International Research Journal of Biological Sciences E-ISSN 2278-3202
Vol. **5(7),** 32-52, July **(2016)** *Int. Res. J. Biological Sci.*

Comparative Study on Bioaccumulation and Translocation of Heavy Metals in some Native Plant Species along the Bank of Chromite Contaminated Damsal Nala of Sukinda Valley, Odisha, India

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Available online at: www.isca.in, www.isca.me
Received 30th May 2016, revised 8th June 2016, accepted 14th June 2016

Abstract

Present study was conducted during the years 2009 - '10, '10 - '11 and '11 - '12 and investigated the bioaccumulation and translocation of chromium, lead and cadmium in few native plant species based on seasonal and comparative analysis on uncontaminated and contaminated sites of Damsal nala in search of a better phytoremediating plant species. The heavy metal concentration in various plant species showed wide range of seasonal fluctuations in different tissues like root (Cr: 1.99 to 192.24 mg kg^{-1}; Pb: 10.03 to 162.40 mg kg^{-1}; Cd: 4.12 to 30.33 mg kg^{-1}), stem (Cr: zero to 130.15 mg kg^{-1}; Pb: 2.99 to 98.40 mg kg^{-1}; Cd: zero to 23.80 mg kg^{-1}) and leaf (Cr: zero to 111.09 mg kg^{-1}; Pb: zero to 66.12 mg kg^{-1}; Cd: zero to 9.21 mg kg^{-1}). The degree of accumulation of three metals among the native plant species of upstream region was found in the order of Pb > Cd > Cr, whereas in downstream region it was of Cr > Pb > Cd. The degree of accumulation was also tissues-wise different like, root > stem > leaf. Plant-wise accumulation of Cr in upstream region was Syzygium fruticosum > Cassia alata > Ipomoea fistulosa > Hollarhena antidysenterica; lead and cadmium were Syzygium fruticosum > Cassia alata > Hollarhena antidysenterica > Ipomoea fistulosa. But in the downstream region the trend was, for chromium, in the order of Syzygium heyneanum > Cassia alata > Ipomoea fistulosa > Aganosma caryophyllata; for lead and cadmium were in the order of Aganosma caryophyllata > Cassia alata > Syzygium heyneanum > Ipomoea fistulosa and Ipomoea fistulosa > Aganosma caryophyllata > Syzygium heyneanum > Cassia alata respectively. The study of Translocation Ability (TA) revealed that the quantities of heavy metals in root exceeded those in shoot (i.e., stem or leaf). Again, the quantities of heavy metals in the stem exceeded those in leaf.

Keywords: Bioaccumulation, Chromite mining, Damsal nala, Heavy metal, Phytoremediation, Sukinda valley, Translocation Ability (TA).

Introduction

The Sukinda Valley of Odisha is discerned for its ample chromite ore reserves. The pace of chromite mining has been enhanced since last two decades as a consequence of its lofty demand. Damsal nala, the principal surfacewater source of this territory, is unremittingly receiving polluted waste water discharged from different chromite mines. Phytoremediation is a clean technology in which metal-accumulating plant species can confiscate, eliminate or neutralize toxicants from polluted sites[1]. The concept of removal of toxic metals from soil and water thereby has been developed in the process of bioremediation[2]. A few aquatic plant species have been studied and identified for their ability to clean the waste water due to their capacity to breed and sustain in water contaminated by toxic metals[3]. Macrophytes can bioaccumulate metallic constituents. Metal absorption by plants is taken place either through root, leaf or stem. Dissolved chemicals and metals are removed by plants from aquatic solution and are arrested and sequestered into their tissues at least impermanently[4,5]. A few plant species have evolved with their ability to hyperaccumulate toxic metals from surrounding ecosystem without expressing any sign of toxicity[6]. Bioaccumulation of Cr by plant species is depended on its concentration in surrounding ecosystem[7]. Living organisms make complex bond, which hard to break and hence very difficult to excrete by them, with metallic elements within their body parts resulting into hyperaccumulation[8]. Phytoremediation is a green technology and bioremediation by plants can be a better option to remove toxicants from the polluted environment because plants have the ability to detoxify poisonous elements and to grow in degraded ecosystem[9-11]. Bioavailability, bioaccumulation and translocation of metallic components in aquasystem are attaining great importance of study throughout the world. Some researchers have analysed the level of metals of various water resources together with bottom sediment as well as inhabitant fishes of Damsal Nala of Sukinda Valley[12-17]. Some insufficient investigations have been recorded on the bioaccumulation and translocation of metallic elements on locally available wild plant species. The present work aimed to study the bioaccumulation and translocation of heavy metals in some native plant species growing naturally along the bank of chromite contaminated Damsal nala on seasonal and comparative basis in the uncontaminated and contaminated sites of Damsal nala in the quest of a competent phytoremediating plant species.

Materials and Methods

Description of the study area: Sukinda Valley is surrounded by Daitari hill range on one side and the Mahagiri hill range on the other side. The entire mine drainage of the area flows towards NW (North-West) and finally joins the Damsal nala which after originating from Daitari hill ultimately meet the major river, Bramhani. Damsal nala is perennial in nature and most of the mine wastes are discharged into it. For comparison and convenience of the study the area can be demarcated into two regions – upstream (relatively less polluted or uncontaminated) and downstream (heavily polluted or contaminated). Sukinda valley region is located in the Jajpur district of Odisha. The entire area is situated in the south-western quadrant (topo-sheet no. 73G/12 and 73G/16) and is lying between latitude $21^0 0'$ to $21^0 3'$N and longitude $85^0 43'$ to $85^0 52'$E.

Sampling: Native plant species were collected along the banks of upstream and downstream regions of Damsal nala seasonally (winter, summer and monsoon) for the three consecutive years *viz.*, 2009 - '10, '10 - '11 and '11 - '12.

Identification: The plant species accounted during sampling period were identified as per different standard guidelines[18,19].

Analysis of heavy metals: Heavy metals, like Cr, Pb and Cd were extracted from the available plant species following the standard digestion method[20] and estimated by Atomic Absorption Spectrometer (AAS) (Model: GBC AVANTA 932).

Translocation Ability (TA): Translocation Ability was reckoned following the standard method[21].

Table-1
List of native plant species and their respective families

Plant species	Family
Cassia alata (Fringe plant)	Caesalpiniaceae
Holarrhena antidysenterica (Riparian tree)	Apocyanaceae
Ipomoea fistulosa (Fringe plant)	Convolvulaceae
Syzygium fruticosum (Riparian tree)	Myrtaceae
Aganosma caryophyllata (Riparian scandent shrub)	Apocyanaceae
Syzygium heyneanum (Riparian tree)	Myrtaceae

Results and Discussion

Metallic Bioconcentration: Plant serves as a good tool for phytoremediation. Hyperaccumulation capacity of plants is depended on their cytogenetic make up and nature of complex bonding with various metals. The heavy metal concentration in the different tissues of various native plant species growing naturally along the banks of Damsal nala *i.e.*, upstream and downstream regions was recorded during the study periods (Tables 2 - 25).

Table-2
Year-wise and seasonal analysis of chromium (mg kg^{-1}) in *Cassia alata* of upstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	3.12	3.03	3.45	3.20	3.03 - 3.45	0.22	0.13
	Stem	2.03	1.99	2.15	2.06	1.99 - 2.15	0.08	0.05
	Leaf	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2010 - '11	Root	3.33	2.99	3.15	3.16	2.99 - 3.33	0.17	0.01
	Stem	2.03	1.69	1.90	1.87	1.69 - 2.03	0.17	0.01
	Leaf	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2011 - '12	Root	3.15	2.24	3.60	2.99	2.24 - 3.60	0.69	0.40
	Stem	BDL	BDL	1.90	0.63	0.00 - 1.90	1.10	0.63
	Leaf	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Table-3
Year-wise and seasonal analysis of chromium (mg kg^{-1}) in *Holarrhena antidysenterica* of upstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	2.03	2.00	2.63	2.22	2.00 - 2.63	0.35	0.20
	Stem	1.12	0.99	1.15	1.09	0.99 - 1.15	0.08	0.05
	Leaf	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2010 - '11	Root	2.12	2.03	2.39	2.18	2.03 - 2.39	0.19	0.11
	Stem	1.03	1.00	1.12	1.05	1.00 - 1.12	0.06	0.03
	Leaf	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2011 - '12	Root	2.33	1.99	2.45	2.26	1.99 - 2.45	0.24	0.14
	Stem	1.06	BDL	1.15	0.74	0.00 - 1.15	0.64	0.37
	Leaf	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Table-4
Year-wise and seasonal analysis of chromium (mg kg^{-1}) in *Ipomoea fistulosa* of upstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	3.12	1.99	3.33	2.81	1.99 - 3.33	0.72	0.42
	Stem	1.03	BDL	1.15	0.73	0.00 - 1.15	0.63	0.36
	Leaf	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2010 - '11	Root	3.15	2.69	3.45	3.10	2.69 - 3.45	0.38	0.22
	Stem	BDL	1.03	1.21	0.75	0.00 - 1.21	0.65	0.37
	Leaf	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2011 - '12	Root	3.03	2.93	3.39	3.12	2.93 - 3.39	0.24	0.14
	Stem	1.12	BDL	1.00	0.71	0.00 - 1.12	0.61	0.35
	Leaf	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Table-5
Year-wise and seasonal analysis of chromium (mg kg^{-1}) in *Syzygium fruticosum* of upstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	4.03	3.33	4.12	3.83	3.33 - 4.12	0.43	0.25
	Stem	2.15	1.99	2.03	2.06	1.99 - 2.15	0.08	0.05
	Leaf	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2010 - '11	Root	3.12	3.00	3.45	3.19	3.00 - 3.45	0.23	0.13
	Stem	1.93	1.96	2.15	2.01	1.93 - 2.15	0.12	0.07
	Leaf	0.57	BDL	0.63	0.40	0.00 - 0.63	0.35	0.20
2011 - '12	Root	3.33	3.06	3.36	3.25	3.06 - 3.36	0.16	0.09
	Stem	2.12	1.90	2.03	2.02	1.90 - 2.12	0.11	0.06
	Leaf	0.66	BDL	BDL	0.22	0.00 - 0.66	0.38	0.22

Table-6
Year-wise and seasonal analysis of chromium (mg kg^{-1}) in *Aganosma caryophyllata* of downstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	112.15	115.24	121.12	116.17	112.15 - 121.12	4.56	2.63
	Stem	75.24	80.12	83.33	79.56	75.24 - 83.33	4.07	2.35
	Leaf	57.63	55.39	60.21	57.74	55.39 - 60.21	2.41	1.39
2010 - '11	Root	114.36	120.33	125.24	119.98	114.36 - 125.24	5.45	3.15
	Stem	76.39	82.21	85.15	81.25	76.39 - 85.15	4.46	2.57
	Leaf	55.15	56.60	59.60	57.12	55.15 - 59.60	2.27	1.31
2011 - '12	Root	110.12	124.66	132.30	122.36	110.12 - 132.30	11.27	6.51
	Stem	75.33	83.21	90.12	82.89	75.33 - 90.12	7.40	4.27
	Leaf	50.15	57.15	61.66	56.32	50.15 - 61.66	5.80	3.35

Table-7
Year-wise and seasonal analysis of chromium (mg kg^{-1}) in *Cassia alata* of downstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	150.12	144.66	159.15	151.31	144.66 - 159.15	7.32	4.23
	Stem	122.33	115.15	120.24	119.24	115.15 - 122.33	3.69	2.13
	Leaf	95.27	96.99	90.36	94.21	90.36 - 96.99	3.44	1.99
2010 - '11	Root	152.12	150.57	166.66	156.45	150.57 - 166.66	8.88	5.13
	Stem	118.18	120.60	125.33	121.37	118.18 - 125.33	3.64	2.10
	Leaf	95.96	99.24	101.03	98.74	95.96 - 101.03	2.57	1.48
2011 - '12	Root	157.15	148.15	169.33	158.21	148.15 - 169.33	10.63	6.14
	Stem	118.36	120.12	130.15	122.88	118.36 - 130.15	6.36	3.67
	Leaf	101.12	100.06	111.09	104.09	100.06 - 111.09	6.08	3.51

Table-8
Year-wise and seasonal analysis of chromium (mg kg^{-1}) in *Ipomoea fistulosa* of downstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	124.36	120.12	130.33	124.94	120.12 - 130.33	5.13	2.96
	Stem	48.15	50.39	66.12	54.89	48.15 - 66.12	9.79	5.65
	Leaf	31.63	30.15	27.21	29.66	27.21 - 31.63	2.25	1.30
2010 - '11	Root	131.15	113.57	141.12	128.61	113.57 - 141.12	13.95	8.05
	Stem	60.30	51.33	70.24	60.62	51.33 - 70.24	9.46	5.46
	Leaf	30.33	32.12	30.33	30.93	30.33 - 32.12	1.03	0.59
2011 - '12	Root	129.63	124.47	137.54	130.55	124.47 - 137.54	6.58	3.80
	Stem	61.15	49.30	59.27	56.57	49.30 - 61.15	6.37	3.68
	Leaf	27.03	27.24	33.06	29.11	27.03 - 33.06	3.42	1.97

Table-9
Year-wise and seasonal analysis of chromium (mg kg^{-1}) in *Syzygium heyneanum* of downstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	190.03	175.66	192.24	185.98	175.66 - 192.24	9.00	5.20
	Stem	112.12	102.33	105.36	106.60	102.33 - 112.12	5.01	2.89
	Leaf	95.39	90.03	92.33	92.58	90.03 - 95.39	2.69	1.55
2010 - '11	Root	175.36	155.60	190.24	173.73	155.60 - 190.24	17.38	10.03
	Stem	103.60	90.12	114.33	102.68	90.12 - 114.33	12.13	7.00
	Leaf	91.33	77.30	90.00	86.21	77.30 - 91.33	7.74	4.47
2011 - '12	Root	169.99	150.69	177.27	165.98	150.69 - 177.27	13.73	7.93
	Stem	101.39	92.24	103.33	98.99	92.24 - 103.33	5.92	3.42
	Leaf	90.36	75.03	91.51	85.63	75.03 - 91.51	9.20	5.31

Chromium becomes detrimental if present in high amount. The total chromium concentration of *Cassia alata* (root: 2.24 to 3.60 mg kg^{-1}; stem: zero to 2.15 mg kg^{-1}), *Holarrhena antidysenterica* (root: 1.99 to 2.63 mg kg^{-1}; stem: zero to 1.15 mg kg^{-1}) and *Ipomoea fistulosa* (root: 1.99 to 3.45 mg kg^{-1}; stem: zero to 1.21 mg kg^{-1}) collected from upstream region showed short range of seasonal variations in root and stem. Whereas, the total chromium concentration level in the leaf of these plant species was found below the detection limit (BDL) throughout the entire period of the study.

The total chromium concentration of *Syzygium fruticosum* (root: 3.00 to 4.12 mg kg^{-1}; stem: 1.90 to 2.15 mg kg^{-1}) collected from upstream region also showed short range of seasonal fluctuations in root and stem. Whereas, the total chromium concentration in the leaf of *Syzygium fruticosum* collected from upstream region of Damsal nala was found below the detection limit during 2009 - '10, but fluctuated in small range (zero to 0.66 mg kg^{-1}) during the years 2010 - '11 and 11 - '12. The total chromium concentration of *Aganosma caryophyllata* (root: 110.12 to 132.30 mg kg^{-1}; stem: 75.24 to 90.12 mg kg^{-1}; leaf: 50.15 to 61.66 mg kg^{-1}), *Cassia alata* (root: 144.66 to 169.33 mg kg^{-1}; stem: 115.15 to 130.15 mg kg^{-1}; leaf: 90.36 to 111.09 mg kg^{-1}), *Ipomoea fistulosa* (root: 113.57 to 141.12 mg kg^{-1}; stem: 48.15 to 70.24 mg kg^{-1}; leaf: 27.03 to 33.06 mg kg^{-1}) and *Syzygium heyneanum* (root: 150.69 to 192.24 mg kg^{-1}; stem: 90.12 to 114.33 mg kg^{-1}; leaf: 75.03 to 95.39 mg kg^{-1}) collected from downstream region of Damsal nala varied seasonally in low to moderate range in their different plant parts *i.e.*, root, stem and leaf.

Water hyacinth was applied successfully to purify the acidified mine discharged water containing toxic metallic constituents[22]. The bioremediation of different metals by *T. angustifolia* was also reported[23,24]. The high accumulation rates of heavy metals in the macrophytes growing along the sides of the effluent discharge channel made them suitable for phytoremediation of heavy metals from contaminated medium[25]. High accumulation of chromium and lead by *V. spiralis* collected from industrially polluted area was also accounted[26].

Lead is a dreadful toxic heavy metal and could be accumulated in high amount in some macrophytes and plant species. The lead concentration of *Cassia alata* (root: 31.15 to 36.66 mg kg^{-1}; stem: 20.24 to 24.30 mg kg^{-1}; leaf: 10.03 to 12.03 mg kg^{-1}), *Holarrhena antidysenterica* (root: 19.33 to 23.36 mg kg^{-1}; stem: 9.99 to 12.25 mg kg^{-1}; leaf: 1.21 to 4.21 mg kg^{-1}), *Ipomoea fistulosa* (root: 10.03 to 11.57 mg kg^{-1}; stem: 2.99 to 4.24 mg kg^{-1}; leaf: zero to 1.25 mg kg^{-1}) and *Syzygium fruticosum* (root: 90.33 to 125.27 mg kg^{-1}; stem: 50.15 to 98.40 mg kg^{-1}; leaf: 10.24 to 66.12 mg kg^{-1}) collected from upstream region of Damsal nala depicted low to moderate range of seasonal fluctuations in different tissues like root, stem and leaf. Whereas, the concentration of lead of *Aganosma caryophyllata* (root: 53.99 to 162.40 mg kg^{-1}; stem: 30.12 to 67.42 mg kg^{-1}; leaf: 17.66 to 43.80 mg kg^{-1}) and *Cassia alata* (root: 77.33 to 99.09 mg kg^{-1}; stem: 60.12 to 73.12 mg kg^{-1}; leaf: 41.24 to 60.12 mg kg^{-1}) collected from downstream region of Damsal nala showed moderate to high range of seasonal variations in root, stem and leaf.

But the concentration of lead in *Ipomoea fistulosa* (root: 19.12 to 24.33 mg kg^{-1}; stem: 11.00 to 14.15 mg kg^{-1}; leaf: 5.15 to 9.36 mg kg^{-1}) and *Syzygium heyneanum* (root: 44.24 to 70.12 mg kg^{-1}; stem: 33.40 to 62.24 mg kg^{-1}; leaf: 30.60 to 48.18 mg kg^{-1}) collected from downstream region of Damsal nala fluctuated seasonally in low to moderate range in root, stem and leaf.

Lead is mostly concentrated in the root region due to its meagre mobility[27].

The uptake, distribution and accumulation of lead are depended on its mobility in addition to its contest with various heavy metals contained by plants[28].

Table-10
Year-wise and seasonal analysis of lead (mg kg^{-1}) in *Cassia alata* of upstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	32.03	30.45	33.13	31.87	30.45 - 33.13	1.35	0.78
	Stem	20.24	21.15	24.30	21.90	20.24 - 24.30	2.13	1.23
	Leaf	11.15	10.12	11.03	10.77	10.12 - 11.15	0.56	0.32
2010 - '11	Root	31.12	30.15	36.66	32.64	30.15 - 36.66	3.51	2.03
	Stem	21.12	20.66	23.33	21.70	20.66 - 23.33	1.43	0.83
	Leaf	10.03	10.45	11.30	10.59	10.03 - 11.30	0.65	0.37
2011 - '12	Root	32.24	31.15	36.06	33.15	31.15 - 36.06	2.58	1.49
	Stem	21.06	20.30	23.33	21.56	20.30 - 23.33	1.58	0.91
	Leaf	10.60	11.15	12.03	11.26	10.60 - 12.03	0.72	0.42

Table-11
Year-wise and seasonal analysis of lead (mg kg^{-1}) in *Holarrhena antidysenterica* of upstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	19.33	20.27	23.36	20.99	19.33 - 23.36	2.11	1.22
	Stem	10.15	11.12	12.15	11.14	10.15 - 12.15	1.00	0.58
	Leaf	2.24	3.21	1.21	2.22	1.21 - 3.21	1.00	0.58
2010 - '11	Root	20.27	21.12	22.24	21.21	20.27 - 22.24	0.99	0.57
	Stem	11.63	10.40	10.33	10.79	10.33 - 11.63	0.73	0.42
	Leaf	4.21	3.24	3.12	3.52	3.12 - 4.21	0.60	0.35
2011 - '12	Root	19.57	19.39	21.24	20.07	19.39 - 21.24	1.02	0.59
	Stem	9.99	10.03	10.45	10.17	9.99 - 10.45	0.25	0.14
	Leaf	4.12	2.15	3.66	3.31	2.15 - 4.12	1.03	0.59

Table-12
Year-wise and seasonal analysis of lead (mg kg^{-1}) in *Ipomoea fistulosa* of upstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	10.12	10.03	11.09	10.41	10.03 - 11.09	0.59	0.34
	Stem	4.12	3.99	4.24	4.12	3.99 - 4.24	0.12	0.07
	Leaf	1.03	BDL	1.12	0.72	0.00 - 1.12	0.62	0.36
2010 - '11	Root	11.15	10.12	11.45	10.91	10.12 - 11.45	0.70	0.40
	Stem	4.03	3.25	4.15	3.81	3.25 - 4.15	0.49	0.28
	Leaf	1.12	0.66	BDL	0.89	0.00 - 1.12	0.32	0.18
2011 - '12	Root	10.99	10.12	11.57	10.89	10.12 - 11.57	0.73	0.42
	Stem	2.99	4.03	3.66	3.56	2.99 - 4.03	0.53	0.31
	Leaf	BDL	BDL	1.25	0.42	0.00 - 1.25	0.72	0.42

Table-13
Year-wise and seasonal analysis of lead (mg kg^{-1}) in *Syzygium fruticosum* of upstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	92.33	90.33	93.93	92.20	90.33 - 93.93	1.80	1.04
	Stem	50.15	52.12	52.03	51.43	50.15 - 52.12	1.11	0.64
	Leaf	15.27	10.24	16.24	13.92	10.24 - 16.24	3.22	1.86
2010 - '11	Root	121.15	120.33	125.27	122.25	120.33 - 125.27	2.65	1.53
	Stem	92.03	98.40	90.33	93.60	90.33 - 98.40	4.25	2.45
	Leaf	56.15	66.12	60.66	60.98	56.15 - 66.12	4.99	2.88
2011 - '12	Root	110.12	105.15	112.33	109.20	105.15 - 112.33	3.68	2.12
	Stem	76.33	66.30	66.66	69.76	66.30 - 76.33	5.69	3.28
	Leaf	50.12	45.57	40.03	45.24	40.03 - 50.12	5.05	2.92

Table-14
Year-wise and seasonal analysis of lead (mg kg^{-1}) in *Aganosma caryophyllata* of downstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	162.40	53.99	72.93	96.44	53.99 - 162.40	57.90	33.43
	Stem	63.80	30.12	43.33	45.75	30.12 - 63.80	16.97	9.80
	Leaf	42.24	17.66	30.27	30.06	17.66 - 42.24	12.29	7.10
2010 - '11	Root	149.15	70.42	73.36	97.64	70.42 - 149.15	44.63	25.77
	Stem	67.42	41.12	43.69	50.74	41.12 - 67.42	14.50	8.37
	Leaf	39.69	27.24	30.36	32.43	27.24 - 39.69	6.48	3.74
2011 - '12	Root	150.36	75.30	79.27	101.64	75.30 - 150.36	42.24	24.39
	Stem	63.00	43.57	45.21	50.59	43.57 - 63.00	10.78	6.22
	Leaf	43.80	30.12	30.33	34.75	30.12 - 43.80	7.84	4.53

Table-15
Year-wise and seasonal analysis of lead (mg kg^{-1}) in *Cassia alata* of downstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	90.03	79.33	92.21	87.19	79.33 - 92.21	6.89	3.98
	Stem	67.75	60.12	71.80	66.56	60.12 - 71.80	5.93	3.42
	Leaf	45.27	43.36	55.45	48.03	43.36 - 55.45	6.50	3.75
2010 - '11	Root	95.27	80.12	99.09	91.49	80.12 - 99.09	10.03	5.79
	Stem	69.66	60.21	73.12	67.66	60.21 - 73.12	6.68	3.86
	Leaf	52.15	45.33	59.51	52.33	45.33 - 59.51	7.09	4.09
2011 - '12	Root	96.03	77.33	97.27	90.21	77.33 - 97.27	11.17	6.45
	Stem	70.12	61.15	70.21	67.16	61.15 - 70.21	5.20	3.00
	Leaf	59.03	41.24	60.12	53.46	41.24 - 60.12	10.60	6.12

Table-16
Year-wise and seasonal analysis of lead (mg kg^{-1}) in *Ipomoea fistulosa* of downstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	19.12	17.93	21.12	19.39	19.12 - 21.12	1.61	0.93
	Stem	11.03	12.21	11.00	11.41	11.00 - 12.21	0.69	0.40
	Leaf	6.15	5.15	6.03	5.78	5.15 - 6.15	0.55	0.32
2010 - '11	Root	21.60	19.36	24.33	21.76	19.36 - 24.33	2.49	1.44
	Stem	11.66	13.03	14.15	12.95	11.66 - 14.15	1.25	0.72
	Leaf	9.33	7.45	9.36	8.71	7.45 - 9.36	1.09	0.63
2011 - '12	Root	23.21	21.12	23.66	22.66	21.12 - 23.66	1.35	0.78
	Stem	11.63	12.36	12.42	12.14	11.63 - 12.42	0.44	0.25
	Leaf	6.15	7.51	7.36	7.01	6.15 - 7.51	0.75	0.43

Table-17
Year-wise and seasonal analysis of lead (mg kg^{-1}) in *Syzygium heyneanum* of downstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	70.12	68.48	69.36	69.32	68.48 - 70.12	0.82	0.47
	Stem	60.80	62.24	60.27	61.10	60.27 - 62.24	1.02	0.59
	Leaf	40.80	41.12	40.12	40.68	40.12 - 41.12	0.51	0.29
2010 - '11	Root	67.39	52.36	62.24	60.66	52.36 - 67.39	7.64	4.41
	Stem	56.32	45.40	50.12	50.61	45.40 - 56.32	5.48	3.16
	Leaf	48.18	32.20	38.66	39.68	32.20 - 48.18	8.04	4.64
2011 - '12	Root	44.24	56.36	62.24	54.28	44.24 - 62.24	9.18	5.30
	Stem	33.40	48.18	55.39	45.66	33.40 - 55.39	11.21	6.47
	Leaf	30.60	41.12	47.72	39.81	30.60 - 47.72	8.63	4.98

Table-18
Year-wise and seasonal analysis of cadmium (mg kg^{-1}) in *Cassia alata* of upstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	7.03	6.12	7.24	6.80	6.12 - 7.24	0.59	0.34
	Stem	3.15	3.06	3.12	3.11	3.06 - 3.15	0.05	0.03
	Leaf	1.12	1.03	1.15	1.10	1.03 - 1.15	0.06	0.03
2010 - '11	Root	6.03	6.15	6.99	6.39	6.03 - 6.99	0.52	0.30
	Stem	1.96	2.03	2.96	2.32	1.96 - 2.96	0.56	0.32
	Leaf	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2011 - '12	Root	6.15	5.27	7.15	6.19	5.27 - 7.15	0.94	0.54
	Stem	2.33	BDL	2.63	1.65	0.00 - 2.63	1.44	0.83
	Leaf	1.06	BDL	BDL	0.35	0.00 - 1.06	0.61	0.35

Table-19
Year-wise and seasonal analysis of cadmium (mg kg^{-1}) in *Holarrhena antidysenterica* of upstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	5.57	5.24	5.96	5.59	5.24 - 5.96	0.36	0.21
	Stem	2.98	3.03	3.12	3.04	2.98 - 3.12	0.07	0.04
	Leaf	1.03	1.21	1.27	1.17	1.03 - 1.27	0.12	0.07
2010 - '11	Root	7.03	6.93	7.12	7.03	6.93 - 7.12	0.09	0.05
	Stem	3.24	3.33	3.15	3.24	3.15 - 3.33	0.09	0.05
	Leaf	1.13	1.20	1.16	1.16	1.13 - 1.20	0.03	0.02
2011 - '12	Root	5.15	6.27	6.21	5.88	5.15 - 6.27	0.63	0.36
	Stem	2.30	3.21	3.03	2.85	2.30 - 3.21	0.48	0.28
	Leaf	BDL	1.19	BDL	0.40	0.00 - 1.19	0.69	0.40

Table-20
Year-wise and seasonal analysis of cadmium (mg kg^{-1}) in *Ipomoea fistulosa* of upstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	5.06	5.09	5.12	5.09	5.06 - 5.12	0.03	0.02
	Stem	1.45	1.36	1.66	1.49	1.36 - 1.66	0.15	0.09
	Leaf	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2010 - '11	Root	5.15	5.00	5.06	5.07	5.00 - 5.15	0.07	0.04
	Stem	1.24	1.12	1.75	1.37	1.12 - 1.75	0.33	0.19
	Leaf	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2011 - '12	Root	4.99	4.12	5.45	4.85	4.12 - 5.45	0.67	0.39
	Stem	1.33	1.03	1.72	1.36	1.03 - 1.72	0.35	0.20
	Leaf	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Table-21
Year-wise and seasonal analysis of cadmium (mg kg^{-1}) in *Syzygium fruticosum* of upstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	6.12	5.75	6.36	6.08	5.75 - 6.36	0.31	0.18
	Stem	3.03	2.99	2.15	2.72	2.15 - 3.03	0.50	0.29
	Leaf	0.36	BDL	BDL	0.12	0.00 - 0.36	0.21	0.12
2010 - '11	Root	7.24	7.15	8.12	7.50	7.15 - 8.12	0.54	0.31
	Stem	4.66	4.60	5.10	4.79	4.60 - 5.10	0.27	0.16
	Leaf	1.36	1.33	1.45	1.38	1.33 - 1.45	0.06	0.03
2011 - '12	Root	6.62	6.69	6.72	6.68	6.62 - 6.72	0.05	0.03
	Stem	3.12	4.03	3.98	3.71	3.12 - 4.03	0.51	0.29
	Leaf	BDL	1.03	BDL	0.34	0.00 - 1.03	0.59	0.34

Table-22
Year-wise and seasonal analysis of cadmium (mg kg^{-1}) in *Aganosma caryophyllata* of downstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	30.33	9.24	12.36	17.31	9.24 - 30.33	11.38	6.57
	Stem	23.80	3.90	5.60	11.1	3.90 - 23.80	11.03	6.37
	Leaf	9.12	3.40	5.20	5.91	3.40 - 9.12	2.92	1.69
2010 - '11	Root	11.12	7.66	12.21	10.33	7.66 - 12.21	2.38	1.37
	Stem	7.27	2.60	7.33	5.73	2.60 - 7.33	2.71	1.56
	Leaf	3.36	1.00	4.09	2.82	1.00 - 4.09	1.61	0.93
2011 - '12	Root	10.33	9.66	12.15	10.71	9.66 - 12.15	1.29	0.74
	Stem	6.12	6.21	8.24	6.86	6.12 - 8.24	1.20	0.69
	Leaf	2.96	3.12	4.90	3.66	2.96 - 4.90	1.08	0.62

Table-23
Year-wise and seasonal analysis of cadmium (mg kg^{-1}) in *Cassia alata* of downstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	12.15	9.30	15.12	12.19	9.30 - 15.12	2.91	1.68
	Stem	6.12	5.20	10.00	7.11	5.20 - 10.00	2.55	1.47
	Leaf	4.57	4.00	9.00	5.86	4.00 - 9.00	2.74	1.58
2010 - '11	Root	11.66	5.15	14.27	10.36	5.15 - 14.27	4.70	2.71
	Stem	6.24	2.20	10.12	6.19	2.20 - 10.12	3.96	2.29
	Leaf	4.39	1.00	9.21	4.87	1.00 - 9.21	4.13	2.38
2011 - '12	Root	10.66	6.12	16.21	10.10	6.12 - 16.21	5.05	2.92
	Stem	6.27	3.21	10.24	6.57	3.21 - 10.24	3.52	2.03
	Leaf	5.12	1.96	7.90	4.99	1.96 - 7.90	2.97	1.71

Table-24
Year-wise and seasonal analysis of cadmium (mg kg^{-1}) in *Ipomoea fistulosa* of downstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	16.36	7.03	19.96	14.45	7.03 - 19.96	6.67	3.85
	Stem	9.12	2.12	10.60	7.28	2.12 - 10.60	4.53	2.61
	Leaf	4.03	1.03	4.00	3.02	1.03 - 4.03	1.72	0.99
2010 - '11	Root	15.24	6.12	16.66	12.67	6.12 - 16.66	5.72	3.30
	Stem	9.03	2.40	9.12	6.85	2.40 - 9.12	3.85	2.22
	Leaf	3.00	1.15	3.25	2.47	1.15 - 3.25	1.15	0.66
2011 - '12	Root	16.21	7.51	20.30	14.67	7.51 - 20.30	6.53	3.77
	Stem	10.03	3.33	12.03	8.46	3.33 - 12.03	4.56	2.69
	Leaf	3.12	1.24	5.15	3.17	1.24 - 5.15	1.95	1.13

Table-25
Year-wise and seasonal analysis of cadmium (mg kg^{-1}) in *Syzygium heyneanum* of downstream region

Year	Tissue	Winter	Summer	Monsoon	Mean	Range	SD	SE
2009 - '10	Root	12.32	6.15	16.24	11.57	6.15 - 16.24	5.09	2.94
	Stem	7.24	3.00	12.80	7.68	3.00 - 12.80	4.91	2.83
	Leaf	3.36	1.00	4.60	2.99	1.00 - 4.60	1.83	1.06
2010 - '11	Root	11.12	9.12	15.39	11.88	9.12 - 15.39	3.20	1.85
	Stem	5.39	5.00	10.18	6.86	5.00 - 10.18	2.88	1.66
	Leaf	3.27	4.60	5.18	4.35	3.27 - 5.18	0.98	0.57
2011 - '12	Root	12.36	10.24	15.24	12.61	10.24 - 15.24	2.51	1.45
	Stem	6.72	6.12	9.39	7.41	6.12 - 9.39	1.74	1.01
	Leaf	4.15	4.15	5.12	4.47	4.15 - 5.12	0.56	0.32

Cadmium is a systemic poison. Concentration of cadmium in *Cassia alata* (root: 5.27 to 7.24 mg kg^{-1}; stem: zero to 3.15 mg kg^{-1}) collected from upstream region of Damsal nala depicted short range of seasonal variations in root and stem. Whereas, concentration of cadmium in the leaf of *Cassia alata* collected from upstream region of Damsal nala was found below the detection limit during 2010 - ’11, but fluctuated seasonally in short range (leaf: zero to 1.15 mg kg^{-1}) during the years 2009 - ’10 and 11 - ’12. Concentration of cadmium of *Holarrhena antidysenterica* (root: 5.15 to 7.12 mg kg^{-1}; stem: 2.30 to 3.33 mg kg^{-1}; leaf: zero to 1.27 mg kg^{-1}) and *Syzygium fruticosum* (root: 5.75 to 8.12 mg kg^{-1}; stem: 2.15 to 5.10 mg kg^{-1}; leaf: zero to 1.45 mg kg^{-1}) collected from upstream region of Damsal nala varied seasonally in short range in root, stem and leaf. Concentration of cadmium of *Ipomoea fistulosa* (root: 4.12 to 5.45 mg kg^{-1}; stem: 1.03 to 1.75 mg kg^{-1}) collected from upstream region of Damsal nala showed short range of seasonal fluctuations in root and stem. Whereas, concentration of cadmium in the leaf of *Ipomoea fistulosa* collected from upstream region was found below the detection limit throughout the entire period of study. Concentration of cadmium of *Aganosma caryophyllata* (root: 7.66 to 30.33 mg kg^{-1}; stem: 2.60 to 23.80 mg kg^{-1}; leaf: 1.00 to 9.12 mg kg^{-1}) collected from downstream region of Damsal nala depicted wide range of seasonal fluctuations in root, stem and leaf. Concentration of cadmium of *Cassia alata* (root: 5.15 to 16.21 mg kg^{-1}; stem: 2.20 to 10.24 mg kg^{-1}; leaf: 1.00 to 9.21 mg kg^{-1}) *and Syzygium heyneanum* (root: 6.15 to 16.24 mg kg^{-1}; stem: 3.00 to 12.80 mg kg^{-1}; leaf: 1.00 to 5.18 mg kg^{-1}) collected from downstream region of Damsal nala showed low to high range of seasonal variation in root, stem and leaf. Whereas, the concentration of cadmium of *Ipomoea fistulosa* (root: 6.12 to 20.30 mg kg^{-1}; stem: 2.12 to 12.03 mg kg^{-1}; leaf: 1.03 to 5.15 mg kg^{-1}) collected from downstream region of Damsal nala varied seasonally in moderate to high range. Hyperaccumulation of cadmium was reported in some food grains cultivated on lands contaminated with cadmium enriched effluents[29]. Amount of Pb 0.032 mg l^{-1} in root and 0.027 mg l^{-1} in leaf, and Cd 0.004 mg l^{-1} in root and 0.001 mg l^{-1} in leaf of *H. verticillata* collected from a man-made waterbody affected by coal mine discharges was estimated[30].

The degree of accumulation of different heavy metals among the native plant species of upstream region was found in the order of Pb > Cd > Cr, whereas in the downstream region the order of accumulation of these heavy metals was Cr > Pb > Cd. The order of heavy metal accumulation in the different tissues of available plant species was root > stem > leaf. Generally, the concentrations of metallic elements in root are 1 to 2 times greater than shoot[31]. Root of water hyacinth was shown to accumulate almost three to fifteen times higher heavy metals than shoot[32]. The degree of accumulation of chromium in upstream region among the different plant species was in the order of *Syzygium fruticosum* > *Cassia alata* > *Ipomoea fistulosa* > *Hollarhena antidysenterica*; for lead and cadmium it was similar of *Syzygium fruticosum* > *Cassia alata* > *Hollarhena antidysenterica* > *Ipomoea fistulosa*. In downstream region for chromium, it was found in the order of *Syzygium heyneanum* > *Cassia alata* > *Ipomoea fistulosa* > *Aganosma caryophyllata*; for lead and cadmium it was of *Aganosma caryophyllata* > *Cassia alata* > *Syzygium heyneanum* > *Ipomoea fistulosa* and *Ipomoea fistulosa* > *Aganosma caryophyllata* > *Syzygium heyneanum* > *Cassia alata* respectively. Heavy metal toxicity may produce necrosis and chlorosis in plants[33]. Plants can tolerate high amount of toxic metals within their body because they can sequester the metallic components into the vacuole (inactive cellular compartment) and thereby separating it from active cellular sites[34]. Metallic elements, together with other nutrients, are mobilized and absorbed by plant roots as cations from surrounding ecosystem and are transferred into the plasma membrane driven by active proton pump channels[35]. Positive relation between metal accumulation in aquatic macrophytes and water and sediment was reported by several researchers[26,30,36].

Translocation Ability (TA): The findings of Translocation Ability (TA) give us a hint for the choice of plant species that has developed tolerance against various poisonous elements and are competent hyperaccumulators. Translocation Ability (TA) within different parts (*viz*., root to stem, root to leaf and stem to leaf) of various native plant species growing naturally along the banks of Damsal nala of upstream and downstream regions for heavy metals are recorded in the Tables 26 - 49.

Table-26
Year-wise and seasonal analysis of TA of chromium in *Cassia alata* of upstream region

Year	**Tissue**	**Winter**	**Summer**	**Monsoon**
2009 - '10	Root to stem	1.54	1.52	1.60
	Root to leaf	-	-	-
	Stem to leaf	-	-	-
2010 - '11	Root to stem	1.64	1.77	1.66
	Root to leaf	-	-	-
	Stem to leaf	-	-	-
2011 - '12	Root to stem	-	-	1.89
	Root to leaf	-	-	-
	Stem to leaf	-	-	-

Table-27
Year-wise and seasonal analysis of TA of chromium in *Holarrhena antidysenterica* of upstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	1.81	2.02	2.29
	Root to leaf	-	-	-
	Stem to leaf	-	-	-
2010 - '11	Root to stem	2.06	2.03	2.13
	Root to leaf	-	-	-
	Stem to leaf	-	-	-
2011 - '12	Root to stem	2.20	-	2.13
	Root to leaf	-	-	-
	Stem to leaf	-	-	-

Table-28
Year-wise and seasonal analysis of TA of chromium in *Ipomoea fistulosa* of upstream region

Year	**Tissue**	**Winter**	**Summer**	**Monsoon**
2009 - '10	Root to stem	3.03	-	2.90
	Root to leaf	-	-	-
	Stem to leaf	-	-	-
2010 - '11	Root to stem	-	2.61	2.85
	Root to leaf	-	-	-
	Stem to leaf	-	-	-
2011 - '12	Root to stem	2.70	-	3.39
	Root to leaf	-	-	-
	Stem to leaf	-	-	-

Table-29
Year-wise and seasonal analysis of TA of chromium in *Syzygium fruticosum* of upstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	1.87	1.67	2.03
	Root to leaf	-	-	-
	Stem to leaf	-	-	-
2010 - '11	Root to stem	1.62	1.53	1.60
	Root to leaf	5.47	-	5.48
	Stem to leaf	3.39	-	3.41
2011 - '12	Root to stem	1.57	1.61	1.65
	Root to leaf	5.04	-	-
	Stem to leaf	3.21	-	-

Table-30
Year-wise and seasonal analysis of TA of chromium in *Aganosma caryophyllata* of downstream region

Year	**Tissue**	**Winter**	**Summer**	**Monsoon**
2009 - '10	Root to stem	1.49	1.44	1.45
	Root to leaf	1.95	2.08	2.01
	Stem to leaf	1.31	1.45	1.38
2010 - '11	Root to stem	1.50	1.46	1.47
	Root to leaf	2.07	2.13	2.10
	Stem to leaf	1.38	1.45	1.43
2011 - '12	Root to stem	1.46	1.50	1.47
	Root to leaf	2.20	2.18	2.15
	Stem to leaf	1.50	1.46	1.46

Table-31
Year-wise and seasonal analysis of TA of chromium in *Cassia alata* of downstream region

Year	**Tissue**	**Winter**	**Summer**	**Monsoon**
2009 - '10	Root to stem	1.23	1.26	1.32
	Root to leaf	1.58	1.49	1.76
	Stem to leaf	1.28	1.19	1.33
2010 - '11	Root to stem	1.29	1.25	1.33
	Root to leaf	1.58	1.52	1.65
	Stem to leaf	1.23	1.21	1.24
2011 - '12	Root to stem	1.33	1.23	1.30
	Root to leaf	1.55	1.48	1.52
	Stem to leaf	1.17	1.20	1.17

Table-32
Year-wise and seasonal analysis of TA of chromium in *Ipomoea fistulosa* of downstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	2.58	2.38	1.97
	Root to leaf	3.93	3.98	4.79
	Stem to leaf	1.52	1.67	2.43
2010 - '11	Root to stem	2.17	2.21	2.01
	Root to leaf	4.32	3.54	4.65
	Stem to leaf	1.99	1.60	2.32
2011 - '12	Root to stem	2.12	2.52	2.32
	Root to leaf	4.80	4.57	4.16
	Stem to leaf	2.26	1.81	1.79

Table-33
Year-wise and seasonal analysis of TA of chromium in *Syzygium heyneanum* of downstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	1.69	1.72	1.82
	Root to leaf	1.99	1.95	2.08
	Stem to leaf	1.17	1.14	1.14
2010 - '11	Root to stem	1.69	1.73	1.66
	Root to leaf	1.92	2.01	2.11
	Stem to leaf	1.13	1.17	1.27
2011 - '12	Root to stem	1.68	1.63	1.72
	Root to leaf	1.88	2.01	1.94
	Stem to leaf	1.12	1.23	1.13

Table-34
Year-wise and seasonal analysis of TA of lead in *Cassia alata* of upstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	1.58	1.44	1.36
	Root to leaf	2.87	3.01	3.00
	Stem to leaf	1.81	2.12	2.20
2010 - '11	Root to stem	1.47	1.46	1.57
	Root to leaf	3.10	2.88	3.24
	Stem to leaf	2.11	1.98	2.06
2011 - '12	Root to stem	1.53	1.53	1.55
	Root to leaf	3.04	2.79	3.00
	Stem to leaf	1.99	1.82	1.94

Table-35
Year-wise and seasonal analysis of TA of lead in *Holarrhena antidysenterica* of upstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	1.90	1.82	1.92
	Root to leaf	8.63	6.31	19.30
	Stem to leaf	4.53	3.46	10.04
2010 - '11	Root to stem	1.74	2.03	2.15
	Root to leaf	4.81	6.52	7.13
	Stem to leaf	2.76	3.21	3.31
2011 - '12	Root to stem	1.96	1.93	2.03
	Root to leaf	4.75	9.02	5.80
	Stem to leaf	2.42	4.66	2.85

Table-36
Year-wise and seasonal analysis of TA of lead in *Ipomoea fistulosa* of upstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	2.46	2.51	2.62
	Root to leaf	9.82	-	9.90
	Stem to leaf	4.00	-	3.79
2010 - '11	Root to stem	2.77	3.11	2.76
	Root to leaf	9.95	15.33	-
	Stem to leaf	3.60	4.92	-
2011 - '12	Root to stem	3.68	2.51	3.16
	Root to leaf	-	-	9.26
	Stem to leaf	-	-	2.93

Table-37
Year-wise and seasonal analysis of TA of lead in *Syzygium fruticosum* of upstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	1.84	1.73	1.80
	Root to leaf	6.05	8.82	5.78
	Stem to leaf	3.28	5.09	3.20
2010 - '11	Root to stem	1.32	1.22	1.39
	Root to leaf	2.16	1.82	2.06
	Stem to leaf	1.64	1.49	1.49
2011 - '12	Root to stem	1.44	1.59	1.68
	Root to leaf	2.20	2.31	2.81
	Stem to leaf	1.52	1.45	1.66

Table-38
Year-wise and seasonal analysis of TA of lead in *Aganosma caryophyllata* of downstream region

Year	**Tissue**	**Winter**	**Summer**	**Monsoon**
2009 - '10	Root to stem	2.54	1.79	1.68
	Root to leaf	3.84	3.06	2.41
	Stem to leaf	1.51	1.70	1.43
2010 - '11	Root to stem	2.21	1.71	1.68
	Root to leaf	3.76	2.58	2.42
	Stem to leaf	1.70	1.51	1.44
2011 - '12	Root to stem	2.39	1.73	1.75
	Root to leaf	3.43	2.50	2.61
	Stem to leaf	1.44	1.45	1.49

Table-39
Year-wise and seasonal analysis of TA of lead in *Cassia alata* of downstream region

Year	**Tissue**	**Winter**	**Summer**	**Monsoon**
2009 - '10	Root to stem	1.33	1.32	1.28
	Root to leaf	1.99	1.83	1.66
	Stem to leaf	1.50	1.39	1.29
2010 - '11	Root to stem	1.37	1.33	1.35
	Root to leaf	1.83	1.77	1.66
	Stem to leaf	1.34	1.33	1.23
2011 - '12	Root to stem	1.37	1.26	1.38
	Root to leaf	1.63	1.87	1.62
	Stem to leaf	1.19	1.48	1.17

Table-40
Year-wise and seasonal analysis of TA of lead in *Ipomoea fistulosa* of downstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	1.73	1.47	1.92
	Root to leaf	3.11	3.48	3.50
	Stem to leaf	1.79	2.37	1.82
2010 - '11	Root to stem	1.85	1.49	1.72
	Root to leaf	2.31	2.60	2.60
	Stem to leaf	1.25	1.75	1.51
2011 - '12	Root to stem	2.00	1.71	1.90
	Root to leaf	3.77	2.81	3.21
	Stem to leaf	1.89	1.65	1.69

Table-41
Year-wise and seasonal analysis of TA of lead in *Syzygium heyneanum* of downstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	1.15	1.10	1.15
	Root to leaf	1.72	1.66	1.73
	Stem to leaf	1.49	1.51	1.50
2010 - '11	Root to stem	1.20	1.15	1.24
	Root to leaf	1.40	1.63	1.61
	Stem to leaf	1.17	1.41	1.30
2011 - '12	Root to stem	1.32	1.17	1.12
	Root to leaf	1.45	1.37	1.30
	Stem to leaf	1.09	1.17	1.16

Table-42
Year-wise and seasonal analysis of TA of cadmium in *Cassia alata* of upstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	2.23	2.00	2.32
	Root to leaf	6.28	5.94	6.30
	Stem to leaf	2.81	2.97	2.71
2010 - '11	Root to stem	3.08	3.03	2.36
	Root to leaf	-	-	-
	Stem to leaf	-	-	-
2011 - '12	Root to stem	2.64	-	2.72
	Root to leaf	5.80	-	-
	Stem to leaf	2.20	-	-

Table-43
Year-wise and seasonal analysis of TA of cadmium in *Holarrhena antidysenterica* of upstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	1.87	1.73	1.91
	Root to leaf	5.41	4.33	4.69
	Stem to leaf	2.89	2.50	2.46
2010 - '11	Root to stem	2.17	2.08	2.26
	Root to leaf	6.22	5.77	6.14
	Stem to leaf	2.87	2.77	2.71
2011 - '12	Root to stem	2.24	1.95	2.05
	Root to leaf	-	5.27	-
	Stem to leaf	-	2.70	-

Table-44
Year-wise and seasonal analysis of TA of cadmium in *Ipomoea fistulosa* of upstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	3.49	3.74	3.08
	Root to leaf	-	-	-
	Stem to leaf	-	-	-
2010 - '11	Root to stem	4.15	4.46	2.89
	Root to leaf	-	-	-
	Stem to leaf	-	-	-
2011 - '12	Root to stem	3.75	4.00	3.17
	Root to leaf	-	-	-
	Stem to leaf	-	-	-

Table-45
Year-wise and seasonal analysis of TA of cadmium in *Syzygium fruticosum* of upstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	2.02	1.92	2.96
	Root to leaf	17.00	-	-
	Stem to leaf	8.42	-	-
2010 - '11	Root to stem	1.55	1.55	1.59
	Root to leaf	5.32	5.38	5.60
	Stem to leaf	3.43	3.46	3.52
2011 - '12	Root to stem	2.12	1.66	1.69
	Root to leaf	-	6.49	-
	Stem to leaf	-	3.91	-

Table-46
Year-wise and seasonal analysis of TA of cadmium in *Aganosma caryophyllata* of downstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	1.27	2.37	2.21
	Root to leaf	3.33	2.72	2.38
	Stem to leaf	2.61	1.15	1.08
2010 - '11	Root to stem	1.53	2.95	1.67
	Root to leaf	3.31	7.66	2.98
	Stem to leaf	2.16	2.60	1.79
2011 - '12	Root to stem	1.69	1.55	1.47
	Root to leaf	3.49	3.10	2.48
	Stem to leaf	2.07	1.99	1.68

Table-47
Year-wise and seasonal analysis of TA of cadmium in *Cassia alata* of downstream region

Year	Tissue	Winter	Summer	Monsoon
2009 - '10	Root to stem	1.98	1.79	1.51
	Root to leaf	2.66	2.32	1.68
	Stem to leaf	1.34	1.30	1.11
2010 - '11	Root to stem	1.87	2.34	1.41
	Root to leaf	2.66	5.15	1.55
	Stem to leaf	1.42	2.20	1.10
2011 - '12	Root to stem	1.70	1.91	1.58
	Root to leaf	2.08	3.12	2.05
	Stem to leaf	1.22	1.64	1.30

Table-48
Year-wise and seasonal analysis of TA of cadmium in *Ipomoea fistulosa* of downstream region

Year	**Tissue**	**Winter**	**Summer**	**Monsoon**
2009 - '10	Root to stem	1.79	3.32	1.88
	Root to leaf	4.06	6.82	4.99
	Stem to leaf	2.26	2.06	2.65
2010 - '11	Root to stem	1.69	2.55	1.83
	Root to leaf	5.08	5.32	5.13
	Stem to leaf	3.01	2.09	2.81
2011 - '12	Root to stem	1.62	2.25	1.69
	Root to leaf	5.19	6.06	3.94
	Stem to leaf	3.21	2.68	2.34

Table-49
Year-wise and seasonal analysis of TA of cadmium in *Syzygium heyneanum* of downstream region

Year	**Tissue**	**Winter**	**Summer**	**Monsoon**
2009 - '10	Root to stem	1.70	2.05	1.27
	Root to leaf	3.67	6.15	3.53
	Stem to leaf	2.15	3.00	2.78
2010 - '11	Root to stem	2.06	1.82	1.51
	Root to leaf	3.40	1.98	2.97
	Stem to leaf	1.65	1.09	1.96
2011 - '12	Root to stem	1.84	1.67	1.62
	Root to leaf	2.98	2.47	2.98
	Stem to leaf	1.62	1.47	1.83

The study of TA revealed that the quantities of heavy metals in root exceeded in shoot (*i.e*., stem or leaf). Again the quantities of heavy metals in stem exceeded those in leaf. TA of heavy metals in *Cassia alata* of upstream region was found in the order of Pb > Cr > Cd. TA of heavy metals in *Holarrhena antidysenterica* of upstream region was found in the order of Pb > Cd > Cr. TA of heavy metals in *Ipomoea fistulosa* of upstream region was found in the order of Cr > Pb > Cd. TA of heavy metals in *Syzygium fruticosum* of upstream region was found in the order of Pb > Cr > Cd. TA of heavy metals in *Aganosma caryophyllata* of downstream region was found in the order of Cr > Cd > Pb. TA of heavy metals in *Cassia alata* of downstream region was found in the order of Cr > Pb > Cd. TA of heavy metals in *Ipomoea fistulosa* of downstream region was found in the order of Pb > Cd > Cr. TA of heavy metals in *Syzygium heyneanum* of downstream region was found in the order of Pb > Cr > Cd. TA is vital because it determines the metallic distribution among various tissues of plants[37]. TA of heavy metals was in the order of Cu > Pb > Cd > Ni > Zn in water hyacinth wherein a larger value of TA implies a poorer translocation capability[32].

Conclusion

In the upstream region, *Syzygium fruticosum* showed highest bioaccumulation capacity than other plant species in regard to heavy metals like chromium, lead and cadmium and hence may be considered for its phytoremediating properties. But in the downstream region, along with *Syzygium heyneanum* the *Aganosma caryophyllata* and *Ipomoea fistulosa* may also be used for phytoremediation purposes for heavy metals like chromium, lead and cadmium respectively in regard to their highest bioaccumulation capacity for those respective metals.

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