Water Quality, Soil Characteristics and Vegetation Diversity Along Effluent-dominated Rivers in Western Rajasthan, India

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Abstract

This study aimed at analysing water quality of effluent-dominated seasonal rivers and its impacts on soil and vegetation. Effluent-inflicted, river-edge and non-polluted areas were selected at 5 places along Luni, Bandi and Jojari rivers in western Rajasthan. Water of rivers exhibited high pH (7.6-8.6), electrical conductivity (EC 2.45-38.3 dSm⁻¹), total dissolved and suspended solids, alkalinity and Na (1.50-30.00 gL⁻¹), K, Ca and Mn (25.2-2439.3 µgL⁻¹) concentrations and low NH₄-N (1.08-20.69 mgL⁻¹), NO₃-N (0.44-9.10 mgL⁻¹) and PO₄-P (3.10-13.40 mgL⁻¹). Most variables were highest for Luni and lowest for Bandi River. Cu, Co, Se, Cd and Pb concentrations were <180 µgL⁻¹. Soil pH, EC and PO₄-P were highest along Bandi, whereas NH₄-N, NO₃-N and K were highest along Jojari River in both 0-30 and 30-60 cm soil layers. Effluent-inflicted soils exhibited high pH, EC and PO₄-P, whereas non-polluted soils showed high NH₄-N, NO₃-N and K availability. These soil variables decreased downstream. Plant species number ranged between 34 along Luni and 20 along Jojari (total 10 trees, 10 shrubs and 29 herbaceous). Species richness (R) and diversity (H') of trees were highest along Bandi. Shrubs and herbaceous R, H' and evenness (e') were high along Luni. Least diverse vegetation was along Jojari. Non-polluted area exhibited high tree R and H', whereas river-edge showed high herbaceous R and H'. Effluent-inflicted area showed high salts and low diversity, but dominated by *Aeluropus lagopoides*, *Paspalum virgatum*, *Phragmites karka*, *Tamarix ericoides*, etc., which can be used in restoring such degraded urban areas.

Highlights

- Low quality water of effluent-dominated Luni, Bandi and Jojari River had affected soil and vegetation diversity negatively.
- Effluent-inflicted soil had high pH, EC, PO₄-P and low diversity than control area with high NH₄-N, NO₃-N, K and diversity.
- Species appearing in new habitat can be utilized in restoring and greening such degraded areas.

1 Introduction

Urbanization is the fastest growing and one of the most destructive land-use type to local ecosystems. Urban population has been increased in India by 14.5-fold over the period 1901–2011, i.e. from a modest base of 25.8 million persons in 1901 to 377.11 million in 2011. Such urbanization contributes to accelerated loss of many native species because of deleterious effects of water pollution caused by municipal and industrial effluents of industrial and urban areas (Kaur et al. 2012). In India, the amount of sewage and industrial wastewater generated are 61.75 billion liter and 0.5 billion liter per day, respectively against the treatment capacity of 21.96 billion liter per day only (Roy 2020). In most of the cases, a major portion of the generated effluents are discharged into nearby water bodies, drainage lines or river systems (Preisner 2020). Luni River and its tributaries like Bandi and Jojari are examples that receive industrial effluents from Balotra (Barmer), Pali and Jodhpur cities in arid western Rajasthan affecting their natural environment (Bothra 2019). These seasonal rivers have now become effluent dominated systems in terms of flow, water quality and systems integrity (Bischel et al. 2013; Luthy et al. 2015). Depending on effluent quality and the amount of organic and inorganic loads, the quality of newly developed habitat may be enhanced or adversely affected, with varying consequences for different flora and fauna along the river courses (Drury et al. 2013; Ahmed et al. 2014). Changes in composition of sediment deposited also influence habitats quality for some species. Continuous discharge of effluents also transforms these seasonal rivers into

perennial ones altering floral and faunal composition and facilitates the establishment of some new species based on adaptation towards modified environment (Brooks et al. 2006; Bothra 2019).

Despite some positive effects of maintaining stream flow, protecting ecological integrity and sustaining societal benefits like novel riparian and aquatic habits, improved aesthetic values and ground water recharge in arid environment such discharged effluents deteriorate soil quality and affects abundance of native vegetation and agricultural production as well (Ali et al. 2014; Vantarakis et al. 2016; Hajihashemi et al. 2020). There is need to conserve the native species and effectively utilize the coming up novel species and diverse ecosystems developed along the rivers receiving such wastewaters and effluents in urban and suburban environments. Such growing vegetations defers ecological degradation by taking up trace elements and salts from the soil, water or air and retains them for a long time (Subramani et al. 2014; Kidd et al. 2015; Madejón et al. 2017). This process also creates opportunities for commercial biomass production and sequestration of excess minerals in the plant system (Sharma and Ashwath 2006; Mahmoud and Ghoneim 2016). A number of plants like *Arundo donax*, *Brachiaria decumbense*, *B. mutica*, *Cyperus* spp., *Digitaria bicornis*, *Juncus effuses*, *Leptochloa fusca*, *Ludwigia parviflora*, *Pennesetum purpureum*, *Phragmites australis*, *Scirpus americanus*, *Typha latifolia*, *T. angustifolia*, *Vetiveria* species, etc reduces pollution loads of industrial effluents (Klomjek and Nitorisavut 2005; Shehzadi et al. 2014). These plants also permit the possibility of transforming materials containing heavy metals and toxic organic compounds, which are difficult to treat by the common effluent plants. The accumulation of minerals in plants and soils however, depends on species, soils (pH, texture and cation exchange capacity) and wastewater characteristics (Singh and Aggarwal 2012; Ashraf et al. 2019). This requires survey and identification of plants of effluent-dominated river systems for selecting appropriate species for their effective use in treating wastewater and utilizing their potential in remediating wastewater contaminated soil in urban and suburban areas (Ghazaryan et al. 2019; Skrynetska et al. 2018).

Therefore, the objectives of this work were to: (i) assess quality of water flowing in Luni, Bandi and Jojari rivers in arid western Rajasthan; (ii) quantify vegetation diversity along these river systems; and (iii) to identify dominant species growing in effluent dominated river areas for their use in phytoremediation programmes.

2 Materials And Methods

2.1 Site conditions

This study was conducted along Luni, Bandi and Jojari rivers located in Barmer (24° 58' to 26° 32' N and 70° 05' to 72° 52' E), Pali (24° 45' to 26° 29' N and 72° 47' to 74° 18' E) and Jodhpur (26° 00' to 27° 37' N and 72° 55' to 73° 52' E) districts situated in arid western Rajasthan (Fig. 1). The climate of the region is characterized by extremes of temperatures, uncertain rainfall, high potential evapotranspiration and strong winds. Landscape of the region is variable ranging between sandy plains to isolated hills. Maximum temperature rises up to 50°C, whereas minimum temperature drops down to freezing point during winter season. Rainfall in the studied areas showed high temporal and spatial variations. Average annual rainfall in Barmer, Pali and Jodhpur are 346.8 mm, 607.3 mm and 309.3 mm respectively with 70% coefficient of annual rainfall variations indicating inter-annual variability in rainfall and influence vegetation composition and production. Rainfall was greater in Barmer and Pali districts in August than other months, whereas it was greater in July in Jodhpur district as compared to the other months (Fig. 2). Most of the rain fell between July to September by southwest monsoon, which begins in the last week of July and lasts till middle of September. Soils are sandy to sandy loam in texture with low soil organic

carbon and nutrients. Soil depth varies with physiographic conditions of the area. The vegetation of the area is xerophytic in nature and most of the plant species are spiny and smaller in leaf size (Champion and Seth 1968; Bhandari 1990).

2.2 Experimental design and vegetation survey

River Luni (Barmer), Bandi (Pali) and Jojari (Jodhpur) receive effluents from Balotra (Barmer), Pali and Jodhpur city respectively (Fig. 1). Five sites were selected along each river for sampling of water samples and study of vegetation structure and composition (Fig. 1a). Different sites were located between Dhundhara and Tilwara in Barmer district along Luni River, Punayata in Pali and Nehra dam in Barmer along Bandi River and between Kharada Randhir in Jodhpur and Doli in Barmer along the Jojari River. At each site, three micro-habitats like effluent-inflicted riverbed, river edge and a non-polluted control were identified. Survey was conducted during non-monsoon period of January to March 2018. Thus water sampling site were 15 (5 along each river) and vegetation study plots were 45 (3 river $\times$ 5 site $\times$ 3 micro-habitats).

Trees and shrubs were enumerated and measured 72 km stretch along the Luni, 38 km stretch along the Bandi and 48 km stretch along the Jojari Rivers by laying out plots of 20 m $\times$ 20 m size at effluent-inflicted riverbed, river edge and non-polluted control areas. For herbaceous species nested plots of 1 m $\times$ 1 m size were laid in the centre of above mentioned plots. Thus there were 15 main plots along each river course. All trees and shrubs species available in the plots were counted for their population and measured for diameter at breast height (dbh, 1.37 m height)/collar diameter (15 cm above soil surface) and total height. Plants were identified as per taxonomical classification using standard literature (Bhandari 1990). In case of multiple stem particularly for the shrubs, individual tillers were measured and converted to a single value using equation (Chojnacky 1999):

$$CD = \sqrt{d_1^2 + d_2^2 + d_3^2 + \dots + d_n^2} \dots\dots\dots (1)$$

Here CD in single value collar diameter and d is diameter of individual tiller.

2.3 Water collection and analysis

Water sample were collected from the selected five sites of each river mentioned above and were transported to laboratory for analysis (Fig. 1a). These water samples were filtered through Whatmann 42 filter paper and stored at 4 °C. Each sample was analyzed for pH, electrical conductivity (EC), total dissolved solid (TDS), total suspended solid (TSS), alkalinity, basic cations, and concentrations of macro- and micro-nutrients (OMA 1990). TSS, TDS, total alkalinity, nitrogen and phosphorus were determined following standard methods (OMA 1990). Mineral elements were estimated using Inductively Coupled Plasma Mass Spectrometry (ICPMS) model-iCAPQc-2422R.

2.4 Soil and plant sampling and analysis

Soil samples were collected from five sites along the river and in 0–30 and 30–60 cm soil layers from effluent-inflicted, river-edge and non-polluted (control) micro-habitats. Leave samples of *Prosopis juliflora* and *Salvadora persica* were collated from effluent inflicted and non-polluted micro-habitats. All soil samples were brought to laboratory and air dried, ground and passed through 2 mm sieve for further analysis. Sieved soil samples were subjected to various physico-chemical and nutrients like pH, EC, available ammonium nitrogen, available nitrate nitrogen, available phosphorous and available potassium (Jackson 1973). Soil organic carbon was determined by partial oxidation method of Walkley and Black (1934) using potassium dichromate ($K_2Cr_2O_7 \cdot 5H_2O$) as the

oxidant, Ferrous ammonium sulphate ($\text{FeSO}_4 (\text{NH}_4)_2 \text{SO}_4 \cdot 6\text{H}_2\text{O}$) as the reducing agent and diphenylamine as the indicator. Leaves samples were air dried, grounded and their mineral elements were estimated using Inductively Coupled Plasma Mass Spectrometry (ICPMS) model-iCAPQC-2422R.

2.5 Calculation of vegetation diversity

Diversity variables like species richness (R), Shannon-Wiener diversity index (H'), species dominance (D), species evenness (e') and Importance value Index (IVI) were calculated following standard procedure (Whitford 1949; Curtis and Cotton 1956; Phillips 1959; Shannon and Wiener, 1963; Misra, 1968). Population of all species of habit tree, shrub and herbaceous vegetation (herbs, sedges and grasses) were counted manually from the plots/micro-habitats laid along the river courses of the Luni, Bandi and Jojari. The population of individual species was summed up for the plot for each plant habit and converted into number per ha for tree and shrubs and number per square meter for herbaceous vegetation.

2.6 Statistical analysis

All data collected were subjected to analysis of variance using SPSS statistical package. Data were analysed using one way ANOVA, where river, site and microhabitats were the main factors. Since soil parameters were assessed in different soil layers, different soil variables like pH, EC, $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, $\text{PO}_4\text{-P}$, different metals were analyzed using one-way ANOVA for each soil layer. Soil parameters of 0–30 cm and 30–60 cm soil layers were tested using paired t-test. To obtain relations among river water quantity and vegetation diversity and soil variables, Pearson correlation coefficient was calculated.

3. Result

3.1 Water quality of rivers

Water samples collected from different locations along the rivers indicated significant ($p < 0.05$) variations in most of the water quality parameters (Table 1). Waters of these rivers were alkaline (pH 7.6–8.6) and highly saline (EC 2.45–38.3 dSm^{-1}) in nature and had high ($p < 0.05$) TDS (1.26–30.86 g L^{-1}), TSS (0.14–5.39 g L^{-1}) and alkalinity (24–250 mg L^{-1}). Likewise concentrations of Na (1.50–30.00 g L^{-1}), K (29.0–1100.0 mg L^{-1}) and Ca (136.0–3800.0 mg L^{-1}) were also high ($p < 0.05$) in most of the samples, whereas available $\text{NH}_4\text{-N}$ (1.08–20.69 mg L^{-1}), $\text{NO}_3\text{-N}$ (0.44–9.10 mg L^{-1}) and $\text{PO}_4\text{-P}$ (3.10–13.40 mg L^{-1}) were low ($p < 0.05$) according to Indian standard of irrigation water. Concentrations of Cu, Co, Se, Cd and Pb were $< 180 \mu\text{g L}^{-1}$, but Mn was high (25.2–2439.3 $\mu\text{g L}^{-1}$). Average water EC, TDS, TSS, alkalinity, Na, $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ were higher ($p < 0.05$) in Luni River, pH and Cu concentration were higher ($p < 0.05$) in Bandi river, and K, Ca, $\text{PO}_4\text{-P}$, Mn, Co, Cd and Pb concentrations were higher ($p < 0.05$) in the water flowing in Jojari river as compared to the other rivers. While considering different sites, most of the water quality parameters were highest at Balotra- the highest effluent loading point in Luni River, whereas TDS, Ca, Co and Cu showed increasing trend from Dhundhara to Tilwara. Along Bandi River, highest values of water quality parameters were nearby Pali city, but did not show any trend except a decreasing trend in TDS and Cu concentration along the river course. Most of the water quality parameters were highest at Kharada Randhir and showed a decreasing trend, whereas Mn, Co, Cu and Se exhibited an increasing trend between Kharada Randhir and Doli.

Table 1 Changes in quality of effluent-dominated water flowing in Luni, Bandi and Jojari Rivers at different locations in western Rajasthan

Water parameter	Site of sampling					
Luni River	Dhundhara	Samdari	Balotra	Jasol	Tilwara	Average
pH	8.60	8.50	8.30	7.60	8.20	8.24
EC (dSm ⁻¹)	12.19	27.50	13.06	7.38	38.20	19.67
TDS (g L ⁻¹)	7.29	11.71	7.49	5.45	30.86	12.56
TSS (g L ⁻¹)	0.39	5.39	0.43	0.33	3.23	1.95
Alkalinity (mg L ⁻¹)	120.0	128.0	184.0	100.0	120.0	130.4
Na (g L ⁻¹)	5.80	8.90	8.90	2.30	17.80	8.74
K (mg L ⁻¹)	79.0	148.0	159.0	57.0	126.0	113.8
Ca (mg L ⁻¹)	720.0	980.0	1030.0	1360.0	1480.0	1114.0
PO ₄ -P (mg L ⁻¹)	7.70	5.60	3.10	3.50	6.80	5.34
NH ₄ -N (mg L ⁻¹)	2.84	18.91	20.69	3.89	1.08	9.48
NO ₃ -N (mg L ⁻¹)	0.44	7.00	9.10	1.04	0.46	3.61
Mn (mg L ⁻¹)	0.05	0.09	1.33	1.23	1.01	0.74
Co (µg L ⁻¹)	0.80	2.62	2.75	2.79	3.71	2.53
Cu (µg L ⁻¹)	26.72	39.80	63.28	69.41	67.05	53.25
Se (µg L ⁻¹)	0.38	0.19	1.35	1.52	1.58	1.00
Cd (µg L ⁻¹)	0.02	0.06	0.13	0.15	0.12	0.10
Pb (µg L ⁻¹)	0.03	0.05	0.06	0.07	0.07	0.06
Bandi River	Pali	Punayata	Jawadia	Gadwara	NehraBandh	Average
pH	8.30	8.60	7.90	8.30	8.20	8.26
EC (dSm ⁻¹)	7.77	5.12	6.64	7.13	6.75	6.68
TDS (g L ⁻¹)	4.75	3.28	3.88	4.19	3.51	3.92
TSS (mg L ⁻¹)	0.31	0.26	0.36	0.32	0.26	0.30
Alkalinity (mg L ⁻¹)	124.0	60.0	44.0	88.0	80.0	79.2
Na (g L ⁻¹)	4.00	2.90	2.90	2.90	2.90	3.12
K (mg L ⁻¹)	68.0	79.0	166.0	84.0	166.0	112.6
Ca (mg L ⁻¹)	550.0	420.0	440.0	500.0	440.0	470.0

PO ₄ -P (mg L ⁻¹)	7.00	7.70	8.50	7.50	5.30	7.20
NH ₄ -N (mg L ⁻¹)	5.00	7.20	6.90	2.40	2.30	4.76
NO ₃ -N mg L ⁻¹)	2.50	3.20	2.50	0.90	0.80	1.98
Mn(µg L ⁻¹)	47.09	83.92	26.19	32.13	25.20	42.91
Co (µg L ⁻¹)	0.80	0.76	0.75	0.79	1.29	0.88
Cu (µg L ⁻¹)	126.72	179.80	123.28	109.41	93.16	126.47
Se (µg L ⁻¹)	2.35	2.11	1.35	2.52	2.82	2.23
Cd (µg L ⁻¹)	0.04	0.07	0.03	0.05	0.04	0.05
Pb(µg L ⁻¹)	0.33	0.46	0.57	0.47	0.33	0.43
Joari River	KhardaRandhir	Salawas	BhanduKalla	Dhawa	Doli	Average
pH	8.50	7.80	8.00	7.90	8.00	8.04
EC (dSm ⁻¹)	38.30	7.35	6.46	6.00	2.45	12.11
TDS (g L ⁻¹)	21.55	4.94	3.76	3.27	1.26	6.96
TSS (g L ⁻¹)	4.76	0.34	0.22	0.35	0.14	1.16
Alkalinity (mg L ⁻¹)	250.0	48.0	36.0	24.0	36.0	78.8
Na (mg L ⁻¹)	30.00	4.30	4.00	3.10	1.50	8.58
K (mg L ⁻¹)	700.0	1100.0	93.0	83.0	29.0	401.0
Ca (mg L ⁻¹)	3800.0	900.0	560.0	520.0	136.0	1183.2
PO ₄ -P (mg L ⁻¹)	13.40	9.40	6.40	8.30	7.40	8.98
NH ₄ -N (mg L ⁻¹)	5.68	3.29	1.92	4.24	2.02	3.43
NO ₃ -N mg L ⁻¹)	2.42	1.34	0.64	1.52	0.95	1.37
Mn(mg L ⁻¹)	0.32	2.44	1.45	1.05	1.92	1.44
Co (µg L ⁻¹)	2.43	12.64	8.13	6.08	17.57	9.37
Cu (µg L ⁻¹)	60.28	65.41	70.56	49.87	85.63	66.35
Se (µg L ⁻¹)	0.00	0.44	0.64	0.88	2.16	0.82
Cd (µg L ⁻¹)	0.14	1.82	0.09	0.06	0.04	0.43
Pb(µg L ⁻¹)	1.23	0.51	0.17	0.04	0.28	0.45

3.2 Soil characteristics

Soil pH, electrical conductivity (EC), soil available phosphorus ($\text{PO}_4\text{-P}$), ammonium nitrogen ($\text{NH}_4\text{-N}$), nitrate nitrogen ($\text{NO}_3\text{-N}$) and exchangeable potassium (K) were higher ($p < 0.05$ except K) in upper 0–30 cm (8.62 unit, 4.01 dSm^{-1} , 16.21 mg kg^{-1} , 2.83 mg kg^{-1} , 1.21 mg kg^{-1} and 219.2 mg kg^{-1} respectively) as compared to 30–60 cm (8.33 unit, 2.46 dSm^{-1} , 9.65 mg kg^{-1} , 1.60 mg kg^{-1} , 0.75 mg kg^{-1} and 189.9 mg kg^{-1} respectively) soil layer across all (Fig. 3). While considering the rivers, soil pH ($p < 0.05$), EC and available $\text{PO}_4\text{-P}$ were highest along Bandi River, whereas $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and K ($p < 0.05$) were highest along Jojari River (Fig. 3A left panels). Lowest value of soil pH was along Jojari River, EC, $\text{PO}_4\text{-P}$ and K along Luni River, and $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ along the Bandi River. Among micro-habitats, soils of effluent-inflicted areas were high in pH, EC and $\text{PO}_4\text{-P}$ (Fig. 3A middle panels). Availability of $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and K were highest in non-polluted soils (control area), whereas their lowest values were at river edge (Fig. 3B middle panels). The variations between highest and lowest values (0–60 cm soil layer) were 0.24, 5.96-fold, 1.40-fold, 1.34-fold, 1.23-fold, and 1.52-fold in soil pH, EC, $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, $\text{PO}_4\text{-P}$, and K respectively. While considering sites along the river, soil pH, $\text{PO}_4\text{-P}$, $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ decreased downstream, whereas EC and K showed quadratic relationships. In this, soil EC was highest at starting point (i.e., Kharada Randhir along Jojari, Pali along Bandi River and Dhundhara along Luni River) decreased to lowest at second point and increased again at the last sampling site. Average soil K was highest at second site and decreased at both upstream and downstream.

3.3 Vegetation diversity

Total 49 species were recorded along the Luni, Bandi and Jojari rivers courses (Annexure 1). This included 10 trees, 10 shrubs and 29 herbaceous species (16 herbs, 3 sedges and 10 grasses). There were 34 (6 tree species, 9 shrubs, 8 herbs, 2 sedges and 9 grass species) species recorded along Luni River. It was followed by 24 species (8 trees, 3 shrubs, 8 herbs and 5 grasses) along the Bandi River. Numbers of species recorded along the Jojari River was lowest, i.e. 6 trees, 2 shrubs, 6 herbs, 1 sedge and 5 grasses. Species richness (R) and Shannon-Weiner diversity index (H') of trees and shrubs dominance (D) were highest along Bandi River, R and H' of shrubs and herbaceous species and species evenness (e') of trees, shrubs and herbaceous species were highest along Luni, and tree and herbaceous species D were highest ($p < 0.05$) along Jojari River (Table 2). Jojari River exhibited lowest vegetation diversity. While considering microhabitats, species R and H' of trees and shrubs, shrub e' and herbaceous D were highest ($p < 0.05$) in non-polluted area (Table 2). Tree and shrubs D, tree e' ($p < 0.05$) and herbaceous R and H' were highest ($p < 0.05$) at river edge dominated by *P. juliflora*, *P. cineraria*, *Acacia nilotica*, *Salvadora persica*, *Calotropis procera* and *Aerva persica*, whereas *Tamarix ericoides* and *Phragmites karka* were recorded at both river edge as well as effluent-inflicted areas (Annexure 1). Plant species flourishing along river edge were relatively more as compared to the number of species in effluent-inflicted area. Order of micro-habitats was: non-polluted > river edge > effluent-inflicted area for number of species of trees and shrubs and river edge > non-polluted > effluent-inflicted area for herbaceous species. Common herbaceous species growing in effluent-inflicted area (high e') of three rivers were *Aeluropus lagopoides*, *Blumea* spp., *Cynodon dactylon*, *Paspalum virgatum*, *Glinus lotoides*, *Heliotropium curassavicum*, *Schoenoplectus articulatus*, *Solanum surattense*, *Suaeda fruticosa* and *Typha angustifolia*.

Table 2

Vegetation diversity under the influence of micro-habitats along different river courses in arid western Rajasthan

Water parameter	Site of sampling					
Luni River	Dhundhara	Samdari	Balotra	Jasol	Tilwara	Average
pH	8.60	8.50	8.30	7.60	8.20	8.24
EC (dSm ⁻¹)	12.19	27.50	13.06	7.38	38.20	19.67
TDS (g L ⁻¹)	7.29	11.71	7.49	5.45	30.86	12.56
TSS (g L ⁻¹)	0.39	5.39	0.43	0.33	3.23	1.95
Alkalinity (mg L ⁻¹)	120.0	128.0	184.0	100.0	120.0	130.4
Na (g L ⁻¹)	5.80	8.90	8.90	2.30	17.80	8.74
K (mg L ⁻¹)	79.0	148.0	159.0	57.0	126.0	113.8
Ca (mg L ⁻¹)	720.0	980.0	1030.0	1360.0	1480.0	1114.0
PO ₄ -P (mg L ⁻¹)	7.70	5.60	3.10	3.50	6.80	5.34
NH ₄ -N (mg L ⁻¹)	2.84	18.91	20.69	3.89	1.08	9.48
NO ₃ -N (mg L ⁻¹)	0.44	7.00	9.10	1.04	0.46	3.61
Mn (mg L ⁻¹)	0.05	0.09	1.33	1.23	1.01	0.74
Co (µg L ⁻¹)	0.80	2.62	2.75	2.79	3.71	2.53
Cu (µg L ⁻¹)	26.72	39.80	63.28	69.41	67.05	53.25
Se (µg L ⁻¹)	0.38	0.19	1.35	1.52	1.58	1.00
Cd (µg L ⁻¹)	0.02	0.06	0.13	0.15	0.12	0.10
Pb (µg L ⁻¹)	0.03	0.05	0.06	0.07	0.07	0.06
Bandi River	Pali	Punayata	Jawadia	Gadwara	NehraBandh	Average
pH	8.30	8.60	7.90	8.30	8.20	8.26
EC (dSm ⁻¹)	7.77	5.12	6.64	7.13	6.75	6.68
TDS (g L ⁻¹)	4.75	3.28	3.88	4.19	3.51	3.92
TSS (mg L ⁻¹)	0.31	0.26	0.36	0.32	0.26	0.30

R species richness, *H'* species diversity index, *D* species dominance, *e'* species evenness

Water parameter	Site of sampling					
Alkalinity (mg L ⁻¹)	124.0	60.0	44.0	88.0	80.0	79.2
Na (g L ⁻¹)	4.00	2.90	2.90	2.90	2.90	3.12
K (mg L ⁻¹)	68.0	79.0	166.0	84.0	166.0	112.6
Ca (mg L ⁻¹)	550.0	420.0	440.0	500.0	440.0	470.0
PO ₄ -P (mg L ⁻¹)	7.00	7.70	8.50	7.50	5.30	7.20
NH ₄ -N (mg L ⁻¹)	5.00	7.20	6.90	2.40	2.30	4.76
NO ₃ -N mg L ⁻¹)	2.50	3.20	2.50	0.90	0.80	1.98
Mn(µg L ⁻¹)	47.09	83.92	26.19	32.13	25.20	42.91
Co (µg L ⁻¹)	0.80	0.76	0.75	0.79	1.29	0.88
Cu (µg L ⁻¹)	126.72	179.80	123.28	109.41	93.16	126.47
Se (µg L ⁻¹)	2.35	2.11	1.35	2.52	2.82	2.23
Cd (µg L ⁻¹)	0.04	0.07	0.03	0.05	0.04	0.05
Pb(µg L ⁻¹)	0.33	0.46	0.57	0.47	0.33	0.43
Jojari River	KhardaRandhir	Salawas	BhanduKalla	Dhawa	Doli	Average
pH	8.50	7.80	8.00	7.90	8.00	8.04
EC (dSm ⁻¹)	38.30	7.35	6.46	6.00	2.45	12.11
TDS (g L ⁻¹)	21.55	4.94	3.76	3.27	1.26	6.96
TSS (g L ⁻¹)	4.76	0.34	0.22	0.35	0.14	1.16
Alkalinity (mg L ⁻¹)	250.0	48.0	36.0	24.0	36.0	78.8
Na (mg L ⁻¹)	30.00	4.30	4.00	3.10	1.50	8.58
K (mg L ⁻¹)	700.0	1100.0	93.0	83.0	29.0	401.0
Ca (mg L ⁻¹)	3800.0	900.0	560.0	520.0	136.0	1183.2
PO ₄ -P (mg L ⁻¹)	13.40	9.40	6.40	8.30	7.40	8.98
NH ₄ -N (mg L ⁻¹)	5.68	3.29	1.92	4.24	2.02	3.43

R species richness, *H'* species diversity index, *D* species dominance, *e'* species evenness

Water parameter	Site of sampling					
NO ₃ -N mg L ⁻¹)	2.42	1.34	0.64	1.52	0.95	1.37
Mn(mg L ⁻¹)	0.32	2.44	1.45	1.05	1.92	1.44
Co (µg L ⁻¹)	2.43	12.64	8.13	6.08	17.57	9.37
Cu (µg L ⁻¹)	60.28	65.41	70.56	49.87	85.63	66.35
Se (µg L ⁻¹)	0.00	0.44	0.64	0.88	2.16	0.82
Cd (µg L ⁻¹)	0.14	1.82	0.09	0.06	0.04	0.43
Pb(µg L ⁻¹)	1.23	0.51	0.17	0.04	0.28	0.45
SNo	River	Micro-habitat	Diversity variables			
			R	H'	D	e'
1	Luni	Non-polluted	6	0.81	0.65	0.45
		River edge	2	0.56	0.63	0.81
		Effluent-inflicted	0	0.00	0.00	0.00
2	Bandi	Non-polluted	7	1.30	0.38	0.67
		River edge	2	0.30	0.83	0.28
		Effluent-inflicted	1	0.00	1.00	0.00
3	Jojari	Non-polluted	5	0.58	0.77	0.33
		River edge	3	0.54	0.73	0.49
		Effluent-inflicted	2	0.15	0.93	0.22
Shrub						
1	Luni	Non-polluted	6	1.48	0.29	0.83
		River edge	2	0.33	0.82	0.47
		Effluent-inflicted	0	0	0	0
2	Bandi	Non-polluted	2	0.69	0.50	1.00
		River edge	1	0.00	1.00	0.00
		Effluent-inflicted	1	0.00	1.00	0.00
3	Jojari	Non-polluted	1	0.00	1.00	0.00
R species richness, H' species diversity index, D species dominance, e' species evenness						

Water parameter		Site of sampling				
		River edge	2	0.90	0.47	0.82
		Effluent-inflicted	1	0.00	1.00	0.00
Herbs						
1	Luni	Non-polluted	11	1.98	0.16	0.83
		River edge	14	2.29	0.13	0.87
		Effluent-inflicted	6	1.63	0.22	0.91
2	Bandi	Non-polluted	3	1.03	0.37	0.94
		River edge	10	1.44	0.31	0.69
		Effluent-inflicted	8	1.39	0.33	0.67
3	Jojari	Non-polluted	5	0.63	0.68	0.39
		River edge	5	1.08	0.39	0.67
		Effluent-inflicted	4	0.92	0.49	0.66
<i>R</i> species richness, <i>H'</i> species diversity index, <i>D</i> species dominance, <i>e'</i> species evenness						

3.4 Plant mineral status

Different mineral elements like As, Cd, Cr, Cu, Fe, Pb, Hg, Sn and Zn were estimated in two tree species viz. *P. juliflora* and *S. persica* growing in the effluent-inflicted as well as non-polluted soils. Concentrations of these mineral elements were greater in the leaves of the plants growing in effluent-inflicted soils as compared to those growing in the normal soils (Table 3). However, concentrations of Cd and Cr were relatively high in leaves of *S. persica* as compared to the leaves of *P. juliflora*, whereas the concentrations of As, Cu, Fe, Pb, Hg and Zn were greater in leaves of *P. juliflora* than in *S. persica*. Concentration of Sn observed almost similar in both the species.

Table 3
Concentrations of different mineral elements in plants growing under normal and effluent inflicted soils along Jojari River

SNo.	Element	<i>Prosopis juliflora</i>		<i>Salvadorapersica</i>	
		Control	Effluent-inflicted	Control	Effluent-inflicted
1	Arsenic (As)	0.025	0.040	0.019	0.035
2	Cadmium (Cd)	0.66	0.690	1.71	1.74
3	Chromium (Cr)	2.80	4.90	6.59	7.30
4	Copper (Cu)	23.45	41.98	17.04	18.14
5	Iron (Fe)	248.89	284.01	149.19	164.98
6	Lead (Pb)	22.10	24.89	6.58	7.38
7	Mercury (Hg)	0.036	0.077	0.042	0.057
8	Tin (Sn)	10.56	11.22	10.79	12.09
9	Zinc (Zn)	169.67	173.12	11.25	17.90

3.5. Correlations

Soil pH was correlated positively to water pH, alkalinity and herbaceous H' and negatively to water Mn and Cu concentrations. Soil EC showed positive correlations with water Cd and shrub dominance, but negative correlation to herbaceous e'. Soil available NO₃-N showed positive correlations with alkalinity and water Na and Ca concentrations, whereas soil PO₄-P was positively correlated to water Se. Soil K showed negative correlations with water pH, herb H' and e' and positive correlation with water Mn, Cd and shrub dominance (Table 4). Water TDS and alkalinity were correlated positively to herbaceous H' ($r = 0.308$ to 0.340 , $n = 45$, $p < 0.05$) and negatively to herbaceous D ($r = 0.253$ to 0.308). Water available PO₄-P was correlated positively to tree ($r = 0.341$), shrub ($r = 0.331$) and herbaceous ($r = 0.556$) species dominance, and negatively to herbaceous R ($r = -0.419$), H' ($r = -0.560$, $p < 0.01$) and e' ($r = -0.469$). Likewise water available NH₄-N and NO₃-N had positive correlations ($r = 0.258$ – 0.402 , $p < 0.05$) with herbaceous R, H' and e' and negative with species dominance ($r = -0.332$ to -0.379 , $p < 0.05$). Concentrations of water K, Mn, Co and Pb were correlated positively to herbaceous D ($r = 0.339$ – 0.528) and negatively ($r = -0.200$ to -0.501 , $p < 0.05$) to herbaceous R', H' and e'.

Table 4

Correlations between soil variables in different soil layers and effluent quality parameters and vegetation diversity variables along different rivers in western Rajasthan

Effluent/ vegetation variables	Soil variables								
	pH30	pH60	EC30	EC60	NH ₄ ⁻ N30	NO ₃ ⁻ N30	PO ₄ ⁻ P30	K30	K60
pH	0.323*	0.346*	-	-	-	-	-	-	-0.348*
Alkalinity	0.488**	0.530**	-	-	-	0.370*	-	-	-
Na	-	-	-	-	-	0.374*	-	-	-
Ca	-	-	-	-	0.440**	0.532**	-	-	-
Mn	-0.478**	-0.504**	-	-	-	-	-	-	0.366*
Cu	-0.525**	-0.466**	-	-	-	-	-	-	-
Se	-	-	-	-	-0.365*	-0.346*	0.306*	-	-
Cd	-	-	-	0.327*	-	-	-	-	0.546*
SDom	-		0.299*	-	-	-	-	0.295*	-
HDiv	-	0.298*	-	-	-	-	-	-0.376*	-0.389*
HDom	-	-0.339*	-	-	-	-	-	0.423**	0.460**
He'	-	-	-	-0.302*	-	-	-	-0.383**	-0.393**
<i>SDom</i> Shrub dominance, <i>HDiv</i> Herbaceous diversity, <i>HDom</i> herbaceous species dominance, <i>He'</i> herbaceous species evenness									

Annexure 1 Availability of different species of tree, shrubs, herbs and grasses along river courses in western Rajasthan

River	Spp no.	Species	Habit	Micro-habitat		
				Non-polluted	River edge	Effluent-inflicted
Luni	1	<i>Prosopisjuliflora</i>	Tree	160.9	154.4	-
Luni	2	<i>Salvadorapersica</i>	Tree	35.1	145.6	-
Luni	3	<i>Salvadoraoleoides</i>	Tree	40.6	-	-
Luni	4	<i>Prosopis cineraria</i>	Tree	27.1	-	-
Luni	5	<i>Acacia tortilis</i>	Tree	21.3	-	-
Luni	6	<i>Acacia nilotica</i>	Tree	14.9	-	-
Luni	7	<i>Tamarixericoides</i>	Shrub	99.8	268.1	-
Luni	8	<i>Aervapersica</i>	Shrub	23.3	31.9	-
Luni	9	<i>Lyciumbarbarum</i>	Shrub	82.4	-	-
Luni	10	<i>Calotropisprocera</i>	Shrub	39.3	-	-
Luni	11	<i>Crotolariaburhia</i>	Shrub	28.2	-	-
Luni	13	<i>Ziziphusnummularia</i>	Shrub	27.0	-	-
Luni	14	<i>Alhagimauroorum</i>	Shrub	+	+	-
Luni	15	<i>Blumea</i> spp.	Herb	-	+	+
Luni	16	<i>Corchorusdepressus</i>	Herb	+	-	
Luni	17	<i>Glinuslotoides</i>	Herb	+	+	+
Luni	18	<i>Heliotropiumindica</i>	Herb	+	-	
Luni	19	<i>Heliotropiumcurassavicum</i>	Herb	-	+	+
Luni	20	<i>Pulicariacrispa</i>	Herb	+	+	-
Luni	21	<i>Sonchusarvensis</i>	Herb	-	+	-
Luni	22	<i>Suaedafruticosa</i>	Herb	-	+	+
Luni	23	<i>Cyperusarenarius</i>	Sedge	+	-	
Luni	24	<i>Cyperusrotundus</i>	Sedge	-	+	-
Luni	25	<i>Aeluropuslagopoides</i>	Grass	-	+	+
Luni	26	<i>Aristidamutabilis</i>	Grass	+		
Luni	27	<i>Paspalumvaginatum</i>	Grass	-	-	+
Luni	28	<i>Dactylocteniumindicum</i>	Grass	+		
Luni	29	<i>Desmostachyabipinnata</i>	Grass	+	+	-
Luni	30	<i>Eragrostisciliaris</i>	Grass	+	+	-

Luni	31	<i>Eragrostis minor</i>	Grass	+	+	-
Luni	32	Grass bush unknown	Grass	-	+	-
Luni	33	<i>Schoenoplectus articulatus</i>	Grass	-	+	-
Bandi	1	<i>Prosopis juliflora</i>	Tree	151.1	224.5	300.0
Bandi	2	<i>Salvadora persica</i>	Tree	-	75.5	-
Bandi	3	<i>Capparis decidua</i>	Tree	49.7	-	-
Bandi	4	<i>Leucaena leucocephala</i>	Tree	34.9	-	-
Bandi	5	<i>Tecomella undulata</i>	Tree	19.4	-	-
Bandi	6	<i>Salvadora oleoides</i>	Tree	18.7	-	-
Bandi	7	<i>Albizia lebeck</i>	Tree	15.0	-	-
Bandi	8	<i>Prosopis cineraria</i>	Tree	11.2	-	-
Bandi	9	<i>Acacia jacquemontii</i>	Shrub	148.7	-	-
Bandi	10	<i>Calotropis procera</i>	Shrub	151.3	-	-
Bandi	11	<i>Tamarix ericoides</i>	Shrub	-	300.0	300.0
Bandi	12	<i>Blumea</i> spp.	Herb	-	+	+
Bandi	13	<i>Datura metel</i>	Herb	-	+	-
Bandi	14	<i>Echinopsechinatus</i>	Herb	-	+	-
Bandi	15	<i>Glinus lotoides</i>	Herb	-	+	+
Bandi	16	<i>Heliotropium curassavicum</i>	Herb	-	+	+
Bandi	17	<i>Solanum surattense</i>	Herb	-	-	+
Bandi	18	<i>Tephrosia purpurea</i>	Herb	+	+	-
Bandi	19	<i>Xanthium strumarium</i>	Herb	-	+	+
Bandi	20	<i>Cynodon dactylon</i>	Grass	-	+	+
Bandi	21	<i>Paspalum virgatum</i>	Grass	-	-	+
Bandi	22	<i>Desmostachya bipinnata</i>	Grass	+	-	-
Bandi	23	<i>Perotis indica</i>	Grass	+	-	-
Bandi	24	<i>Schoenoplectus articulatus</i>	Grass	-	+	+
Joari	1	<i>Prosopis juliflora</i>	Tree	144.1	171.5	248.2
Joari	2	<i>Acacia nilotica</i>	Tree	-	94.7	-
Joari	3	<i>Prosopis cineraria</i>	Tree	30.2	33.8	51.8
Joari	4	<i>Salvadora oleoides</i>	Tree	95.8	-	-
Joari	5	<i>Capparis decidua</i>	Tree	20.1	-	-

Jojari	6	<i>Salvadorapersica</i>	Tree	9.8	-	-
Jojari	7	<i>Calotropisprocera</i>	Shrub	300.0	211.7	
Jojari	8	<i>Phragmiteskarka</i>	Grass	-	88.3	300.0
Jojari	9	<i>Cassia italica</i>	Herb	+	-	-
Jojari	10	<i>Echinopsechinatus</i>	Herb	+	-	-
Jojari	11	<i>Heliotropiumcurassavicum</i>	Herb	-	+	+
Jojari	12	<i>Partheniumhysterophorus</i>	Herb	+		-
Jojari	13	<i>Peristrophepaniculata</i>	Herb	+	+	-
Jojari	14	<i>Solanumsurattense</i>	Herb	-	+	-
Jojari	15	<i>Typhaangustifolia</i>	Sedge	-	-	+
Jojari	16	<i>Aeuleuopuslagopoides</i>	Grass	-	+	+
Jojari	17	<i>Paspalumvirgatum</i>	Grass	-	-	+
Jojari	18	<i>Eragrostisciliaris</i>	Grass	+	-	-
Jojari	19	<i>Saccharummunja.</i>	Grass	-	+	-
Jojari	20	<i>Schoenoplectusarticulatus</i>	Grass	-	+	+
				46	41	24

4 Discussions

4.1 Water quality

Luni, Bandi and Jojari rivers are rainfed and extent of their flow depends on the seasonal distribution of monsoon rainfall. These rivers are transporting however, effluents of varying chemical properties from the different industrial units of Balotra, Pali and Jodhpur cities throughout the year and thus water quality of these rivers were heavily influenced by chemical characteristics of the industrial discharge (de Medeiros et al. 2017). High EC, TDS, TSS, Na, Ca and Mn concentrations had made the water flowing in these unfit for irrigation purpose based on the water reuse criteria and guidelines of WHO (2006) and US EPA (2012). Although water of Bandi River was relatively better but high Ca and Mn in the water of Jojari River and those of EC, TDS, TSS, alkalinity and Na in the water of Luni river were deteriorated the water quality for irrigation and such elevated salt concentrations and organic compounds has adversely affected soil, vegetation and ground water quality (Schacht and Marschner 2015; Kaboosi 2017). This may lead animal and human exposed to slow poisoning by heavy metals accumulation due to the indirect utilization of fodder/ vegetables grown on the soil irrigated by such types of wastewater (Balkhair and Ashraf 2016). Low availability of $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and $\text{PO}_4\text{-P}$ in these waters also reduced their nutritional quality. No clear trend in water quality parameters between Dhundara and Tilwara along Luni River and between Pali and Nehra dam was because of highest discharge of effluents from Balotra, whereas effluent loading was highest at initial two sites along Bandi River. However, a clear trend in most water quality parameters from Kharada Randhir to Doli was because of multicity of functions like flow restrictions and sedimentations,

dilution, aeration, natural die-off and exposure to intense radiations (Ensink et al. 2009; Fadaeifard et al. 2012; Glinska-Lewczuk et al. 2016). Although the impact of man-made pollutants on the water quality of these rivers was visible but effects of land use, vegetation growing and nutrient loads from the adjoining areas have also strong bearing on the water quality (Santy et al. 2020).

4.2 Soil characteristics

Changes in soil physico-chemical properties were the impact of various anthropogenic activities and land use including heavy metals accumulation and sedimentation along the river courses (Yan et al. 2018). Significantly high values of most soil variables in upper 0–30 cm than in 30–60 cm soil layer was an obvious pattern observed in the region (Kumar et al. 2009). However, significantly high soil pH, EC, and available $\text{PO}_4\text{-P}$ along Bandi River and those of $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and K along Jojari River as compared to the other rivers was because of varying chemical composition of the water disposed-off, vegetation characteristics growing in the area and the level of nutrient/metal uptake by the growing vegetation (Batty et al. 2000; Begum et al. 2011; Kaur and Sharma 2014). This was supported by high concentrations of many metal ions in the leaves of *P. juliflora* and *S. persica* growing in effluent-inflicted soils as compared to those growing in non-polluted soils.

Highest pH, EC and $\text{PO}_4\text{-P}$ in effluent-inflicted soils and $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and K at the river edge with 0.24 unit, 5.96-fold, 1.40-fold, 1.34-fold, 1.23-fold, and 1.52-fold variations in respective soil variables between the micro-habitats was the impacts of both wastewater characteristics and uptake of salt or nutrients by the growing vegetation. Dikinya and Areola (2010) had also recorded high salt and heavy metals in wastewater irrigated soils than non-polluted ones depending on additions through wastewater and uptake by the growing vegetation and species characteristics as shown by high concentration of Cd and Cr in leaves of *S. persica* and those of As, Cu, Fe, Pb, Hg and Zn in leaves of *P. juliflora* (Gowda et al. 2003; Bansal 2004; Paul et al. 2005; Raj et al. 2006). The lowest level of soil nutrients at river-edge was due to increased nutrient mobility and uptake by diverse vegetation growing in this area as compared to effluent-inflicted as well as non-polluted areas (Nouri et al. 2009; Xie et al. 2016). Thus effluents-dominated water flowing in the river had increased alkalinity and salinity and reduced the availability of $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and $\text{PO}_4\text{-P}$ (Legros et al. 2013; Lucas et al. 2013; Kessler et al. 2014). However, the positive effects were increase of organic matter and nutrients in the soil favouring vegetation cover depending on plant tolerance to such environments (Assmann et al. 2007; Nouri et al. 2009). A general trend of decrease in soil pH, $\text{PO}_4\text{-P}$, $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ downstream indicated improvement in soil quality because of reduced contamination by the effluents and aerial deposition contaminants with distance from the cities (Laghlimi et al. 2015).

4.3 Vegetation diversity

Low rainfall and arid climate influencing soil moisture and temperature in the regions were responsible for less diverse (49 species along these rivers courses) vegetation in the region (Mcneely 2003; Zhang et al. 2020). Relatively high tree diversity along Bandi and lowest along Jojari river was related to rainfall (highest in Pali and lowest in Jodhpur), whereas prevailing arid environment and soil water availability for a shorter period favoured shrub and herbaceous diversity along Luni river (Silva-Flores et al. 2014; Terra et al. 2018). Greater number of shrub than tree species indicated a typical structure of arid region in terms of these two plant habits (Sharma et al. 2018). However, variations in number of species along different rivers appeared to be due to environmental condition of the newly developed micro-habitats and chemical characteristics of wastewater flowing in the river through industrial discharge and soil derived through sedimentation and deposition (Yaseen and Scholz 2019). Low tree and shrubs diversity in the effluent-inflicted and river-edge areas than that in non-polluted ones were

because of wastewater that had enhanced alkalinity, salinity and metal concentration in the soils and resulted in the emergence of some new species adapting to the modified environment and influenced the plant diversity and community structure along these rivers (Ahmed et al. 2014).

Occurrence of *P. juliflora*, *P. cineraria*, *T. ericoides*, *P. karka*, *A. lagopoides*, *Blumea* spp., *C. dactylon*, *P. virgatum*, *G. lotoides*, *H. curassavicum*, *S. articulata*, *S. surattense*, *S. fruticosa* and *T. angustifolia* in effluent-inflicted area indicated dominance of herbaceous species and was because of their high tolerance to the new environment and adaptation to survive in the soils with high pH, EC and available $\text{PO}_4\text{-P}$ and other metallic ions. However, relatively more number of species flourishing along the river edge than effluent-inflicted area was because of increased aeration and nutrient and water availability in this micro-habitat (Dorotoviaova 2013). High values of herbaceous R, H' and e' in effluent-inflicted and river-edge areas as compared to non-polluted area was due to growth of selective species favoured by water and relatively high salts and mineral concentrations in this contaminated soils. It was also shown by positive correlations of herbaceous R, H' and e' with water $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ ($r = 0.258\text{--}0.402$, $p < 0.05$) and negative ($r = -0.200$ to -0.501 , $p < 0.05$) with water K, Mn, Co and Pb concentrations (Dorji et al. 2014). *Aeluropus lagopoides*, *C. dactylon*, *L. fusca*, *D. spicata*, *P. virgatum*, *Zoysia matrella*, *Z. japonica*, *P. australis*, *T. domingensis*, etc are tolerance to waterlogging because of better ability to control the uptake of metal ions (Ashraf et al., 2017), salt-tolerant behaviour (Sargeant et al. 2006; Rogers et al. 2005) and metal accumulation (Mahmoud and Ghoneim 2016).

5. Conclusion And Recommendations

Soils properties and plant diversity in the studied region were influenced by climatic conditions and physico-chemical characteristics of the effluents discharged into the rivers. High pH, salinity, TDS, TSS, alkalinity and Na, K, Ca and Mn concentrations and low $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and $\text{PO}_4\text{-P}$ had not only made the effluent-dominated water of these rivers unfit for irrigation Bandi < Jojari < Luni, but had also influenced the soil characteristics (high pH, EC and $\text{PO}_4\text{-P}$ along Bandi and high $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and K along Jojari River) and vegetation composition negatively along the river courses. Combined effects of effluent and vegetation had resulted in high pH, EC and $\text{PO}_4\text{-P}$ in effluent-inflicted and $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and K in non-polluted soils with 0.24 unit, 5.96-fold, 1.40-fold, 1.34-fold, 1.23-fold, and 1.52-fold variation in respective parameter between the micro-habitats. Arid climate, rainfall and effluent-dominated water were the factors responsible low diverse vegetation, i.e. 49 species with dominance of herbaceous species. Trees and herbaceous diversities were favoured by rainfall (soil water) and shrub diversity by soil water stress. Non-polluted area was more diverse with typical arid vegetation, whereas effluent-inflicted area had vegetation tolerant to high soil salt and saline water. River edge area was medium in diversity with limited number of shrubs and trees. *P. juliflora*, *P. cineraria*, *A. nilotica*, *S. persica*, *T. ericoides*, *P. karka*, *C. procera*, *A. persica*, *A. lagopoides*, *Blumea* spp., *C. dactylon*, *P. virgatum*, *G. lotoides*, *H. curassavicum*, *S. articulata*, *S. fruticosa* and *T. angustifolia* growing in effluent-inflicted and river edge areas were tolerant to wastewater contaminated soils and have remediation capacity and hence can be utilised in increasing green cover and enhancing environmental quality of urban areas. Focus should be given on enhancing the remediation efficiency and rehabilitation centering to the plants contributing to social and economic development of the regional population.

Declarations

About Data Availability Statements

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

There is no any conflict of interest

Authors' contributions

All authors contributed to the study conception and design. Experimental design, data analysis and manuscript writing was done by G. Singh, soil water and plant sample collection and data collection were done by P.R. Nagora, CTO and Deeak Mishra, Research Scholar and laboratory analysis was performed by Parul Haksar, Junior Project Fellow. All authors read and approved the final manuscript.

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Figures

Figure 1

Location of study site and sampling sites along Luni, Bandi and Jojari Rivers in western Rajasthan (a), effluents discharged from Jodhpur, Pali and Balotara cities flowing through Jojari (b), Bandi (c) and Luni River (d), respectively. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Rainfall pattern in different districts in western Rajasthan

Figure 3

A Changes in soil pH, EC, soil available PO₄-P influenced by flowing wastewater, sites and micro-site along Jojari, Bandi and Luni rivers. Error bars are ± 1 SE of 9/15 replications. S1, S2, S3, S4 and S5 are study sites like KharadaRandhir, Salavas, BhanduKalan, Dhawa and Doli along Jojari, Pali, Punayata, Jawadia, Gadawara and Nehra Dam along Bandi, and Dhundhara, Samadari, Balotara, Jasol and Titwara along Luni River, respectively B Changes in soil available NH₄-N and NO₃-N and potassium under the influence of wastewater flowing, sites and position of soil samplings along Jojari, Bandi and Luni rivers. Error bars are ± 1 SE 9/15 multiple replications. S1, S2, S3, S4 and S5 as in Fig.3A