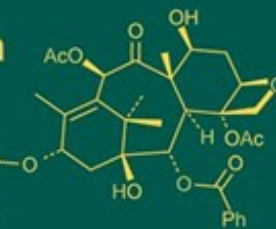
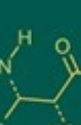
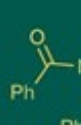


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Effect of treated and untreated sewage water irrigation on soil properties, nutrient uptake and performance of China aster (*Callistephus Chinensis* L.)

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ABSTRACT

A field experiment was conducted at the College of Horticulture, Kolar, Karnataka, during the summer season of 2023–24 to evaluate the effects of treated and untreated sewage water irrigation on irrigation-water quality, growth, flowering, yield, nutrient accumulation and postharvest soil properties of China aster. The experiment was laid out in a randomized complete block design with seven irrigation treatments and three replications, viz. borewell water, raw sewage water, 1:1 borewell + raw sewage water, alternate borewell + raw sewage water, treated sewage water, 1:1 borewell + treated sewage water and alternate borewell + treated sewage water. Raw sewage water contained higher suspended and dissolved solids, nutrients and trace elements than treated sewage water, whereas treated sewage water showed lower organic load and *E. coli* counts. Raw sewage irrigation produced the highest plant height at 90 days after transplanting (34.33 cm), secondary branches (17.33 plant⁻¹), plant spread (560.01 cm²), total dry matter (32.07 g plant⁻¹), 100-flower fresh weight (168.03 g), flower yield (66.98 g plant⁻¹ and 6.44 t ha⁻¹), and shelf life (3.17 days). Treated sewage water also improved crop performance, recording 32.80 cm plant height, 507.76 cm² plant spread, 27.17 g total dry matter plant⁻¹ and 5.28 t ha⁻¹ flower yield. Plant N, P, K, Ca, Mg, S, Mn, Zn, Cu and B concentrations were generally higher under raw sewage irrigation. Postharvest soil under raw sewage irrigation had higher organic carbon (0.72%), electrical conductivity (1.45 dS m⁻¹), available N (412.74 kg ha⁻¹), P₂O₅ (66.95 kg ha⁻¹), K₂O (263.45 kg ha⁻¹), exchangeable Ca and Mg, micronutrients and microbial populations. Although raw sewage produced the greatest crop response, treated sewage water provided substantial crop and soil benefits with lower contaminant and salinity-related loads. Therefore, treated sewage water has potential as a supplementary irrigation source for floriculture, subject to regular monitoring of salinity, heavy metals and microbiological quality.

Keywords: Wastewater reuse, Sewage irrigation, China aster, Soil fertility, Nutrient uptake, Treated sewage water

Introduction

Increasing scarcity of freshwater resources and growing demand for irrigation water have encouraged the reuse of wastewater in agriculture. Sewage water contains appreciable quantities of plant nutrients and organic matter and therefore has potential as an alternative source of irrigation water. However, its quality varies considerably depending on its origin and degree of treatment. Application of untreated or inadequately treated sewage water may increase soil salinity and nutrient loading and may also introduce potentially toxic elements and microbial contaminants into the soil–plant system. Therefore, proper assessment of wastewater quality and its effects on crop and soil properties is essential for safe and sustainable agricultural reuse (Ayers and Westcot, 1985; who, 1989; Jaramillo and Restrepo, 2017) [1, 2].

Several studies have reported beneficial effects of wastewater irrigation on crop growth and soil fertility due to the additional supply of nitrogen, phosphorus, potassium and other nutrients. Al-Suhaibani *et al.* (2021) [3] reported that treated wastewater influenced plant growth and nutrient uptake, while Alvarez-Holguin *et al.* (2022) [4] observed improved chlorophyll content and biomass production under treated wastewater irrigation. Gatta *et al.* (2016) [5] demonstrated the potential of treated municipal wastewater for irrigation of globe artichoke without adverse effects on crop production under the conditions studied. These findings indicate that suitably treated wastewater can provide both irrigation water and supplementary nutrients to horticultural crops.

Despite these benefits, repeated application of wastewater can alter soil properties. Mapanda *et al.* (2005) [6] reported increased concentrations of heavy metals in soils receiving wastewater irrigation, while Mohammad *et al.* (2003) [7] observed changes in soil and crop properties following long-term wastewater application.

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Thus, wastewater reuse requires a balance between its agronomic benefits and the possible risks associated with salts, nutrients and trace elements.

China aster (*Callistephus chinensis* L.) is an important annual floricultural crop cultivated for loose flowers, cut flowers, garlands and ornamental purposes. Since the harvested produce is not directly consumed as food, floricultural crops provide a suitable system for evaluating wastewater reuse. However, information on the comparative effects of untreated and treated sewage water on the growth, flowering, flower yield, nutrient accumulation and postharvest soil properties of China aster under field conditions is limited. This is particularly relevant in water-scarce regions where alternative irrigation sources are required.

Therefore, the present study was undertaken to evaluate the effects of treated and untreated sewage water irrigation on water quality, growth, flowering, flower yield and quality, plant nutrient accumulation and postharvest soil properties of China aster variety *Arka Archana* under field conditions. The study also aimed to identify a suitable sewage-water irrigation regime for maintaining crop productivity while minimizing potential adverse effects on soil quality.

Materials and Methods

Experimental site and crop

The experiment was conducted at the College of Horticulture, Tamaka, Kolar, *Karnataka* (13°12' N latitude and 78°17' E longitude), during the summer season of 2023–24. The site falls in the eastern dry zone (Zone 5) of *Karnataka*. The soil was red sandy loam, initially slightly alkaline (pH 7.64) with EC 0.75 dS m⁻¹ and low organic carbon (0.42%), available N (146.85 kg ha⁻¹) and available K₂O (132.86 kg ha⁻¹). China aster variety *Arka Archana* was procured from ICAR-IIHR Bengaluru.

Experimental design and treatments

The experiment was laid out in randomized complete block design with seven treatments and three replications. Each plot measured 2.4 × 2.4 m (5.76 m²), with plants spaced at 30 × 30 cm. Seedlings were transplanted during March 2024.

Table 1. Treatment details of the experiment

Treatment	Irrigation regime
T ₁	Borewell water irrigation (control)
T ₂	Raw sewage water irrigation
T ₃	1:1 borewell water + raw sewage water
T ₄	Alternate borewell water + raw sewage water
T ₅	Treated sewage water irrigation
T ₆	1:1 borewell water + treated sewage water
T ₇	Alternate borewell water + treated sewage water

All treatments received 20 t FYM ha⁻¹ and 180:120:60 kg ha⁻¹ N:P₂O₅:K₂O according to the UHS Bagalkot package of practices.

Raw sewage was collected from the inlet and treated sewage from the outlet of the sewage treatment plant at the College of Horticulture, Kolar.

Water, plant and soil analysis

Borewell, treated sewage and untreated sewage waters were analyzed for suspended solids, dissolved solids, BOD, COD, *E. coli*, pH, EC, TDS, carbonate, bicarbonate, chloride, nitrate, sulphate, Ca, Mg, Na, K, micronutrients and selected heavy metals. Irrigation suitability was assessed using EC, TDS, potential salinity, residual sodium carbonate, residual sodium bicarbonate, sodium percentage, sodium ratio, sodium adsorption ratio, permeability index and magnesium adsorption ratio.

Growth observations included plant height and SPAD chlorophyll at 30, 60 and 90 days after transplanting, primary and secondary branches, plant spread and total dry matter. Flowering observations included days to first bud appearance and 50% flowering. Yield observations included average flower diameter, 100-flower fresh weight, flower yield plant⁻¹ and hectare⁻¹, shelf life and vase life. Plant samples were analyzed for N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B. Postharvest soil samples (0–15 cm) were analyzed for bulk density, maximum water-holding capacity, pH, EC, organic carbon, available N, P₂O₅, K₂O, exchangeable Ca and Mg, available S, DTPA-extractable Fe, Mn, Zn and Cu, hot-water-soluble B, and total bacterial, fungal and actinobacterial populations.

Statistical analysis

The experimental data were analysed using Microsoft Excel and OPSTAT statistical software. The experiment was conducted with three replications. Treatment means were compared using the critical difference (CD) at the 5% level of probability.

Results and Discussion

Characteristics and irrigation quality of water sources

Untreated sewage water had the highest suspended solids (23 mg L⁻¹), dissolved solids (868 mg L⁻¹), BOD (4 mg L⁻¹), COD (30 mg L⁻¹), *E. coli* (10 MPN 100 mL⁻¹), pH (8.24), EC (378 µmhos cm⁻¹) and TDS (242 mg L⁻¹). Treated sewage water showed intermediate values, including 17 mg L⁻¹ suspended solids, 776 mg L⁻¹ dissolved solids, BOD 2 mg L⁻¹, COD 10 mg L⁻¹, *E. coli* 2 MPN 100 mL⁻¹, pH 7.80, EC 279 µmhos cm⁻¹ and TDS 179 mg L⁻¹. Borewell water recorded the lowest values for most of these parameters (Table 2).

Sewage waters also contained higher concentrations of Ca, Mg, Na and K and higher concentrations of Fe, Mn, Zn and Cu than borewell water. Pb, Ni, Cd and Cr were not detected in borewell water but were detected in treated and untreated sewage water. Thus, treatment reduced several quality indicators relative to raw sewage, but did not eliminate the presence of all trace elements. The irrigation indices showed that EC classified borewell water as low-salinity and treated and untreated sewage water as medium-salinity water, while SP, SR, SAR, PI and MAR were within the ranges. The study consequently identified treated sewage water as the more balanced wastewater source for irrigation.

Table 2. Selected irrigation-water quality characteristics

Parameter	Borewell	Treated sewage	Untreated sewage
Suspended solids (mg L ⁻¹)	8	17	23
Dissolved solids (mg L ⁻¹)	700	776	868
BOD (mg L ⁻¹)	ND	2	4
COD (mg L ⁻¹)	ND	10	30
<i>E. coli</i> (MPN 100 mL ⁻¹)	ND	2	10
pH	7.65	7.80	8.24
EC (µmhos cm ⁻¹)	220	279	378
TDS (mg L ⁻¹)	141	179	242

(continued on next page)

Parameter	Borewell	Treated sewage	Untreated sewage
Ca (meq L ⁻¹)	104	153	202
Mg (meq L ⁻¹)	97	136	192
Na (meq L ⁻¹)	76	91	129
K (meq L ⁻¹)	5	14	22
Pb (ppm)	ND	0.95	1.05
Ni (ppm)	ND	0.86	0.91
Cd (ppm)	ND	0.60	0.68
Cr (ppm)	ND	0.02	0.06

Growth and flowering response

Sewage-water irrigation significantly enhanced plant growth compared with borewell water. At 90 days after transplanting, plant height was 34.33 cm under raw sewage water and 32.80 cm under treated sewage water compared with 26.80 cm under borewell water. Raw sewage also produced the highest SPAD value at 90 days (40.65), followed by alternate borewell + raw sewage irrigation (39.53), whereas borewell water recorded 38.80 (Table 3).

Secondary branching and plant spread were significantly improved by sewage irrigation. Raw sewage produced 17.33 secondary branches plant⁻¹ and 560.01 cm² plant spread, compared with 14.07 secondary branches and 265.68 cm² under borewell water. Treated sewage water produced 15.13 secondary branches and 507.76 cm² plant spread. Total dry matter was 32.07 g plant⁻¹ under raw sewage and 27.17 g plant⁻¹ under treated sewage compared with 17.10 g plant⁻¹ under borewell water. These results are in agreement with the findings of Alvarez-Holguin *et al.* (2022) [4] in barley and Kumar *et al.* (2023) [8] in *Datura innoxia*.

Table 3. Growth and yield response of China aster

Treatment	Height 90 DAT (cm)	SPAD 90 DAT	Secondary branches plant ⁻¹	Spread (cm ²)	Dry matter (g plant ⁻¹)
T ₁	26.80	38.80	14.07	265.68	17.10
T ₂	34.33	40.65	17.33	560.01	32.07
T ₃	31.07	39.03	14.47	433.88	25.13
T ₄	28.60	39.53	14.33	388.91	19.30
T ₅	32.80	39.26	15.13	507.76	27.17
T ₆	30.80	39.01	14.13	401.81	19.67
T ₇	29.27	39.13	14.20	314.46	19.23
S.Em ±	1.04	0.39	0.78	19.77	1.09
CD @ 5%	3.22	1.19	2.41	60.94	3.37

Flowering was accelerated by sewage irrigation. The first bud appeared at 37.00 days and 50% flowering occurred at 64.33 days under raw sewage water, compared with 41.67 and 71.00 days, respectively (Table 4), under borewell water. Treated sewage water produced intermediate values of 39.33 and 66.67 days.

Flower yield and quality

Raw sewage irrigation produced the highest 100-flower fresh weight (168.03 g), flower yield per plant (66.98 g) and flower yield per hectare (6.44 t ha⁻¹). Treated sewage irrigation produced 155.19 g, 59.75 g plant⁻¹ and 5.28 t ha⁻¹, respectively. Borewell irrigation

recorded 125.38 g, 42.13 g plant⁻¹ and 2.76 t ha⁻¹. Average flower diameter did not differ significantly.

Shelf life differed significantly and was highest under raw sewage water (3.17 days), followed by treated sewage water (2.83 days), while borewell water recorded 2.17 days. Vase life did not differ significantly and ranged from 6.33 to 7.67 days. The increased yield under sewage irrigation is consistent with the greater nutrient supply and vegetative growth observed in the sewage water treatments. These results are in line with results obtained by Rinu *et al.* (2024) [9] in China aster. Al-Huqail *et al.* (2023) [10] found that sewage sludge amendments enhanced the marigold flower yield, supporting the role of wastewater nutrients in floriculture.

Table 4. Flowering, flower weight and flower quality

Treatment	First bud (days)	50% flowering (days)	Flower diameter (cm)	100-flower weight (g)	Yield plant ⁻¹ (g)	Yield (t ha ⁻¹)	Shelf life (days)	Vase life (days)
T ₁	41.67	71.00	4.35	125.38	42.13	2.76	2.17	6.33
T ₂	37.00	64.33	4.71	168.03	66.98	6.44	3.17	7.67
T ₃	39.67	68.67	4.45	147.97	55.11	4.42	2.33	7.33
T ₄	39.67	68.00	4.45	149.66	55.80	4.21	2.50	7.00
T ₅	39.33	66.67	4.54	155.19	59.75	5.28	2.83	7.67
T ₆	40.33	68.33	4.40	140.82	49.93	3.57	2.67	7.00
T ₇	40.00	68.67	4.37	142.65	50.20	3.57	2.33	7.33
S.Em ±	0.72	1.71	0.20	6.91	3.43	0.16	0.20	0.45
CD @ 5%	2.22	5.25	NS	21.28	10.58	0.49	0.61	NS

(continued on next page)

Plant nutrient concentration

Raw sewage irrigation has the highest concentrations of the major nutrients (Fig. 1) N (6.47%), P (0.86%) and K (4.26%), compared with 3.21, 0.43 and 2.23%, respectively, under borewell water. It also produced the highest Ca (1.43%), Mg (1.01%) and S (0.51%). Among micronutrients, Mn, Zn, Cu and B reached 135.58, 53.88, 20.31 and 78.59 ppm, respectively, under raw sewage irrigation. Treated sewage generally produced intermediate concentrations. Iron did not differ significantly among treatments. The results indicate that sewage water

supplied appreciable nutrients to the crop. At the same time, the greater accumulation of micronutrients and trace metals in sewage-water-irrigated systems supports the need for periodic monitoring when sewage water is used repeatedly, even for non-food crops. These results are corroborated with findings from previous studies that have observed increased micronutrients concentration in plants irrigated with sewage water, highlighting the potential of sewage effluents as a source of trace elements essential for plant growth (Rodrigues *et al.*, 2024) [11].

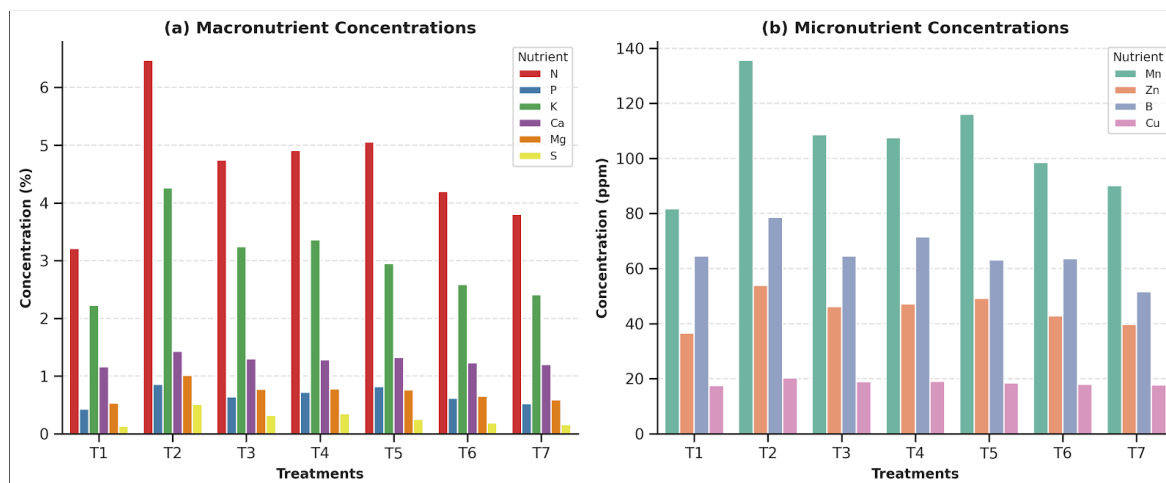


Figure 1. Nutrient concentration in China aster plant as influenced by treated and untreated sewage water irrigation levels

Postharvest soil properties influenced by different sewage irrigation levels

Bulk density and maximum water-holding capacity did not differ significantly among treatments, although raw sewage irrigation reduced bulk density to 1.34 Mg m^{-3} and increased maximum water-holding capacity to 43.56% (Table 5). Soil pH was also not significantly affected and ranged from 6.74 to 7.79. Raw sewage irrigation resulted in the highest EC (1.45 dS m^{-1}) and organic carbon (0.72%), while borewell water resulted in 0.84 dS m^{-1} and 0.54%, respectively. Available N, P_2O_5 and K_2O were also highest under raw sewage water (412.74 , 66.95 and $263.45 \text{ kg ha}^{-1}$), with treated sewage giving

more moderate values (238.83 , 38.69 and $147.89 \text{ kg ha}^{-1}$). Exchangeable Ca and Mg and available S were enhanced by sewage irrigation. Raw sewage produced $6.16 \text{ cmol(p}^+) \text{ kg}^{-1}$ Ca, $3.41 \text{ cmol(p}^+) \text{ kg}^{-1}$ Mg and 28.63 ppm S compared with 0.64 , 0.40 and 14.94 , respectively, under borewell irrigation. DTPA-extractable Fe, Mn, Zn and Cu and hot-water-soluble B were also significantly higher under raw sewage irrigation. Treatments with treated sewage water and mixed irrigation maintained moderate enrichment, indicating that sewage water acts as a rich source of micronutrients in addition to macronutrients (Mapanda *et al.*, 2005; Sharma *et al.*, 2007) [6, 12].

Table 5. Properties of postharvest soils of China aster as influenced by treated and untreated sewage water irrigation levels

Treatment	BD (Mg m^{-3})	MWHC (%)	pH	EC (dS m^{-1})	OC (%)	Avail. N (kg ha^{-1})	Avail. P_2O_5 (kg ha^{-1})	Avail. K_2O (kg ha^{-1})
T ₁	1.43	38.16	7.67	0.84	0.54	227.87	33.34	161.43
T ₂	1.34	43.56	6.74	1.45	0.72	412.74	66.95	263.45
T ₃	1.36	41.43	7.15	1.25	0.61	323.86	49.85	212.85
T ₄	1.35	41.28	6.94	1.09	0.63	318.26	41.28	208.74
T ₅	1.38	40.78	7.79	0.93	0.61	238.83	38.69	147.89
T ₆	1.40	39.12	7.76	0.87	0.59	226.45	36.52	144.86
T ₇	1.41	39.44	7.73	0.85	0.57	224.87	35.12	144.42
S.Em ±	0.06	1.89	0.34	0.04	0.02	13.57	2.08	8.81
CD @ 5%	NS	NS	NS	0.15	0.08	41.83	6.43	27.15

Soil microbial populations

Sewage water irrigation increased postharvest microbial populations. Raw sewage produced $432 \times 10^7 \text{ CFU g}^{-1}$ bacteria, $17 \times 10^4 \text{ CFU g}^{-1}$ fungi and $71 \times 10^5 \text{ CFU g}^{-1}$ actinobacteria, compared with 39×10^7 , 9×10^4 and $9 \times 10^5 \text{ CFU g}^{-1}$, respectively (Table 6), under borewell water. Treated sewage water also increased microbial counts (368×10^7 bacteria, 15×10^4 fungi and 54×10^5 actinobacteria), although values were lower than those under raw sewage. This suggests that organic matter and nutrient inputs associated with sewage stimu-

lated soil microbial activity during the experimental period. Biological parameters such as bacteria, fungi, and actinobacteria populations were strongly influenced by sewage water treatments. Application of 100 per cent untreated sewage water irrigation supported significantly higher microbial counts compared to borewell water, reflecting the contribution of organic matter and nutrients to microbial growth. However, treated sewage water and mixed irrigations also enhanced microbial activity, though to a lesser extent than raw sewage water. These results suggested that sewage water irrigation promotes a more biologically active soil environment, which

could improve nutrients cycling and soil health (Mohammad *et al.*, 2003) [7].

Table 6. Postharvest soil microbial populations

Treatment	Bacteria ($\times 10^7$ CFU g ⁻¹)	Fungi ($\times 10^4$ CFU g ⁻¹)	Actinobacteria ($\times 10^5$ CFU g ⁻¹)
T ₁	39	9	9
T ₂	432	17	71
T ₃	256	10	22
T ₄	264	11	20
T ₅	368	15	54
T ₆	192	14	16
T ₇	172	12	18
S.Em $\pm$	12.69	0.58	1.69
CD @ 5%	39.11	1.78	5.22

The experiment showed a clear nutrient-growth relationship: the water source with the highest nutrient and organic load produced the strongest vegetative growth, nutrient accumulation, and flower yield. Raw sewage water therefore produced the highest agronomic response. However, the same treatment also produced the highest EC, organic carbon, available nutrients, micronutrients and plant nutrient concentrations, indicating greater loading of soluble salts and elements into the soil-plant system.

Treated sewage water represented an intermediate response. It improved plant height, branching, biomass and flower yield relative to borewell water while reducing the contaminant and organic-load indicators measured in raw sewage. In a practical sewage water reuse system, treated effluent is therefore the more appropriate option for irrigation, provided water quality, soil salinity, trace elements, and microbial indicators are monitored regularly.

Conclusion

Treated and untreated sewage water significantly altered China aster growth, flowering, yield, plant nutrient concentration and postharvest soil fertility compared with borewell irrigation. Raw sewage water produced the maximum plant growth and flower yield, reaching 6.44 t ha⁻¹, but also resulted in the greatest accumulation of salts, organic carbon, available nutrients and micronutrients in the soil. Treated sewage water produced a substantial yield of 5.28 t ha⁻¹ while maintaining lower contaminant and salinity-related loads than raw sewage water. Treated sewage water therefore shows potential as a supplementary irrigation source for China aster. Long-term field studies are required before recommending continuous use, with particular emphasis on salinity, heavy-metal accumulation and microbiological safety.

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Conflict of interest

The authors declare that there is **no conflict of interest** related to the present work.

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