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Anurag Jain
Ph.D. Research scholar Tropical Forest Research Institute, Jabalpur, Madhya Pradesh, India

GR Rao
Ex Director, Tropical Forest Research Institute, Jabalpur, Madhya Pradesh, India

Avinash Jain
Scientist F, Tropical Forest Research Institute, Jabalpur, Madhya Pradesh, India

M Rajkumar
Scientist D, Tropical Forest Research Institute, Jabalpur, Madhya Pradesh, Indfia

Corresponding Author:
GR Rao
Ex Director, Tropical Forest Research Institute, Jabalpur, Madhya Pradesh, India

To study species composition and distribution of trees species and estimation of carbon stock potential of a riparian forest along upper Narmada region of Madhya Pradesh

Anurag Jain, GR Rao, Avinash Jain and M Rajkumar

Abstract
Riparian Forest areas are known as the three-dimensional ecotones and it is the transition zone between the terrestrial and aquatic ecosystems. Natural riparian corridors are the most diverse, dynamic, and complex habitats on the terrestrial portion of Earth. These riparian forests can play an important role in mitigating and adaptation of climate change because a considerable amount of carbon dioxide is stored in these natural ecosystems which act as a vital buffer regulating the atmospheric level of carbon dioxide by sequestering it from the atmosphere. A riparian buffer of 100 m has been created on both sides of the Narmada River using GIS software and based on that, the buffer area falls under three districts of Madhya Pradesh *viz*., Mandla, Jabalpur and Seoni. The riparian forests along Narmada River in Madhya Pradesh are divided into three classes according to the density of the forest i.e., very dense forest (canopy density ≥ 70%), moderately dense forest (canopy density between 40-70%) and open forest (tree canopy density between 10-40%). A total of 35 tree species belonging to 23 families were recorded from the three different classes of forest along the Narmada River. The dominant tree species found in all the above three classes are *Tectona grandis*, *Terminalia arjuna*, *Lannea coromandelica*, *Diospyros melanoxylon*, *Chloroxylon swietenia etc*. The species richness was highest at the MDF (29) followed by VDF (23) and OF (17). The total biomass C-stock in VDF, MDF and OF class has been estimated as 90.75 t ha^{-1}, 56.88 t ha^{-1} and 30.58 t ha^{-1} respectively. The total C-stock is equal to 112.79 t ha^{-1}, 74.11 t ha^{-1} and 42.95 t ha^{-1} in VDF, MDF and OF respectively. The purpose of this paper was to compare the community composition, species diversity, distribution and tree population structure and carbon sequestration potential of riparian forest in Narmada river.

Keywords: Riparian forest, riparian buffer ecotone, riparian corridors, species diversity, species richness, carbon sequestration, VDF, MDF, OF, C-stock etc.

1. Introduction

The word riparian is derived from the Latin word Riparius, which means "the environment surrounding water bodies" (streams, rivers, ponds, lakes) [1]. The term ***riparian forest*** refers to floodplain vegetation or vegetation directly adjacent to rivers and streams [1, 2]. Therefore, Riparian forests are forested areas adjacent to water bodies like streams, rivers, lakes, canals, marshes, estuaries, etc. [1, 3]. The soil and water available in riparian forests are better, and they function similar to human lungs and kidneys in cleaning and recycling the air and water. The riparian forest extends laterally from the active channel to the uplands, thereby including active floodplains and the immediately adjacent terraces. Riparian plant communities along the rivers are sensitive to anthropogenic interference [4] and are dynamic, species rich [5] and resulting disturbance adapted communities.

Species richness patterns in the riparian corridor change in response to the dynamics of flood disturbance [6] but moderate flooding at regular intervals is required to sustain high levels of eco-diversity in riparian ecosystems [2]. Riparian forests next to the streams and river banks have been almost entirely eliminated outside the protected areas [7]. Moreover, there has not been much quantitative estimation of riparian diversity in Indian rivers. In India, few quantitative plant biodiversity inventories were investigated in riparian forests of Chalakkudy river [8]; Valapattanam river [9] and Meenachil river basin [11] of Kerala and Cauvery river of Tamil Nadu [10].

Forests play an important role in mitigating and adapting to climate change, largely by sequestering carbon dioxide from the atmosphere [12].

The forest acts as an important natural barrier preventing climate change because it sequesters and stores more carbon than any other terrestrial ecosystem. Carbon sequestration by forests has attracted much interest as a mitigation approach, as it has been considered a relatively inexpensive means of addressing climate change immediately [13]. The forests and its vegetation sequester atmospheric carbon and therefore, play a major role in energy and mass exchange on earth and maintain the sustainability of life on the earth [14]. When forests grow, carbon is sequestered from the atmosphere and absorbed in wood, leaves and soil. Because forests can capture and store carbon over an extended period of time, they are considered as carbon sinks [12]. Consequently, mature forests are huge storehouse of carbon. The young trees which grow at faster rates also work as carbon sinks. The bigger and older the trees, the higher is their ability to cycle and sequester carbon [15].

The objectives of this paper were to compare the community composition, species diversity, distribution and tree population structure and carbon sequestration potential of riparian forest in Narmada river. Understanding the knowledge of species diversity is a useful tool in plant ecology and forestry to compare the composition of different species. Quantitative analysis of trees from riparian forest will provide valuable information for riparian forest assessment and improve our knowledge by the identification of ecologically useful species as well as species of special concern, thus identifying conservation efforts for sustainability of riparian forest eco-diversity. To maximize biodiversity conservation, rapid inventory of tree species that provides crucial information on various species diversity will represent an important tool to escalate our ability to conserve degraded and deforested riparian zones [16].

Materials and methods

Criteria for selection of sites

The study was carried out in the year 2020-2021 after the rainy season. A riparian buffer of 100 m has been created [17] on both sides of the Narmada River using GIS software. A riparian forest along the Narmada River in Madhya Pradesh is classified into three different classes based on its density, such as very dense forests (tree canopy density of 70% or more), moderately dense forests (tree canopy density of 40-70%), and open forests (tree canopy density of 10-40%) [18]. Based on that, the riparian buffer area falls under three districts of Madhya Pradesh *viz*., Mandla, Jabalpur and Seoni (Table 1). Ground truthing was carried out after visiting this forest with the support of Forest Department staff. Subsequently, the length of the Reserve Forest is calculated by the reconnaissance survey. Depending on the length of the forest at every 300 m a quadrat of 0.1 ha is laid at each site and necessary observations were recorded.

To study the phytosociology of tree species

Density, abundance, frequency, species richness and basal area per hectare is estimated to measure the structure and heterogeneity of the riparian vegetation. A measure of relative frequency, relative density, relative dominance (relative basal area), and Importance Value Index (IVI) [19] is computed for each forest class. Species diversity, dominance and evenness are also evaluated.

Carbon stock estimation in vegetation and soil.

1. Soil Carbon

Walkley and Black wet oxidation method was employed to assess the organic carbon content of the soil [20]. It is expressed in percentage. The amount of Soil organic carbon (SOC) that was stored in a soil was calculated by multiplying the organic carbon with weight of the soil (bulk density and depth) for 30cm depth and expressed as tons/ha (t/ha) as the equation given by Broos and Baldock, 2008, i.e.

SOC (t/ha) = Depth (cm) x Bulk Density (g/cm^3) x Organic Carbon Content (%) [21].

2. Tree Carbon

Above ground biomass (AGB) in the trees was quantified by non-destructive method using following allometric equations against GBH:

1. *Tectona grandis*	2. $y = 3.174\ x - 21.27$
3. *Terminalia arjuna*	4. $y = 3.10\ x - 84.98$
5. *Azadirachta indica*	6. $y = 3.272\ x - 73.29$
7. Other species	8. $y = 0.007\ x^2 + 1.898\ x - 32.69$

where, y = AGB (kg); x = GBH (cm)

These equations have been developed at TFRI Jabalpur by destructive method [22]. The belowground biomass (BGB) has been calculated by multiplying the above ground biomass (AGB) by 0.26 factors as the root-shoot ratio [23].

Below ground biomass =AGB x 0.26

Total biomass is the sum of the above and below ground biomass [24].

Total Biomass (t)=AGB+BGB

Generally, for any plant species 50% of its biomass is considered as carbon [25, 26].

Carbon stock= Total biomass/2

Results and discussion

Species composition and distribution of trees

As shown in Table 2, the riparian forest in the upper region of the Narmada River is divided into three classes: very dense forest (VDF), moderately dense forest (MDF), and open forest (OF). A total of 35 tree species belonging to 23 families were recorded from the three different classes of forest along the Narmada River. The species richness was highest at the MDF (29) followed by VDF (23) and OF (17). At VDF class, a total of 363 tree individuals representing 23 species belonging to 19 families were identified whereas, at MDF class, a total of 583 tree individual representing 29 species belonging to 22 families were identified and in OF class, 172 individual trees representing 18 tree species belonging to 16 families were recorded. A high species richness results in a higher level of community stability due to its greater diversity [27]. A total of 31 tree species were reported around Khok river of Garhwal Himalaya, India by Iqbal *et al*., 2012 [28]. Sunil *et al*., 2016 [10] recorded 177 tree species from the Cauvery River riparian forest. Leishangthem, and Singh, 2018 [29] recorded 29 tree species from the riparian forests along the Dhiku river in Nagaland.

Based on the IVI obtained, *Tectona grandis* has the highest IVI (123.25) followed by the *Terminalia arjuna* (34.25) and *Lannea coromandelica* (16.83) and lowest in *Sterculia urens* (2.26) in VDF class (Table 3a). In MDF class *Tectona grandis* has the highest IVI (106.40) followed by *Diospyros melanoxylon* (24.97), *Terminalia arjuna* (21.78) and *Annona squamosa* has the lowest IVI (0.82) (Table 3b) whereas, in the OF class *Tectona grandis* has the highest IVI (94.43) followed by *Chloroxylon swietenia* (38.71), *Lannea coromandelica* (29.53) whereas, *Mallotus philippensis* has the lowest IVI (2.82) as shown in Table 3c. Thus, from the IVI values, *Tectona grandis* is the most dominant tree species which occurred in all the three classes of forests followed by *Diospyros melanoxylon, Lannea coromandelica, Lagerstroemia parviflora, Terminalia tomentosa, Sterculia urens, Madhuca indica, Chloroxylon swietenia, Butea monosperma* and *Cassia fistula*. As IVI values give a complete picture of the social structure of species within a community, they can be used to identify dominant species and to create an association of dominant species [30]. Figure 2a, 2b and 2c depicts the IVI of the Riparian tree species of the three classes *viz*., VDF, MDF and OF respectively of upper Narmada river in relation to their availability of suitable niche. Table 4 shows the diversity indices of riparian trees of all the three classes of forest. The highest Shannon's Index H′ was recorded in MDF Class (2.048) whereas lowest H′ was recorded in VDF Class (1.731). High value of H′ at the MDF class would be representative of a more diverse community. The diversity index (H') for some of the Indian riparian forests were 1.07 (Dikhu River) [31], 5.6 (Cauvery river) [10], 3.06 (Khoh river) [28], 1.43-1.84 (Chalakkudy river) [8], and 2.43-5.4 (Natta, 2000) [31]. Simpson's diversity index (D) for VDF, MDF and OF are 0.378, 0.278 and 0.222 respectively. The low value of Simpson's index of dominance and relatively lower value of evenness shows that few species like *Tectona grandis*, *Terminalia arjuna*, *Diospyros melanoxylon*, *Lannea coromandelica*, *Chloroxylon swietenia* etc. dominate the community while other species are randomly distributed in the community.

Total biomass and Carbon stock

Above ground and below ground biomass were estimated to calculate the total biomass of the forest. The total standing biomass as well as carbon stock of Riparian forest was presented in table 5.

The total standing biomass in VDF class has been estimated as 181.51 t ha^{-1} in which above ground and below ground biomass accounted for 144.05 t ha^{-1} and 37.45 t ha^{-1} respectively. The total biomass C-stock in VDF class has been estimated as 90.75 t ha^{-1}.

The total standing biomass in MDF class has been estimated as 113.77 t ha^{-1} in which above ground and below ground biomass accounted for 90.29 t ha^{-1} and 23.48 t ha^{-1} respectively. The total biomass C-stock in MDF class has been estimated as 56.88 t ha^{-1} similarly in OF the total standing biomass has been estimated as 61.16 t ha^{-1} in which above ground and below ground biomass accounted for 48.54 t ha^{-1} and 12.62 t ha^{-1} respectively. The total biomass C-stock in OF class has been estimated as 30.58 t ha^{-1}.

Total C-Stock

The Soil Carbon Stock in VDF, MDF and OF is estimated to be 22.04 t ha^{-1}, 17.22 t ha^{-1} and 12.37 t ha^{-1} respectively. The Tree Carbon Stock is estimated to be 90.753 t ha^{-1}, 56.884 t ha^{-1} and 30.578 t ha^{-1} in VDF, MDF and OF respectively. As shown in Figure 3, the total carbon stock is the sum of tree carbon stock and soil carbon stock, which is 112.791 t ha^{-1} in VDF, 74.107 t ha^{-1} in MDF, and 42.953 t ha-1 in OF (Table 6).

Table 1: Geo referenced location of study sites.

Division	Range	Landmark	Category	Latitude	Longitude	Elevation
Jabalpur	Bargi	Saliwada	DF	22°52'36.88"	79°54'23.44"	469
			DF	22°52'40.77"	79°54'26.66"	477
			DF	22°52'44.36"	79°54'33.16"	478
		Garhgorakhpur	DF	22°51'47.23"	79°54'06.80"	438
Mandla	Mandla	Chapri Ryt	DF	22°39'27.94"	80°30'08.75"	459
			DF	22°39'13.42"	80°30'18.26"	462
			DF	22°38'40.41"	80°30'00.24"	456
Jabalpur	Bargi	Saliwada	MDF	22°52'33.69"	79°54'24.69"	457
		Garhgorakhpur	MDF	22°52'03.45"	79°53'55.55"	427
			MDF	22°51'32.69"	79°54'21.30"	422
			MDF	22°51'41.25"	79°54'24.21"	443
			MDF	22°51'48.02"	79°54'14.46"	433
			MDF	22°51'44.58"	79°54'19.79"	440
	Shahpura	New bhedaghat	MDF	23°07'53.18"	79°47'38.33"	366
Mandla	Mandla	ChapriRyt	MDF	22°39'05.44"	80°30'10.59"	460
			MDF	22°38'55.66"	80°30'02.66"	455
			MDF	22°38'28.47"	80°30'04.20"	452
			MDF	22°38'22.61"	80°30'05.81"	460
			MDF	22°38'13.81"	80°30'08.35"	454
			MDF	22°38'07.28"	80°30'08.99"	456
			MDF	22°38'00.53"	80°30'07.91"	451
Seoni	Shikara	Payli	MDF	22°50'35.25"	79°54'42.22"	425
			MDF	22°50'23.59"	79°54'44.90"	432
			MDF	22°50'48.73"	79°54'41.96"	436
Jabalpur	Bargi	Saliwada	OF	22°53'14.27"	79°54'23.41"	451
			OF	22°53'10.63"	79°54'29.09"	456
			OF	22°51'57.25"	79°53'59.65"	448
			OF	22°51'59.21"	79°53'58.45"	433
			OF	22°51'51.46"	79°53'58.13"	434
	Shahpura	New bhedaghat	OF	23°07'37.56"	79°47'41.46"	385
			OF	23°07'45.99"	79°47'36.85"	378
			OF	23°07'59.25"	79°47'45.90"	358

Table 2: Composition and distribution of trees in riparian forest along Narmada river in upper Narmada region of M.P.

S. No.	Scientific name	Family	VDF	MDF	OF
1	*Acacia catechu*	Leguminosae	-	-	#
2	*Adina cardifolia*	Rubiaceae	#	#	-
3	*Aegle marmelos*	Rutaceae	#	#	-
4	*Annona squamosa*	Annonaceae	-	#	-
5	*Anogeissus latifolia*	Combretaceae	#	#	#
6	*Azadirachta indica*	Meliaceae	-	#	-
7	*Bauhinia racemosa*	Leguminosae	-	-	#
8	*Buchanania lanzan*	Anacardiaceae	-	#	-
9	*Butea monosperma*	Faboideae	#	#	#
10	*Careya arborea*	Lecythidaceae	#	#	-
11	*Cassia fistula*	Caesalpinioideae	#	#	#
12	*Chloroxylon swietenia*	Rutaceae	#	#	#
13	*Cordia myxa*	Ehretiaceae	#	#	-
14	*Dalbergia paniculata*	Leguminosae	-	#	-
15	*Diospyros melanoxylon*	Ebenaceae	#	#	#
16	*Emblica offcinalis*	Euphorbiaceae	-	#	-
17	*Ficus glomerata*	Moraceae	#	#	-
18	*Ficus religiosa*	Moraceae	-	#	-
19	*Ficus virens*	Moraceae	-	-	#
20	*Garuga pinnata*	Burseraceae	#	#	-
21	*Holoptelea integrifolia*	Ulmaceae	#	#	#
22	*Lagerstroemia parviflora*	Lythraceae	#	#	#
23	*Lannea coromandelica*	Anacardiaceae	#	#	#
24	*Madhuca indica*	Sapotaceae	#	#	#
25	*Mallotus philippensis*	Euphorbiaceae	-	-	#
26	*Miliusa tomentosa*	Annonaceae	#	#	#
27	*Mitragyna parviflora*	Rubiaceae	-	#	-
28	*Schleichera oleosa*	Sapindaceae	#	#	-
29	*Semecarpus anacardium*	Anacardiaceae	#	-	-
30	*Sterculia urens*	Sterculiaceae	#	#	#
31	*Syzygium cumini*	Myrtaceae	#	#	-
32	*Tectona grandis*	Lamiaceae	#	#	#
33	*Terminalia arjuna*	Combretaceae	#	#	-
34	*Terminalia tomentosa*	Combretaceae	#	#	#
35	*Vachellia nilotica*	Fabaceae	-	-	#

#, presence; -, absent

Table 3(A): Quantitative analysis of trees in VDF class of riparian forest of Narmada River

Very Dense Forest											
S. No.	Common Name	Scientific name	Family	TNI	Density	Frequency (%)	Area	RD	RF	RDo	IVI RD+RF+RDo
1	Amaltas	*Cassia fistula*	Caesalpinioideae	8	1.14	28.57	0.71	2.20	3.92	1.82	7.95
2	Arjun	*Terminalia arjuna*	Combretaceae	25	3.57	28.57	9.11	6.89	3.92	23.45	34.25
3	Bel	*Aegle marmelos*	Rutaceae	3	0.43	28.57	0.14	0.83	3.92	0.35	5.10
4	Bhilva	*Semecarpus anacardium*	Anacardiaceae	1	0.14	14.29	0.06	0.28	1.96	0.16	2.40
5	Bhirra	*Chloroxylon swietenia*	Rutaceae	15	2.14	28.57	1.01	4.13	3.92	2.59	10.64
6	Chirol	*Holoptelea integrifolia*	Ulmaceae	4	0.57	28.57	0.32	1.10	3.92	0.81	5.84
7	Dhawa	*Anogeissus latifolia*	Combretaceae	11	1.57	57.14	0.89	3.03	7.84	2.30	13.17
8	Gular	*Ficus glomerata*	Moraceae	6	0.86	28.57	0.97	1.65	3.92	2.49	8.07
9	Gunja	*Lannea coromandelica*	Anacardiaceae	20	2.86	57.14	1.35	5.51	7.84	3.47	16.83
10	Haldu	*Adina cardifolia*	Rubiaceae	3	0.43	28.57	0.11	0.83	3.92	0.29	5.04
11	Jamun	*Syzygium cumini*	Myrtaceae	4	0.57	28.57	0.44	1.10	3.92	1.13	6.15
12	Kari	*Miliusa tomentosa*	Annonaceae	1	0.14	14.29	0.01	0.28	1.96	0.02	2.26
13	Kekad	*Garuga pinnata*	Burseraceae	2	0.29	14.29	0.07	0.55	1.96	0.17	2.69
14	Kosum	*Schleichera oleosa*	Sapindaceae	3	0.43	28.57	0.34	0.83	3.92	0.87	5.61
15	Kullu	*Sterculia urens*	Sterculiaceae	1	0.14	14.29	0.01	0.28	1.96	0.02	2.26
16	Kumbhi	*Careya arborea*	Lecythidaceae	2	0.29	28.57	0.15	0.55	3.92	0.39	4.86
17	Lasoda	*Cordia myxa*	Ehretiaceae	4	0.57	28.57	0.36	1.10	3.92	0.92	5.95
18	Lendiya	*Lagerstroemia parviflora*	Lythrceae	5	0.71	42.86	0.22	1.38	5.88	0.57	7.83
19	Mahua	*Madhuca indica*	Sapotaceae	2	0.29	14.29	0.40	0.55	1.96	1.03	3.54
20	Palash	*Butea monosperma*	Faboideae	2	0.29	14.29	0.37	0.55	1.96	0.96	3.47
21	Sagon	*Tectona grandis*	Lamiaceae	219	31.29	100.00	19.12	60.33	13.73	49.19	123.25
22	Saja	*Terminalia tomentosa*	Combretaceae	5	0.71	14.29	1.37	1.38	1.96	3.52	6.86
23	Tendu	*Diospyros melanoxylon*	Ebenaceae	17	2.43	57.14	1.35	4.68	7.84	3.47	15.99
Total				363	51.86	728.57	38.87	100.00	100.00	100.00	300.00

Table 3(B): Quantitative analysis of trees in MDF class of riparian forest of Narmada River.

Moderate Dense Forest											
S. No.	**Common Name**	**Scientific name**	**Family**	**TNI**	**Density**	**Frequency (%)**	**Area**	**RD**	**RF**	**RDo**	**IVI RD+RF+RDo**
1	Amaltas	*Cassia fistula*	Caesalpinioideae	9	0.529	35.294	0.287	1.544	3.704	0.502	5.749
2	Aomla	*Emblica offcinalis*	Euphorbiaceae	1	0.059	5.882	0.063	0.172	0.617	0.110	0.899
3	Arjun	*Terminalia arjuna*	Combretaceae	22	1.294	52.941	7.125	3.774	5.556	12.449	21.778
4	Bel	*Aegle marmelos*	Rutaceae	6	0.353	23.529	0.269	1.029	2.469	0.470	3.968
5	Bhirra	*Chloroxylon swietenia*	Rutaceae	2	0.118	11.765	0.167	0.343	1.235	0.291	1.869
6	Char	*Buchanania lanzan*	Anacardiaceae	5	0.294	23.529	0.148	0.858	2.469	0.259	3.585
7	Chirol	*Holoptelea integrifolia*	Ulmaceae	5	0.294	23.529	0.802	0.858	2.469	1.401	4.728
8	Dhawa	*Anogeissus latifolia*	Combretaceae	15	0.882	64.706	3.158	2.573	6.790	5.519	14.882
9	Dhovan/ fansi	*Dalbergia paniculate*	Leguminosae	1	0.059	5.882	0.061	0.172	0.617	0.106	0.895
10	Gular	*Ficus glomerata*	Moraceae	2	0.118	5.882	0.118	0.343	0.617	0.207	1.167
11	Gunja	*Lannea coromandelica*	Anacardiaceae	19	1.118	35.294	1.235	3.259	3.704	2.159	9.121
12	Haldu	*Adina cardifolia*	Rubiaceae	5	0.294	29.412	0.526	0.858	3.086	0.920	4.864
13	Jamun	*Syzygium cumini*	Myrtaceae	7	0.412	35.294	0.909	1.201	3.704	1.589	6.493
14	Kari	*Miliusa tomentosa*	Annonaceae	11	0.647	17.647	0.470	1.887	1.852	0.822	4.561
15	Kekad	*Garuga pinnata*	Burseraceae	2	0.118	11.765	0.099	0.343	1.235	0.173	1.751
16	Kosum	*Schleichera oleosa*	Sapindaceae	4	0.235	23.529	0.237	0.686	2.469	0.414	3.569
17	Kullu	*Sterculia urens*	Sterculiaceae	2	0.118	11.765	0.287	0.343	1.235	0.502	2.080
18	Kumbhi	*Careya arborea*	Lecythidaceae	1	0.059	5.882	0.076	0.172	0.617	0.134	0.922
19	Lasoda	*Cordia myxa*	Ehretiaceae	2	0.118	11.765	0.070	0.343	1.235	0.122	1.699
20	Lendiya	*Lagerstroemia parviflora*	Lythraceae	27	1.588	76.471	1.504	4.631	8.025	2.629	15.285
21	Mahua	*Madhuca indica*	Sapotaceae	20	1.176	70.588	2.077	3.431	7.407	3.629	14.467
22	Mundi	*Mitragyna parviflora*	Rubiaceae	5	0.294	17.647	0.112	0.858	1.852	0.196	2.905
23	Neem	*Azadirachta indica*	Meliaceae	4	0.235	17.647	0.440	0.686	1.852	0.768	3.306
24	Palash	*Butea monosperma*	Faboideae	19	1.118	58.824	2.001	3.259	6.173	3.497	12.929
25	Peepal	*Ficus religiosa*	Moraceae	2	0.118	11.765	1.795	0.343	1.235	3.136	4.714
26	Sagon	*Tectona grandis*	Verbenaceae	294	17.294	94.118	26.380	50.429	9.877	46.093	106.399
27	Saja	*Terminalia tomentosa*	Combretaceae	21	1.235	82.353	4.221	3.602	8.642	7.374	19.618
28	Sita fal	*Annona squamosa*	Annonaceae	1	0.059	5.882	0.021	0.172	0.617	0.036	0.825
29	Tendu	*Diospyros melanoxylon*	Ebenaceae	69	4.059	82.353	2.573	11.835	8.642	4.495	24.973
Total				583	34.294	952.941	57.233	100	100	100	300

Table 3(C): Quantitative analysis of trees in OF class of riparian forest of Narmada River.

Open Forest											
S. No.	**Common Name**	**Scientific name**	**Family**	**TNI**	**Density**	**Frequency (%)**	**Area**	**RD**	**RF**	**RDo**	**IVI RD+RF+RDo**
1	Aasto	*Bauhinia racemose*	Leguminosae	1	0.125	12.5	0.040	0.581	2.174	0.268	3.024
2	Amaltas	*Cassia fistula*	Caesalpinioideae	1	0.125	12.5	0.023	0.581	2.174	0.156	2.911
3	Bamura	*Vachellianilotica*	Fabaceae	1	0.125	12.5	0.028	0.581	2.174	0.189	2.944
4	Bhirra	*Chloroxylon swietenia*	Rutaceae	23	2.875	75	1.850	13.372	13.043	12.299	38.715
5	Chirol	*Holoptelea integrifolia*	Ulmaceae	1	0.125	12.5	0.206	0.581	2.174	1.372	4.128
6	Dhawa	*Anogeissus latifolia*	Combretaceae	9	1.125	50	1.641	5.233	8.696	10.914	24.843
7	Gunja	*Lannea coromandelica*	Anacardiaceae	16	2	62.5	1.407	9.302	10.870	9.358	29.530
8	Kari	*Miliusa tomentosa*	Annonaceae	4	0.5	37.5	0.258	2.326	6.522	1.716	10.564
9	Khair	*Acacia catechu*	Leguminosae	2	0.25	25	0.039	1.163	4.348	0.257	5.768
10	Kullu	*Sterculia urens*	Sterculiaceae	11	1.375	50	1.641	6.395	8.696	10.910	26.001
11	Lendia	*Lagerstroemia parviflora*	Lythraceae	5	0.625	25	0.347	2.907	4.348	2.306	9.560
12	Mahua	*Madhuca indica*	Sapotaceae	1	0.125	12.5	0.062	0.581	2.174	0.414	3.169
13	Pakur	*Ficus virens*	Moraceae	1	0.125	12.5	0.026	0.581	2.174	0.173	2.929
14	Palash	*Butea monosperma*	Faboideae	4	0.5	37.5	0.311	2.326	6.522	2.069	10.916
15	Sagon	*Tectona grandis*	Lamiaceae	73	9.125	62.5	6.185	42.442	10.870	41.123	94.434
16	Saja	*Terminalia tomentosa*	Combretaceae	5	0.625	37.5	0.723	2.907	6.522	4.809	14.238
17	Tendu	*Diospyros melanoxylon*	Ebenaceae	13	1.625	25	0.240	7.558	4.348	1.597	13.503
18	Sindoori	*Mallotus philippensis*	Euphorbiaceae	1	0.125	12.5	0.010	0.581	2.174	0.069	2.825
Total				172	21.5	575	15.039	100	100	100	300

Table 4: Diversity indices of riparian trees in all the three classes of forest *viz.*, VDF, MDF and of

S. No	Diversity Indices	VDF	MDF	OF	Average
1	Species richness (S)	23	29	18	23.33
2	Shannon- Weiner's diversity index (H')	1.731	2.048	2.021	1.933
3	Simpsons diversity index (D)	0.378	0.278	0.222	0.293

Table 5: Total Tree biomass and C-Stock of Riparian forest

S. No.	Forest Class	AGB (t ha^{-1})	BGB (t ha^{-1})	Total Biomass (t ha^{-1})	C-Stock (t ha^{-1})
1	VDF	144.05	37.45	181.51	90.75
2	MDF	90.29	23.48	113.77	56.88
3	OF	48.54	12.62	61.16	30.58

Table 6: Total C-Stock (t ha^{-1}) in all three classes of forest

S. No.	Forest Class	C-Stock trees (t ha^{-1})	C-Stock soil (t ha^{-1})	Total C-Stock (t ha^{-1})
1	VDF	90.75	22.04	112.79
2	MDF	56.88	17.22	74.10
3	OF	30.58	12.37	42.95

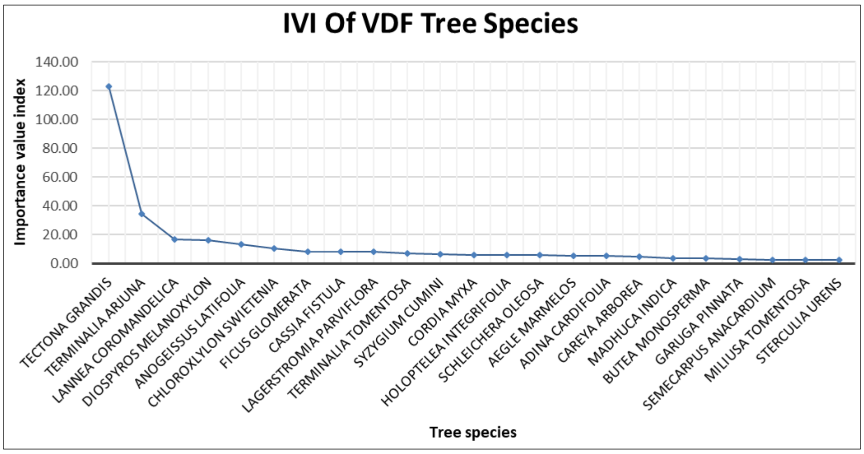

Fig 2 (a): IVI of Riparian tree species in VDF class

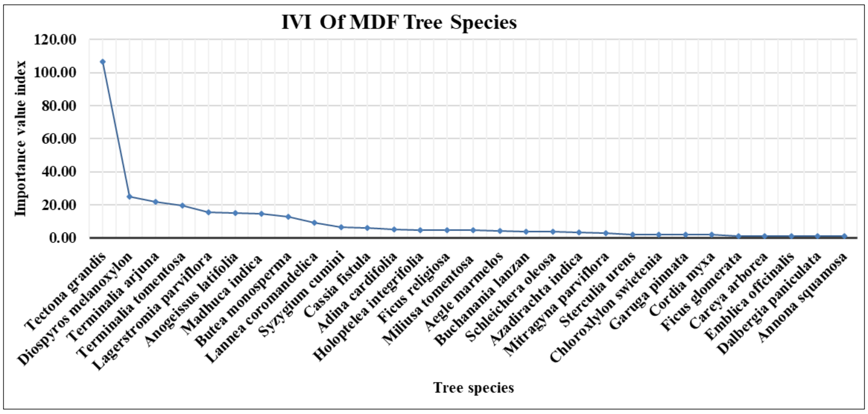

Fig 2(b): IVI of Riparian tree species in MDF class

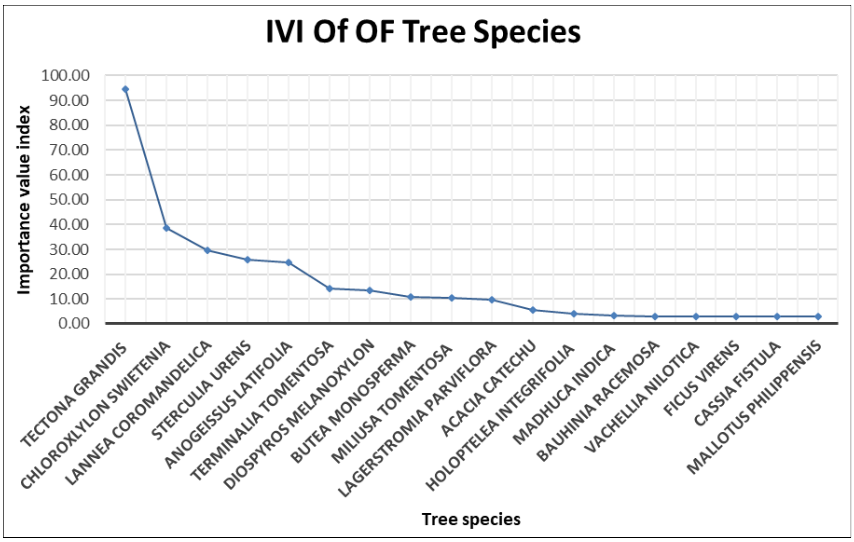

Fig 1(c)*:* IVI of riparian tree species in *of* class

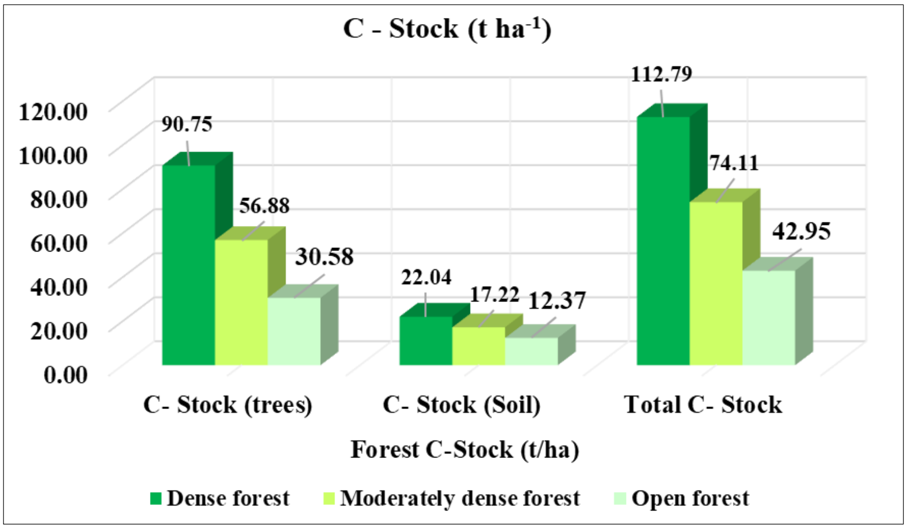

Fig 3: Total C-Stock of Riparian forest (t ha^{-1})

Summary and Conclusion

The aboveground biomass production under three different forest density classes varies from 48.54 t ha^{-1} in OF to 144.05 t ha^{-1} in VDF and the below ground biomass varies from 12.62 t ha^{-1} in OF to 37.45 t ha^{-1} in VDF. The trend of carbon stock under different sites was similar to biomass production and it varies from 30.58 t ha^{-1} in OF to 90.75 t ha^{-1} in VDF during the present study. The above ground biomass and below ground biomass in the present study differ from site to site due to different types of plant community structures, variations in plant species, composition of forests or succession stages caused by some anthropogenic practices in different sites of forest ecosystems. Some sites having a high density of young plants with small girth size usually have a low biomass. On the other hand, some mature sites with large diameter trees harbor higher biomass as compared to sites having a high tree density. Wood collection by surrounding villages and stone mining have also resulted in the destruction of forests and thus the reduction of biomass. All of the above factors are responsible for site to site variation of biomass production and such types of external as well as internal factors found in this research are supported by a number of workers. The Tree Carbon Stock also varies from 90.75 t ha^{-1} in VDF to 30.58 t ha^{-1} in OF. According to Pande, 2005 poor soil depth and soil structure of any site can be responsible for low above ground biomass [32]. The remaining sites were stabilized with an average number of trees, basal area, and biomass. Despite differences in biomass between different forest sites, medium-size boles exhibit greater carbon sequestration potential than large-bole forests [33]. The range of total tree biomass production and total carbon stock (including tree and soil) of the riparian forest in present study were varied from 61.16 t ha^{-1} to 181.51 t ha^{-1} and 42.95 t ha^{-1} to 112.79 t ha^{-1} respectively. However, the earlier researcher in different forests reported quite low amount in their reports such as 27.6 t ha^{-1} by George *et al*., (1990) [34], 19 t ha^{-1} and 28.68 t ha^{-1} by Singh *et al*., (1991) [35], 24 t ha^{-1} by Devagiri *et al*., (2013) [36], 28.1 t ha^{-1} to 85.3 t ha^{-1} by Pande, (2005) [32]. Also these results could be compared with the other available biomass and carbon estimation of different forest types in India. Chaturvedi *et al*., (2011) [37] estimated that carbon stock ranged from 15.6 t ha^{-1} to 151 t ha^{-1} in tropical dry forest of India. Bhat *et al*., (2003) [38] reported that the accumulation of biomass in the tropical rain forest of Western Ghat ranges from 92 t ha^{-1} to 268.49 t ha^{-1} while FAO (2007) [39] estimated the average carbon density at 35 t ha^{-1} in India. Hence, our present study shows that Riparian forests along Narmada river have the greater potential for sequestering high amounts of carbon from the atmosphere which will act as an important natural break on climate change. Therefore, Riparian forest can play an important role in mitigating and adaptation of climate change.

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