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Effect of Treated Sewage Effluents on Plant Cover and Soil at Wadi Al Rummah, Qassim Region, Saudi Arabia

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Abstract

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The effect of tertiary treated sewage effluents on the plant cover and the physico-chemical properties of the surface soil (environmental characteristics) before and after the Al Rass sewage plant was investigated. The data were illustrated via TWINSPAN and canonical correspondence analysis (CCA). Five sites, 1 km apart, after the discharge point and one site (control site) before the sewage plant were examined. Eleven vegetation characteristics and ten physico-chemical properties of surface soil were studied. The obtained results revealed that discharging of treated sewage effluents altered quantitatively and qualitatively the pattern of species dominance and the physico-chemical properties of the soil. Soil electrical conductivity (EC), total dissolved solids (TDS), organic matters (OM), soluble cations, and soluble anions showed increased values compared to the control (resulting in salination), whereas soil pH decreased as a result of sewage disposal. It was also noticed that the physico-chemical values of EC, TDS, Ca^{++}, Mg^{++}, Na^{+}, Cl^{-} after the sewage plant were higher than the permissible limits for agriculture recommended by FAO, whereas K^{+} and HCO_3^{-} were within the recommended values. The dominance of *Suaeda vermiculata* Forssk. ex J.F.Jmel. after the sewage plant and its absolute absence before the sewage plant may be used as an environmental bioindicator of pollution.

Keywords: bioindicator of pollution; physico-chemical properties; salination; species dominance; *Suaeda vermiculata*

Collection, treatment, and safe disposal of sewage effluents in the environment are direct reflection of urbanization and development of human civilization. Inadequately treated sewage effluent will result in a significant negative impact on the environment (Dutto *et al.* 2012) and public health (Vrijheid 2000; Akpor & Munchie 2011).

In Saudi Arabia, several studies were done to assess the quality of sewage treatment plants in various regions of the country (Saleem *et al.* 2003; Risk *et al.* 2009; Al Jasser 2011; Gutub 2013), however, no previous study was conducted on Al Rass sewage plant.

Sewage treatments generally involve three degrees of treatments designated as primary (mechanical), secondary (biological), and tertiary treatments (FAO 1992). Treated sewage effluents may be discharged as land filling (Barberio *et al.* 2013), in ground waters (Dhania & Rani 2014), and in oceans and rivers (Ji *et al.* 2013), without being utilized. Utilization of sewage effluents requires knowledge of their characteristics to assess their environmental impact (Yoshida *et al.* 2013) and health risks (Khan *et al.* 2008).

At Al Rass (Qassim Region, Saudi Arabia), tertiary treated sewage effluents are discharged in the downstream of Wadi Al Rummah (seasonal stream), in the vicinity of the urban area at Al Rass Governorate without being utilized but contribute to ground water recharge and landscape irrigation. Long-term landscape irrigation with treated sewage effluents will affect the plant cover of the area, the animals grazing these plants, and the human beings consuming these animals (Van de Graaff *et al.* 2002; Angin *et al.* 2004; Condron *et al.* 2014).

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The present study has been carried out to assess the effect of treated sewage effluents discharged from the Al Rass sewage plant on the physico-chemical properties of the soil and plant distribution at Wadi Al Rummah, Qassim Region, Saudi Arabia.

MATERIAL AND METHODS

Study area. The Qassim Region is located in the central part of Saudi Arabia, and at the central part of the Saharo-Arabian floristic region (Al Nafie 2008). The climate of the Qassim Region is characterized by very hot dry summers and mild to cool winters (Abd El Rehman 1986). Mean monthly precipitation is 11.4 mm with mean monthly air temperature of 15–34°C. The relative humidity during winter ranges from 14 to 72%, whereas during summer, it ranges from 8 to 31% (Abderrahman *et al.* 1991).

The sewage plant at Al Rass governorate was established in October 1996, it is located in the northwest of Al Rass city, specifically at longitude 25°56'N, and latitude 43°28'E. It occupies an area of about 4 km^2. Daily discharge capacity of the Plant is about 25 000 m^3 and it operates using the tertiary treatment system in addition to the active sludge processing unit (sludge treatment). The approximate dry matter content of the effluent (TSS) is 5–10 mg/l.

The soils of the Qassim Region are classified as Entisols (Torriorthents, Torrifluvents, Torripsamments), and Aridisols (Salorthids, Paleortids, Gypsiorthids) (Al-Mashhady *et al.* 1991). At Wadi Al Rummah, the silt fractions are classified as Torrifluvent, whereas the clay fraction contains mainly palygorskite and smectite- mica interstratification with smaller amounts of kaolinite, traces of quartz, and occasionally chlorite (Mashhady *et al.* 1980).

Sampling sites. Five sampling sites, 1 km apart, and one control site before the effluent discharge point at Al Rass sewage plant were sampled along the main channel of Wadi Al Rummah.

Plant sampling and analysis. Five randomly selected quadrats (10 × 10 m) were examined at each site, with a total of 30 quadrats (25 after and 5 before the sewage plant). Vegetation sampling involved quantitative and qualitative parameters of all perennial plant species at each of the sampling quadrats. Five plant characteristics (life form, chorotype, frequency, density, and abundance) were studied for the various plant species encountered in these quadrats, whereas six collection sites characteristics were examined (total number of species, species richness, index of biodiversity, Simpson's index, Simpson's index of biodiversity, and α diversity index) before and after the sewage plant discharge point.

Soil sampling and analysis. Five soil samples per site were collected at a depth of 0–30 cm and mixed together in a composite soil sample. A total number of 30 composite soil samples (5 before and 25 samples after the sewage plant) from the six sites were examined. Soil samples were collected in a clean polythene bags, dried, ground, and passed through a 2 mm sieve. For each soil sample, ten physico-chemical parameters were determined by various techniques (Walkley & Black 1934; Jones 2001). These parameters were pH, electrical conductivity (EC), total dissolved solids (TDS), organic matters (OM), four soluble cations (Ca^{++}, Mg^{++}, K^+, Na^+), and two soluble anions (HCO_3^-, Cl^-).

These parameters were estimated from saturated soil paste extracts, which involve saturating the air-dried (~250 g) soil samples with distilled water and subsequent extraction under partial vacuum of the liquid phase.

Data analysis. The vegetation data matrix (6 sites and 7 species) was classified using TWINSPAN (Hill 1979). The relationships between the vegetation data and the soil characteristics were studied via the canonical correspondence analysis (CCA) using CANOCO for MS Windows, Version 4.5 (ter Braak & Smilauer 2002).

RESULTS

Plants characteristics. Out of the 30 quadrats studied in the six sites examined (five quadrats each), a total number of seven perennial plant species were encountered. Table 1 showed an almost absolute

Figure 1. *Suaeda vermiculata* Forssk. ex J.F. Jmel., close view

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Table 1. Abundance (%) of various species encountered in the six sites examined after and before the Al Rass sewage plant

No.	Plant species	After sewage plant					Before sewage plant
		site 1	site 2	site 3	site 4	site 5	site 6
1	*Suaeda vermiculata* Forssk. ex J.F.Jmel.	99.82	86.67	65.22	8.53	42.10	0
2	*Pulicaria undulata* (L.) C.A.Mey.	0.18	13.34	34.78	90.96	45.61	66.93
3	*Citrullus colocynthis* (L.) Schrad.	0	0	0	0	11.70	6.30
4	*Haloxylon salicornicum* (Moq.) Bunge ex Boiss.	0	0	0	0	0	25.98
5	*Cynodon dactylon* (L.) Pers.	0	0	0	0.52	0	0
6	*Tamarix nilotica* (Ehrenb.) Bunge	0	0	0	0	0.58	0
7	*Atriplex leucoclada* Boiss.	0	0	0	0	0	0.79

Table 2. Life form, chorotype, frequency, density, and abundance of the species recorded at the study area

Families and species		Life form	Chorotype	Frequency	Density	Abundance
Chenopodiaceae						
1	*Suaeda vermiculata*	Ch	SA	100	16.0	59.22
2	*Haloxylon salicornicum*	Ch	IT, SU	16.7	0.55	2.04
3	*Atriplex leucoclada*	Ch	SA, IT	3.3	0.02	0.06
Asteraceae						
1	*Pulicaria undulata*	Th	SA, SU	83.3	10.0	36.75
Cucurbitaceae						
1	*Citrullus colocynthis*	H	SA, ME	30.0	0.47	1.73
Poaceae						
1	*Cynodon dactylon*	Th	COSM	3.3	0.03	0.12
Tamaricaceae						
1	*Tamarix nilotica*	Ph	SA	3.3	0.02	0.06

Th – Therophytes; Ch – Chamaephytes; Ph – Phanerophytes; H – Hemicryptophytes; SA – Saharo-Arabian; IT – Irano-Turanian; SU – Sudano-Zambezian; ME – Mediterranean; COSM – Cosmopolitan

abundance of *Suaeda vermiculata* Forssk. ex J.F.Jmel. (99.82%) (Figure 1) with respect to the other species at site 1 at point zero of sewage discharge. At the subsequent sites (sites 2–5), *S. vermiculata* shared abundance mainly with *Pulicaria undulata.* Before sewage plant (control site, site 6), *S. vermiculata* was not encountered in any of the quadrats examined, and the area was alternatively dominated by *P. undulata* (L.) C.A.Mey. (66.93%) and *Haloxylon salicornicum* (Moq.) Bunge ex Boiss. (25.98%).

Table 2 presents data on the life form, chorotypes, frequency, density, and abundance of various species recorded in the study area. It shows that *S. vermiculata* has the highest frequency, density, and abundance.

Table 3 provides six species characteristics at various study sites. It shows that the sites most affected by the discharged effluents (sites 1 and 2) have the highest number of species, the lowest species richness, and the lowest index of biodiversity. The control site (site 6) has the highest species richness and index of biodiversity.

Soil (environmental) characteristics. Nine soil characteristics for a total of 30 soil samples before and after the Al Rass sewage plant are presented in

Table 3. Total number of species (*N*), species richness (S), index of biodiversity (I), Simpson's index (D), Simpson's index of biodiversity (1-D), and α-diversity (α) of various sites before and after the Al Rass sewage plant

Sites	*N*	S	I	D	1-D	α
1	568	2	0.004	0.195	0.805	1.2
2	225	2	0.009	0.619	0.381	1.8
3	138	2	0.014	0.641	0.359	2.0
4	387	3	0.008	0.829	0.171	2.2
5	171	4	0.023	0.452	0.548	3.2
6	127	4	0.310	0.579	0.421	3.0

Table 4. Physico-chemical characteristics of surface soil in six sites before and after the Al Rass sewage plant

Site	pH	EC (dS/m)	TDS (ppm)	OM (%)	Soluble cations				Soluble anions	
					Ca^{++}	Mg^{++}	K^+	Na^+	HCO_3^-	Cl^-
					(meq/l)					
1	7.5	38.1	24 352	1.3	123.6	76.4	3.7	189.0	3.8	307.5
2	7.7	44.8	28 656	1.6	160.0	98.3	4.4	195.8	3.8	380.5
3	8.1	3.5	2 222.7	1.4	12.88	7.61	0.4	17.78	2.45	28.3
4	7.8	4.9	3 129	3.0	18.2	10.7	0.6	32.1	1.7	34.4
5	8.0	5.6	3 555	1.3	22.2	10.2	0.7	30.0	2.4	40.2
Mean	7.82	19.38	12 382.8	1.72	67.38	40.64	1.96	92.78	2.83	158.18
STD	0.24	20.30	12 989.1	0.73	69.23	43.35	1.93	90.99	0.24	20.30
6	8.0	5.7	3 623	1.2	18.2	10.1	0.7	33.2	2.7	36.4

EC – electrical conductivity; TDS – total dissolved solids; OM – organic matters

Table 4. The physico-chemical analysis of sites 1 and 2 (nearest to the discharge point) showed considerably higher values compared to values of the subsequent sites (sites 3–5), without uniform trends.

Table 5 shows that the pH values before the sewage plant are lower than the values after the sewage plant, whereas all the other studied physico-chemical properties show higher values with respect to the control. The chlorides (Cl^-) show the highest increase whereas the bicarbonates (HCO_3^-) show the lowest increase.

Sites grouping. The application of TWINSPAN (Hill 1979) to the abundance of species (7 species), vegetation data (6 variables), and environmental variables (10 variables) matrix along the 6 sites indicated two main vegetation groups at level 1 and three vegetation groups at level 2 (Figure 2), representing possible classes of habitat quality. Group A represents sites 1 and 2, group B represents sites 3–5, whereas group C represents site 6 (control site).

Plant cover – vegetation characteristics. The relationship between the abundant species and the vegetation characteristics studied for the six sites examined is illustrated in Figure 3.

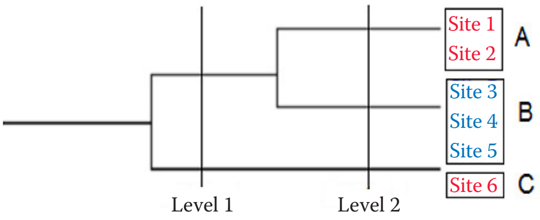

Figure 2. A dendrogram illustrating the presence of three groups of sites (at level 2), using TWINSPAN analysis for the 6 sites examined before and after the Al Rass sewage plant

Table 5. Physico-chemical characteristics of surface soil before and after the Al Rass sewage plant

Parameters		FAO (1992) permissible limits	Before sewage plant	After sewage plant (mean value)	% change (before and after sewage plant)
pH		6.5–8.4	8.0	7.82	– 2.25
EC (dS/m)		0–3	5.7	19.38	+ 240.0
TDS (ppm)		0–2000	3 623	12 382	+ 241.8
OM (%)			1.2	1.7	+ 41.7
Soluble cations (meq/l)	Ca^{++}	0–20	18.2	67.38	+ 270.2
	Mg^{++}	0–5	10.1	40.64	+ 302.4
	K^+	0–2	0.7	1.96	+ 180.0
	Na^+	0–40	33.2	92.78	+ 179.5
Soluble anions (meq/l)	HCO_3^-	0–10	2.7	2.83	+ 4.8
	Cl^-	0–30	36.4	158.18	+ 334.6

EC – electrical conductivity; TDS – total dissolved solids; OM – organic matters

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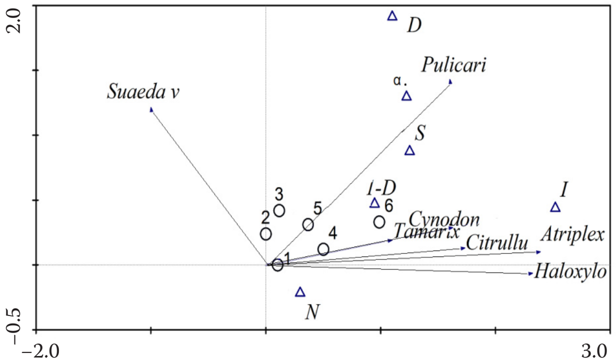

Figure 3. Canonical correspondence analysis (CCA) biplot of axis 1 and axis 2, of abundant species (names abbreviated) (shown as arrows) and vegetation characteristics (in letters) (shown as triangles), in the 6 sites examined (shown as circles) before and after the Al Rass sewage plant

Figure 4 shows the presence of three vegetation groups with respect to vegetation characteristics. It shows also that *Cynodon dactylon*, *Tamarix nilotica*, *Citrullus colocynthis*, *Atriplex leucoclada,* and *Haloxylon salicornicum* Group III) (with acute angles between vectors and axes) have strong positive correlation, weak correlation with *Pulicaria* (Group II), and negative correlation with *Suaeda vermiculata* (Group I). It shows also that the sites after the sewage plant (sites 1–5) are closer to the centre of the canonical axes (and hence weak association) compared to the site before the sewage plant (site 6). *Pulicaria undulata* is mostly correlated with Simpson's index (D), α-diversity (α), and species richness (S).

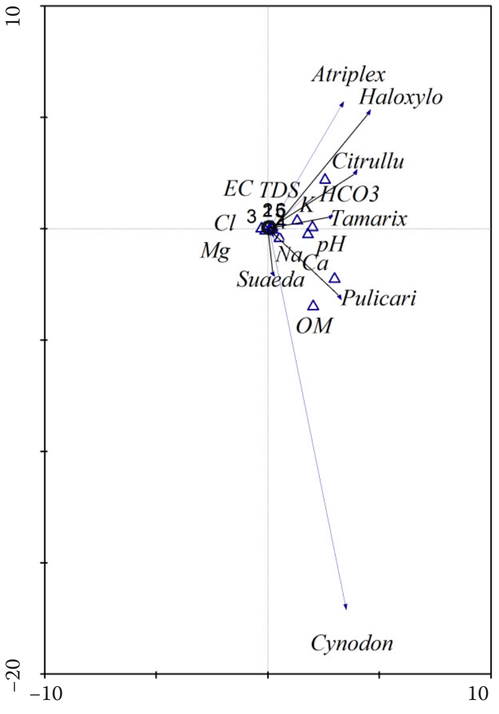

Figure 4. Canonical correspondence analysis (CCA) biplot of axis 1 and axis 2, of abundant species (names abbreviated) (shown as arrows) and environmental variables (letters) (shown as triangles), in the 6 sites examined, before and after the Al Rass sewage plant

Plant cover – environmental characteristics. The environmental effect on species abundance in the six sites examined is illustrated in Figure 4. It shows the presence of three vegetation groups with respect to environmental variables. It shows also that the environmental variables studied, *Suaeda vermiculata, Pulicaria undulata*, *Tamarix nilotica*, *Citrullus colocynthis*, and the six sites are relatively close to the centre of the canonical axes, indicating a weak association. *Cynodon dactylon* with a longer vector exhibits a greater range of variation. The latter species together with *Atriplex leucoclada* and *Haloxylon salicornicum*, although have longer vectors, are negatively correlated.

DISCUSSION

The present study represents a quantitative and qualitative account of the vegetation–environment relationship in five sites examined after the sewage plant (1 km apart) and one site before the sewage plant, at Wadi Al Rummah, Qassim Region, using TWINSPAN and CCA.

The six sites examined were classified into three groups by TWINSPAN (Figure 2). Site 6 (before the sewage plant) is quite distinct from the rest of the sites after the sewage plant, and sites 1 and 2 (closest to the sewage plant) are classified in a separate group different from sites 3–5. Since these two sites are 1 km apart, it seems that the effect of the sewage plant within 2 km from the discharge point (sites 1 and 2) is quite different from the rest of the sites after the sewage plant.

Application of the CCA to the abundant species and the vegetation characteristics in the six sites examined showed the presence of three vegetation groups and the negative correlation of *Suaeda vermiculata* (Group I) with Groups II and III (Figure 3).

Suaeda vermiculata was encountered to show almost absolute abundance (99.82%) at point zero of sewage dispersal (site 1), and in the following sites its abundance decreased till it shared dominance with *Pulicaria undulata* at site 5. Contrarily, before the sewage plant (site 6 – control site), *S. vermiculata* was not encountered in all quadrats examined, and the area was alternatively dominated by *P. undulata* and *H. salicornicum*. This change in the composition of the dominant plant communities of the area in response to sewage disposal was also noticed by Vasseur *et al.* (2000), Lassoued *et al.* (2013), and Tarrason *et al.* (2014). The dominance of *S. vermiculata* after the sewage plant and its absolute absence before the sewage plant may be used as an environmental bioindicator. The distribution of the other wild species present was also changed, but to a lesser extent.

Application of the CCA to the abundant species and environmental characteristics in the six sites examined (Figure 4) showed the presence of three vegetation groups, a weak association between the species of group II, and a correlation between the soil organic matters and the abundance of *Suaeda vermiculata*.

Sewage effluents discharged after the sewage plant (sites 1–5) showed marked increase compared to the control (site 6). The increase in soil organic matters as a result of the disposal of sewage was also reported by Mtshali *et al.* (2014), Hamuda and Ligetvari (2011), and Leinweber *et al.* (1996). It seems that such an increase in soil organic matter, and its effects on the physical, chemical, and biological properties of the soil (Clapp *et al.* 1986; Cooperband 2002) create a selective preference for the growth of *S. vermiculata*, as revealed by the CCA studies.

All physico-chemical parameters (environomental characteristics) studied showed an increase in values as a result of the disposal of effluents, except soil pH values. The decrease in pH values was also reported by Arvas *et al.* (2011). It may be attributed to organic acids produced during sewage decomposition (Hussein 2009), and/or to nitrification of nitrogen–ammonia from sewage (Stamatiadis *et al.* 1999).

Chloride showed the highest increase in the physico-chemical parameters examined. It is a vital constituent of human diet, neither biodegraded nor absorbed readily on mineral soil, readily precipitated (CEQG 2011), and it is considered an important parameter in detecting contamination of groundwater by sewage (Yamakanamard *et al.* 2011). Treated sewage disposal contributing positively to the increase of chlorides was also reported by Kelly *et al.* (2010). These chlorides can cause significant disruption in the ecology balance of the area (Apte Sagar *et al.* 2011). It was also noticed that physico-chemical values such as EC, TDS, Ca^{++}, Mg^{++}, Na^+, Cl^- were higher than the permissible limits for agriculture recommended by FAO (Ayers & Westcot 1994), whereas K^+ and HCO_3^- were within the recommended values.

Henkel (2015) regarded the increase in the soluble cations (Ca^{++}, Mg^{++}, Na^+, K^+) and soluble anions (HCO_3^- and Cl^-) responsible for salination (increase in salinity) of the soil. In the present study, a pronounced increase in the concentration of these ions was observed. Hence, the treated sewage effluents at Al Rass led to salination of the soil. Salination of the soil caused by the dispersal of sewage effluents was also reported by Yerasi *et al.* (2013), Perez-Espinosa *et al.* (2008), and Alobaidy *et al.* (2010).

In spite of the usage of a tertiary sewage plant, the discharged effluents altered the pattern of species dominance and the physico-chemical properties of the soils. For the improvement of the situation, it is recommended to check the proper operation and maintenance of the sewage plant periodically, safeguard the grazing animals inhabiting the area and the re-use of the discharged water whenever possible to avoid ground water recharge and landscape irrigation.

CONCLUSIONS

- The application of TWINSPAN showed that the six sites examined can be classified into three groups, with site 3 (unaffected by sewage effluents) is quite distinct from the rest of the sites.
- The application of CCA to the abundant species versus the vegetation and environmental characteristics showed the presence of three vegetation groups, with *Suaeda vermiculata* exhibiting negative correlation with the rest of plant species, and the soil organic matter correlates with its abundance.
- The absolute abundance of *S. vermiculata* at point zero of sewage disposal can be used as environmental bioindicator of sewage pollution.
- Sewage effluents led to the decrease of pH values and the increased values of the other 9 physico-chemical parameters studied in the area.
- Among the 10 physico-chemical parameters studied, chlorides showed the highest increase.
- The values of the physico-chemical parameters (EC, TDS, Ca^{++}, Mg^{++}, Na^+, Cl^-) were higher than the permissible limits recommended by FAO, whereas (K^+ and HCO_3^-) were within the recommended limits at the study area.
- The treated sewage effluents led to salination of the soil in the study area.

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