Int. J. Environ. Sci. Technol. (2012) 9:361–370
DOI 10.1007/s13762-012-0039-5

ORIGINAL PAPER

Soil chemical changes resulting from irrigating with petrochemical effluents

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Received: 16 September 2010 / Revised: 23 May 2011 / Accepted: 19 October 2011 / Published online: 23 March 2012

Abstract Irrigating food crops with treated wastewater is a popular management option in India. This study evaluated the impacts of land application of treated petrochemical effluent on soil chemical properties. Soil samples were collected from different depths from sites irrigated with petrochemical effluent for 2 years and from control sites. The effluent collected was analysed for different physic–chemical properties and its impact on *Lagenaria siceraria* (Bottle gourd) growth. 100% concentrated effluent was used for the study and compared with the control. It was observed that application of effluent significantly increased the major cations and anions in the field. On the basis of the study, it may be suggested that treated petrochemical effluent can be used as an alternate source for irrigating crops as it increases the nutrient content of the soil. The overall application indicates a lavishing growth of *L. siceraria* crop in petrochemical irrigated soil than control sites. This study provides information for better understanding of changes in soil properties due to land application of petrochemical effluent. These changes must be considered in developing possible criteria for preserving delicate ecosystems.

Keywords Soil quality · Heavy metal · Petrochemical industries · Wastewater

Introduction

Water is critical for sustainable development and is indispensable for human health and well-being round the globe. Water quality, which is influenced by various natural processes and anthropogenic activities, is now worldwide current environmental issue in research (Srivastava et al. 2008, 2011). In India, agriculture is the largest single user of water with about one-third of fresh water being currently used for the irrigation. With increasing pressure on fresh water resources, there is need to conserve this important valuable natural resource. Non-conventional water resources such as treated wastewater represent complementary water resources and can be used as an alternative to fresh water irrigation (Angelakis and Bontoux 2001; Friedler 2001; Al-Jayyousi 2003; Anderson 2003; Toze 2006).

The oil industry has made great technological advances since exploration began 150 years ago (Kerr 1998; Campbell 2001; Hirsch et al. 2005; Rajesh et al. 2009; Refaat 2009). Indian refineries have been provided stable and higher returns than the predicted ones. Currently, India has oil refining capacity of 2.6 million barrels per day against domestic consumption of about 2.2 million barrels per day. The refining capacity is expected to rise to 4.84 million bpd by 2012, an increase of 62% from current levels. According to an estimate from India's Petroleum

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ministry, the country ranks sixth in the world in terms of petroleum demand. In future, India is projected to replace South Korea and emerge as the fourth largest consumer of energy after United States, China and Japan.

The optimum utilization and benefits from crude oil are derived by converting crude oil (through processing in petrochemical) into a wide range of products such as petroleum fuels, lubricants, bitumen and waxes based on market demand (Speight and Knovel 2002; Ojumu et al. 2005; Speight 2007). For processing, the Oil and Natural Gas Corporation (petrochemical) uses a large amount of water and generates about approximately 0.6 barrels of wastewater per barrel of oil processed. This equates to 1.7 billion gallons of wastewater that must be treated to meet environmental discharge (Wong and Hung 2004; Devold 2007). This water was contaminated by waste oil and other impurities from refining processes. Its uncontrolled disposal may result in the degradation of environment and depreciation of aesthetic quality (Hegg et al. 1978; Fano et al. 1986; Pessala et al. 2004). Therefore, petroleum refineries around the world have adopted different technological options to manage the wastes generated during the refining process and stocking of crude oil (Joseph and Joseph 2009). (Lee et al. 2004) suggested a two-stage sequencing batch reactor system for the treatment of oily wastewater. Electrocoagulation of phenol using aluminium electrodes has emerged as a promising process to remove phenol from petrochemical waste (Ojumu et al. 2005; Abdelwahab et al. 2009). Biological degradation has also been reported, pseudomonas strains have a strong ability to degrade kerosene, gasoline, diesel, engine oil and crude oil (Obayori et al. 2009; Rajesh et al. 2009). Due to the strict enforcement of environmentalists and environmental government regulators, industries are opting for reuse of effluent for irrigation purposes in agricultural fields. Though the concept seems to be promising, the real success can be attributed only if there is no toxic accumulation in the long run. The prevention of such problems lies in the detailed analysis of different industrial effluents and their treatment before discharge and even more crucial is the effect produced by the effluent on soil, water and crop plants (Aziz et al. 1996; Bond 1998; NE and JC 2005; Tandi et al. 2005; Ganeshamurthy et al. 2008; Singh and Agrawal 2008; O'Connor et al. 2008; Rajesh et al. 2009). Nutrient supplying potential of petrochemical effluent is directly related to the type of crude oil used in refinery, which in turn depends on the source of crude oil. The petrochemical effluent has been found to contain nearly all major cations and anions (Sharma 2010). The effect of wastewater application on the land varied with soil type, wastewater characteristics and the vegetation of the irrigated soil (Pound and Crites 1973; Magesan et al. 2000).

Oil and Natural Gas Corporation (petrochemical) is most valuable company situated in Gujarat state which is about 13 km away from Surat, contributes 77% of India's natural gas production (Fig. 1). Hazira plant of petrochemical has a great importance due to its contribution of gas production. It has various unit viz., LPG, recovery, gas sweetening, gas dehydration, condensation, fractionation, dew points depression and boiler unit. The wastewater treatment plant of petrochemical, Hazira is designed to treat wastewater and meet the water quality standards. Hazira wastewater unit releases 15,000 m^3/day. Preliminary work has also been reported on the irrigational utility of petrochemical wastewater (Schmidt et al. 1975; Al-A'ama and Nakhla 1995; Aziz et al. 1995; Sastry and Sundaramoorthy 1996; Hussain et al. 2002). Some works have been done on the performance of a few crops irrigated with wastewaters discharged from various sources (Day et al. 1979; Chakrabarti and Chakrabarti 1988; Greene et al. 1980; Day et al. 1981; Reddy et al. 1990; Herpin et al. 2007). The present study was designed to attain comprehensive information on the effect of treated-gas processing effluent on soil characteristics temporally and to assess its suitability as an alternate source of fresh water irrigation.

Materials and methods

Field experiments and sampling

The impact of various dilutions of petrochemical effluent on soil properties was studied under field experiments. The experiment was laid out in random block design. The sizes of plots are 20 × 20 m^2. The seeds of *L. siceraria* were sown at the rate of 20 per plot at random on the leveled and moistened sandy loam soil. The seeds were placed about 3–4 cm depth as per the garden guide available on http://www.gardenguides.com. Soil samples collected from the fresh-water-irrigated fields were taken as pre-treated soil and considered as control. The samples were taken between 10.00 am to 12.00 pm every month, for the period March 2005–February 2007. All samplings represent instantaneous soil and water quality at the particular time. These samples are collected from 0 to 15 cm depth as the average root depth of bottle gourd plant lies in-between this range, also confirmed through the measurements of some previous plants.

Irrigation water analysis

The effluent was collected from the Surat petrochemical in pre-cleaned polyethylene bottles of 2-L capacity with necessary precautions. The collected water samples were divided in two bottles. One bottle was acidified with nitric

Fig. 1 Location of Surat Refinery (Petrochemical), India (Source: http://www.mapsofindia.com)

acid to pH < 2 and stored at 4°C for the later analysis of the heavy metals. These were carried out according to the protocols of ultra-trace-metal analysis (Bruland et al. 1979) using AAS-Graphite furnace technique, and Zn was determined using AAS method (Shimadzu, 6800). The other bottle was stored at 4°C without the addition of preservatives for the analysis of major water parameters. The effluent was then analyzed for different physic–chemical properties (i.e., TH, TDS, Ca^{2+}, Mg^{2+}, alkalinity, Cl^{-}, SO_4^{2-}, carbonate, bicarbonate, etc) using the standard methods (APHA et al. 1995) and compared with physic–chemical characteristics of control water. pH and EC were measured using pH conductivity meter in the field. Bicarbonate was determined by potentiometric titration method. Chloride ion is one of the major inorganic anions in water and was estimated by Mohr's titration method. Calcium and magnesium ions were analysed using atomic absorption spectrophotometer (AAS) (Shimadzu, 6800), turbidity by Nephelo-turbidity meter, total hardness by titrimetric method, BOD as per standard method (NEERI 1991), and

Table 1 Physic–chemical characteristics of petrochemical effluent in comparison with control water (all units are in mg/L except pH)

Duration	pH		COD		TDS		TA		TH		O and G		PO_4	
	FW	TW	FW	TW	FW	TW	FW	TW	FW	TW	FW	TW	FW	TW
March 2005–June 2005	7.2 ± 0.005	7.5 ± 0.007	6.3 ± 0.001	28.0 ± 0.007	87.2 ± 0.008	297.0 ± 0.045	58.0 ± 0.012	95.0 ± 0.045	109.0 ± 0.023	197.5 ± 0.013	N.D.	2.0 ± 0.065	14.7 ± 0.005	33.2 ± 0.006
July 2005–Oct 2005	7.2 ± 0.002	7.6 ± 0.006	8.0 ± 0.002	14.1 ± 0.009	172.5 ± 0.012	334.0 ± 0.023	128.5 ± 0.013	128.5 ± 0.034	107.7 ± 0.031	168.2 ± 0.014	N.D.	1.5 ± 0.060	30.0 ± 0.003	59.0 ± 0.007
Nov 2005–Feb 2006	7.1 ± 0.002	7.4 ± 0.006	5.0 ± 0.001	10.6 ± 0.006	126.0 ± 0.013	235.3 ± 0.031	97.7 ± 0.017	130.5 ± 0.043	99.0 ± 0.024	154.8 ± 0.015	N.D.	1.0 ± 0.034	19.7 ± 0.008	37.7 ± 0.008
March 2006–June 2006	7.1 ± 0.001	7.6 ± 0.005	6.1 ± 0.004	11.7 ± 0.005	136.8 ± 0.012	312.0 ± 0.024	105.7 ± 0.012	133.7 ± 0.041	73.0 ± 0.024	106.5 ± 0.015	N.D.	0.93 ± 0.23	21.7 ± 0.009	50.7 ± 0.009
July 2006–Oct 2006	7.6 ± 0.007	7.6 ± 0.002	9.1 ± 0.008	37.2 ± 0.008	156.3 ± 0.021	340.7 ± 0.031	137.0 ± 0.013	133.5 ± 0.014	166.3 ± 0.035	141.3 ± 0.017	N.D.	0.92 ± 0.031	27.7 ± 0.007	34.2 ± 0.007
Nov 2006–Feb 2007	7.4 ± 0.002	7.5 ± 0.007	3.9 ± 0.005	9.60 ± 0.007	101.5 ± 0.014	255.5 ± 0.047	67.5 ± 0.014	111.0 ± 0.013	113.3 ± 0.034	150.0 ± 0.018	N.D.	1.20 ± 0.023	27.7 ± 0.006	60.7 ± 0.005

Duration	NO_3		Ca		Mg		Na		K		Cl^-		SO_4	
	FW	TW	FW	TW	FW	TW	FW	TW	FW	TW	FW	TW	FW	TW
March 2005–June 2005	0.09 ± 0.023	1.5 ± 0.002	13.0 ± 0.004	23.0 ± 0.003	10.8 ± 0.004	17.6 ± 0.004	17.5 ± 0.003	106.5 ± 0.014	3.1 ± 0.004	139.0 ± 0.012	65.8 ± 0.02	28.9 ± 0.003	72.0 ± 0.024	80.0 ± 0.056
July 2005–Oct 2005	0.25 ± 0.002	2.2 ± 0.003	14.8 ± 0.003	20.6 ± 0.002	20.8 ± 0.002	23.3 ± 0.004	27.9 ± 0.002	108.0 ± 0.012	2.4 ± 0.003	133.3 ± 0.023	19.0 ± 0.03	65.8 ± 0.012	70.0 ± 0.038	85.0 ± 0.061
Nov 2005–Feb 2006	0.32 ± 0.003	1.4 ± 0.004	17.1 ± 0.004	26.8 ± 0.004	14.6 ± 0.002	43.6 ± 0.008	40.1 ± 0.004	150.0 ± 0.017	3.6 ± 0.002	132.5 ± 0.045	19.5 ± 0.007	71.5 ± 0.023	68.0 ± 0.033	88.0 ± 0.033
March 2006–June 2006	0.36 ± 0.005	1.9 ± 0.002	15.1 ± 0.008	25.7 ± 0.003	7.90 ± 0.001	17.8 ± 0.005	23.4 ± 0.005	147.3 ± 0.019	2.9 ± 0.004	130.3 ± 0.076	3.60 ± 0.001	71.1 ± 0.030	58.0 ± 0.025	74.0 ± 0.042
July 2006–Oct 2006	1.3 ± 0.005	0.57 ± 0.001	15.2 ± 0.004	26.6 ± 0.009	14.2 ± 0.005	23.6 ± 0.004	24.3 ± 0.004	140.0 ± 0.020	3.4 ± 0.005	124.5 ± 0.025	4.30 ± 0.003	40.4 ± 0.039	74.0 ± 0.033	78.0 ± 0.012
Nov 2006–Feb 2007	0.08 ± 0.005	1.0 ± 0.001	10.9 ± 0.003	26.1 ± 0.005	4.60 ± 0.001	8.7 ± 0.002	30.8 ± 0.006	238.0 ± 0.031	4.8 ± 0.005	132.5 ± 0.033	3.90 ± 0.001	94.3 ± 0.046	56.0 ± 0.018	68.0 ± 0.014

FW Fresh water, *TW* treated petrochemical effluent

COD by potassium dichromate open reflex method (APHA et al. 1995).

Soil analysis

Soil samples were air dried, sieved through a 2 mm mesh and homogenized and then were analyzed for different physic–chemical, cation-exchange capacity, hydrogen ion concentration, EC, organic carbon, N, P, Na, K, Ca^{2+}, Mg^{2+}, $SO_4{}^{2-}$, alkalinity, heavy metals mainly Fe, Pb, Zn, Co, Cr and Cu. Soil analysis was done as per the methods given in USDA Handbook No. 60 (Richards 1954). All heavy metal concentrations in solution phase were determined by using AAS. Extractable metals were determined by AAS (Shimadzu, 6800) using DTPA as single extractant (Lindsay 1978).

Statistical analysis

The data obtained were subjected to mean and standard deviation. The relationship between various soil parameters was analysed through correlation coefficients following (Nagelkerke 1991). The data were analysed on SPSS 17.0 software. The coefficient of correlation (r) is a measure of the strength of the straight-line or linear relationship between two variables. The correlation coefficient takes on values ranging between +1 and −1. +1 indicates a perfectly positive linear relationship, while 0 and −1 indicate no or perfectly negative correlation, respectively (Hedges and Olkin 1985; Nagelkerke 1991). The mathematical equation for r computation is:

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2}\sqrt{n(\sum y^2) - (\sum y)^2}}$$

where x and y are the variables chosen for the analysis and n is the number of pairs of data.

Results and discussion

Characterization of effluent

Petrochemical effluent was found to be having high amount of nutrients than that of control as well as Central Pollution Control Board standards (Table 1). The effluent had normal hydrogen ion concentration within the range (7.4–7.6) of CPCB standards given in 2000 (http://www.cpcb.nic.in). Electrical conductivity, total dissolved solids and other characteristics were also higher than the control water but within the CPCB standards limit. Such a nutritious effluent might help to accumulate the required nutrients in the soil, and hence, it can result in the better growth of crop plants.

Table 2 Physic–chemical properties of soil of both sites before irrigation (all units are in mg/100 gm except pH)

Parameters	Control	Petrochemical
pH	7.8 ± 0.010	7.8 ± 0.010
Electrical conductivity	0.81 ± 0.012	0.83 ± 0.010
Available phosphorus (mg/100 gm)	0.72 ± 0.090	0.76 ± 0.080
Total alkalinity (mg/100 gm)	54 ± 1.02	68 ± 1.00
Organic matter	0.60 ± 0.031	0.58 ± 0.020
Calcium (mg/100 gm)	19.8 ± 0.02	21.0 ± 0.015
Magnesium (mg/100 gm)	7.5 ± 0.210	7.9 ± 0.016
Sodium (mg/100gm)	2.5 ± 0.067	2.8 ± 0.078
Potassium (mg/100 gm)	3.1 ± 0.132	5.8 ± 0.012
Sulphate (mg/100 gm)	4.8 ± 0.013	5.1 ± 0.013
Nitrate (mg/100 gm)	12.1 ± 0.048	14.0 ± 0.052

Characterization of soil before and after irrigating with fresh water and petrochemical effluent

The soil before irrigating with petrochemical effluent was analysed for different physic–chemical properties (Table 2). The soil was slightly alkaline in nature with very low electrical conductivity (0.780 $\mu\Omega$). The cation exchange capacity and water holding capacity of the pre-treated soil were observed to be slightly lesser than that of treated soils. Temporally, the soil was supplemented with petrochemical effluent under 100% concentrated regularly for irrigation in the field in triplicates. Impact of petrochemical effluent on different physic–chemical properties of soil was studied as shown in Table 3. The decrease in bulk density and specific gravity of the soil might have occurred due to the different concentrated petrochemical effluent irrigation. When soil is irrigated with petrochemical effluent, water holding capacity was found to be improved at each successive level of plant growth. The water holding capacity of the soil ranged from 32.12% under control 39.02% at 100% effluent concentration. The hydrogen ion concentration of the petrochemical effluent treated-soil showed an increase from 8.5 to 8.6 at different concentrations of effluent during various time intervals. This might be due to the high value of alkalinity and soluble salts present in the petrochemical effluent (Sharma 2010). The higher electrical conductivity at fresh-water-irrigated soil was 1.26 $\mu\Omega$ reported in the period between November 2006 and February 2007 and in soil of treated effluent irrigated was 3.06 $\mu\Omega$ during July 2006–October 2006. The irrigation of treated effluent has increased the soil conductivity.

Organic matter of the treated soil irrigated with different concentrations of the effluent increased with the increase in concentration of the petrochemical effluent and ranged from 0.43 to 1.37%. Organic matter was reported

Table 3 Physic–chemical characteristics of soil in comparison with control soil after irrigation (all units are in mg/100 gm except pH)

Duration	pH		EC		AP		TA		OM		Ca	
	FW	TW	FW	TW	FW	TW	FW	TW	FW	TW	FW	TW
March 2005–June 2005	8.0 ± 0.05	8.6 ± 0.25	1.11 ± 0.06	1.16 ± 0.1	7.7 ± 0.5	15.7 ± 0.7	58.0 ± 4.0	139.0 ± 9.0	0.069 ± 0.01	0.43 ± 0.03	22.1 ± 1.1	21.0 ± 1.4
July 2005–Oct 2005	8.4 ± 0.21	8.6 ± 0.2	1.07 ± 0.01	1.79 ± 0.1	3.3 ± 0.21	7.81 ± 0.81	77.3 ± 4.0	128.0 ± 8.5	0.265 ± 0.03	0.505 ± 0.04	26.7 ± 1.2	32.5 ± 1.2
Nov 2005–Feb 2006	8.3 ± 0.18	8.6 ± 0.9	1.21 ± 0.20	2.8 ± 0.3	1.3 ± 0.31	2.62 ± 0.40	101.5 ± 5.9	135.0 ± 6.2	0.494 ± 0.04	0.498 ± 0.04	30.0 ± 1.0	54.0 ± 2.7
March 2006–June 2006	8.1 ± 0.05	8.5 ± 0.2	1.25 ± 0.13	2.21 ± 0.9	0.89 ± 0.24	1.45 ± 0.37	72.2 ± 5.9	163.75 ± 12	0.523 ± 0.04	1.12 ± 0.08	23.1 ± 2.2	38.3 ± 1.6
July 2006–Oct 2006	8.5 ± 0.05	8.5 ± 0.05	1.22 ± 0.05	3.06 ± 0.04	1.11 ± 0.06	2.7 ± 0.05	117.8 ± 9.0	131.0 ± 10	0.913 ± 0.02	1.15 ± 0.04	30.3 ± 1.97	51.2 ± 9.3
Nov 2006–Feb 2007	8.3 ± 0.05	8.6 ± 0.05	1.26 ± 0.13	2.76 ± 0.03	1.21 ± 0.09	3.5 ± 0.05	113.3 ± 6.3	139.3 ± 4.1	0.793 ± 0.07	1.37 ± 0.12	30.7 ± 2.3	49.6 ± 0.7

Duration	Mg		Na		K		SO_4		NO_3	
	FW	TW	FW	TW	FW	TW	FW	TW	FW	TW
March 2005–June 2005	10.1 ± 1.4	13.8 ± 0.83	2.5 ± 0.5	3.6 ± 0.6	3.1 ± 0.7	5.81 ± 0.9	5.6 ± 0.5	7.2 ± 0.6	13.1 ± 3.4	63.0 ± 2.1
July 2005–Oct 2005	11.27 ± 2.0	13.7 ± 0.80	4.1 ± 0.5	4.8 ± 0.6	4.0 ± 0.6	5.68 ± 0.3	4.5 ± 0.3	6.1 ± 0.6	16.1 ± 0.12	59.5 ± 1.2
Nov 2005–Feb 2006	7.5 ± 0.40	23.5 ± 0.30	7.8 ± 0.4	7.7 ± 0.1	3.8 ± 0.5	7.53 ± 0.6	4.8 ± 0.5	8.1 ± 0.6	18.0 ± 0.16	80.0 ± 2.3
March 2006–June 2006	7.41 ± 0.4	7.4 ± 0.41	6.5 ± 0.3	8.3 ± 0.1	4.6 ± 0.5	5.4 ± 0.3	5.5 ± 0.2	7.5 ± 0.4	19.3 ± 0.95	80.0 ± 6.6
July 2006–Oct 2006	7.9 ± 0.3	26.5 ± 0.60	7.9 ± 0.3	13.3 ± 0.1	2.9 ± 0.2	4.8 ± 0.2	4.8 ± 0.3	8.1 ± 0.1	21.0 ± 1.25	80.3 ± 0.9
Nov 2006–Feb 2007	6.8 ± 0.3	34.3 ± 2.9	7.8 ± 0.1	28.6 ± 0.4	3.0 ± 0.3	13.0 ± 0.6	6.0 ± 0.2	7.41 ± 0.5	18.8 ± 1.64	72.0 ± 0.9

Table 4 Heavy metal concentration (mg/L) in the effluent and Central Pollution Control Board (CPCB) standard

Metals	Proportion (mg/L)	Standard CPCB (2000) (mg/L)
Cadmium	0.0–0.02	2.0
Cobalt	ND	0.05
Copper	0.08–0.09	3.0
Iron	0.07–0.09	5.0
Lead	0.02–0.06	1.0
Nickel	0.0–0.17	5.0
Zinc	0.35	15

maximum after 20 months of continuous irrigation of treated effluent of petrochemical in Novmber 2006–February 2007. This increase in organic carbon could be due to high amount of organic source in petrochemical effluent or may be due to the growth of microorganisms responsible for decomposition of organic materials in the soils (Parnas 1975). The increased cation exchange capacity could be due to the higher availability of cations in petrochemical effluent. The alkalinity of the soil increased with the increase in effluent concentrations and varied between 169.90 and 184.21 mg/kg. The sulphate of the soil showed an increase with 100% concentrated effluent in comparison with the control. Sulphate content was maximum during July 2006–October 2006 in control water and during November 2005–February 2006 in treated effluent. The available nutrients of the soil viz., nitrogen, phosphorous, potassium, and sodium increased from 59.5 to 80.01 mg/100 g, 1.45 to 15.7 mg/100 g, 4.8 to 13.0 mg/100 g and 3.6 to 28.6 mg/100 g, respectively under different effluent concentrations. The highest calcium content (54.0 mg/100gm) was observed in the soil of petrochemical site during the period of November 2006–February 2007. It was the highest in fresh-water-grown soil (30.73 mg/100gm) in the months of November 2006–Febuary 2007.

Nitrate was relatively higher in the soil of petrochemical site, which was found in the range of 59.5–80.3 mg/100 gm. It was relatively lower 13.1–21.0 mg/100gm in fresh-water-grown soil. Nitrate content of the soil of petrochemical site during March 2005–October 2005 was lower. But later on, it was increased after the irrigation of treated effluent. This increase might be attributed to their high concentrations in the effluent used for irrigating the soil. Similar observations were also noted by (Aziz et al. 1995, 1996). The effect of the Surat petrochemical effluent on DTPA-extractable heavy metal contents (Table 4). The heavy metals studied were Fe, Pb, Zn, Co, Cr and Cu. All the above heavy metals were found below the permissible limit given by CPCB in 2000.

Table 5 Correlation coefficient (*r*) value calculated within soil (1–10), within fresh water (11–19) and in-between soil and fresh water (1–10 and 11–19*)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1.00																		
2	0.61	1.00																	
3	−0.66	−0.37	1.00																
4	0.60	0.41	−0.61	1.00															
5	0.18	0.05	−0.41	0.57	1.00														
6	0.72	0.58	−0.46	0.83	0.40	1.00													
7	−0.46	−0.53	0.60	−0.46	−0.43	−0.47	1.00												
8	0.63	0.59	−0.60	0.93	0.46	0.90	−0.53	1.00											
9	0.62	0.25	−0.13	0.39	−0.03	0.31	0.04	0.35	1.00										
10	0.30	0.11	−0.18	0.41	0.32	0.36	0.20	0.48	0.53	1.00									
11	−0.20	−0.41	0.47	−0.26	−0.67	−0.32	0.56	−0.33	0.32	−0.03	1.00								
12	−0.10	−0.53	−0.07	0.04	0.44	−0.14	0.43	−0.09	0.08	0.48	0.05	1.00							
13	−0.21	−0.47	0.54	−0.28	−0.29	−0.29	0.79	−0.36	0.35	0.46	0.62	0.39	1.00						
14	0.44	−0.20	−0.31	0.23	0.22	0.17	−0.17	0.06	0.33	−0.20	0.04	0.32	−0.20	1.00					
15	0.47	0.15	−0.71	0.57	0.56	0.38	−0.32	0.56	0.30	0.45	−0.27	0.57	−0.31	0.46	1.00				
16	0.42	0.45	−0.57	0.29	0.43	0.31	−0.42	0.38	−0.02	0.30	−0.42	0.23	−0.41	0.03	0.64	1.00			
17	0.30	−0.12	−0.29	0.27	0.20	−0.14	−0.11	−0.02	0.52	−0.03	0.21	0.21	0.06	0.53	0.29	0.08	1.00		
18	0.13	−0.15	−0.51	0.62	0.74	0.29	−0.12	0.52	0.16	0.66	−0.27	0.67	0.01	0.11	0.76	0.41	0.25	1.00	
19	−0.40	−0.16	0.18	0.33	0.15	0.19	−0.14	0.36	−0.19	0.08	0.17	−0.09	−0.08	−0.29	−0.01	−0.18	−0.24	0.31	1.00

pH	Con.	AP	TA	OM	Ca	Mg	Na	K	NO_3^-	pH	TA	COD	PO_4	NO_3^-	Ca	Mg	Na	K
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

Table 6 Correlation coefficient (*r*) value calculated within soil (1–10), within petrochemical effluent (11–19) and in-between soil and fresh water (1–10 and 11–19)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1.00																		
2	−0.24	1.00																	
3	−0.39	−0.52	1.00																
4	−0.50	−0.10	0.79	1.00															
5	0.01	0.17	−0.02	−0.17	1.00														
6	−0.15	0.94	−0.65	−0.21	0.15	1.00													
7	−0.17	0.68	−0.15	0.01	0.41	0.63	1.00												
8	−0.50	0.77	−0.33	0.16	−0.19	0.82	0.49	1.00											
9	0.09	0.41	−0.13	−0.12	0.58	0.24	0.36	−0.18	1.00										
10	−0.20	0.71	−0.40	−0.05	0.00	0.81	0.53	0.71	0.19	1.00									
11	−0.03	−0.12	0.42	0.32	0.20	−0.20	0.37	−0.22	0.11	−0.33	1.00								
12	−0.03	0.24	−0.34	−0.04	−0.11	0.35	0.00	0.45	−0.32	0.12	−0.01	1.00							
13	0.24	−0.82	0.56	0.10	−0.17	−0.80	−0.37	−0.66	−0.28	−0.36	0.01	−0.48	1.00						
14	−0.55	−0.07	0.32	0.33	−0.06	−0.22	−0.27	0.09	−0.25	−0.55	0.10	0.18	−0.26	1.00					
15	0.51	−0.06	−0.21	−0.36	0.08	−0.14	−0.06	−0.38	0.09	−0.50	0.20	−0.20	−0.07	0.16	1.00				
16	0.30	0.27	−0.13	0.04	0.09	0.14	0.02	0.07	0.27	0.04	−0.34	0.30	−0.15	0.01	0.07	1.00			
17	−0.17	0.36	−0.30	0.01	−0.04	0.47	0.00	0.56	−0.16	0.46	−0.39	0.83	−0.38	0.01	−0.53	0.46	1.00		
18	−0.06	0.40	−0.21	0.09	−0.21	0.44	0.36	0.58	−0.23	0.36	0.08	0.79	−0.33	−0.05	−0.39	0.40	0.74	1.00	
19	0.14	−0.15	0.14	−0.12	0.13	−0.21	0.20	−0.40	0.27	−0.16	0.37	−0.82	0.26	−0.22	0.46	−0.57	−0.94	−0.71	1.00

pH	Con.	AP	TA	OM	Ca	Mg	Na	K	NO_3^-	pH	TA	COD	PO_4	NO_3^-	Ca	Mg	Na	K
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

Table 7 Effect of petrochemical effluent on plant height (cm ± SE)

Duration	Plant height of *Lagenaria siceraria* L. (cm ± S.D.)		
	Days	Control	Petrochemical effluent
March 2005–June 2005	10 days	6.0 ± 0.005	14.0 ± 0.090
	20 days	12.5 ± 0.012	42.0 ± 0.250
	30 days	18.0 ± 0.023	50.0 ± 0.320
July 2005–Oct 2005	10 days	6.5 ± 0.004	15.0 ± 0.089
	20 days	12.0 ± 0.020	39.0 ± 0.120
	30 days	17.0 ± 0.018	49.0 ± 0.098
Nov 2005–Feb 2006	10 days	6.2 ± 0.005	13.0 ± 0.085
	20 days	12.0 ± 0.005	41.0 ± 0.090
	30 days	16.9 ± 0.025	52.0 ± 0.220
March 2006–June 2006	10 days	5.9 ± 0.002	14.5 ± 0.079
	20 days	11.2 ± 0.022	39.5 ± 0.450
	30 days	16.4 ± 0.023	47.0 ± 0.320
July 2006–Oct 2006	10 days	7.5 ± 0.014	17.0 ± 0.098
	20 days	12.0 ± 0.020	40.0 ± 0.220
	30 days	19.0 ± 0.021	53.0 ± 0.081
Nov 2006–Feb 2007	10 days	5.9 ± 0.005	11.0 ± 0.065
	20 days	11.0 ± 0.005	38.0 ± 0.078
	30 days	15.8 ± 0.045	62.0 ± 0.170

Correlation analysis of soil with petrochemical effluent and fresh water

The correlation analysis between physic–chemical parameters of soil after irrigation with petrochemical effluent was given in Tables 5 and 6. The results showed positive significant correlation among all the physic–chemical parameters of the soil except with bulk density and specific gravity.

Effect of petrochemical effluent on plant height

The effect of the effluent on plant height of bottle gourd crop plant is shown in Table 7. The length of bottle gourd plants cultivated at petrochemical site was higher than the plants of control site on 10th day. The growth was slower in the period between 10 and 30 days after germination in bottle gourd of control site than petrochemical site. Maximum plant height was reported in petrochemical effluent in the period of November 2006–February 2007, after 30 days of plant growth. This might be due to the availability of more nutrients in the effluent as compared to control.

Conclusion

This study showed that petrochemical effluent has considerable prospect to use as an irrigation source in India. It provides farmers with a high-nutrient water supply with a reliable and low-cost system for wastewater disposal. The study showed that application of petrochemical effluent enhanced the growth of bottle gourd plant in all replicates. This study is important to evaluate the monitoring programm at a reclaimed water irrigation site to satisfy regulatory discharge requirements, and to provide timely information regarding the potential accumulation of constituents that may reach toxic concentrations. The study is important to appraise short and long-term effects of effluent irrigation. The results can be used both as a tactical planning tool to address broad-scale water vulnerability concerns and also as a premeditated guide to help managers in designing efficient pollution control measures.

Acknowledgments Authors are highly thankful to the Department of Biosciences, Veer Narmad South Gujarat University, Surat, Gujarat, India for providing the necessary facilities for the research. Authors would also like to thanks Oil and Natural Gas Corporation, India for their help and support during the analysis.

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