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Effects of Irrigation with Treated and Untreated Wastewater on Nutrient, Toxic Metal Content, Growth and Yield of Coriander (*Coriandrum sativum* L.)

Mohammed Abdullah Alghobar, Sidduraiah Suresha*

Department of Environmental Science, Yuvaraja's College, University of Mysore, Mysore, Karnataka, India

Email address:

algobar@gmail.com (M. A. Alghobar), sureshakumar12@yahoo.com (S. Suresha)

*Corresponding author

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Abstract: The study was conducted in Vidyaranyapuram area in the South West of Mysore, Karnataka. It was aimed to investigate the concentration of macronutrients and trace metals of arable soils and to compare by those irrigation with wastewater on soil and coriander plant (*Coriandrum sativum* L.), grown during its growth period. Twenty one samples each of water, soil and coriander plant were collected from different sites. Treatments included untreated wastewater (UWW); treated wastewater (TWW) and ground water (GW) as control. The used water sources when evaluated as irrigation water according to the FAO system of water quality classification were found suitable for use in leaching and irrigating the saline soils especially for short duration crops. The results indicated that use of wastewater for irrigation led to significant differences in mean values of pH, EC, N, P, Ca, Mg, Na, Mn, Cu, Zn, Cd, Ni, Pb and Cr of soil as compared to the control GW irrigated soil sample. N, P, K, Ca, Mg and Na contents also increase in leaves of coriander crop significantly higher than the GW irrigated control plants, irrigation with different proportions of wastewater showed significantly higher concentrations of heavy metals like Fe, Mn, Zn, Cu, Ni, Pb and Cr in leaf tissues of coriander crop, except for Cd and Co, as compared to the control treatment GW. The results indicated that irrigation of coriander with UWW and TWW affect negatively on growth and yield parameters of coriander; these effects could be attributed to accumulation of micronutrients and macronutrients in soil. These results suggest that UWW and TWW effluents of Vidyaranyapuram area not fit for be utilization as a important sources of water for irrigating coriander crop, as they show it did have significant harmful effects on crop productivity.

Keywords: Heavy Metals, Wastewater, Coriander, Nutrient, Growth and Yield

1. Introduction

Water resources management including unconventional resources (i.e., groundwater, drainage water and wastewater effluent) is considered as an urgent issue for the expansion of area under irrigated agriculture. That the reuse of such alternative water resources becomes part of the official policy of actual and future extension programs for the agricultural development in India.The hazardous effects are mainly dependent on the soil nature and water quality, besides the kinds of the crops grown and applied irrigation system. The accumulation of Cd, Cr, Co, Cu, Fe, Mn, Ni, Pb, and Zn in soilless cultivation was relatively higher than in soil cultivation due to the fact that in soilless media nutrients are directly taken up by plants but the soil acts as a filter to reduce uptake of heavy metals by the plant [1]. Various adverse effects have been observed on soil characteristics where irrigated with discharged water. The nutrient status of soil will get altered and this is affecting the physic-chemical characteristics of the soil. Also the heavy metals in the soil are showing high concentration, in the range of Cd 5.0 to 5.7 mg/kg; Fe 30 to 2460 mg/kg, Mn 393.7 to 1231 mg/kg and Co 16 to 40 mg/kg [2]. Excessive accumulation of heavy metals in agricultural soils may not only result in environmental contamination, but lead to elevated heavy metal uptake by crops, which may affect food quality and safety. The crops analysed have shown heavy contamination with Cd, Cu, Pb and Zn. The plants (beans, maize, peppers and sugarcane) also contained concentrations of heavy metals above the permissible levels with the four regulated elements Cd, Cu, Pb and Zn [3]. Annual heavy metal loading rates showed that in the course of 5–60 years, all studied heavy metals would get exceeded their permitted limits in soils, by the use of wastewater in urban horticulture enriched soils posing potential environmental and health risks in the long-run [4]. Heavy metals such as b, Mn, Co, Zn, Cd, Cu,Ni, Fe, As and Cr, accumulation in soils is of great concern in agricultural production due to the adverse effects on food safety and marketability, crop growth due to phytotoxicity, and environmental health on soil organisms [5].Irrigation by untreated wastewater is the main reason for the accumulation of heavy metals in vegetables [6, 7]. The ranges for various metals in wastewater- irrigated plants are 116-378, 12-69, 5.2-16.8 and 22-46 mg/kg for Fe,Mn, Cu and Zn, respectively. The highest mean levels of Fe and Mn were detected in mint and spinach, whereas the levels of Cu and Zn were highest in carrot [8]. A number of studies showed elevated levels of heavy metals in vegetables grown in areas having long-term use of treated or untreated wastewater [9, 10]. Though the wastewater contains low levels of heavy metals (Fe, Mn, Pb, Cd, and Cr), the soil and plant samples showed higher values due to their accumulation. The trend of metal accumulation in wastewater-irrigated soil is in the order: Fe > Mn > Pb > Cr > Cd [11]. Irrigation with treated wastewater increased significantly ($P \leq .05$) the soil ECe; major elements contents such as Na, Cl, Ca, Mg and fertilizer elements like N, P and K and heavy metals such as Cu, Zn, Co, Cd, Pb and Ni increased and have led to decreased the soil pH, and caused significant increase of these elements in different parts of corn plant [12]. Wastewater irrigation increased the concentrations of OM, EC, N, K, and P in soil while pH of the soils decreased. Also by wastewater the concentration of heavy metals (Fe, Cu, Zn, Mn, Cd and Ni) showed significant increase (except Cd) compared to the freshwater andshowed increasing of P and K contents of different parts in beans [13]. Using wastewater in sugar beet irrigation led to increase in N, P and K of soils after harvesting in addition to the dry matter content [14]. The objectives of this research included to evaluate the changes in the chemical attributes in soil and coriander crop grown with different wastewater irrigation strategies and their ecological risk assessment, as also forecasting of heavy metal accumulation causing ecological risk in the study area.

2. Materials and Methods

2.1. Study Sites

The survey was conducted around Vidyaranyapuram sewage treatment plant area of Mysore city. In these areas farmers use wastewater (treated and untreated) for irrigation of coriander crop. This area, which is selected as experimental site, farmers use wastewater directly for irrigating crops. The experimental sites were located surrounding the Vidyaranyapuram sewage treatment plant. Three adjacent agricultural fields were selected at three separate sites. The first experimental site soil untreated wastewater (UWW) is being regularly irrigated with wastewater from the Vidyaranyapuram sewage treatment plant. Irrigation is done to farmland through regular flooding with wastewater without any treatment, at the time of sampling the crop grown was coriander. The second experimental site soil with treated wastewater (TWW) was also located in Vidyaranyapuram in the vicinity of the first experimental site at approximately 1.5 km, but on opposite side to the site of sewage treatment plant station. The farmers irrigate this field with treated wastewater (TWW) obtained from sewage treatment plant station; here also the crop grown at the time of sampling was coriander. The third experimental site, which was used as control site ground water (GW), was located at about 5 km from Vidyaranyapuram sewage treatment plant station. Irrigation of the field only occurs with well water and the soil was cultivated with coriander.

2.2. Soil and Water Sampling and Analysis

Soil samples were collected randomly in triplicate by using an Auger and were taken at three depths (0-20, 20-40 and 40-60 cm) in each block, during planting. The soil collected from each depth was mixed, dried, crushed and sieved through a 2 mm sieve. The prepared soil samples were then stored in polyethylene bottles for analyses. Water samples were collected at fortnightly intervals during the grow the period of crops from the study area; all water samples were collected in 2000 ml polythene bottles and transported immediately for laboratory analysis. The concentrations of heavy metals in the soils were determined after digestion using the Hossner method [15]. The total concentrations of Fe, Mn, Cu, Zn, Cd, Ni, Pb, Co and Cr were determined by ICP-OES (Perkin Elmer, Model 8000 DV). Means for elements were calculated from triplicate samples. Water analysis was performed according to the standard methods [16]. The results of the analysis of different water samples used in the current study are presented in Table 1.

2.3. Plant Sampling and Analysis

Coriander plant samples were collected randomly in triplicate from fields during the irrigation period, leaves of coriander plants were hand collected, and were washed with double distilled water to remove airborne pollutants. All samples were then oven-dried in a hot air oven at 70-80°C for 24 h to remove moisture. Dried samples were powdered using a pestle and mortar and sieved through muslin cloth and then 0.5 g of the dried plant tissues were analyzed for the following macro- and micronutrients: N, P, K, Ca, Mg,Na, Fe, Mn, Cu, Zn, Cd, Ni, Pb, Co and Cr.N concentration was determined after mineralization with sulphuric acid by "Kjeldahl method" [17]. Na and K were by flame emission, P by colorimetric method [18]. Ca, Mg, Fe, Mn, Cu, Zn, Cd, Ni, Pb, Co and Cr concentrations were determined by inductively coupled plasma optical emission spectrometry (ICP-OES, Perkin Elemer model 8000 DV).

2.4. Plant Growth and Yield Measurement

The plants were harvested before fruits were fully ripe but sufficiently hard and greenish yellow in color or semi-dry, and observations pertaining to growth and yield were recorded for plant height, number of branches, biomass (fresh and weight in g/plant) and yield components including number of umbels/plant, weight of 1000 seeds.

2.5. Statistical Analysis

The layout of the experiment was in randomized complete block design (RCBD) as described by [19]. The three treatments were replicated three times. The means among all used treatments were compared by Duncan's Multiple Range Test, at P≤.05 using SAS procedures [20].

3. Results and Discussion

3.1. Water-Quality Parameters

The results of analysis of wastewater presented in Table 1 has revealed that it was alkaline and the average EC, pH, TDS and the observed nutrient contents including some heavy metals were within the permissible limits of FAO guidelines for irrigation water quality. The BOD and COD at all the sampling points were higher than the FAO values of 100 and 500 mg/l respectively for the discharged wastewater used for irrigation. High COD and BOD concentrations observed in the waste water might be due to the use of chemicals, which are organic or inorganic that are having oxygen Demand in nature. The electrical conductivity (EC) of 1285, 1132 and 1023 µS/cm for UWW, TWW and GW respectively, ranged based on salinity classes of irrigation watersand it is 780–2340 µS/cmof irrigation water [21]. It is not advisable to use more saline water on soils with restricted drainage, even with adequate drainage, best management practices for salinity controls may be required, and the salt tolerance of the plants to be irrigated should also to be considered. The wastewater is an important source of nutrients and can be used for irrigation under controlled condition [22]. Wastewater contains considerable amounts of total nitrogen (75.9 mg/l), phosphate (5.31 mg/l), and potassium (29 mg/l) which are considered essential nutrients for maintaining productivity levels (plant growth) and soil fertility. All heavy metals analysed in irrigation water were not at elevated levels except Cd, which was found at elevated levels in wastewater and groundwater (Table 1). On the average, the level of Cd in the two sources was s more than three times than the recommended level of 0.01 mg/l. Micronutrients and heavy metals concentrations in the wastewater are relatively lower than standard norms prescribed for wastewater reuse for irrigation. But with continuous application of wastewater these metallic elements could get accumulated in the soil. Sewage effluent has the capacity to contribute cumulative nutrients (N, P, K, Zn, Fe and Cu) [23].

Table 1. *Characteristics of the untreated and treated wastewaters and ground water used for irrigation.*

Untreated wastewater				**Treated wastewater**				**Groundwater**			
Parameters		**Parameters**		**Parameters**		**Parameters**		**Parameters**		**Parameters**	
T°C	25	Cl mg/l	85	T°C	25	Cl mg/l	129	T°C	25	Cl mg/l	21
pH	7.68	N mg/l	75.9	pH	7.98	N mg/l	58.9	pH	8.07	N mg/l	0.63
EC µS/cm	1285	P mg/l	5.31	EC µS/cm	1132	P mg/l	3.16	EC µS/cm	1023	P mg/l	0.055
DO mg/l	Nil	SO_4 mg/l	21	DO mg/l	3.6	SO_4 mg/l	20	DO mg/l	5.7	SO_4 mg/l	44
COD mg/l	847	Fe mg/l	2.39	COD mg/l	392	Fe mg/l	2.49	COD mg/l	24	Fe mg/l	0.069
BOD mg/l	608	Mn mg/l	0.123	BOD mg/l	53	Mn mg/l	0.085	BOD mg/l	9	Mn mg/l	0.036
TDS mg/l	638	Cu mg/l	0.06	TDS mg/l	658	Cu mg/l	<0.05	TDS mg/l	712	Cu mg/l	<0.05
Ca mg/l	54.85	Zn mg/l	0.187	Ca mg/l	48.14	Zn mg/l	0.200	Ca mg/l	52.12	Zn mg/l	0.237
Mg mg/l	39.46	Cd mg/l	0.035	Mg mg/l	42.11	Cd mg/l	0.039	Mg mg/l	46.18	Cd mg/l	0.038
Na mg/l	51	Ni mg/l	0.090	Na mg/l	52	Ni mg/l	0.052	Na mg/l	49	Ni mg/l	0.037
K mg/l	29	Pb mg/l	0.057	K mg/l	23	Pb mg/l	0.055	K mg/l	17	Pb mg/l	0.058
CO_3 mg/l	ND	Co mg/l	0.050	CO_3 mg/l	ND	Co mg/l	0.051	CO_3 mg/l	65	Co mg/l	0.050
HCO_3 mg/l	269	Cr mg/l	0.046	HCO_3 mg/l	382	Cr mg/l	0.032	HCO_3 mg/l	487	Cr mg/l	0.025

DO: Dissolved oxygen, COD: chemical oxygen demand, BOD: biological oxygen demand, TDS: total dissolved salts, ND: non detectable

3.2. Effect of Untreated and Treated Wastewater and Groundwater Irrigation on Soil

3.2.1. Physical Parameters of Soil

Soil texture is an important soil characteristic that drives crop production and field management. The textural class of a soil is determined by the percentage of sand, silt, and clay [24]. The results of the present study showed that there was similarity for soil texture of TWW and GW were sandy except the UWW was sandy loam (Table 2). The soils of the sites classified as red sandy soil in GW while UWW and TWW were light gray sandy loam and light gray sandy. Bulk

Density and Porosity of soil samples ranging (1.43 - 1.60 g/cm³) and (40 - 46%) respectively. Sandy soils have relatively high bulk density since total pore space in sands is less than silt and clay soils [25]. Effect of sand content on soil bulk density was found to be higher than that of the other soil properties. Clayey soils tend to have lower bulk densities and higher porosities than sandy soils [26]. Field application of all types of wastewater significantly increased soil cation exchange capacity (CEC) [27]. These are consistent with our results showed that the cation exchange capacity (CEC) was higher in the soils with UWW and TWW than in the soils with GW. The values of CEC soil were UWW, 19.34 Meq/100g, TWW 16.44 Meq/100g and GW 7.02 Meq/100g. When the wastewater was irrigated with TWW and GW, CEC values of the soil decreased in the following order: UWW > TWW> GW. At soil irrigated with GW the organic content of the sand is very low, hence the low CEC. The sandy soil has a good permeability and a low CEC (few exchange sites), retains less water and naturally loses water as well as soluble salts from the root zone [28].

Table 2. *Physical Parameters of Soil Samples.*

Treatments	Particle Size distribution, %			Textureclass	Colour	Bulk density(g/cm³)	Calculation of porosity %	CECMeq/100g
	Sand	Silt	Clay					
UWW	78.56	20.38	0.76	Loamy sand	Light grey	1.43	46	19.34
TWW	95.34	4.20	0.46	Sandy	Light grey	1.53	42	16.44
GW	92.47	7.27	0.26	Sandy	Red	1.60	40	7.02

Table 3. *Mean values of chemical contents of soils irrigated with untreated and treated wastewater and ground water.*

Parameters	Soil UWW	Soil TWW	Soil GW
pH	6.58c	7.49b	8.04a
EC µs/cm	279a	239ab	198b
Ca %	0.71a	0.76a	0.63a
Mg %	0.52a	0.50a	0.41b
Na %	0.052a	0.051b	0.045b
K %	0.073a	0.0.71a	0.070a
Cl %	0.001b	0.001b	0.002a
N %	0.39a	0.38a	0.068b
P %	0.072a	0.051b	0.039b
SO_4 %	0.0023a	0.0017a	0.0010a
Fe %	5.67a	5.08a	4.29a
Mn mg/kg	258a	219b	129c
Cu mg/kg	180a	161b	93d
Zn mg/kg	301a	247b	203c
Cd mg/kg	19a	14b	11b
Ni mg/kg	69a	42b	33b
Pb mg/kg	53a	38b	27c
Co mg/kg	17a	17a	15a
Cr mg/kg	99a	79b	44c

Means followed by different letters in the same row are significantly different according to Duncan's multiple range tests at P≤0.05.

3.2.2. Nutrients and Heavy Metals in Soil

Irrigation with wastewater effluent increased most of the macro elements in the soil, Table 3 shows pH and EC values of soil profiles. Applying wastewater for irrigation significantly decreased soil pH in UWW and TWW than in the control GW, probably due to the high organic matter content in the irrigation water. The soil pH decreased as a result of wastewater irrigation which might be due to higher input of organic matter [29]. EC content increased for UWW, TWW and GW to 279, 239 and 198 μScm^{-1} respectively. This increase in soil salinity may be the result high electrical conductivity of the wastewater (Table 3). Alsomany reported similar increase in the salt content of soils after wastewater irrigation led to increase soil EC [30, 31, 32]. From the results it is observed that the concentration of N significantly increased in the soil of UWW and TWW irrigated soils as compared to the control GW. This is due to the content of high concentrations of nitrogen, in untreated and treated wastewater which is 0.39 and 0.38 mg/l respectively as can be seen from Table 2. Many investigations, including long and short term studies, showed that soil fertility increased as a consequence of irrigation with wastewater [32, 33].As regards the concentrations of exchangeable cations and anions Mg, Na and P there were significant differences observed on mean values for different sites like UWW, TWW and GW which were 0.52, 0.50 and 0.41%, 0.052, 0.051 and 0.045%and 0.072, 0.051, and 0.039% respectively, which increased due to wastewater irrigation, whereas K, Ca and SO_4 were not significantly different between these sites. Significantly higher values of exchangeable cations have been reported in soils irrigated using paper mill effluent [34].The exchangeable cations like Mg and Na increased in both the field experiment soils due to the application of both inorganic and organic ameliorants along with green manure under poor quality irrigation water [35]. Irrigation with different of wastewater samples showed higher concentrations of heavy metals (Fe, Cu, Zn, and Co) in soil as compared to Vinogradov who found 3.7% for Fe, for Cu 40 mg/kg, for Zn 50 mg/kg and for Co 16 mg/kg [36]. The results showed an increase in concentration of Mn, Cu, Zn, Cd, Ni, Pb and Cr in two treatments (UWW, TWW) compared to the control GW, but other heavy metals exhibited lower values. This is due to the wastewater samples contained lower amounts of heavy metals.

3.3. Effect of Wastewater Irrigation on Growth, Yield and Mineral Content

3.3.1. Plant Growth and Yield

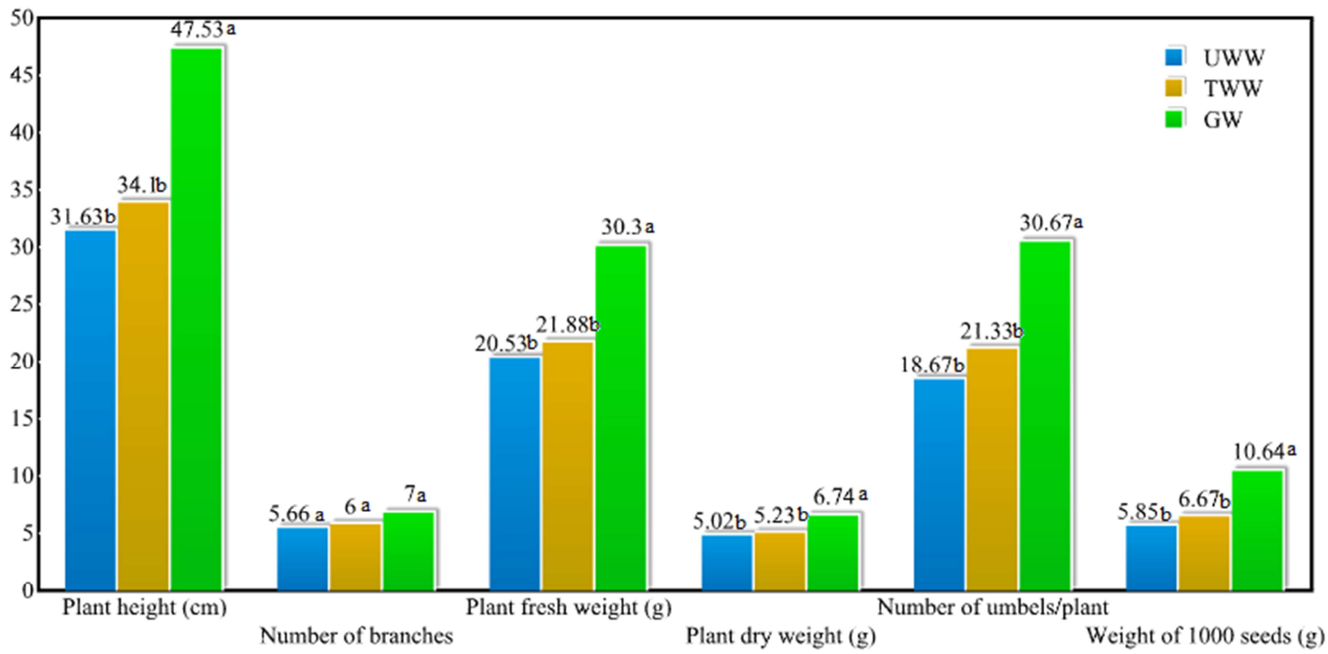
Data presented in Fig.1 clearly show that different irrigation treatments done with treated and untreated wastewater significantly affected the growth and yield of coriander plants. The plant height significantly decreased when irrigated with UWW and TWW and increased with control treatment (GW). There were no significant differences with regard to the effect of different irrigation treatments on the number of branches per coriander plant. The heaviest plant fresh weights of 30.30, 21.88 and 20.53 g were obtained by treatments of GW, TWW and UWW, respectively. Increasing irrigation with UWW and TWW decreased the number of umbels/hill. The results also indicated that 1000 seeds weight followed the same order of as that of seed yield with irrigation by untreated and treated wastewater. The 1000 seeds weights were 10.64, 6.67 and 5.85 g for irrigation with GW, TWW and UWW, respectively (Fig. 1). From these results, it could be concluded that the growth and yield characters of coriander were not improved as a result of irrigation with untreated and treated wastewater; the high concentration of trace metals affected ultimately by lowering the growth and yield attributing factors when irrigated by UWW and TWW as compared to GW control. These effects could be attributed to higher accumulation of micronutrients and macronutrients in soil and plant, when the mean values were highly significant as indicated by the present study.

3.3.2. Macro Elements (N, P, K, Ca, Mg and Na) Content in Coriander Plant

Nutrients content of coriander crop grown in experimental sites irrigated with wastewater are presented in Fig. 2. Irrigation with wastewater significantly affected nutrient uptake by coriander plant. The highest N, P, K, Ca, Mg and Na contents in plants are in untreated and treated wastewater irrigated soils (Fig. 2). Wastewater irrigation not only increased macronutrients contents, but also enhanced micronutrient contents of the plants [22, 37].The content of macro elements increased with increasing wastewater treatment and are in the order UWW> TWW> GW in coriander crop.

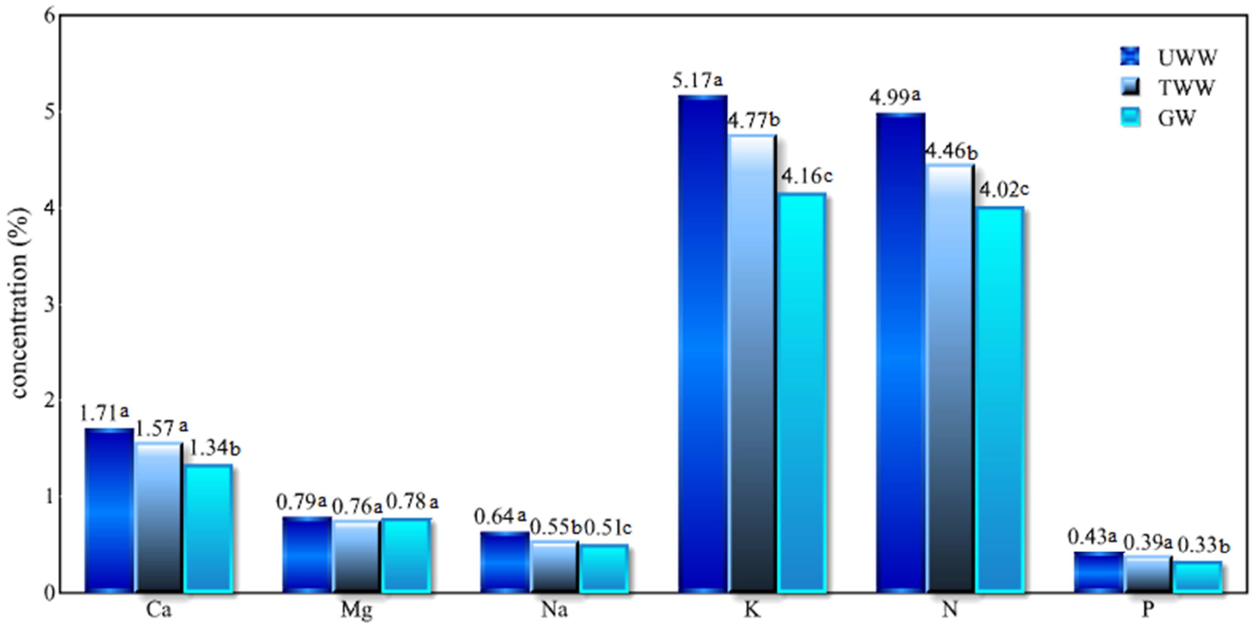
3.3.3. Heavy Metal (Fe, Mn, Cu, Zn, Cd, Ni, Pb, Co and Cr) Content in Coriander Plant

Application of wastewater generally changes the physicochemical characteristics of soil and consequently heavy metal uptake by coriander crop. The heavy metals concentrations in coriander samples collected from the three experimental sites irrigated with sewage water and from soil irrigated with ground water are shown in Fig. 3. Heavy metal accumulation is significantly (P≤0.05) high in leaves of coriander irrigated with UWW, TWW as compared with control treatment GW. The highest concentrations were comprised of by such heavy metals Fe, Mn, Zn, Cu, Ni, Pb and Cr. The lowest concentrations were those of Cd and Co in coriander leaves. This is in consistent with reports about higher concentrations of heavy metals in vegetables from sewage-irrigated areas as compared to clean water-irrigated control areas [38, 8, 39, 40]. In general, micro-elements content of coriander plant irrigated with wastewater (UWW and TWW) were significantly higher than ground water treatment in Vidyaranyapuram. Similar results have been reported by others studies also [13, 41].



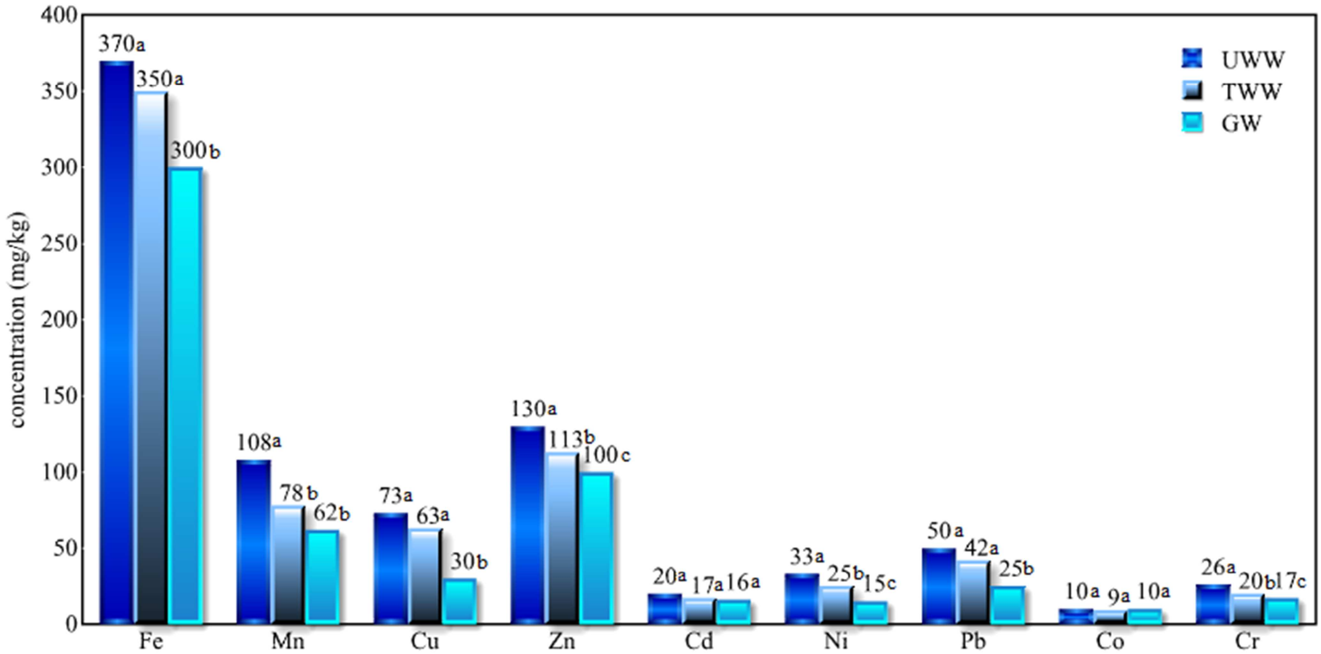
Values within the same group followed by different letters indicate significant differences by Duncan's multiple range tests at ($p<0.05$).

Figure 1. *Effect of irrigation with treated and untreated wastewater on growth and yield of coriander (Coriandrum sativum L.).*



Values within the same group followed by different letters indicate significant differences by Duncan's multiple range tests at (p<0.05).

Figure 2. *Mean values of Macro elements in coriander plant irrigated with untreated and treated wastewater and control ground water.*



Values within the same group followed by different letters indicate significant differences by Duncan's multiple range tests at (p<0.05).

Figure 3. *Mean values of heavy metal in coriander plant irrigated with untreated and treated wastewater and ground water.*

4. Conclusion

The results of the present study showed that use of treated and untreated wastewater for irrigation purposes in the study area changed the soil quality (pH, EC, N, P, Ca, Mg and Na) and increased heavy metal concentration (Mn, Cu, Zn, Cd, Ni, Pb and Cr) in soil. The results showed highly significant increase in the concentration of N, P, K, Ca, Mg and Na in plants irrigated with UWW and TWW as compared to GW control. Also from the present study it is evident that the concentrations of Fe, Mn, Zn, Cu, Ni, Pb and coriander crop grown in UWW and TWW irrigated area were significantly higher compare to the coriander grown in GW irrigated control area. The application of either UWW or TWW effluents showed negative effect on the growth and yield parameters of coriander in Vidyaranyapuram area in the South West of Mysore with excessive accumulation of toxic elements in soil and plants, which may prove toxic. Wastewater irrigation affected chemical properties and fertility status in soil and several folds buildup of nutrients and trace metals in soils and coriander plant under study indicated that there is an increase in trace metals contamination beyond maximum permissible limit if such wastewater use is continual for long irrigation for coriander plant. Thus timely monitoring of wastewater irrigation on soil and coriander crop is essential to maintain soil chemical status for consumption of safe coriander grown on them.

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