, 75%, and 100%) together with di-ammonium phosphate (DAP) at 100 kg/ha (0.7 g/5 kg) on the agronomic parameters of Vigna unguiculata L. in Kharif and Zaid season. Various parameters were considered in this study, including shoot length, root length, number of leaves, flowers, pods, fresh and dry biomass, chlorophyll content, leaf area index, and yield. The majority of the agronomic parameters decreased with an increase in SME concentration. However, 50% dilution of SME gave the highest values among all treatments after 90 days of irrigation.

Research Methodology

The methodology that has been developed in the present research has been very carefully designed so that the effects of different effluents produced by various industries could be seen on the morphology and composition of certain plants in controlled and field experiments. This methodology is designed to investigate physicochemical properties of industrial waste, effect of industrial waste on soil properties and bio-chemical reactions as a result thereof with help of specific crops such as rice, wheat, spinach, and mustard.

Study Area

The investigation was carried out in two major industrial districts of Eastern Uttar Pradesh—Jaunpur and Varanasi, located within the Indo-Gangetic alluvial plains. Major effluent sources include distilleries and sugar mills in Shahganj and Mungra Badshahpur (Jaunpur), and textile dyeing and tannery units in Lohta and Ramnagar (Varanasi).

Collection and Preservation of Effluent Samples

Effluent samples were collected directly from main discharge outlets of the selected industries using acid-washed polyethylene containers. The containers were rinsed with the same effluent before collection to avoid contamination. Each sample (5 L) was immediately brought to the laboratory and analyzed within 24 hours. Samples were stored at 4°C to minimize microbial and chemical changes prior to analysis.

Sampling Points

Industry	Location	Type of Effluent	Coordinates
Distillery	Shahganj (Jaunpur)	Spent wash	25.68°N, 82.69°E
Sugar Mill	Mungra Badshahpur	Washing and	25.75°N, 82.67°E

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	(Jaunpur)	clarification discharge	
Textile Unit	Lohta (Varanasi)	Dye bath wastewater	25.32°N, 82.95°E
Tannery	Ramnagar (Varanasi)	Chrome tanning effluent	25.28°N, 82.98°E

Samples were stored at 4°C to minimize microbial and chemical changes prior to analysis.

Analysis of Effluent Samples

The physico-chemical parameters were analyzed following APHA (2017) and Trivedy & Goel (1986) protocols. Analytical results were compared with CPCB and BIS standards for industrial wastewater discharge.

Soil Analysis

The soil analysis included pH, EC, Organic Carbon, Available Nitrogen, Available Phosphorus, Available Potassium and DTPA-extractable Metals.

Experimental Design

A completely randomized design (CRD) was adopted with five effluent concentrations (0%, 25%, 50%, 75%, and 100%) for each effluent type. Each treatment was replicated thrice for all four crops.

- **Soil type:** Sandy loam (pH 7.2, EC 1.1 dS/m)
- **Pot size:** 30 cm × 25 cm (5 kg soil)
- **Number of treatments:** 5
- **Replications:** 3

- **Total pots:** 4 crops × 5 treatments × 3 = 60 pots
- **Irrigation frequency:** Every 5 days
- **Duration:** 45–110 days depending on crop

Crop Details

Seeds were procured from ICAR–IARI (New Delhi) to ensure genetic uniformity. Prior to seed germination, the seeds were initially sterilized on the surface using 0.1% mercuric chloride solution and later washed with distilled water.

Morphological Studies

Morphological traits were recorded at vegetative and reproductive stages. Germination, seedling length, vigor index, plant height, leaf area, number of leaves, fresh & dry weight, panicle length, number of tillers or siliquae, yield, 1000-grain weight, and biomass were recorded.

Vigor Index (VI):

VI = Germination (%) × (Root length + Shoot length)

Biochemical Analysis

Plant samples were washed, shade-dried, and homogenized using pre-chilled mortar and pestle. Chlorophyll-a, Chlorophyll-b, and Total Chlorophyll were quantified using the technique recommended by Arnon (1949) involving the use of 80% acetone as an extraction solvent. The carotenoid content was estimated spectrophotometrically at 480 nm using the method of Lichtenthaler and Wellburn (1983).

Proline Content

Determined by Bates et al. (1973) using acid ninhydrin; absorbance measured at 520 nm.

Summary of Methodological Approach

Step	Description	Purpose
Effluent collection & analysis	Sampling from four industrial sources	Determine pollution profile
Soil sampling	Pre- and post-experiment analysis	Assess soil quality variation
Pot experiments	Controlled crop exposure	Evaluate morphological & biochemical responses
Biochemical assays	Pigments, osmolytes, antioxidants	Quantify stress responses
Metal analysis	AAS-based quantification	Trace contaminant uptake
Data analysis	ANOVA, DMRT, PCA	Validate and interpret findings

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Results

The results of experimentation, both conducted in laboratory as well as in field, for evaluating the impact of different types of industrial effluents like distillery spent wash, sugar mill effluents, textile dyeing effluents, and tannery effluents on morphological, physiological, and biochemical.

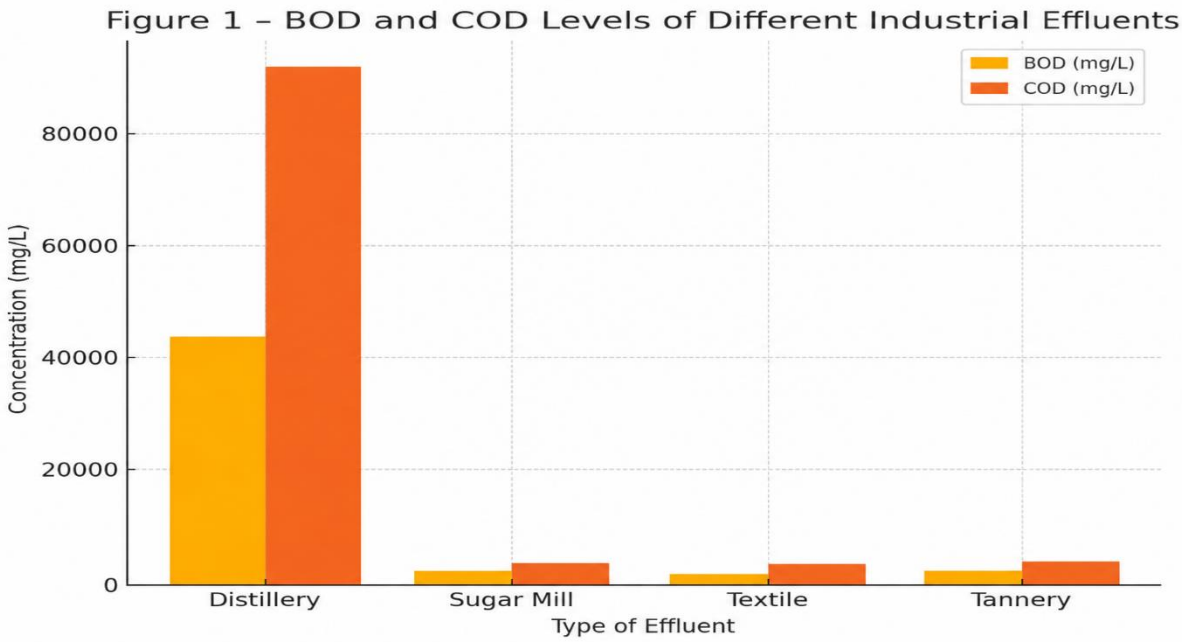
1. **Physico-Chemical Characteristics of Industrial Effluents**

The effluents collected from four major industrial sources showed wide variation in their pH, EC, BOD, COD, and metal concentrations (Table 4.1).

Table 1 – Physico-Chemical Characteristics of Collected Industrial Effluents (Mean ± SE)

Parameter	Distillery	Sugar Mill	Textile	Tannery
pH	4.6 ± 0.1	7.3 ± 0.2	8.7 ± 0.1	6.8 ± 0.2
EC (dS/m)	14.2 ± 0.5	3.8 ± 0.2	6.5 ± 0.3	8.2 ± 0.3
BOD	43,500 ± 250	1,850 ± 50	1,250 ± 30	1,900 ± 45
COD	89,600 ± 400	3,200 ± 120	2,900 ± 100	3,400 ± 150
Total Dissolved Solids (TDS)	9,200 ± 120	1,450 ± 80	1,980 ± 60	2,560 ± 75
Cr (mg L^{-1})	0.25 ± 0.01	ND	0.36 ± 0.02	5.20 ± 0.15
Pb (mg L^{-1})	0.13 ± 0.01	0.08 ± 0.01	0.26 ± 0.02	0.71 ± 0.03

Figure 1 – Graph Showing BOD and COD Levels of Different Effluents



Observation: Distillery effluent → Highest BOD and COD (nearly 20× higher than BIS limits).

2. **Effect of Effluent Irrigation on Soil Quality**

Continuous application of industrial wastes by means of irrigation resulted in significant alterations of soil properties under all treatments in contrast to the control treatment ($p<0.05$).

Table 2 – Changes in Soil Properties After 60 Days of Effluent Irrigation

Parameter	Control	Distillery (50%)	Sugar (50%)	Textile (50%)	Tannery (50%)
pH	7.2	8.1	7.8	8.4	8.6
EC (dS/m)	1.1	3.2	2.6	3.9	4.3
Organic Carbon (%)	0.62	0.82	0.76	0.68	0.65
Available N (kg/ha)	275	355	330	310	295
Available P (kg/ha)	18.4	23.5	22.0	19.6	21.4
Exchangeable Na (%)	5.1	12.2	8.4	15.6	16.3

Interpretation: Distillery and sugar effluents increased organic carbon and nitrogen due to organic residues, whereas textile and tannery effluents elevated EC and sodium, indicating salinity and sodicity stress.

3. Morphological (Form) Responses of Crops

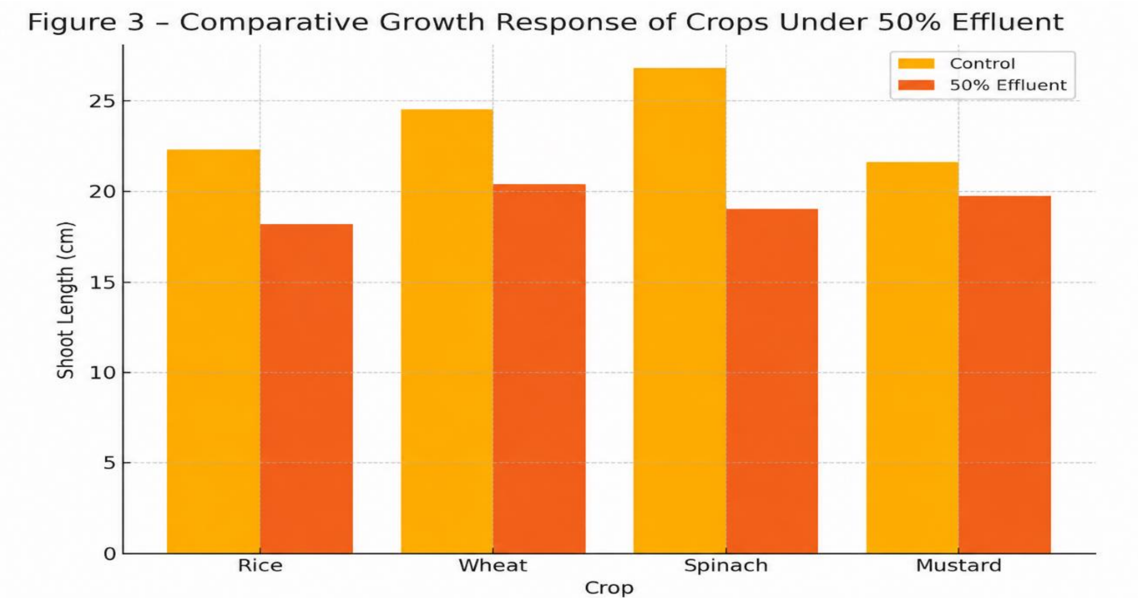
The effect of inhibition of the plant morphology due to effluent irrigation was noted at higher concentrations of the effluents, which included seedling growth inhibition, leaf growth inhibition, and delayed flowering.

Table 3 – Effect of Effluent Concentration on Germination and Growth (Mean ± SE)

Crop	Treatment	Germination (%)	Root Length (cm)	Shoot Length (cm)	Fresh Weight (g)
Rice	Control	95 ± 1.2	12.8 ± 0.5	22.3 ± 0.9	3.21 ± 0.12
Wheat	25%	92 ± 1.0	11.5 ± 0.3	20.5 ± 0.7	3.10 ± 0.11
Spinach	50%	81 ± 1.3	9.4 ± 0.4	18.2 ± 0.6	2.86 ± 0.08
Mustard	75%	67 ± 1.5	7.2 ± 0.5	15.4 ± 0.5	2.12 ± 0.06
Wheat	100%	48 ± 1.1	5.8 ± 0.3	12.1 ± 0.4	1.64 ± 0.05

ANOVA results indicated significant reductions ($p < 0.01$) in shoot and root lengths at ≥50% effluent concentration.

Figure 3 – Comparative Growth Response of Crops Under 50% Effluent Irrigation



(Observation: Mustard tolerated effluent better than rice and spinach, possibly due to stronger antioxidant defense mechanisms (Saud et al., 2022).

Discussion

Effluent Characteristics and Pollution Load

Based on the findings from the current research, it is evident that the effluents released from industrial activities have an impact on the morphology, physiology, and biochemistry of important crops planted in Jaunpur and Varanasi. The response obtained is dependent upon the type of effluent, its concentration, and crop used for testing.

High levels of BOD (43,000 mg/L) and COD (89,000 mg/L) were found in the distillery effluent, reflecting large amounts of organic material present in the waste water (Kukreja, 2012). The acidic to alkaline pH range observed indicates variable chemical composition and incomplete treatment. Such effluents alter soil pH and conductivity, affecting microbial activity and nutrient cycling (Ghosh et al., 2017). High COD and TDS levels reduce soil aeration, limit water infiltration, and induce physiological drought conditions for plants.

Morphological and Growth Responses

A clear dose-dependent reduction in seed germination and root elongation was observed across all crops. At 100% effluent concentration, germination declined by more than 40% in rice and spinach.

Plant height, leaf number, and biomass declined progressively with increasing effluent concentration. Rice and spinach were the most sensitive, while mustard showed relative tolerance, maintaining higher biomass at moderate concentrations.

Biochemical Alterations in Plants

Chlorophyll a, chlorophyll b, and carotenoids showed considerable decrease for all the treated plants where the maximum amount of decrease was seen in those plants treated with textile and tannery effluents. The decrease in chlorophyll content signifies poor structure of chloroplasts and inadequate photosynthesis process.

An increase in proline content in all crops under effluent irrigation suggests activation of osmotic adjustment mechanisms.

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