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Toxic wastewater treatability study by soil aquifer treatment (SAT) with adsorbent

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Abstract
Soil aquifer treatment (SAT) is a most proficient innovation which depends on broad physical and biogeochemical forms in the underground water and aquifer for water quality change. In this investigation, the conveyance, quantitative changes and, in addition, the speciation qualities of heavy metals in various depths of soils of a 2-year worked laboratory-scale SAT are investigated. A greater part of the heavy metals in the energized secondary effluent are effectively caught by the consistent state worked SAT. Here, the removal efficiency of SAT with and without adsorbent is conveyed for parameters like pH, total dissolved solids, total solids, chloride, COD, TKN, potassium, phosphate, copper, zinc, nickel and hexavalent chromium. The investigations are completed by utilizing toxic wastewater and fluctuating adsorbents, for example, eucalyptus leaves, sawdust and mosambi peel (MP). Here, the soil types of clayey sand, inorganic silt with sand (MI SAND) and silty sand are utilized and their properties are resolved. To enhance the removal efficiency of SAT for expulsion of heavy metals, distinctive adsorbents and, in addition, different soil tests are utilized. In the light of investigation, the SAT system with adsorbent is more effective in treating toxic wastewater.

Keywords SAT · Eucalyptus leaves · Sawdust · Mosambi peel · Toxic wastewater · Adsorbent

1 Introduction

As a result of the rapid population growth and urbanization, water demands continued to expand in the domestic, agricultural and industrial sectors, further reducing accessible water resources (Quanrud et al. 2003a, Barakat 2011). Also In future the volume of wastewater produced by these areas might be increased that places stress on the existing wastewater facilities (Candela et al. 2007). In developing countries, wastewater will either be released after partial treatment in order to obtain water or it will not be

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addressed due to the lack of financial resources and technical expertise to create wastewater treatment facilities at secondary or tertiary effluent levels (Chen 2004). This recommends the reuse of water in developing countries, but it is not necessary to increase health effects and degrade water bodies (Scheurer et al. 2009; Du et al. 2017). To productively lessen the pressure on freshwater resources, pre-treatment of freshwater to the level of primary effluent can be combined with practically and naturally stable innovation method, i.e., soil aquifer treatment (SAT) (Asano and Cotruvo 2004; Wilcox et al. 2016). In our work, the adsorbents such as eucalyptus leaves (EL), sawdust (SD) and mosambi peel (MP) are selected, which are usually accessible materials from the local surrounding of Bangalore.

The quick development in population and urbanization rates will apply more stress on accessible water resources because of increment in water interest for nourishment generation. Besides, the over exploitation of groundwater, makes abundance of natural replenishment, quick decrease in groundwater levels and inevitable consumption of groundwater resources. Therefore, to overcome these issues, there is an urgent need for artificial storage of water by suitable facilities (Díaz-Cruz and Barceló 2008). SAT is among the advances that can dependably and reliably create treated wastewater of adequate quality (Garfí et al. 2017; Wells et al. 2016). SAT has been observed to be a minimal effort manageable tertiary wastewater treatment technology, which can produce high-quality effluent from secondary treated wastewater for consumable and non-consumable utilizations (Pedrero et al. 2016; Nema et al. 2001). SAT using primary effluent (PE) could be an attractive option in many developing countries where there is no or minimal wastewater treatment and where there is a need to increase the existing water resources to meet the increasing water demand for different water uses (Sharma et al. 2011; Yuan et al. 2017). Combining the penetrated wastewater with the groundwater and the moderate development through the aquifer builds the contact time with the aquifer material prompting further cleaning of the water (Sgroi et al. 2016; Bdour et al. 2009). A few SAT forms enhance water quality amid permeation through the unsaturated zone before it got scattered and weakened (Quanrud et al. 2003b). The execution of SAT framework is site particular and is controlled by wastewater quality, hydrogeology and term of sewage application on the invasion basins (Amy and Drewes 2007). Moreover, the SAT framework in conjunction with adsorbents may treat the wastewater containing metals to a superior degree (Drewes et al. 2003; Abel et al. 2013). Various research works have already existed in the literature which depended on the portrayal of wastewaters, treatment choices accessible and their appropriateness and examinations completed in this field. Some of the works are reviewed here. During the initial phase of soil aquifer treatment (SAT) for in situ characterization of the transition zone between oxic and suboxic conditions, a known product from oxic transformation of the X-ray contrast medium iopromide was introduced by (Muntau et al. 2017). Two wet–dry cycles of a full-scale infiltration basin were monitored to characterize hydraulic retention times, redox conditions, removal of bulk organic parameters and the fate of chemicals of emerging concern (CECs). Further transformation into persistent products detected in the combined drainage outlet indicates that dissolved oxygen had been introduced to the system before sample collection. Wei et al. (2017) have evaluated the removal, fate and degradation pathway of erythromycin (ERY) in secondary effluent during SAT via the laboratory-scale SAT tests. Aerobic biodegradation plays the predominant role for ERY removal, contributing more than 60% reduction in ERY when recharged with synthetic secondary effluent. Destruction of 14-member macro-cyclic lactone ring and breakdown of two cyclic sugars (L-cladinose and D-desosamine) were main removal pathways for ERY degradation and produced six new intermediates.

Sharma and Kennedy (2017) has provided an overview of SAT systems for wastewater treatment and reuse, and summarizes design, removal efficiencies as well as cost aspects of SAT using infiltration basins. The contaminant's RE of SAT system, however, depends on several factors, including source water quality, local hydro-geological conditions and process conditions applied. The performance of SAT system can be further improved by proper site selection and appropriate design of its components, including pre- and post-treatment. Rudrashetti et al. (2017) have described the effectiveness of engineered soil aquifer treatment (e-SAT) to remove a commonly used antimicrobial agent [sulfamethoxazole (SMX)] from wastewater. It illustrated the evolution of microbial community in the soil and revealed sulfur-oxidizing bacteria were enriched after exposure to SMX, which was a useful finding for further studies at gene/pathway level to understand the molecular mechanism in the biological biodegradation of SMX in the e-SAT system (Mukherjee et al. 2015; Bansal et al. 2009). Soil heating to high temperatures was examined by Nadav et al. (2017) for its efficiency in organic matter (OM) content reduction and increased infiltration. Chemical analysis of OM extracted from the heat-treated soils revealed reduction in hydrophobic substances as a consequence of increased temperatures by soil heating. In model ponds built to simulate large infiltration basins, OM content was reduced as a result of intensive and moderate soil heating in comparison with the untreated pond. However, no reduction in water repellency and only slight changes in infiltration rate were found as a consequence of soil heating.

The exhibited procedure is plainly portrayed in detail. The rest of this article is sorted out as takes after; the current research work is examined in Sect. 2. The recommended strategy accomplishment and the related discussions are given in Sect. 3, and Sect. 4 concludes the paper. In the proposed method, intensive clarification is clarified.

2 System description

2.1 Methodology and materials

2.1.1 Description of SAT

Soil aquifer treatment (SAT) is a land-based managed aquifer recharge (MAR) innovation method, which is progressively embraced as a helpful auxiliary that intends to dependably improve the water assets and diminish aimless release of treated wastewater to water bodies. SAT is a geo-cleaning framework; before it blends with the local groundwater, the aquifer is energized with mostly treated wastewater through unsaturated soil strata. The porosity of a given soil sample is the ratio of the volume of voids to the total volume of the given soil mass. The air content is defined as the ratio of volume of air void to the volume of voids. Water content is defined as the ratio of weight of water to the weight of solids in a given mass of soil.

2.1.2 Characterization of soil

The soil samples collected from different places of Bangalore are analyzed and classified into clayey sand (SC) (CV Raman Nagar), MI with sand (Uttarahalli) and silty sand (SM) (Nelamangala). The soil properties of the experimental variables are shown in Table 1.

Table 1 Properties of experimental variables

S. no.	Variables	Particulars
1	Soil types	SC, MI with SAND, SM
2	Soil depth	90 cm
3	Ponding depth	35 cm
4	Wastewaters	Hexavalent chromium, nickel, zinc and copper
5	Adsorbents	Eucalyptus leaves (Nilgiri leaves), saw dust, Citrus limetta (mosambi peel)
6	Depth of adsorbents	15 cm
7	Positioning of adsorbent	20% from the bottom of column

2.1.3 SAT column simulation

An adapted soil-column system simulated aquifer conditions in arrangement of four 1.5-m columns (diameter 6 inches) are created and worked for a period of over 2 year (Wei et al. 2016; Lian et al. 2013). Influents are applied to the research facility-scale SAT framework with a peristaltic pump, at that point uniformly conveyed over the soil surface utilizing a mini-sprinkler. The columns are operated in downstream mode and are therefore thought to be prevalently unsaturated. The wastewater to be tested is supported by the overhead tank in these columns. Spill out of overhead tank is adjusted to the point that the steady ponding depth of 35 cm is kept up over the soil mass in the column. However, over flow pipe is likewise fitted to the columns to take care of ponding depth. So as to prevent the escape of soil, the bottom of each column is plugged with 60-μm mesh inside. Further, the reducer is fitted to the plug to empower the smooth gathering of effluent and the columns are mounted on the stand. Depth of soil is 90 cm, and depth of adsorbent with 15 cm is maintained. When conducting experiment with adsorbent, the adsorbent is placed at a height of 20% from the base of the column. The treated wastewater samples are collected from the base of the column and are analyzed for various parameters. For each predetermined condition of experimentation, the soil and adsorbents are filled once again in the column. For each feeding, the column is permitted to saturate for the initial 500 ml of the toxic wastewater, effluent flow is disposed, and after that, two effluent samples are collected for each 500 ml sample effectively (Gavrilescu 2004). The experimental simulation of SAT for the removal of toxic wastewater is shown in Fig. 1.

2.1.4 Soil sampling

Soil samples utilized as a part of the columns are collected from three better places, and the types of soil utilized here are clayey sand (SC), inorganic silt with sand (MI SAND) and silty sand (SM). Core cutter samples are taken and are analyzed for various soil characteristics and the geotechnical properties of soils according to IS classification. The parameters analyzed include percentage of gravel, sand, silt and clayey from wet sieve analysis and hydrometer analysis, field moisture content and field density by core cutter method, liquid limit by Casagrande method, plastic limit, plasticity index, and free swell index. It is planned to maintain the dry density of soil filled in the columns same as that of field dry density of soil. Under such conditions, the results obtained, inferences drawn and thereby

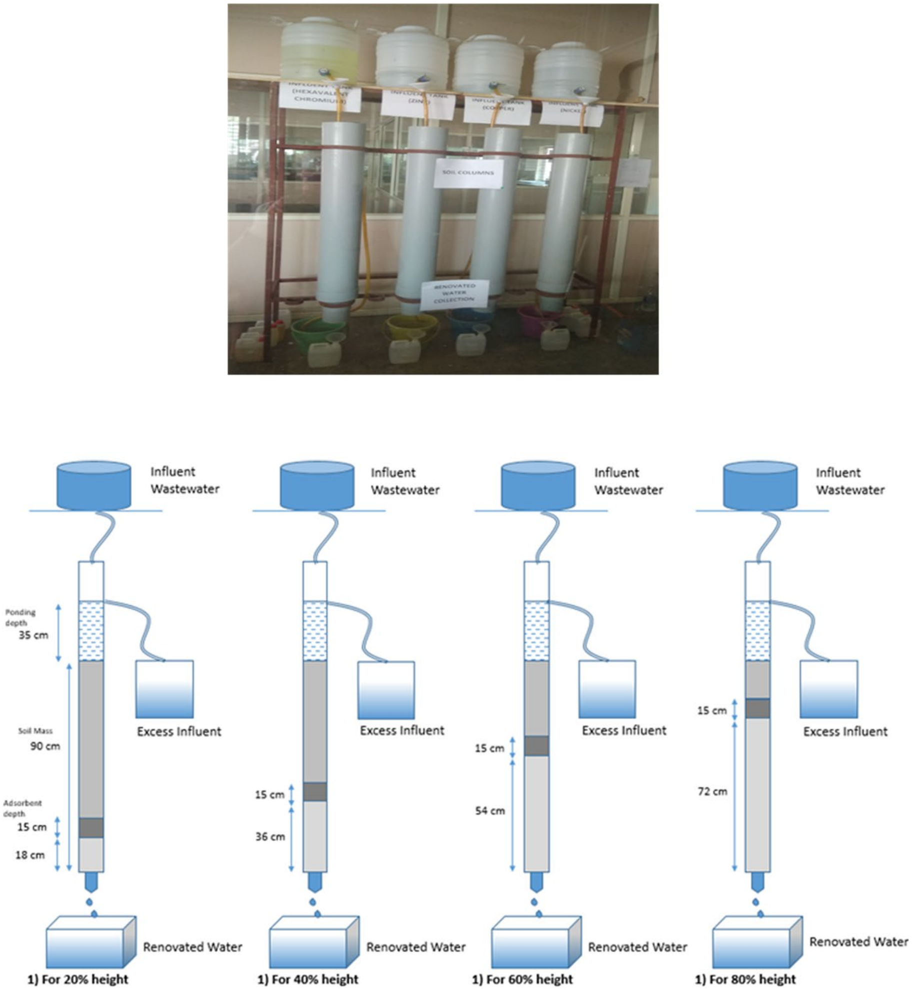

Fig. 1 **a** Experimental simulation of soil aquifer treatment (SAT) system. **b** Line diagram of SAT system without and with adsorbent

design parameters established can be used directly to design SAT system for in situ condition. Thus, soil samples collected from the field were so filled into the columns such that dry density of soil filled in the column is same as that of soil in the field. Sample soils are shown in Fig. 2.

2.2 Water quality of the SAT influent

The toxic wastewater collected from different units of the industry contained heavy metals is utilized as influent of the SAT system which demonstrated a water quality of hexavalent chromium of 7.32, nickel of 6.5, zinc of 6.32 and copper of 7.2. The geotechnical properties of the soils used for experimentation are shown in Table 2. Wastewater

Fig. 2 Soil samples of SAT

Table 2 Geotechnical properties of the soils used for experimentation

S. no.	Parameters	Values		
		Soil-I	Soil-II	Soil-III
1	Field density			
	Inplace density (gm/cc)	1.80	1.66	1.76
	Inplace dry density (gm/cc)	1.62	1.50	1.50
2	Field moisture content (%)	11.33	10.65	17.26
3	Specific gravity (G)	2.60	2.59	2.65
4	Differential free swell (%)	15.4	12.1	17.6
5	Liquid limit (%)	37.5	36.4	53.9
6	Plastic limit (%)	21.7	NP	29.7
7	Plasticity index (%)	15.8	NP	24.2
8	Permeability (cm/s)	12.3×10^{-5}	9.4×10^{-4}	11.9×10^{-5}
9	Direct shear test			
	C (kg/cm^2)	0.10	0.28	0.16
	Φ (°)	23.0	18.0	22.0
10	Compaction test (light)			
	$\gamma_{d\max}$ (gm/cc)	1.78	1.63	1.72
	O.M.C (%)	12.96	11.56	12.24
11	Sieve analysis			
	% of Gravel	5.10	5.50	14.5
	% of Sand	53.7	40.9	35.8
	% of Silt and Clayey	41.2	53.6	49.7
12	Hydrometer analysis			
	% of Clayey	22.0	1.4	19.7
	% of Silt	19.2	52.2	30.0
Soil classification		SC	MI with sand	SM

Fig. 3 Wastewater feeding arrangement

Fig. 4 Wastewater effluent collection system

feeding arrangement and effluent collection system are shown in Figs. 3 and 4 respectively. The characteristics of wastewater used for experimentation is given in Table 3.

2.2.1 Adsorbents

With the end goal of this experimentation, three adsorbents are used which is shown in Fig. 5. These adsorbents are usually accessible materials from the local surrounding of Bangalore. And these physical and chemical properties are given in Table 4. The absorbents utilized here are given as follows:

- Eucalyptus leaves (Nilgiri leaves)
- Saw dust
- Citrus limetta (mosambi peel)

Table 3 Characteristics of wastewater used for experimentation

S. no.	Parameters	Contents in wastewaters stated[a]			
		Cr^{+6}	Nickel	Zinc	Copper
1	pH	7.32	6.5	6.32	7.2
2	Total solids (mg/L)	400	323	210	230
3	TDS (mg/L)	285	247	195	210
4	COD (mg/L)	160	240	150	180
5	Chloride (mg/L)	150	92	110	150
6	TKN (mg/L)	105	130	135	160
7	Phosphate (mg/L)	6	6	6	6
8	Potassium (mg/L)	4	4	4	4
9	Hexavalent chromium (Cr^{+6}) (mg/L)	4	ND	ND	ND
10	Zinc (mg/L)	ND	ND	7	ND
11	Nickel (mg/L)	ND	5	ND	ND
12	Copper (mg/L)	ND	ND	ND	5

[a]Average values of two samples

ND not detected

Fig. 5 Adsorbents of SAT simulation

Table 4 Physical–chemical properties of adsorbents used for experimentation

S. no.	Parameter	Values[a]		
		Saw dust	Eucalyptus leaves	Mosambi peel (Citrus limetta)
1	pH	7.3	6.71	5.28
2	EC (μs/s)	0.102	0.34	0.23
3	TDS (mg/L)	0.123	0.087	0.092
4	Hexavalent chromium (Cr^{+6}) (mg/L)	0.0083	0.013	0.0079
5	Zinc (mg/L)	0.1973	0.004	0.0025
6	Nickel (mg/L)	AB	0.0029	0.003
7	Copper (mg/L)	AB	0.03	0.042

[a]*AB* absent

2.2.1.1 Eucalyptus leaves (Nilgiri leaves) Eucalyptus leaves are dealt with according to methodology given by Wei et al. (2016), Mishra et al. (2010). Leaves of eucalyptus are gathered and washed three times with refined water. The sample is then sun-dried for 2 days, and after that, the leaves are grounded and sieved through 1-mm Indian standard (IS) mesh.

2.2.1.2 Sawdust Sawdust was dealt with according to the methodology given by Bilquees et al. (1999). Sawdust is obtained from saw mills and washed in distilled water and dried and washed with dilute hydrochloric acid for its activation of adsorbent characteristics and again washed with distilled water and dried and finally heated in oven and stored in an airtight container. It is sieved through IS mesh No. 50-60 and washed a few times with refined water, and afterward, it is treated with 0.1 M aqueous solution of disodium hydrogen phosphate for 24 h. Further, it is separated and washed a few times till no phosphate is discharged in washing. Once again, they are dried at 40 °C in an oven and utilized for experimentation.

2.2.1.3 Citrus limetta (mosambi peel) The details about the citrus limetta (mosambi peel) are referred from the reference Rughoonundun et al. (2012). The external peels of the fruit are gathered, dried, chopped, cleaned and soaked in refined water for 24 h. The soaked peels are sun-dried and powdered. Now the size of the particles is acceptable for the experimentation (Krishna and Swamy 2011, 2012). The tests and analysis are handled by different samples of 3 absorbents of 15 cm in three different types of soil at 20% height from the bottom of the column, and their results are discussed in Sect. 3.

2.3 Mass balance calculations

The concentration of heavy metal in recharged influent and effluent is accounted in mg/L, and its concentration in the packed soil is in mg/g. Therefore, it is necessary to calculate the mass balance between the input–output heavy metals and the accumulated heavy metals in soil during SAT operation. Theoretically, the loss of heavy metals in the recharged influent and effluent is equivalent to the net accumulation of heavy metals in the packed soil (Karvelas et al. 2003; Muñoz-Carpena et al. 2015).

The input–output accumulation of heavy metal in different depths of soil column via the mass balance of influent and effluent is ascertained in view of the following formula

$$M_{\text{in}}^{\text{out}} = (C_{\text{in}} - C_{\text{out}}) \times V_{\text{water}} \tag{1}$$

where $M_{\text{in}}^{\text{out}}$ is the accumulated heavy metal in SAT column during recharging of the secondary effluent, C_{in} represents the average concentration of heavy metal in secondary effluent obtained from upper water sampling ports, C_{out} represents the average concentration of heavy metal in SAT effluent obtained from lower water sampling ports and V_{water} denotes the volume of the recharged secondary effluent. In the packed soil, the linear expression of net accumulation of the heavy metals is expressed in the following equation (Liu et al. 2016)

$$M_{\text{acc}} = \int \rho \pi r^2 \times \left(C_{\text{soil}} - C_{\text{soil}}^{\text{original}} \right) h \, \mathrm{d}h \tag{2}$$

where accumulation of estimated heavy metals in the packed soil of SAT column can be represented as M_{acc}, average concentration of heavy metals in the different depths of soil can be referred as C_{soil}, average concentration of heavy metals before secondary effluent recharging of the packed soil can be specified as $C_{\text{soil}}^{\text{original}}$, radius of the SAT column and density of the packed dry soil can be specified as *r* and *ρ*, and depth of the soil is the *h*. The mass balance of elements of copper, nickel, zinc and hexavalent chromium during the secondary effluent recharging at different depths of soil during the operation of SAT is calculated and compared which is clarified in the following section.

3 Results and discussion

This segment presents findings from the three trials performed at three distinctive soils, clayey sand (SC), inorganic silt with sand (MI SAND) and silty sand (SM), at three different adsorbents, EL, SD and MP. The execution of the SAT on the wastewater and results of analysis conveyed under varied conditions and discussions are discussed. The heavy metal ions can be recycled, and the high removal efficiency in four successive cycles in the SAT system can be retained. The performance of the SAT framework on the distinctive types of soil without and with adsorbent at 20% height from the bottom of the column is examined which is clarified in the following subsection.

3.1 Performance of the SAT system on clayey sand (SC)

The mean concentration of elemental copper, nickel, zinc and hexavalent chromium in secondary effluent of clayey sand is efficiently expelled by the distinctive adsorbent at the height of 20% from the bottom of the column.

Table 5 demonstrates the execution of SAT system with and without adsorbent for the expulsion of copper metal. Clayey sand is utilized to expel the total dissolved solids (TDS), total solids (TS), chloride, COD, TKN, potassium, phosphate and copper which are available in toxic wastewater. It is recorded that the clayey sand evacuates TDS 52.6%, TS 54.28%, chloride 53.12%, COD 57.77, TKN 58%, phosphate 63.33%, potassium 49.25% and copper 40% without utilizing the absorbent. The removal efficiency (RE) of copper with adsorbents EL, SD and MP is observed to be 80%, 98.2% and 63%, respectively. Similarly, Tables 6, 7 and 8 demonstrate the execution of the SAT framework with and without adsorbent for the removal of nickel, zinc and hexavalent chromium metal individually. The clayey sand with absorbents EL, SD and MP at 20% height is observed which evacuate all parameters successfully.

Figure 6 demonstrates the execution of clayey sand with and without adsorbents. The RE of copper with adsorbents EL, SD and MP is observed to be 80%, 98.2% and 63% separately which is shown in Fig. 6a. The evacuation proficiency of soil without absorbent is 40% which is considerably lesser than soil with adsorbent. Similarly, the RE of nickel, zinc and hexavalent chromium in clayey sand with and without adsorbent is shown in Fig. 6b–d, respectively. With practical limitation, expulsion efficiency of all parameters in toxic wastewater is recorded without great difference.

3.2 Performance of the SAT system on silty sand(SM)

The mean concentration of elemental copper, nickel, zinc and hexavalent chromium in secondary effluent of silty sand is proficiently evacuated by the diverse absorbent at the height of 20% from the bottom of the column. Table 9 demonstrates the execution of SAT system with and without adsorbent for the removal of copper metal at 20% height. The silty sand is utilized to remove the TDS, TS, chloride, COD, TKN, potassium, phosphate and copper

Table 5 SAT performance in the removal of copper on clayey sand without and with adsorbent at 20% height

Adsorbent		EL			SD			MP			Without adsorbents		
No.	Parameters	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)
Clayey sand (copper removal)													
1	pH	7.2	6.85	–	7.2	6.56	–	7.2	7	–	7.2	6.8	–
2	TDS (mg/L)	210	65	69.05	210	55	73.80	210	76	63.81	210	63	52.60
3	TS (mg/L)	230	87	62.17	230	78	66.08	230	87	62.17	230	54	54.28
4	Chloride (mg/L)	160	49	69.37	160	51	68.12	160	56	65	160	43	53.12
5	COD (mg/L)	180	53	70.55	180	53	70.55	180	65	63.88	180	40	57.77
6	TKN (mg/L)	150	47	68.66	150	46	69.33	150	36	76	150	33	58
7	Phosphate (mg/L)	6	1.6	73.33	6	1.3	78.33	6	1.85	69.16	6	1	63.33
8	Potassium (mg/L)	4	1.86	53.5	4	1.6	60	4	1.3	67.5	4	1.23	49.25
9	Copper (mg/L)	5	1	80	5	0.09	98.2	5	1.85	63	5	2	40

[a] *RAT* result after treatment, *IC* initial concentration, *RE* removal efficiency

Table 6 SAT performance in the removal of nickel on clayey sand without and with adsorbent at 20% height

Adsorbent		EL			SD			MP			Without adsorbents		
No.	Parameters	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)
Clayey sand (nickel removal)													
1	pH	6.5	7.6	–	6.5	7.56	–	6.5	7.8	–	6.5	7.56	–
2	TDS (mg/L)	247	58	76.51	247	35	85.83	247	61	75.30	323	78	65.85
3	TS (mg/L)	323	86	73.37	323	54	83.28	323	82	74.61	247	54	68.14
4	Chloride (mg/L)	92	28	69.56	92	16	82.60	92	12	86.95	92	33	54.13
5	COD (mg/L)	240	58	75.833	240	38	84.16	240	47	80.41	240	53	67.91
6	TKN (mg/L)	130	39	70	130	12	90.77	130	29	77.69	130	29	67.69
7	Phosphate (mg/L)	6	1.5	75	6	1	83.33	6	1	83.33	6	1.6	63.33
8	Potassium (mg/L)	4	1	75	4	1.34	66.5	4	1.12	72	4	1.3	57.5
9	Nickel (mg/L)	5	1.3	74	5	0.65	87	5	0.96	80.8	5	1.68	56.4

Table 7 SAT performance in the removal of zinc on clayey sand without and with adsorbent at 20% height

Adsorbent		EL			SD			MP			Without adsorbents		
No.	Parameters	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)
Clayey sand (zinc removal)													
1	pH	6.32	6	–	6.32	6	–	6.32	6	–	6.32	6	–
2	TDS (mg/L)	195	69	64.61	195	43	77.94	195	51	73.84	210	56	63.33
3	TS (mg/L)	210	78	62.85	210	60	71.42	210	60	71.42	195	46	60.41
4	Chloride (mg/L)	110	39	64.55	110	21	80.90	110	29	73.634	110	27	55.45
5	COD (mg/L)	150	39	74	150	33	78	150	45	70	150	33	68
6	TKN (mg/L)	135	43	68.14	135	32	76.29	135	39	71.11	135	29	58.51
7	Phosphate (mg/L)	6	2.3	61.66	6	0.87	85.5	6	1.34	77.66	6	1.65	52.5
8	Potassium (mg/L)	4	1.78	55.5	4	0.67	83.25	4	1.23	69.25	4	1	54
9	Zinc (mg/L)	7	2	71.42	7	0.35	95	7	0.4	94.28	2	2.4	65.71

Table 8 SAT performance in the removal of hexavalent chromium on clayey sand without and with adsorbent at 20% height

Adsorbent		EL			SD			MP			Without adsorbents		
No.	Parameters	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)
Clayey sand (hexavalent chromium removal)													
1	pH	7.32	6.86	–	7.32	7	–	7.32	7	–	7.32	6.8	–
2	TDS (mg/L)	285	90	68.42	285	35	87.71	285	98	65.65	400	110	62.5
3	TS (mg/L)	400	87	78.25	400	57	85.75	400	166	58.5	285	76	63.33
4	Chloride (mg/L)	105	45	57.17	105	22	79.04	105	47	55.23	105	29	52.39
5	COD (mg/L)	160	36	77.5	160	27	83.12	160	61	61.875	160	32	60
6	TKN (mg/L)	150	50	66.66	150	32	78.66	150	59.5	60.33	150	26	62.66
7	Phosphate (mg/L)	6	1.26	79	6	0.6	90	6	1.64	72.66	6	1.45	65.83
8	Potassium (mg/L)	4	0.5	87.5	4	0.2	95	4	1.2	70	4	1	65
9	Cr^{+6} (mg/L)	4	1.09	72.75	4	0.3	92.5	4	1.15	80	4	1.3	67.5

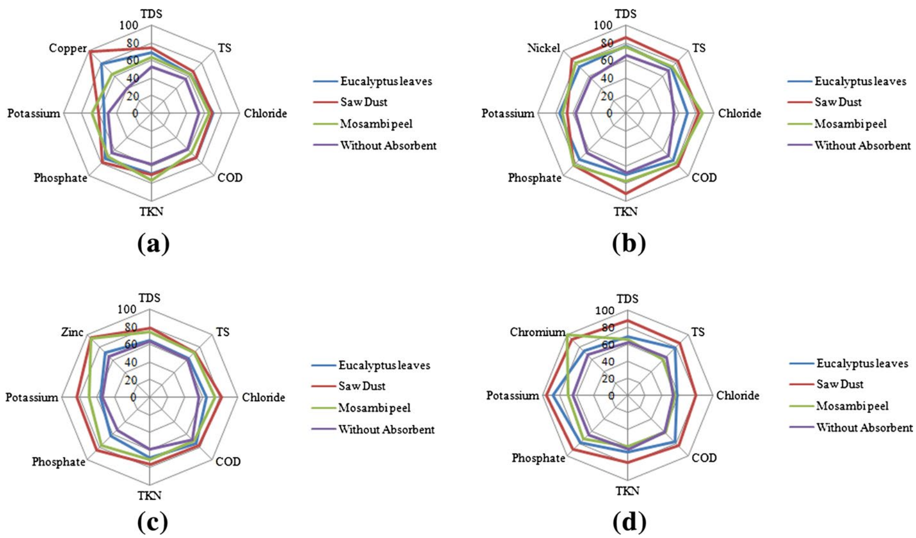

Fig. 6 RE of all parameters in clayey sand with and without adsorbents **a** copper, **b** nickel, **c** zinc and **d** hexavalent chromium

which are present in toxic wastewater. It is recorded that the silty sand expels TDS 63.04%, TS 64.76%, chloride 64.37%, COD 68.33%, TKN 68.66%, phosphate 68.33%, potassium 65% and copper 63% without utilizing the adsorbent. The RE of copper with adsorbents EL, SD and MP is observed to be 97.32%, 94% and 88.8% individually. The expulsion proficiency of soil without adsorbent is considerably lesser than soil with adsorbent, and it is obviously given in Table 6. Similarly, Tables 10, 11 and 12 demonstrate the performance of the SAT system with and without adsorbent for the evacuation of nickel, zinc and hexavalent chromium metal individually. The silty sand with adsorbents EL, SD and MP at 20% height is observed which remove all parameters viably.

Figure 7 demonstrates the execution of silty sand without and with adsorbents at 20% height from the bottom of the column. The silty sand with adsorbents EL, SD and MP at 20% height is observed which expel all the parameters successfully. The RE of copper with adsorbents EL, SD and MP is found to be 96.2%, 98.2% and 94%, respectively, which is shown in Fig. 6a. The RE of soil without adsorbent is 63% which is considerably lesser than soil with adsorbent. Similarly, the RE of nickel, zinc and hexavalent chromium in silty sand with and without adsorbent is shown in Fig. 7b–d, respectively. With pragmatic confinement, evacuation effectiveness of all parameters in toxic wastewater is recorded without awesome contrast.

3.3 Performance of the SAT system on MI sand (inorganic silt with sand)

The mean concentration of elemental copper, nickel, zinc and hexavalent chromium in secondary effluent of MI sand is proficiently expelled by the different adsorbent at the height of 20%. Table 13 demonstrates the execution of SAT system with and without adsorbent for the removal of copper metal at 20% height. The MI sand is utilized to expel the TDS, TS, chloride, COD, TKN, potassium, phosphate and copper which are available in toxic

Table 9 SAT performance in the removal of copper on silty sand without and with adsorbent at 20% height

Adsorbent		EL			SD			MP			Without adsorbents		
No.	Parameters	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)
Silty sand (copper removal)													
1	pH	7.2	6.75	–	7.2	6.7	–	7.2	6.65	–	7.2	7	–
2	TDS (mg/L)	210	60	71.42	210	53	74.76	210	42	80	230	62	63.04
3	TS (mg/L)	230	76	66.95	230	74	67.82	230	55	76.08	210	53	64.76
4	Chloride (mg/L)	160	45	71.87	160	42	73.75	160	43	73.12	160	41	64.37
5	COD (mg/L)	180	52	71.11	180	56	68.88	180	45	75	180	39	68.33
6	TKN (mg/L)	150	41	72.66	150	34	77.33	150	36	76	150	32	68.66
7	Phosphate (mg/L)	6	1.54	74.33	6	0.06	99	6	1.35	77.5	6	1	63.33
8	Potassium (mg/L)	4	0.97	75.75	4	1	75	4	1	75	4	1	65
9	Copper (mg/L)	5	0.5	96.2	5	0.09	98.2	5	0.3	94	5	1.35	63

Table 10 SAT performance in the removal of nickel on silty sand without and with adsorbent at 20% height

Adsorbent		EL			SD			MP			Without adsorbents		
No.	Parameters	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)
Silty sand (nickel removal)													
1	pH	6.5	6.8	–	6.5	7.8	–	6.5	7	–	6.5	7	–
2	TDS (mg/L)	247	78	68.42	247	30	87.85	247	66	73.27	323	76	56.47
3	TS (mg/L)	323	115	64.39	323	48	85.13	323	88	72.75	247	65	63.68
4	Chloride (mg/L)	92	36	60.86	92	18	80.43	92	34	63.04	92	32	55.21
5	COD (mg/L)	240	73	69.58	240	31	87.08	240	56	76.66	240	56	56.66
6	TKN (mg/L)	130	43	66.97	130	19	85.38	130	39	70	130	36	52.32
7	Phosphate (mg/L)	6	2	66.66	6	0.8	86.66	6	1.4	76.66	6	1.3	58.33
8	Potassium (mg/L)	4	0	65	4	1	75	4	0.82	79.5	4	1	5
9	Nickel (mg/L)	5	1.66	66.8	5	0.95	80.92	5	1.4	72	5	1.8	64

Table 11 SAT performance in removal of zinc on silty sand without and with adsorbent at 20% height

Adsorbent		EL			SD			MP			Without adsorbents		
No	Parameters	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)
Silty sand (zinc removal)													
1	pH	6.32	6.14	–	6.32	6.2	–	6.32	6.2	–	6.32	6.2	–
2	TDS (mg/L)	195	55	71.79	195	45	76.92	195	58	70.25	210	48	67.14
3	TS (mg/L)	210	64	69.52	210	53	74.76	210	65	69.04	195	58	60.25
4	Chloride (mg/L)	110	32	70.90	110	23	79.09	110	35	68.18	110	28	64.54
5	COD (mg/L)	150	39	74	150	39	74	150	46	69.33	150	33	68
6	TKN (mg/L)	135	42	68.88	135	33	75.55	135	43	68.14	135	27	60
7	Phosphate (mg/L)	6	1.7	71.66	6	0	70	6	1.5	75	6	1.6	63.33
8	Potassium (mg/L)	4	1.76	56	4	1.4	65	4	1.36	66	4	1.2	60
9	Zinc (mg/L)	7	1.3	81.45	7	2	71.421	7	0.8	88.57	7	1.5	68.54

Table 12 SAT performance in the removal of hexavalent chromium on silty sand without and with absorbent at 20% height

Adsorbent		EL			SD			MP			Without adsorbents		
No	Parameters	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)
Silty sand (hexavalent chromium removal)													
1	pH	7.32	6.87	–	7.32	7.12	–	7.32	7	–	7.32	6.5	–
2	TDS (mg/L)	285	80	71.92	285	65	77.19	285	68	76.14	400	113	61.75
3	TS (mg/L)	400	120	70	400	97	75.75	400	106	73.5	285	75	63.68
4	Chloride (mg/L)	105	32	69.52	105	30	71.42	105	25	76.19	105	27	64.28
5	COD (mg/L)	160	42	73.75	160	43	73.12	160	35	78.12	160	39	65.62
6	TKN (mg/L)	150	55	63.33	150	32	78.66	150	36	76	150	33	68
7	Phosphate (mg/L)	6	1.52	74.66	6	0.95	84.16	6	1.45	75.83	6	1.2	60
8	Potassium (mg/L)	4	1.6	60	4	1.2	70	4	1.15	71.25	4	1	65
9	Hexavalent chromium (mg/L)	4	1.25	68.75	4	1.01	74.75	4	0.6	85	4	0.86	68.5

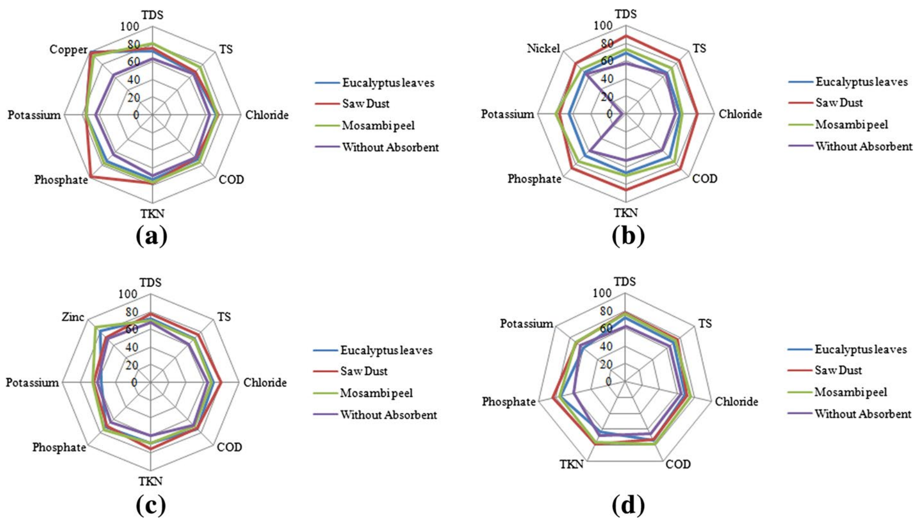

Fig. 7 RE of all parameters in silty sand with and without adsorbents **a** copper, **b** nickel, **c** zinc and **d** hexavalent chromium

wastewater. It is recorded that the MI sand expels TDS 61.73%, TS 63.33%, chloride 61.87%, COD 63.88%, TKN 64%, phosphate 65%, potassium 50% and copper 60% without utilizing the adsorbent. The evacuation effectiveness of copper with absorbents EL, SD and MP is found to be 97.32%, 94% and 88.8% individually. The RE of soil without absorbent is significantly lesser than soil with adsorbent, and it is clearly shown in Table 10. Similarly, Tables 14, 15 and 16 represents the execution of the SAT system with and without adsorbent for the removal of nickel, zinc and hexavalent chromium metal individually. The MI sand with adsorbents EL, SD and MP at 20% height is observed which evacuate all parameters viably.

Figure 8 demonstrates the execution of MI sand with and without adsorbents at 20% height from bottom of the column. The MI sand with adsorbents EL, SD and MP at 20% height is observed which evacuate all the parameters viably. The RE of copper with absorbents EL, SD and MP is observed to be 97.32%, 94% and 88.8% separately which is shown in Fig. 6a. The evacuation proficiency of soil without adsorbent is 60% which is impressively lesser than soil with adsorbent. Also, the evacuation productivity of nickel, zinc and hexavalent chromium in MI sand with and without adsorbent is shown in Fig. 8b–d individually. With practical confinement, expulsion effectiveness of all parameters in toxic wastewater is recorded without extraordinary contrast.

3.4 Statistical analysis

In order to investigate the performance of the different types of soil with regard to the different adsorbents, the adsorbent is placed at the height of 20% from the soil column. According to the investigation, the adsorbent is tested under the different parameters of the soil for the removal of heavy metals. The mean, median and standard deviation (SD) metric are calculated under different soil samples that are recorded in Table 16 and are compared with those of the EL, SD and MP adsorbent. Actually, the mean and median

Table 13 SAT performance of MI sand for the removal of copper without and with absorbent at 20% height

Adsorbent		EL			SD			MP			Without absorbents		
No.	Parameters	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)
MI sand (copper removal)													
1	pH	7.2	6.7	–	7.2	6.76	–	7.2	6.62	–	7.2	6.85	–
2	TDS (mg/L)	210	57	72.85	210	76	63.809	210	48	77.14	230	65	61.73
3	TS (mg/L)	230	70	69.56	230	108	53.04	230	55	76.08	210	56	63.33
4	Chloride (mg/L)	160	41	74.37	160	51	68.12	160	53	66.87	160	45	61.87
5	COD (mg/L)	180	38	78.88	180	52	71.11	180	48	73.33	180	47	63.88
6	TKN (mg/L)	150	43	71.33	150	43	71.33	150	43	71.33	150	39	64
7	Phosphate (mg/L)	6	0.86	85.66	6	0.75	87.5	6	1.86	69	6	1.5	65
8	Potassium (mg/L)	4	1.13	71.75	4	1.36	66	4	1.25	68.75	4	1.6	50
9	Copper (mg/L)	5	0.134	97.32	5	0.3	94	5	0.56	88.8	5	1.5	60

Table 14 SAT performance of MI sand for the removal of nickel without and with adsorbent at 20% height

Adsorbent		EL			SD			MP			Without adsorbents		
No.	Parameters	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)
MI sand (nickel removal)													
1	pH	6.5	6.75	–	6.5	7.85	–	6.5	6.65	–	6.5	6.85	–
2	TDS (mg/L)	247	75	69.63	247	45	81.78	247	61	75.30	323	129	50.061
3	TS (mg/L)	323	110	65.94	323	53	83.59	323	88	72.75	247	88	54.37
4	Chloride (mg/L)	92	33	64.13	92	28	69.56	92	36	60.86	92	36	50.86
5	COD (mg/L)	240	95	60.41	240	45	81.25	240	55	77.03	240	88	53.33
6	TKN (mg/L)	130	38	70.76	130	29	77.63	130	41	68.45	130	50	51.54
7	Phosphate (mg/L)	6	1.95	67.5	6	0.86	85.66	6	1	83.33	6	1.6	53.33
8	Potassium (mg/L)	4	1.73	56.75	4	1.25	68.75	4	1.9	52.5	4	1.4	55
9	Nickel (mg/L)	5	1.78	64.4	5	0.74	84.92	5	1.6	68	5	1.6	58

Table 15 SAT performance of MI sand for the removal of zinc without and with adsorbent at 20% height

Adsorbent		EL			SD			MP			Without adsorbents		
No.	Parameters	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)
MI sand (zinc removal)													
1	pH	6.32	6.2	–	6.32	6	–	6.32	6.12	–	6.32	6.3	–
2	TDS (mg/L)	195	57	70.769	195	55	71.79	195	53	72.82	210	65	59.047
3	TS (mg/L)	210	66	68.57	210	63	70	210	67	68.09	195	56	61.28
4	Chloride (mg/L)	110	33	70	110	29	73.63	110	38	65.45	110	32	60.90
5	COD (mg/L)	150	41	72.67	150	39	74	150	53	64.66	150	36	66
6	TKN (mg/L)	135	43	68.15	135	36	73.33	135	43	68.14	135	36	63.33
7	Phosphate (mg/L)	6	1.8	70	6	1	83.33	6	1.76	70.67	6	1.87	68.83
8	Potassium (mg/L)	4	1.6	60	4	1	75	4	1.4	65	4	1.4	55
9	Zinc (mg/L)	7	1	85.71	7	2.13	69.57	7	1.73	75.27	7	3.41	51.18

Table 16 Performance of MI sand for the removal of hexavalent chromium without and with adsorbent at 20% height

Adsorbent		EL			SD			MP			Without adsorbents		
No.	Parameters	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)	IC	RAT	RE (%)
MI sand (hexavalent chromium removal)													
1	pH	7.32	7.2	–	7.32	6.68	–	7.32	7.2	–	7.32	7.2	–
2	TDS (mg/L)	285	110	61.40	285	85	70.17	285	105	63.15	400	123	59.25
3	TS (mg/L)	400	165	58.75	400	120	70	400	180	55	285	85	60.17
4	Chloride (mg/L)	105	43	59.02	105	32	69.52	105	49	53.33	105	30	61.42
5	COD (mg/L)	160	63	60.62	160	43	73.12	160	50	68.75	160	40	65
6	TKN (mg/L)	150	63	58	150	40	73.33	150	63	58	150	32	68.67
7	Phosphate (mg/L)	6	1.8	70	6	0.15	97.5	6	2	66.66	6	1.23	69.5
8	Potassium (mg/L)	4	2	50	4	1.3	67.5	4	1.5	62.5	4	1	65
9	Cr^{+6} (mg/L)	4	2	50	4	0.85	78.75	4	1.45	63.75	4	1.2	60

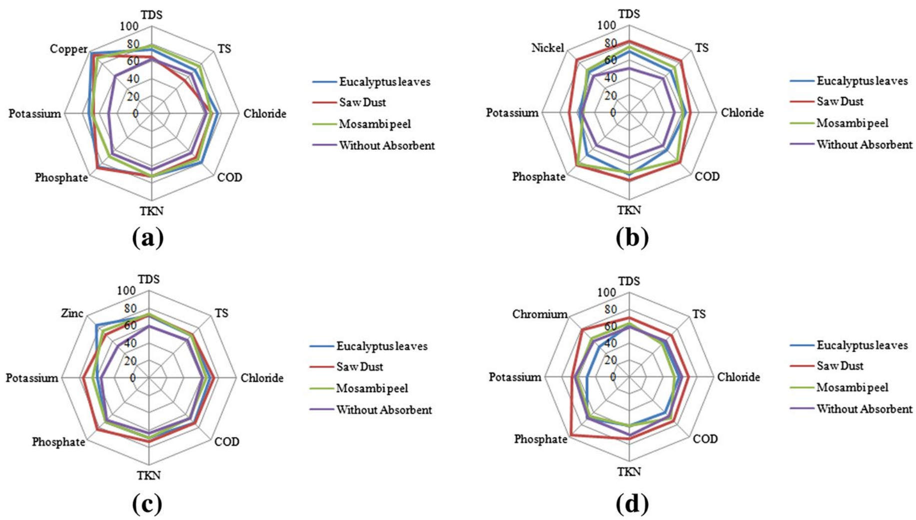

Fig. 8 RE of all parameters in MI sand with and without adsorbents **a** copper, **b** nickel, **c** zinc and **d** hexavalent chromium

metric represent the quality of the results obtained by each adsorbent, and the SD shows the robustness of the adsorbent in removing the heavy metals. For ease of observation, the best results obtained by the adsorbent are shown in bold.

From Table 17, it can be observed that the sawdust significantly outperforms other adsorbent in terms of the value of mean, median and SD, which shows its accomplishment in removing the heavy metals effectively. Also, when it is tested on the silty sand, the obtained results by the sawdust show the highest removal efficiency. It means that sawdust adsorbent on silty sand can provide higher quality and more robust solutions for wastewater.

Figure 9 shows the RE percentage of EL tested under the statistical analysis for different types of soil. It is seen from the figure that the clayey sand and silty sand provide almost the same efficiency percentage which is higher than the MI sand. The SD value is lower for the silty sand when compared with other soil; hence, it achieves high efficiency. Similarly, Figs. 10 and 11 show the RE percentage of sawdust and mosambi peel adsorbent, respectively. From the figure, it can be observed that the sawdust significantly outperforms other adsorbent in terms of mean, median and SD, which shows its accomplishment in removing the heavy metals effectively. Also, when it is tested on the silty sand, the obtained results by the sawdust show the highest removal efficiency. It

Table 17 Statistical performance of different adsorbents for different types of soil

	Eucalyptus leaves			Sawdust			Mosambi peel		
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
SC	70.09	70.82	6.63	77.97	77.44	6.41	71.68	69.95	6.45
SM	70.16	70.01	5.93	81.39	79.97	6.91	74.91	73.57	5.74
MI sand	67.97	66.92	6.92	74.95	74.06	8.44	68.46	68.47	6.51

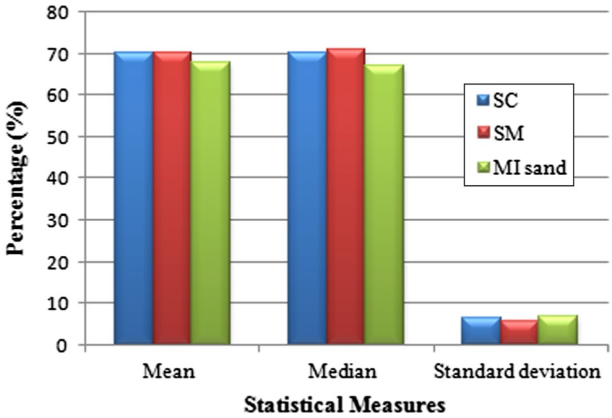

Fig. 9 Statistical analysis of eucalyptus leaves tested under different types of soil

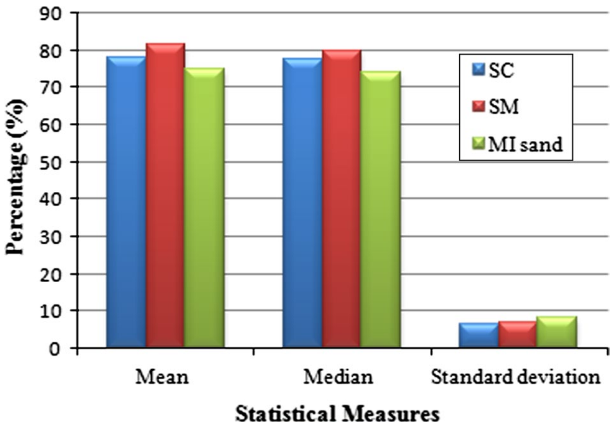

Fig. 10 Statistical analysis of sawdust tested under different types of soil

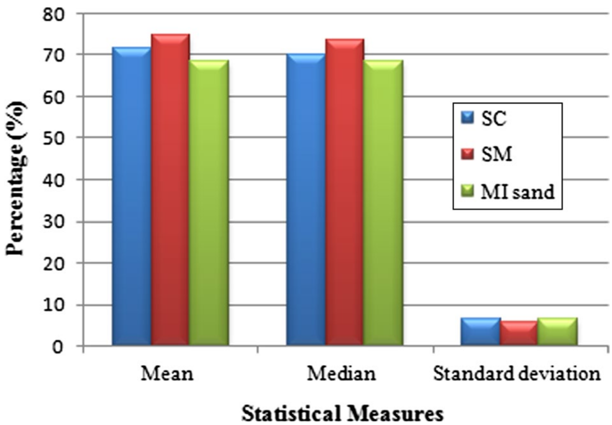

Fig. 11 Statistical analysis of mosambi peel tested under different types of soil

means that sawdust adsorbent on silty sand can provide higher quality and more robust solutions for SAT system.

4 Conclusion

The exploratory investigations demonstrate that the diverse sorts of soil utilized as a part of SAT build the removal efficiency of TS, TDS, chloride, COD, TKN, potassium, phosphate, copper, nickel, zinc and hexavalent chromium in conjunction with EL, SD and MP at the height of 20% from the bottom of the column. Removal efficiency is achieved the best result at the adsorbent height of 20%. The recorded removal efficiency of parameters TS, TDS, chloride, COD, TKN, potassium, phosphate, copper, nickel, zinc and hexavalent chromium are 87.85%, 85.28%, 79.0%, 83.12%, 78.66%, 90%, 95%, 98.2%, 84.92%, 94.28% and 92.5% respectively with the adsorbent. The different soil can be converged with various adsorbents and can used to treat contaminated effluents more adequately. It can be used for additional studies by expanding the concentration. Furthermore it can be utilized as a part of treatment of effluents from industries, along these lines diminishing the level of water pollution from toxic wastewater and industries. The investigation indicates most extreme RE is found in sawdust adsorbent when treated on the silty sand during the SAT performance.

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