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Tree diversity in ravines and their rehabilitation through agroforestry interventions in Bundelkhand Region of India

A.R. Uthappa*[1], S.B. Chavan[1], Mahendra Singh[1], K. B. Sridhar[1], Inder Dev[1], Asha Ram[1], B.N. Sathish[2], Manish Kumar[3], R.P. Dwivedi[1], Ramesh Singh[1], R.K. Singh[1], Rajendra Singh[1], R.K. Tewari[1], A.K. Handa[1] and O.P. Chaturvedi[1]

[1]*ICAR- Central Agroforestry Research Institute, Jhansi-284 003. U.P., India.*

[2]*College of Forestry, UAHS, Ponnampet- 571 216. Karnataka, India.*

[3]*ICAR- Indian Institute of Soil and Water Conservation, R C, Datia-475 661. M.P., India.*

**Corresponding author's Email: aruthappa@gmail.com*

ABSTRACT: The ravine areas are most fragile ecosystem and subjected to various kinds of natural resource losses and threat to biodiversity. Due to unregulated and over exploitation, the forest area under ravines are facing severe threats of losing biodiversity. In this context, a study was conducted to assess the tree diversity of ravine areas in different parts of Bundelkhand *viz.,* Orai, Banda and Datia. In each study site, quadrats of 20 m × 20 m were randomly laid out and the tree diversity were documented. The species diversity, richness and evenness were studied using different indices like Shannon, Simpson, Margalef and Berger-Parker. The relative density and relative frequency were also calculated. In the present study, the Shannon diversity was highest in ravines of Datia (1.887) followed by Banda (1.871) and Orai (1.259). Whereas the Shannon equitability index was found higher in Banda (0.899) followed by Datia (0.859) and Orai (0.782). The lowest value of Simpson diversity was reported in Banda (0.183) followed by Datia (0.194) and Orai (0.333). In Datia (9 species) maximum number of species were recorded, followed by Banda (8 species) and Orai (5 species). The Inverted Berger-Parker dominance was highest in Banda (3.296) followed by Datia (2.804) and Orai (2.500). Hence it indicates that, ravine areas of Banda and Datia are more diverse and healthier than Orai. Further analysis revealed that, the relative density of *Anogeissus pendula* was highest in Orai (40.16%) and Datia (38.18%), whereas *Holoptelea integrifolia* (27.72%) and *Balanites aegyptiaca* (21.85%) population was higher in Banda. The overall diversity of all the three sites was found low. The survey also reported high biotic interferences, which escalates ravine degradation. However, crop cultivation in these lands is not desirable as it leads to accelerated erosion, thus adding to their fast degradation. The best scientific land use of these lands is to place them under permanent vegetation through agroforestry interventions involving forest and fruit trees along with the grasses. The planting and management of indigenous tree species like *Anogeissus pendula, Acacia leucophloea, A. nilotica, Ziziphus spp., Carissa carandas* and *Capparis decidua* will pave the way towards sustaining ravine ecosystem and livelihood of the people.

Key words: Agroforestry, afforestation, Bundelkhand, diversity, ravines and rehabilitation.

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1. INTRODUCTION

With rising global population and ever increasing pressure on agricultural land for industrial and other infrastructural projects, waste land reclamation has become a priority to ensure sustainable food production and environmental conservation. Wind and water are the major agents responsible for the land degradation and due to which about 5334 m tons of soil is lost (16 t ha^{-1}) annually (Mandal *et al.*, 2008). Ravines are the worst form of land degradation and characterized by edaphic, topographic and climatic adversities. Ravines and gullies are distributed over 3.98 m ha area in India (Chaturvedi *et al.*, 2014) and are mainly found in Madhya Pradesh, Uttar Pradesh, and parts of Rajasthan. A rough estimate suggests that every year ravine area expands at a rate of 8000 ha $year^{-1}$ (Sharma *et al.*, 1980). The ravines occur along the rivers Yamuna, Ken, Gomati and Kholas in Uttar Pradesh and along rivers Chambal, Assan, Kalishindh, Betwa and Kshipra in Madhya Pradesh. The climate, topography, and soils of the ravine region are typically harsh and thus adversely affect the composition and growth of the vegetation. Soil degradation is a major factor in ravine formation, and about 15-18 t ha^{-1} soil is lost every year.

Diversity analysis is an important tool for biologists, ecologists and agroforesters to understand the community structure. Various diversity indices are mathematical measures of species diversity in a community and provides important information about rarity and commonness of species in a community. The ravines are characterized by dominance of thorny vegetation and are classified as northern tropical ravine thorn forests (6B/C2) (Champion and Seth, 1968). These ravine areas are facing heavy biotic pressure mainly for agriculture expansion, fuelwood and fodder. Due to unregulated and over exploitation, the forest areas under ravines are facing severe threats of losing biodiversity. Rehabilitation of degraded ravines lands through agroforestry interventions is an important measure to conserve land and water resources for sustaining and improving the production and productivity, and to tackle the impacts of climate change. Agroforestry systems like silvipasture, agrihortisilviculture and agrisilviculture would be the best options for rehabilitation of degraded ravines. Therefore, the present study envisages to assess the tree diversity of ravine areas in Bundelkhand region and to identify the suitable tree based systems for rehabilitation of ravines.

2. MATERIALS AND METHODS

The study was conducted to assess the tree diversity of ravine areas in Bundelkhand region of India. The vegetation survey was carried out in ravines of Tikar forest block (25°54'30" N, 79°32'59" E), Orai, Jalaun; Tindwari forest block (25°43'57" N, 080°26'33" E), Banda and Ratangarh forest block (26°10' 09" N, 78°47' 03" E), Datia in the year 2014-15 (Fig 1). The climate of the ravine regions in Bundelkhand is semi-arid to arid. The average rainfall is low, ranging from 250-750mm and are erratic in nature. For vegetation study, qualitative and quantitative methods were employed. The qualitative

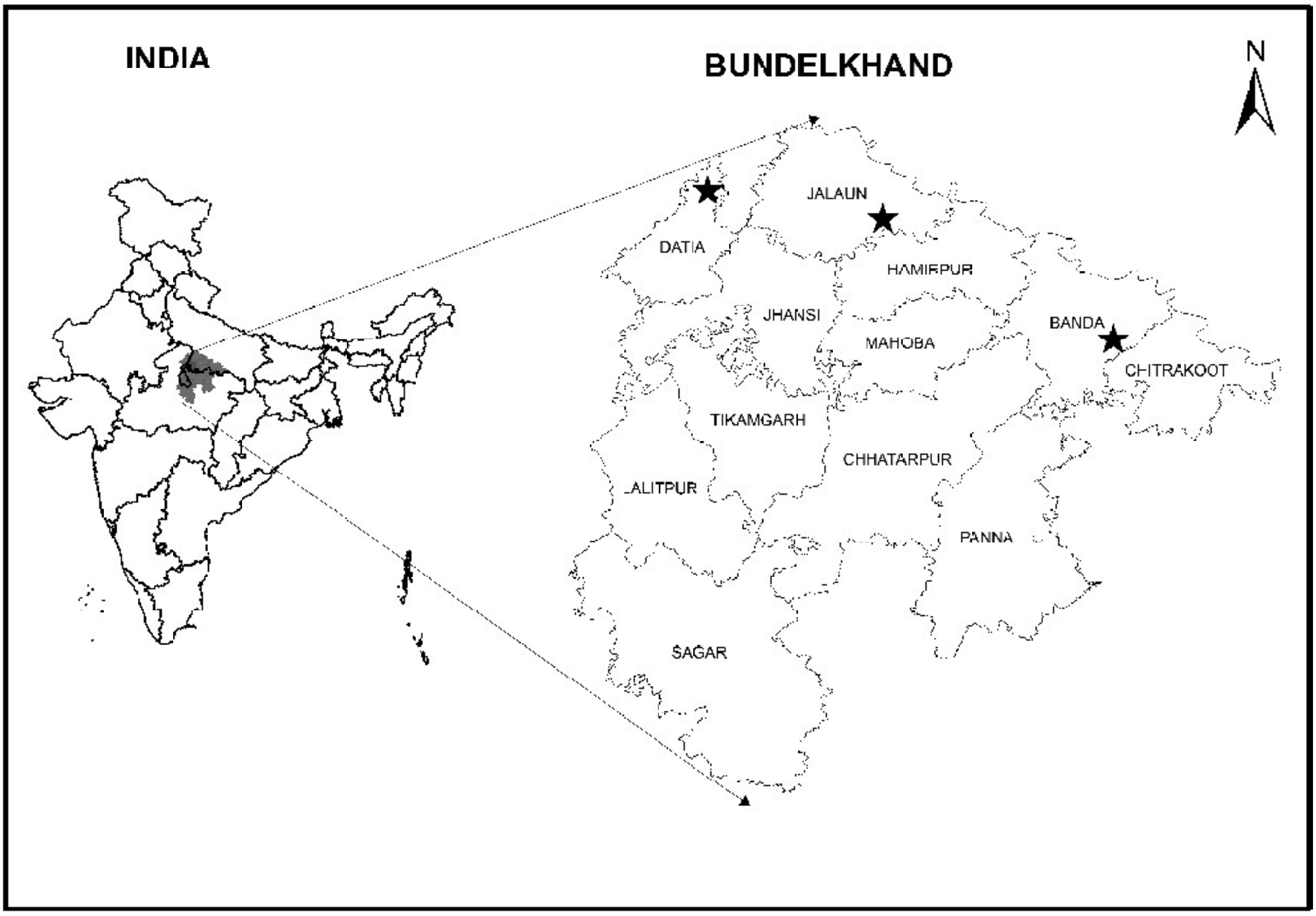

Fig. 1. Study sites at different districts of Bundelkhand region.

method included the collection, identification and verification of plant components using standard flora and herbarium. For analysing the vegetation quantitatively, quadrate method was employed. In each study site, five quadrats of 20m × 20m were randomly laid out and the tree diversity was documented. The relative density and relative frequency were also calculated. The relative abundance curve was plotted to study the species richness and evenness. The diversity indices were calculated using standard formulas.

Relative density

Relative density is the study of numerical strength of a species in relation to the total number of individuals of all the species and was calculated as:

$$\text{Relative density} = \frac{\text{Number of individual of } i^{th} \text{ species}}{\text{Number of individual of the species}} \times 100$$

Relative frequency

The degree of dispersion of individual species in an area in relation to the number of all the species occurred and it can be calculated as

$$\text{Relative frequency} = \frac{\text{Number of occurrence of all the species}}{\text{Number of occurrence of the species}} \times 100$$

Diversity indices

Shannon index of diversity

It is calculated using following formula (Shannon and Weiner, 1963)

$$H' = -\Sigma pi \ln pi$$

Where, H' = Shannon index of diversity

*p*i = the proportion of important value of the i^{th} species

(*p*i =*n*i / N, *n*i is the important value index of i^{th} species and N is the important value index of all the species).

Shannon's equitability (E_H) can be calculated by dividing H' by H_{max} (here $H_{max} = \ln S$). Equitability assumes a value between 0 and 1 with 1 being complete evenness.

$$E_H = H'/H_{max}$$

Simpson index of dominance

The equation used to calculate Simpson's index (Simpson, 1949) was

$$D = \Sigma (pi)^2$$

Where, D = Simpson index of dominance

*p*i = the proportion of important value of the i^{th} species

(*p*i =*n*i / N, *n*i is the important value index of i^{th} species and N is the important value index of all the species).

As D increases, diversity decreases and Simpson's index was therefore usually expressed as 1 – D (Dominance index) or 1/D (Reciprocal Simpson index).

Margalef's index

The species richness was calculated by using the method Margalef's index of richness (Dmg) (Margalef, 1958).

$$Dmg = (S-1)/\ln N$$

Where, S = Total number of species.

N = Total number of individuals.

Berger-Parker dominance

It measures the numerical importance of the most abundant species (Berger and Parker, 1970). It is simply the number of individuals in the dominant taxon relative to N.

$$d = N_{max} / N$$

where, N max is the number of individuals in the most abundant species, and N is the total number of individuals in the sample.

3. RESULTS AND DISCUSSION

Relative density and frequency

Relative density is the study of numerical strength of a species and relative frequency is the degree of dispersion of individual species in an area. The results revealed that (Table 1), the relative density of *Anogeissus pendula* was higher in Orai (40.16%) and Datia (38.18%), whereas *Holoptelea integrifolia* (27.72%) and *Balanites aegyptiaca* (21.85%) population was higher in Banda. The relative frequency of all the species were same in Orai. In Banda and Datia, relative frequency did not vary much among the species and was quite similar among the species. In the earlier studies at ravines of Agra and Gujarat, *Balanites aegyptiaca* was found one of the dominant species (Chauhan *et al.,* 2015; Bhatt

Table 1. Relative density (Rd) and relative frequency (Rf) of different ravine areas of Bundelkhand

Sl No	Species	Orai, Uttar Pradesh		Banda, Uttar Pradesh		Datia, Madhya Pradesh	
		Rd (%)	Rf (%)	Rd (%)	Rf (%)	Rd (%)	Rf (%)
1	*Acacia catechu*	-	-	6.34	11.11	2.83	7.69
2	*Acacia leucophloea*	-	-	7.16	11.11	11.22	12.82
3	*Anogeissus pendula*	40.16	20	-	-	38.18	12.82
4	*Balanites aegyptiaca*	-	-	21.85	13.89	4.94	10.26
5	*Capparis decidua*	3.75	20	-	-	15.06	12.82
6	*Carissa carandas*	4.83	20	-	-	10.28	12.82
7	*Dalbergia sissoo*	-	-	9.24	11.11	-	-
8	*Diospyros melanoxylon*	-	-	-		2.23	7.69
9	*Holoptelea integrifolia*	-	-	27.72	13.89	-	-
10	*Prosopis juliflora*	12.04	20	11.01	13.89	4.26	10.26
11	*Sterculia urens*		-	5.29	11.11		
12	*Ziziphus sp.*	39.22	20	11.39	13.89	11.00	12.82

et al., 2015) but in our study it was observed that *Anogeissus pendula* and *Holoptelea integrifolia* were the dominant species.

Shannon index

Shannon index is a diversity index, which takes into account the number of individuals as well as number of taxa. In present study, the Shannon diversity was highest in ravines of Datia (1.887) followed by Banda (1.871) and Orai (1.259) (Table 2). It varies from zero for communities with only a single taxon to high values for communities with many taxa, each with few individuals. The Shannon diversity index for Indian forests ranged from 0.83 to 4.1 (Parthasarathy *et al*., 1992; Visalakhshi, 1995). In the present study, Shannon diversity index (1.259 to 1.887) reflects the low to moderate plant diversity. Whereas, the Shannon equitability index was found higher in Banda (0.899) followed by Datia (0.859) and Orai (0.782). This infers that species diversity may be higher in Datia, but more consistency in species distribution was found in Banda.

Table 2. Diversity indices for different ravine areas of Bundelkhand

Index	Orai, Uttar Pradesh	Banda, Uttar Pradesh	Datia, Madhya Pradesh
Shannon diversity index	1.259	1.871	1.887
Shannon Equitability	0.782	0.899	0.859
Simpsons Diversity (D)	0.333	0.183	0.194
Dominance Index (1-D)	0.667	0.817	0.806
Reciprocal Simpsons Diversity (1/D)	1.499	1.224	1.241
Margalef index	0.705	1.351	1.646
Berger-Parker Dominance index(d)	0.400	0.303	0.357
Inverted Berger-Parker Dominance (1/d)	2.500	3.296	2.804

Therefore ravines of Banda are more sustainable than Datia and Orai.

Simpson Diversity

Simpson's diversity index is a measure of diversity which takes into account the number of species present, as well as the relative abundance of each species. As species richness and evenness increase, so does diversity. The lowest value of Simpson diversity was reported in ravines of Banda (0.183) followed by Datia (0.194) and Orai (0.333) (Table 2). Whereas, in dominance index highest value was recorded in Banda (0.817) followed by Datia (0.806) and Orai (0.667). Simpson's index for different Indian forests ranged between 0.03 and 0.92 (Bhuyan *et al*., 2003; Deb and Sundriyal, 2011; Devi and Yadava, 2006). Hence it indicates that, ravine areas of Banda and Datia are more diverse and healthier than Orai.

Margalef's index

This index measures the species richness of the area. The results reveal that Datia (1.646) was richer in species compared to Banda (1.351) and Orai (0.705) (Table 2). In Datia (9 species) maximum number of species were recorded, followed by Banda (8 species) and Orai (5 species) (Table 2).

Berger-Parker dominance

Berger-Parker dominance is simply the number of individuals in the dominant taxon relative to total number of individuals (n). It is a simple measure of the numerical importance of the most abundant species. Berger-Parker dominance index of Orai (0.400) was higher compared to Datia (0.357) and Banda (0.303). In Orai and Datia most dominant taxon was *Anogeissus pendula*, whereas in Banda *Holoptelea integrifolia* was the dominant taxon. The reciprocal of the index (1/d) is often used, so that an increase in the value of the index accompanies an increase in diversity and a reduction in dominance. The Inverted Berger-Parker dominance was highest in Banda (3.296) followed by Datia (2.804) and Orai (2.500) (Table 2). This results further validates that ravines of Banda and Datia are biologically more diverse than Orai.

Rank abundance curve

The rank abundance curve visually depicts both species richness and species evenness. The rank abundance curve (Fig 2) clearly states that Datia site (9 species) was more diverse compared to other sites. In Orai and Datia *Anogeissus pendula* was more abundant species, but in Banda *Holoptelea integrifolia* was the abundant species. Species evenness is reflected in the slope of the line that fits the graph. A shallow gradient in Datia and Banda sites indicates high evenness as the abundances of different species are similar. Whereas, a steep gradient indicates low evenness as the high-ranking species have much higher abundances than the low-ranking species. Therefore, Orai site had the least diversity and evenness.

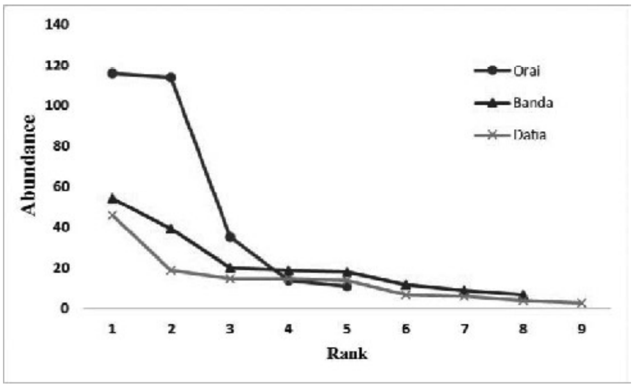

Fig. 2. Rank abundance curve of Orai, Datia and Banda

Cluster analysis

Bray Curtis cluster analysis has resolved into two major clusters (Fig 3). The species of Datia and Orai were grouped into one cluster, while Banda was resolved to another cluster. It was observed that, five species were common between Datia and Orai, thereby clustering them to one group. Whereas, only two species were common between Banda, Datia and Orai.

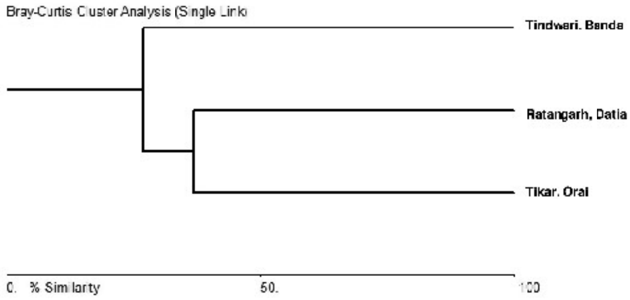

Fig. 3. Cluster analysis of different sites

Ravine rehabilitation

The climate, topography and soils of the ravine region are typically harsh and thus adversely affect the composition and growth of the vegetation. The soils of the ravinous regions are poor in fertility and physical conditions (Dagar and Mall, 1980) as almost all the soil profiles are eroded leaving behind rocky, sandy or stiff clay with poor water retention or water absorbing capacity. The land feature of ravines is rugged and characterized by three distinct parts namely, ravine top or hump, slope and bottom/bed. In general, the depth of ravines ranges from 1 to 20 m but may reach up to 55 m. The most of the ravenous lands are not fit for cultivation of agricultural crops and are classified as non-arable lands. Crop cultivation in these lands is not desirable as it leads to accelerated erosion thus adding to their fast degradation. The best scientific land use for these lands is to place them under permanent vegetation involving forest and fruit trees along with forage grasses and energy plantations. Ravine rehabilitation requires an integrated approach of using soil and water conservation measures along with selection of suitable tree species.

Proper soil and water conservation structures need to be erected, in order to check the uninterrupted flow of runoff into the ravines. Peripheral bunds, permanent drop structures like spillway, brush wood check dams, gabions, live vegetative check dams and trenching were found suitable to rehabilitate the ravines (Chaturvedi *et al.*, 2014). After successful checking of the ravine extension, the most important measure for reducing the risk of degradation of catchments of gullies and marginal lands along the ravines is introduction of trees and grasses in the ravine lands. Depending on the problems and needs of the area, trees may be introduced as alley,

Table 3. Choice of species for ravine rehabilitation

Species	Planting location	Uses
Acacia catechu	Gully slopes and humps	Fuelwood, fodder and Minor Forest Products (MFP)
Acacia leucophloea	Gully slopes	Fodder and fuelwood
Acacia nilotica	Hump top, slope and ravine beds	Fodder, fuelwood, small timber
Acacia tortilis	Hump top, slope and ravine beds	Fuelwood and fodder
Ailanthus excelsa	Gully slopes and humps	Fodder, fuelwood and timber
Albizia lebbeck	Hump top	Fodder and fuelwood
Azadirachta indica	Hump top and beds	Fodder, fuelwood, pesticides and timber
Balanites aegyptiaca	Hump top and slope	Fuelwood and MFP
Brachiaria mutica	Hump top, slope and ravine beds	Fodder, soil binder and silage
Cenchrus ciliaris	Hump top, slope and ravine beds	Fodder, hay, silage and soil conservation
Dalbergia sissoo	Hump top and slope	Fuelwood and small timber
Dendrocalamus strictus	Gully bottom	Poles and fuelwood
Dichanthium annulatum	Hump top and slope	Fodder and Mat
Eucalyptus tereticornis	Gully bottom	Poles and fuelwood
Gmelina arborea	Ravine beds	Small timber
Leucaena leucocephala	Gully slopes and humps	Fodder and fuelwood
Panicum antidotale	Ravine top and slope	Fodder and soil binder
Prosopis juliflora	Hump top, slope and ravine beds	Charcoal, fuelwood and fencing
Soymida febrifuga	Hump top	Fodder, fuel and small timber
Tamarix dioica	Swampy areas in gully bottom	Reclamation of saline soils and fuelwood
Ziziphus sp.	Hump top and slope	Fruit and fuelwood

(Source: Modified from *Sikka et al.*, 2016)

boundary plantation, or scattered tree plantation in the field. The highly eroded soils coupled with extremes of temperature and limitations of moisture hamper the survival and growth of trees. The tree and grass species (Table 3) selected should have ability to withstand stress, fast growing, easy to establish, multipurpose uses, fibrous roots and potential to ameliorate the soil.

Agroforestry interventions

Different agroforestry practices have been applied successfully in reclamation of ravines. Under agrihorticulture systems, fruit trees such as lemon (*Citrus limon*), mango (*Mangifera indica*), ber (*Ziziphus mauritiana*) and aonla (*Emblica officinalis*) can be grown with agricultural crops in humps and gully beds (Verma *et al.*, 1986). In Yamuna ravines at Agra, Prajapati *et al.*, (1993) observed that *Dendrocalamus strictus* produced 30–33 harvestable culms every 3 years after proper establishment at a spacing of 3m × 3m to 8m × 8m bamboo and gave average bamboo yield of 4000 poles ha^{-1}. Cultivation of grasses with the multipurpose trees is also a viable option for economic utilization of ravines. Medium and shallow gullies can be utilized under forest and fruit tree-based pastoral systems. Suitable grass species for protection and improving the fodder availability in ravine regions are *Dichanthium annulatum, Cenchrus ciliaris, Cenchrus setigerus, Panicum antidotale, Panicum maximum, Pennisetum purpureum,* and *Brachiaria mutica*. Ravinous catchments of Chambal at Kota when planted with *Acacia* + *D. annulatum* and *D. annulatumal* one generated 5.8 and 2.6 % of runoff and 1.26 and 0.62 t ha^{-1} of soil loss, respectively compared to 14.7 % of runoff and 3 t ha^{-1} of soil loss from agricultural catchments. Production of 4.5 t ha^{-1} of air dry grass + firewood from such degraded lands proved the effectiveness of grasses and trees as an alternative land use for protection and productive utilization of degraded ravine lands (Sharda and Venkateswarlu, 2007). Sethy *et al.*, (2007) planted *Emblica officinalis* (aonla) on gully humps, bamboo on gully bed and interspace was planted with *Cenchrus ciliaris* and different trenching densities as treatment. The production of aonla fruit ranged from 1.31 t ha^{-1} in control (no trenches) to 6.61 tha^{-1} in treatment involving trenching for trapping75 % runoff, the production of grass ranged from 7.71 to 9.91 t ha^{-1}. Ravine area development will not only contribute to bridging the growing demand and supply gap of food, fodder and fuel, but also helps in restoring livelihood security for resource constraint communities, besides providing improved ecosystem services (Sikka *et al.*, 2016).

4. CONCLUSION

The diversity indices reveals that ravines of Banda and

Datia were more diverse compared to Orai. But overall species diversity and distribution at all the three sites was low. However, crop cultivation would not be a viable option and hence best scientific method is to place them under permanent vegetation consisting of trees and grasses by agroforestry interventions.Ravine rehabilitation requires an integrated approach of treatment of table and marginal lands contributing runoff to the gullies and gullies proper on watershed basis. Rather than introducing exotic species, planting and management of indigenous plant species like *Anogeissus pendula, Acacia leucophloea, A. nilotica, Ziziphu ssp., Carissa carandas* and *Capparis decidua* will pave the way towards sustaining ravine ecosystem and livelihood of the people. For achieving the best results people should also be sensitized, empowered and involved in the ravine rehabilitation program through Joint Forest Management Committee.

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