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Comparative Analyses of Soil Contaminant Levels and Plant Species Diversity at Developing and Disused Oil Well Sites in Qianjiang Oilfield, China

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Oilfield development contaminates soils and waters with crude oil, brine and heavy metals (Hira et al. 1989; Ilangovan and Vivekanandan 1989; Wang et al. 1989; Rattner et al. 1995). Oil well sites are probably the most contaminated places in oilfields. During drilling and crude oil extraction from underground stores, a significant amount of oil and brine discharges into soils at oil well sites by blowouts, container spillages and pipeline ruptures. In oilfields in China, it was estimated that about 0.77—1.85% crude oil discharged into soils at oil well sites during oilfield development (Wang et al. 1989).

Exposure to oil and salt contaminants could evoke toxicological effects in plants. Responses of plants to the contaminant exposure include inhibition of photosynthesis and nitrogen fixation, cessation of growth, reduced reproductive success and mortality (Baker 1971; Gaur and Kumar 1981; Chen and Chiu 1985; Singh and Gaur 1988; Ilangovan and Vivekanandan 1989; Gaur and Singh 1990; Singh and Kumar 1991). These harmful impacts on plants would be expected to result in remarkable loss of biodiversity.

Qianjiang oilfield has been developed for about thirty-five years. Oil well sites in it have long been contaminated with oil and brine since, and plants at the well sites are rare. In the last three years, however, some wells have fallen into disuse. In result, a few plant species have intruded into the disused well sites and formed new populations, and plant species diversity in these places has increased thereby. For benefit of restoration of the disused well sites, it is interesting to know the relationships between contaminant levels and plant biodiversity. The present paper focuses the attention on comparative analyses of soil contaminations by crude oil, salt and some heavy metals and plant species diversity at developing and disused oil well sites.

MATERIALS AND METHODS

Three developing and three disused-for -three-years oil well sites in Qianjiang oilfield were randomly selected as contaminated sites. About twenty kilometers away from the oilfield, two sites located on the margin of a woods were selected

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as presumably uncontaminated reference sites.

The area of an oil well site is about 2000 m^2(40 X 50), with the well at the centre. Three soil samples were randomly taken from each well site in a area about 10-20 m away from around the well, for only in this area at developing oil well sites could some plants be found. Three soil samples were also randomly taken from each of the reference sites. Soil samples were gathered from the top layer of 20 cm thick, placed in plastic bags and labeled by sample numbers and dates. Prior to chemical analysis, each sample was mixed thoroughly and divided into three parts for determining concentrations of crude oil, Cl and heavy metals respectively. 25 g of soil passed through a 0.25 mm mesh was extracted using chloroform. Another 25 g of soil was used for determining water content. The extractions were saponified with KOH/C_2H_5OH solution, then extracted with petroleum ether. The final extractions were used for determining hydrocarbon concentrations by an ultraviolet spectrophotometer (Shimadzu UV-160) (EPBPRC, 1986). The bulk of salt in the brine is NaCl (ca. 95%), with Cl/SO_4 ratio being about 18. Cl concentrations in soil could therefore be proximal estimations of salt contamination levels. 100 g air dried soil was extracted with de-CO_2 water (1 : 5). Cl concentrations of the extractions were determined using potentiometric titration method (Adriano and Doner 1982). For determining heavy metal concentrations, air dried soil samples without stones and pebbles were powdered. 5 g of the soil was put into a beaker and 15 ml HNO_3 and 5 ml HCl were added. The mixtures were heated at 100°C for 6 hr. 15 ml perchloric acid was then added, and the mixtures were heated at 160°C for 2 hr. After cooling, the samples were diluted with 1% HNO_3 and filtered. The solutions were made up to 100 ml with 1% HNO_3. Copper, lead and zinc concentrations were determined by flame atomic absorption spectrometer (AAS) (Shimadzu AA-680), cadmium levels were determined by graphite furnace AAS.

Plant species diversity was surveyed for two times, one in May, the other in September, 1995. Plants were collected exactly at the same sites as the soil samples. Each collection included all individuals of the species found in a 1 m^2 sample plot. Specimens were identified and individual numbers of the species were counted. Finally, collections from developing oil well sites, disused oil well sites and reference sites were pooled respectively.

Student's t test was performed on the concentrations of Cu, Pb, Zn, Cd, crude oil and Cl to compare the three types of sites. Margalef index ($D= (S— 1)/\ln N$) was used to estimate species richness, a measure of species diversity. For estimating plant species constitution associations between the three types of sites, 2 X 2 contingency tables based on species numbers were established, Dagnelie coefficient (Dagnelie 1962) and x^2 values were calculated thereon.

RESULTS AND DISCUSSION

The concentrations of copper, lead, zinc, cadmium, crude oil and Cl in soil samples from developing and disused oil well sites in Qianjiang oilfield and reference sites are shown in Table 1. For concentrations of the four heavy metals, no statistically significant differences between the three types of sites were observed, though those from the oil well sites were somewhat higher. With regard to crude oil and Cl, however, very highly significant differences were detected ($P<0.001$ in all cases). These results suggested that processes of drilling and crude oil extraction from underground stores in the oilfield had not yet, at least not remarkably, caused heavy metal contamination, but had predominantly resulted in crude oil and salt contamination

Table 1. Concentrations (mg/kg) of Cu, Pb, Zn, Cd, crude oil and Cl in soils from developing and disused oil well sites in Qianjiang oilfield and reference sites

	Reference site (n = 6)	Developing well site (n = 9)	Disused well site (n = 9)
Cu	31.30±6.20	34.33±7.07	34.54±6.27
Pb	25.20±5.22	28.02±7.90	31.25±6.82
Zn	70.53±13.40	83.71±19.05	76.95±15.84
Cd	0.119±0.034	0.126±0.024	0.115±0.020
Crude oil	110.90±34.40[a]	1711.85±180.63[b]	254.86±26.89[c]
Cl	33.40±11.24[a]	2866.65±375.58[b]	683.20±89.58[c]

Results are means ± SD. Means with different letters are significantly different from one another ($P<0.001$) according to Student's t test

Supposing there were no statistically significant differences of crude oil and Cl concentrations between and within developing oil well sites in the last three years, mean weathering rates of crude oil and Cl in soils at the disused oil well sites during the same period could be indirectly estimated from the observed concentrations in the well sites (Table 1). On this supposition, calculated from equation $1711.85(1-K_o)^3=254.86$ for crude oil and $2866.65(1-K_c)^3=683.20$ for Cl, the estimating mean weathering rates were $K_o = 0.47$, $K_c = 0.38$. K_o agreed well with reported values from the literature, e. g. , 46.59% (Wang et al. 1989) and ca. 50% (Vandermeulen et al. 1994). If the weathering rates are constant at lower contaminant levels, the time for crude oil and Cl concentrations in soils at oil well sites to decrease to the levels in reference sites could be estimated at 4.31 and 9.31 years respectively when they were disused.

Plant species and species richness indexes in the three types of sites are shown in Table 2. Of the 48 species, 10 were found at both reference and oil well sites, 6 at oil well sites, and 32 at reference sites. Obviously during the oilfield development, most plant species disappeared from the oil well sites. In addition to some mechanical disturbances exerted by drilling and crude oil extraction from underground stores, major impacts on the plants would come from the high levels of soil crude oil and salt (Table 1). In contaminated oilfields only resistant species or populations could survive (Wang et al. 1989). This was probably the reason that at the developing oil well sites, salt-resistant plants belonging to Chenopdiaceae,

Table 2. Plant species (+ shows present) and species richness indexes (D) at developing and disused oil well sites in Qianjiang Oilfield and reference sites.

Species (Family)	Ref. site	Developing well site	Disused well site
Agastache rugosus(Labiatae)	+		
Artemisia subdigitata (Composite)	+		
Astragalus sinicus(Leguminosae)	+		
Capsella bursa-pastoris (Cruciferae)	+		
Chenopodium album (Chenopodiaceae)	+		
Daucus carata (Umbelliferae)	+		
Dendranthema indicum (Composite)	+		
Duchesnea indica (Rosaceae)	+		
Equisetum ramosissimum (Equisetaceae)	+		
Euphorbia helioscopia (Euphorbiaceae)	+		
Kyllinga brevifolia (Cyperaceae)	+		
Lysimachia christinae (Primulaceae)	+		
Medicago hispida (Leguminosae)	+		
Medicago minima (Leguminosae)	+		
Oxalis corniculata (Oxalidaceae)	+		
Paederia scandens (Rubiaceae)	+		
Parathelypteris glanduligera (Thelypteridceae)	+		
Paspalum thunbergii (Gramineae)	+		
Plantago asiatica (Plantaginaceae)	+		
Polygonum hydropiper (Polygonaceae)	+		
Ranunculus ternatus(Ranunculaceae)	+		
Rorippa cantoniensis (Cruciferae)	+		
Rorippa indica (Cruciferae)	+		
Rosa multiflora (Rosaceae)	+		
Rostellularia procumbent (Acanthaceae)	+		
Scutellaria barbata (Labiatae)	+		
Taraxacum mongolicum(Compositae)	+		
Teucrium viseidum(Labiatae)	+		
Trigonotis peduncularis (Boraginaceae)	+		
Verbena officinalis (Verbenaceae)	+		
Viola inconspicua (Violaceae)	+		
Youngia japonica (Composite)	+		
Setaria viridis (Gramineae)	+	+	
Cerastium caespitosum (Coryophyllaceae)	+		+
Digitaria adscendens (Gramineae)	+		+
Galium aparine var tenerum (Rubiaceae)	+		+
Rumex acetosa (Polygonaceae)	+		+
Veronica didyma (Scrophulariaceae)	+		+
Canyza canadensis (Composite)	+	+	+
Cynodon dactylon (Gramineae)	+	+	+
Eclipta prostrata (Composite)	+	+	+
Kochia scoparia (Chenopodiaceae)	+	+	+
Echinochloa colonum (Gramineae)		+	+
Sonchus oleraceus (Composite)		+	+
Scirpus yagara (Cyperaceae)		+	
Alternanthera philoxeroides(Amaranthaceae)			+
Hemistepta lyrata (Composite)			+
Stellaria media (Caryophyllaceae)			+
D	6.0146	1.2518	2.2561

Gramineae and Composite were generally found (Table 2).

Association coefficients, V and X^2, between the three types of sites are given in Table 3. V coefficient is in fact an analogue to Pearson's correlation coefficient r in binary measurement scale. The V values between reference sites and the two types of oil well sites were both negative, whereas the one between the developing and disused oil well sites was positive. It would imply that species constitutions in developing and disused oil well sites were more similar to each other than to those at the reference sites. The X^2 values further indicated that associations between the three types of sites were significant. Although species richness index of the disused oil well sites was larger than that of the developing oil well sites (Table 2.), it was however not significantly different from the latter (positive correlation), but significantly different from that of the reference sites (negative correlation). So more years would take for plant species diversity to recover in the disused oil well sites.

Table 3. V and X^2 values calculated from 2 X 2 contingency tables based on species numbers between the three types of sites.

	Reference vs developing oil well site	Reference vs disused oil well site	Developing vs disused oil well site
v	−0.3381	−0.4504	0.4510
x^2	5.4857*	9.7383**	9.7613**

* (P<0.05), * * (P<0.01) according to chi-square test

As pointed out above, the crude oil and salt contaminants in soils exerted predominant impacts on plants at oil well sites. Plant species diversity would therefor be supposed to increase gradually at some recovering rate with the contaminants progressively declining at the disused oil well sites. Let there were no significant differences of species diversity between and within developing oil well sites during the last three years, mean recovering rate Kp of the species diversity at the disused oil well sites during the same period could be indirectly estimated from the known species richness indexes in develpoing and disused oil well sites (Table 2): $1.2518\ (1 + Kp)^3 = 2.2561$, with $Kp = 0.2170$. At this rate, it would take about 8 years for plant species richness at oil well sites to increase to the levels at the reference sites when they were disused. This estimation compared well with the period of 9.31 years for salt-contaminated soil recovery (see above). It might imply that the salt contamination in the soil was a crucially restrictive factor with plant survival and recovery.

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