Impact of invasive alien plant species, *Lantana camara*, on the species composition, richness and evenness of invaded plant communities in Sidama, Gamogofa and Gedio Zones, Ethiopia

Amare Seifu Assefa (✉ ameseifu21@gmail.com)

Addis Ababa University

Ermias Lulekal Molla

Addis Ababa University

Research Article

Keywords: Control, Diversity, Evenness, Families, Invasions

Posted Date: October 18th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-943114/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Invasive alien species represent one of the major threats to *biodiversity* and all economic sectors. *Lantana camara* has been ranked as the highest impacting invasive plant species in the study areas. However, its impact on *diversity* and *composition* of invaded plant communities has not been well studied. Therefore, the objective of this study was to investigate the impact of *Lantana camara* on species diversity and composition of invaded plant communities in the study areas. A total of 120, 10m X 10m plots were sampled so as to examine its effects of invasions on the species diversity and composition of invaded communities. A total of 109 species were found in the non-invaded areas as compared to 56 in the invaded areas. The number of species decreased by 48.6% in *Lantana camara* invaded areas as compared to the *control*. The *mean evenness* values of the entire invaded sampled study site and that of the control were 0.24 and 0.81 respectively. Thus, the *heterogeneity* of the *invaded* study sites was reduced by 57%. The number of plant families was 44 in the control areas in contrast to only 30 in the *invaded* areas. The number of plant families decreased by 31.8% in the invaded areas as compared to the control. Therefore, it was noted that *Lantana camara* has a serious impact on plant diversity hence the finding calls for an urgent management and control strategy against the spread of *Lantana camara* so as to save the ongoing threat to *biodiversity*.

Introduction

Invasive alien species (IASs) represent one of the primary dangers to biodiversity, human health and all economic sectors, especially in developing countries (Hejda et al., 2009). It has become one of the main causes of economic and ecological damage in most of the countries across the world (Paini et al., 2016). Almost, all ecosystem types on the planet are affected by IASs and they pose one of the biggest threats to biodiversity next to habitat destruction (GEF, 2003, Genovesi and Shine, 2004). Globally, the cost of damage caused by IASs has been estimated to be £1.5 trillion per year – close to 5% of global Gross Domestic Product (GDP). In developing countries, where agriculture accounts for a higher proportion of GDP, the negative impact of IASs on food security as well as on economic performance can be even greater which affect human well-being, contributing to lower food security, harsher living conditions, reduced wealth, social instability and poverty alleviation (IUCN, 2009, BIOCEM-RD, 2016 and Shaheen, 2019).

Globalization through increased trade, transport, travel and tourism will inevitably increase the intentional introduction of organisms to new environments. Various IASs have been introduced to Ethiopia, like other countries in the tropics. Recently, in Ethiopia there are more than 35 Invasive Alien Plant species (IAPSs) spreading at alarming rate, threatening agricultural lands, power dams, rangelands, national parks, lakes, rivers and roadsides. IASs have been identified by the Environmental Policy of Ethiopia (EPE) and the National Biodiversity Strategy and Action Plan (NBSAP) as posing a major threat to biodiversity and economic well-being of the country. Parthenium weed (*Parthenium hysterophorus*), *Prosopis juliflora*, Water hyacinth (*Eichhornia crassipes*) and Lantana weed (*Lantana camara*) are the most known IAPSs in Ethiopia (Rezene Fessehaie and Taye Tessema, 2014).

Lantana camara L. is one of the worst IAPS worldwide. It is erect and a hardy evergreen perennial shrub up to 5 m tall. It is a species of flowering plant within the verbenaceae family. It is native to tropical and subtropical America and the West Indies. It is common as an ornamental plant in all parts of the Flora of Ethiopia within an altitudinal range of 500 to 2500 meter above sea level (Sebsebe Demissew and Hedberg, 2006). The distribution of *Lantana camara* in Ethiopia is great and many ecosystems are affected by this species are cultivated and non-cultivated land, road side, grazing area, rural villages, river side, wetlands, forest and urban areas .It causes the loss of maximum amount biodiversity (Aravind *et al.*,2010, Habtamu Kefelegn, 2015, Kumar *et al.*,2016).

Lantana camara has usually been deliberately introduced into various localities in Ethiopia (particularly urban settings) as an ornamental shrub and has been quickly spread by birds and animals that eat its fruits but cannot digest the woody seeds (Abiyu Enyew and Raja, 2015). In Ethiopia, it is one of the four major IAPSs those posing negative impacts on country's biodiversity. However, no adequate latest evidence exists about the impact of *Lantana camara* on species *diversity (evenness and richness)* and composition. Therefore, this study aims to assess the impact of *Lantana camara* on the *species diversity* and *composition* of invaded plant communities in Sidama, Gamogofa and Gedio Zones, SNNPR, Ethiopia.

Materials And Methods

Description of the study areas

The study was conducted in the three Zones (Gedio, Sidama and Gamogofa) of SNNPR. Gedio zone is located in North eastern part of the region, It roughly lies between 60⁰59-60'62"N, latitude and 38⁰40-380'.43" E, longitude. The altitude ranges from 1500 to 3000 meter above sea level. Sidama is also located in the north eastern part of the region. Its geographic location lies between 6⁰14' and 7⁰18' N, latitude and 37⁰ 92' and 39⁰14' E, longitude with an elevation ranges from 1500 and 2500 m above sea level (Zebene Asfaw and Agren, 2007). Gamo-Gofa zone is named for the Gamo and Gofa peoples, whose homelands lie in this Zone. The administrative center of this zone is Arba Minch (Vaughan, 2003).

Materials

The common equipment and tools used in voucher specimen collection during the study were clippers, field press, newspapers, pencils, camera, measuring tape, diggers, GPS, study location and documentation data form.

Method of data collection

This study was conducted between January 2020 and August 2020 in Sidama, Gedio and Gamogofa Zones, South Nation Nationality People Regional government (SNNPR), Ethiopia. The study zones and districts were selected purposively on the basis of the level of *Lantana camara* invasion with the help of information obtained from Agricultural office of Sidama, Gedio and Gamo-Gofa Zones. Based on the

above selection criteria, from the three zones, three districts were selected. In each Zone one district was selected. Mirab Abaya, Dilla Zuria and Dara districts were selected from Gamo-Gofa, Gedio and Sidama respectively. From each district one kebele (the smallest administrative zone in Ethiopia) was selected. From Mirab Abaya, Woze Kebele was selected while from Dara and Dilla zuria Mechisho and Waleme kebele were selected respectively. In Each Kebele Community forest areas were selected. Accordingly, Woze, Mechisho and Waleme kebele community forests were selected. The impact of *Lantana camara* on the species diversity and composition of invaded plant communities was studied by applying Quadrat Method following (Hejda *et al.*, 2009, Dogra *et al.*, 2009, Lisanework Nigatu, 2010).

Sampling Techniques

To examine the effects of *Lantana camara* invasions on the species *diversity* and *composition* of invaded communities, a total of 120, 10mX10 m quadrats were sampled (*60 quadrats for invaded and 60 quadrats for un-invaded or control*). In each selected district 40 quadrats were laid (20 quadrats for invaded and 20 for non-invaded). In each selected study Kebele, a single quadrat of the set was placed in severely annexed plant communities ("invaded quadrat") where the aggressor was dominant and had a high concealment, and the next quadrat was located in adjacent plant community where *Lantana camara* had no cover (control) purposively. As much as possible, the control was selected to have analogous site conditions (< 10 m) to the invaded quadrat following (Hejda *et al.*, 2009 and Dogra *et al.*, 2009). The location of each quadrat and study sites were recorded with GPS.

A control was selected in order to compare the species *richness*, *evenness* and *composition* of plant communities in the *invaded* and *non-invaded* areas. All the plant species appeared in the invaded and control areas were sampled and identified. Most of the plant species discovered in the quadrats was identified in the field. For species difficult to identify in the field, voucher specimens were collected, pressed and dried properly and transported to Ethiopian Biodiversity Institute for identification and proper naming. The nomenclature of the plant species followed the Flora of Ethiopia and Eritrea.

Method of data analysis

The collected data was analyzed by using SPSS (version 21) and R-package (version 3.6.2). A *descriptive statistical* method was employed to analyze and summarize the data. *Inferential statistical method* was also employed. *Linear Regression Analysis* was used to predict the value of a variable based on the value of another variable. The *percentage* and *number* of *Lantana camara* per study site and per quadrat was taken as the *independent variables* while *diversity of plant species*, *Species richness*, *Simpson_1-D dominance index*, *Shannon-H diversity index* and *Evenness* were taken as the *dependent variable or outcome variable*. Results were also statistically analyzed by PCA to extract the significant correlations from species data set or the correlation between a row (site/plots) and a column (the plant species/variable).

Plant species diversity analysis (Shannon 1949, H') and richness and evenness of each study sites were analyzed. Evenness was calculated as $H'/\ln S$, where S is the species richness expressed as the number of species (Hejda *et al.*, 2009). Simpson index of dominance is calculated using the formula, $D = N(N-1)/\Sigma n_i^2$

($n_i - 1$) Where n_i is the number of individuals in the i^{th} plant species; N is the total number of individuals (Barrantes and Sandoval, 2009). Changes in species richness S , Simpson 1-D index of dominance, Shannon index of diversity H' and evenness between invaded and control quadrats were used to quantify the influence of invasion on these plant communities' characteristics. These changes in plant communities' characteristics between invaded and control sites were used as a measure of the impact of invasion on species richness, evenness, index of dominance, and calculated and compared to find out the loss of plant diversity due to invasion of *Lantana camara*.

Tests of association

Various *inferential statistical* tests were performed on the different types of data collected. The significance impacts of the number of *Lantana camara* on diversity of plant species had been also tested with one way *ANOVA*, while the differences in Margalef's index of species richness, evenness, Simpson and Shannon-H index of diversity between invaded and un-invaded areas were checked with the help of *t test* following Wambua(2010).

Results

Impact of *Lantana camara* on species evenness and richness in the study areas

In the present study there were found a total of 109 species in the control or un-invaded areas as compared to 56 in *Lantana camara* invaded areas. Hence, the number of species lessened by 48.6% in the *Lantana camara* invaded localities as compared to the control. Simpson_1-D index of dominance, Shannon_ H index diversity, Margalef's index of species richness, and evenness index were also reduced via 66.04%, 74.48%, 51.95% and 57% respectively in the *Lantana camara* invaded areas(Table 1).

Table 1
Values of index of diversity for Invaded and non-invaded floral communities

For invaded floral communities			For non-invaded floral communities	
No.	Index of diversity	Values	Index of diversity	Values
1	Taxa_ S	56	Taxa_ S	109
2	Individuals	6720	Individuals	4088
3	Dominance_ D	0.67	Dominance_ D	0.04
4	Simpson_1-D	0.33	Simpson_1-D	0.96
5	Shannon_ H	0.97	Shannon_ H	3.81
6	Margalef	6.24	Margalef	12.99
7.	Equitability (evenness)	0.24	Equitability (evenness)	0.81

The mean Evenness value or Equitability_J of the entire invaded sampled study sites was 0.24 indicated that 24% of the plant communities had uniform distribution while the mean Evenness value of the controls (the entire un-invaded) samples was 0.81 indicated that 81% of the plant communities had uniform distribution. Thus, the heterogeneity of the invaded study sites was reduced by 57%.

Table 2
Impact of *Lantana camara* on the plant communities

No.	Parameters	Control/un-invaded	Invaded	% reduction over control
1.	Richness(Total Species)	109	56	48.6%
2.	Simpson's Index of Dominance (I-D)	0.96	0.33	66.04%
3.	Shannon's Index of Diversity (H')	3.81	0.97	74.48%
4.	Margalef Index of Richness(R)	12.99	6.24	51.95%
5.	Index of Evenness (Es)	0.81	0.24	57.00%

From the study districts, Dara, Mechisho Kebele community forest, was harshly affected by the invasion of *Lantana camara*. In this Kebele community forest, the number of species decreased by 66.15% in the *Lantana camara* invaded area as compared to control. Further, Simpson_1-D index of dominance, Shannon_H index diversity, Margalef's index of species richness, and evenness index were reduced by 78.44%, 83.99%, 70.16% and 78.39% respectively in the *Lantana camara* invaded areas (Table 3).

Table 3
Invaded and Control Floral Communities of Mechisho Kebele community

No.	Invaded Dara		Non Invaded Dara/control	
	Diversity Index	Values	Diversity Index	Values
1.	Taxa_S	22	Taxa_S	65
2.	Individuals	2902	Individuals	1408
3.	Dominance_D	0.79	Dominance_D	0.04
4.	Simpson_1-D	0.21	Simpson_1-D	0.96
5.	Shannon_H	0.58	Shannon_H	3.60
6.	Margalef	2.63	Margalef	8.83
7.	Equitability_J	0.19	Equitability_J	0.86

Concerning to Woze kebele community forest, the number of species decreased by 52.94% in the *Lantana camara* invaded area as compared to control. In addition, Simpson_1-D index of dominance, Shannon_H

index diversity, Margalef's index of species richness, and evenness index were reduced by 65%, 68.55%, 54.49% and 60% respectively in the *Lantana camara* invaded areas as compared to control (Table 4).

Table 4
Invaded and Non Invaded Floral Communities of Woze kebele community forest

No.	Invaded		Non- Invaded /control	
	Diversity Index	Values	Diversity Index	Values
1.	Taxa_S	16	Taxa_S	34
2.	Individuals	3269	Individuals	2309
3.	Dominance_D	0.69	Dominance_D	0.13
4.	Simpson_1-D	0.31	Simpson_1-D	0.87
5.	Shannon_H	0.77	Shannon_H	2.44
6.	Margalef	1.85	Margalef	4.26
7.	Equitability_J	0.28	Equitability_J	0.69

On the other hand, Dilla Zuria (forests in Waleme area) was the least affected by the invasion of *Lantana camara*. In this areas, the number of species decreased by 31.48% in the *Lantana camara* invaded area as compared to control. Moreover, Simpson_1-D index of dominance, Shannon_H index diversity, Margalef's index of species richness, and evenness index were reduced by 32.89%, 47.83%, 31.78% and 42.36% respectively in the *Lantana camara* invaded areas as compared to control (Table 5).

Table 5
Comparisons of various diversity indexes in Invaded and control of Waleme Kebele community forest

No.	Invaded		Non Invaded/control	
	Diversity Index	Values	Diversity Index	Values
1.	Taxa_S	37	Taxa_S	54
2.	Individuals	1478	Individuals	1524
3.	Dominance_D	0.39	Dominance_D	0.09
4.	Simpson_1-D	0.61	Simpson_1-D	0.91
5.	Shannon_H	1.56	Shannon_H	2.99
6.	Margalef	4.93	Margalef	7.23
7.	Equitability_J	0.43	Equitability_J	0.75

Generally, the reduction over control on the plant diversity, Simpson_1-D index of dominance, Shannon_H index diversity, Margalef's index of species richness and evenness index were highest in Mechisho kebele followed by Woze and Waleme kebeles respectively (Table 6). This could be due to the substantial impact of *Lantana camara* invasion in the stated study areas.

Table 6

The decline on the plant diversity, Richness, and Evenness (E) of *Lantana camara* invaded plant communities over control in each of the study Kebele.

No.	Name of study site	Parameters	Control/un-invaded	Invaded	% decline over control
1.	Woze	C	34	16	52.94%
		I-D	0.87	0.31	65.05%
		‘H’	2.44	0.77	68.55%
		R	4.26	1.85	56.49%
		E	0.69	0.28	60.00%
3.	Waleme	C	54	37	31.48%
		I-D	0.91	0.61	32.89%
		‘H’	2.99	1.56	47.83%
		R	7.23	4.93	31.78%
		E	0.75	0.43	42.36%
4.	Mechisho	C	65	22	66.15%
		I-D	0.96	0.21	78.44%
		‘H’	3.6	0.58	83.99%
		R	8.83	2.63	70.16%
		E	0.86	0.19	78.39%
Caution:- Richness(C);Simpson’s Index of Dominance (I-D);Shannon’s Index of Diversity (H’);Margalef Index of Richness(R);Index of Evenness (E)					

Relationships between percentage of *Lantana camara* and species diversity in the study areas

The regression analysis showed a strong negative relationship between the coverage (percentage) of *Lantana camara* and Simpson_1-D index of diversity per quadrat .Hence, the regression equation can be presented as:

$Y = -0.0112X + 1.1924$, where Y is Simpson_1-D index of diversity and X is percentage of *Lantana camara* per quadrat. In this case, $R^2 = 0.9117$ or 91.17% of the dependent variable (Simpson_1-D index of diversity) can be explained by the independent variable (coverage of *Lantana camara*). The regression

equation and the value of R^2 indicated there was a strong negative relationship between the percentage of *Lantana camara* and Simpson_1-D index of diversity. As the percentage of *Lantana camara* increase Simpson_1-D index of diversity decrease (Fig. 2). Similarly, there was strong negative relationship between the percentage of *Lantana camara* and Simpson_1-D index of diversity per study kebele ($Y = -0.013X + 1.406$ with $R^2 = 0.998$) (Fig. 3).

There was also a strong negative linear relationship between Shannon_H index diversity and the percentage of *Lantana camara* per study quadrat and kebele ($Y = -0.0201X + 2.2128$, $R^2 = 0.8471$ and $Y = -0.0332X + 3.466$, $R^2 = 0.9999$ respectively). Generally, Shannon_H index diversity decreased with the corresponding increase in the percentage of *Lantana camara* (Figs. 4 and 5).

The regression analysis also showed a negative relationship between the coverage of *Lantana camara* and species richness per quadrat. Hence, the regression equation can be presented as: $Y = -0.0398X + 7.3319$, where Y is species richness and X is percentage of *Lantana camara* per quadrat. The regression equation indicated that there was a negative relationship between the coverage of *Lantana camara* and species richness. As percentage of *Lantana camara* increased species richness decreased (Fig. 6). In this case, $R^2 = 0.2601$ or 26.01% of the dependent variable (species richness) can be explained by the independent variable (coverage of *Lantana camara*).

Moreover, there also existed strong negative linear relationship between percentage of *Lantana camara* and species evenness per study kebele, hence, the regression equation can be presented as: $Y = -0.0077X + 0.892$, where Y is species evenness and X is percentage of *Lantana camara* per study kebele. In this case, the regression equation and R^2 ($R^2 = 0.967$, or 96.7%) indicated that there was a strong negative relationship between the coverage of *Lantana camara* and species evenness per study kebele or 96.7% of the dependent variable (species evenness) can be explained by the independent variable (coverage of *Lantana camara*). As the coverage of *Lantana camara* increased, species evenness per study kebele decreased (Fig. 7)

Study Invaded Kebele ($R^2 = 0.967$, $p < 0.01$).

The results indicated that there was also strong negative linear relationship between the coverage of *Lantana camara* and evenness of plant species per quadrat. Hence, the regression equation can be presented as: $Y = -0.0117X + 1.3546$, where Y is evenness and X is percentage of *Lantana camara* per study quadrat. In this case, $R^2 = 0.8662$, or 86.62% of the dependent variable (species evenness per study quadrat) can be explained by the independent variable (coverage of *Lantana camara*). Therefore, the regression equation and R^2 value indicated that there was a strong negative relationship between the coverage (percentage) of *Lantana camara* and evenness of plant species (Fig. 8).

Plants per invaded quadrat ($R^2 = 0.8662$, $p < 0.01$).

Furthermore, t-test on differences in Simpson diversity Index ($t = -4.8429$, $df = 11$, $p\text{-value} = 0.00052$), Shannon_ Evenness ($t = -4.4912$, $df = 11$, $p\text{-value} = 0.00091$), Margalef ($t = -4.7824$, $df = 11$, $p\text{-value} = 0.00057$) and Richness ($t = -5.304$, $df = 11$, $p\text{-value} = 0.00025$), between invaded and un-invaded study areas showed that there was significant difference in species diversity (t-test, with $p\text{-value} < 0.05$) between invaded and non-invaded study areas.

Relationship between diversity of plant species and number of individuals *Lantana camara* per quadrat

The study proved that there were considerable variations in the numbers of *Lantana camara* and diversity of plant species per plot which could be able to make a model to show the severity of the invasion. Both the numbers of *Lantana camara* and diversity of plant species contribute to the model. As the number of *Lantana camara* increased, the varieties of plant species decreased. R^2 value indicates how much of the *dependent variable (diversity of plant species)* can be explained by the *independent variables (number of Lantana camara)*. To determine the degree of impact of *Lantana camara* on diversity plant species linear regression analysis was conducted. The regression equation that describes a simple linear regression relationship in a population is expressed as: $Y_i = \alpha + \beta X_i + \epsilon_i$ Where α is the intercept and β is the slope of the relationship, ϵ_i is referred as *residual or error term* and it is the departure of an actual (measured) Y from the estimated Y using the above regression equation ($\hat{Y}$) (Barrantes and Sandoval, 2009, Pallant, 2011). In this study, Y_i is the dependent variable (diversity of plant species) and X_i is the independent variable (number of individual *Lantana camara*).

Hence, the regression equation can be presented as: $Y = -0.0386X + 9.1994$, where Y is diversity of plant species and X is number of *Lantana camara*. In this case, $R^2 = 0.6168$, or 61.68% of the dependent variable (diversity of plant species) can be explained by the independent variable (number of *Lantana camara*). The regression equation and Pearson correlation (-0.785) indicated the existence of strong negative linear relationship between diversity of plant species and number of *Lantana camara* (Fig. 9).

The number of *Lantana camara* per plot (sig. 0.000) had significant influence on the diversity of plant species. Furthermore, there was an inverse relationship between the diversity of plant species and number of *Lantana camara* per each selected study kebele. For instance, the regression equation can be presented as: $Y = -0.091X + 10.591$, $R^2 = 0.614$ for Waleme kebele (Fig. 10) and $Y = -0.03X + 7.064$, $R^2 = 0.611$, Woze kebele (Fig. 11) community forest where Y is diversity of plant species and X is number of *Lantana camara*. Therefore, the regression equation and R^2 values indicated the existence of strong negative linear relationship between diversity of plant species and number of *Lantana camara*.

Generally this study indicated that plant species diversity in *Lantana camara* invaded areas was low. There was significant variation in plant species diversity between the invaded and non-invaded plant community in the study areas ($t = -4.2839$, $df = 59$, $p\text{-value} = 6.868e-05$ which is < 0.05). The significance impacts of the number of *Lantana camara* on diversity of plant species had been also conducted with the help of One way ANOVA which revealed that number of *Lantana camara* had significant impact on the diversity of plant species ($F = 126.62$, $d.f = 1$, $P\text{ value} = 3.267e-16$ which is $P < 0.05$).

Principal Component Analysis (PCA) was also conducted for invaded and non-invaded floral communities of the study areas. As to the non-invaded floral communities, the first two principal components (PC1 and PC2) together accounted for 31.6% of the total variance in data set or 19.9% and 11.7% variance were accounted by the first and second principal components, respectively following by the third principle components. Majority of the species were at the origin or at their average values especially in non-invaded study sites. Moreover, the PCA biplot axis, indicated the separation of the common plant species including *Solanum incanum*, *Datura stramonium*, *Amaranthus caudatus*, *Ageratum conyzoides*, *Ziziphus abyssinica*, *Osyris quadripartita*, *Acacia abyssinica*, *Achyranthes* spp., *Stephania abyssinica* and *Acacia saligna* (Fig. 12).

Concerning to the invaded floral communities, majority of the plots were close together. Moreover, the invaded study areas the first, second and third principle components accounted by 16.7%, 12.3% and 10.9% of the total variance in data set respectively. Therefore, the first three principal components together accounted for 39.9% of the total variance in data set (Fig. 13). On the other hand, plots 52, 53 and 55 were far apart to each other's and from the other plots.

Impact of *Lantana camara* on the composition of plant species in the study areas

Lantana camara invasion heavily damaged the composition and structure of invaded floral communities in the study areas. In this study a comparison in floristic composition was made between *Lantana camara* invaded and non-invaded areas. An entire of 125 plant species (56 plant species in invaded, 109 in control and 38 common to both) belonging to 49 families of plants were identified in this study. From the total plant families 44 of them were recorded in the control area in contrast to only 30 in the *Lantana camara* invaded areas. The number of family decreased via 31.82% in the *Lantana camara* invaded area as compared to control.

In invaded areas, of the 30 plant families, Fabaceae was the highest (14.29%), followed by Euphorbiaceae (8.93 %), and Malvaceae and Myrsinaceae accounted 7.14% each allotting the third place amongst the plant species recorded in the *Lantana camara* invaded study areas (Table 7). In the invaded areas 37.5% of the plant species placed within these four common families.

Table 7
The four most common families in the invaded study sites

No.	Families	Number of species in the given family percentage
1.	Fabaceae	8 14.29
2.	Euphorbiaceae	5 8.93
3.	Malvaceae	4 7.14
4.	Myrsinaceae	4 7.14

In non-invaded areas, of the 44 plant families, Fabaceae was the highest (15.74%), followed by Asteraceae (10.18%), Malvaceae (5.71%) apportioning the third place, and Euphorbiaceae and Celastraceae (4.63%) each allocating the fourth place amongst the plant species recorded in the non-invaded study areas (Table 8). These five families shared 40.89% of species to the over-all flora in non-invaded (controlled) study sites.

Table 8
The seven most common families in three non-invaded study sites (in the control)

No.	Family	Number of species in the given family	Percentage
1.	Fabaceae	17	15.74
2.	Asteraceae	11	10.18
3.	Malvaceae	6	5.71
4.	Celastraceae	5	4.63
5.	Euphorbiaceae	5	4.63
6.	Lamiaceae	4	3.67
7.	Acanthaceae	4	3.67

From 125 plant species identified during the study, 38 plant species were found common in control and invaded areas (Table 9). *Lantana camara* was found to be the most dominant plant species in invaded study sites followed by *Solanum incanum*, *Achyranthes aspera* and *Parthenium hysterophorus* respectively. Trees and shrubs (78.4%) were the major plant species identified during this study. In invaded and control (non- invaded) areas 44% and 34.4% were shrubs and trees respectively.

Table 9. Plant species composition in the control and invaded areas.

No.	Scientific name	Family	C con	Control	Invaded
1.	<i>Acacia abyssinica.</i>	Fabaceae	✓		✓
2.	<i>Acacia oerfota.</i>	Fabaceae	✓		X
3.	<i>Acacia.bussei.</i>	Fabaceae	✓		X
4.	<i>Acacia saligna</i>	Fabaceae	✓		X
5.	<i>Acacia Senegal</i>	Fabaceae	✓		X
6.	<i>Acacia seyal</i>	Fabaceae	✓		X
7.	<i>Acacia Spp.</i>	Fabaceae	✓		X
8.	<i>Acacia tortilis</i>	Fabaceae	✓		✓
9.	<i>Acanthus spp</i>	Acanthaceae	✓		✓
10.	<i>Achyranthes spp.</i>	Amaranthacea	✓		X
11.	<i>Achyranthes aspera</i>	Amaranthaceae	✓		✓
12.	<i>Acokanthera schimperi</i>	Apocynaceae	✓		✓
13.	<i>Agave sisalana</i>	Agavaceae	✓		✓
14.	<i>Ageratum conyzoides</i>	Asteraceae	✓		X
15.	<i>Ajuga Spp.</i>	Lamiaceae	✓		X
16.	<i>Aloe Spp.</i>	Aloaceae	✓		✓
17.	<i>Amaranthus caudatus.</i>	Amaranthaceae	✓		X
18.	<i>Argemone ochroleuca</i>	Papaveraceae	✓		X
19.	<i>Asparagus officinalis</i>	Asparagaceae	X		✓
20.	<i>Asperagus aspera</i>	Asparagaceae	X		✓
21.	<i>Aspilia africana</i>	Astraceae	✓		X
22.	<i>Balanites aegyptiaca</i>	Balanitaceae	✓		✓
23.	<i>Bersama abyssinica</i>	Melianthaceae	X		✓
24.	<i>Cadaba farinose</i>	Capparidaceae	✓		X
25.	<i>Caesalpinia decapetala</i>	Fabaceae	✓		✓
26.	<i>Calpurnia aurea</i>	Fabaceae	✓		✓
27.	<i>Capparis spinosa</i>	Capparisdaceae	✓		X
28.	<i>Capparis tomentosa</i>	Capparaceae	✓		✓

29.	<i>Carissa edulis</i>	Apocynaceae	✓	X
30.	<i>Celtis africana</i>	Ulmaceae	✓	✓
31.	<i>Celtis gomphophylla</i>	Ulmaceae	✓	✓
32.	<i>Cirsium spp.</i>	Asteraceae	✓	X
33.	<i>Cissampelos mucronata</i>	Menispermaceae	X	✓
34.	<i>Cissus aphylla</i>	Vitaceae	✓	X
35.	<i>Cissus.cactiformis</i>	Vitaceae	✓	X
36.	<i>Clausena.anisata</i>	Rutaceae	✓	X
37.	<i>Clematis.hirsute</i>	Ranunculaceae	✓	X
38.	<i>Clematis.longicauda</i>	Ranunculaceae	✓	X
39.	<i>Clutia.abbyssinica.</i>	Euphorbiaceae	✓	✓
40.	<i>Colocasia esculenta.</i>	Araceae	✓	X
41.	<i>Combretum collinum</i>	Combretaceae	X	✓
42.	<i>Combretum molle</i>	Combretaceae	✓	✓
43.	<i>Commelina benghalensis</i>	Commelinaceae	✓	X
44.	<i>Cordia africana</i>	Boraginiaceae	✓	X
45.	<i>Cordia monoica</i>	Boraginaceae	✓	X
46.	<i>Croton macrostachyus.</i>	Euphorbiaceae	✓	X
47.	<i>Cucumis ficifolius</i>	Cucurbitaceae	✓	X
48.	<i>Cynodon dactylon</i>	Poaceae	✓	X
49.	<i>Datura stramonium</i>	Solanaceae	✓	X
50.	<i>Desmodium repandum</i>	Fabaceae	✓	X
51.	<i>Dichrostachys cinrea</i>	Fabaceae	✓	✓
52.	<i>Dicliptera maculate</i>	Acanthaceae	✓	✓
53.	<i>Dodonaea angustifolia</i>	Sapindaceae	✓	X
54.	<i>Dombeya torrida</i>	Sterculiaceae	✓	X
55.	<i>Embelia schimperi</i>	Myrsinaceae	X	✓
56.	<i>Erythrina brucei</i>	Fabaceae	✓	X
57.	<i>Eucalyptus camaldulensis</i>	Myrsinaceae	✓	✓

58.	<i>Euphorbia abyssinica</i>	Euphorbiaceae	✓	✓
59.	<i>Euphorbia pulcherrima</i>	Euphorbiaceae	X	✓
60.	<i>Euphorbia tirucalli</i>	Euphorbiaceae	✓	✓
62.	<i>Ficus thonningii</i>	Moraceae	X	✓
63.	<i>Ficus vasta</i>	Moraceae	✓	X
64.	<i>Galiniera saxifrage</i>	Rubiaceae	X	✓
65.	<i>Gardenia ternifolia</i>	Rubiaceae	X	✓
66.	<i>Gravilla robusta.</i>	Proteaceae	✓	X
67.	<i>Grewia bicolor</i>	Tiliaceae	✓	✓
68.	<i>Hibiscus acetosella.</i>	Malvaceae	✓	X
69.	<i>Hibiscus aethiopicus</i>	Malvaceae	✓	X
70.	<i>Hibiscus.macranthus</i>	Malvaceae	X	✓
71.	<i>Hibiscus Spp.</i>	Malvaceae	✓	X
72.	<i>Hippocratea africana</i>	Celastraceae	✓	X
73.	<i>Hypericum quartinianum</i>	Guttiferae	✓	X
74.	<i>Hypoestes forskaolii</i>	Acanthaceae	X	✓
75.	<i>Ipomoea batatas</i>	Convolvulaceae	✓	X
76.	<i>Ipomoea purpurea</i>	Convolvulaceae	✓	X
77.	<i>Jacaranda Memosifolia</i>	Bignoniaceae	✓	X
78.	<i>Kalanchoe petitiiana</i>	Crassulaceae	✓	X
79.	<i>Lantana camara</i>	Verbenaceae	✓	✓
80.	<i>Maesa lanceolata</i>	Myrsinaceae	✓	✓
81.	<i>Maytenus addat</i>	Celastraceae	✓	X
82.	<i>Maytenus arbutifolia</i>	Celastraceae	✓	✓
83.	<i>Maytenus spp</i>	Celastraceae	✓	X
84.	<i>Melinis repens</i>	Poaceae	X	✓
85.	<i>Microglossa pyrifolia</i>	Asteraceae	✓	✓
86.	<i>Momordica foetida</i>	Cucurbitaceae	X	✓
87.	<i>Myrsine africana</i>	Myrsinaceae	✓	✓

88.	<i>Mytenus africana.</i>	Celastraceae	✓	X
89.	<i>Ocimum lamiifolium</i>	Lamiaceae	✓	✓
90.	<i>Ocimum spp.</i>	Lamiaceae	✓	X
91.	<i>Olea spp</i>	Oleaceae	X	✓
92.	<i>Osyris quadripartita</i>	Santalaceae	✓	✓
93.	<i>PParthenium hysterophorus</i>	Astraceae	✓	✓
94.	<i>Prunus africana</i>	Rosaceae	✓	X
95.	<i>Psidium guajava</i>	Myrtaceae	✓	X
96.	<i>Rhus natalensis</i>	Anacardiaceae	✓	X
97.	<i>Rhus vulgaris</i>	Anacardiaceae	✓	X
98.	<i>Ricinus communis</i>	Euphorbiaceae	✓	X
99.	<i>Roza abysinica.</i>	Rosaceae	✓	X
100.	<i>Rumex abyssinicus</i>	Polygonaceae	✓	X
101.	<i>Rumex.nervosus.</i>	Polygonaceae	✓	X
102.	<i>Schrebera alata.</i>	Oleaceae	X	✓
103.	<i>Senna didymobotrya</i>	Fabaceae	✓	✓
104.	<i>Senna occidentalis.</i>	Fabaceae	✓	✓
105.	<i>Senna Spp.</i>	Fabaceae	✓	X
106.	<i>Senra incana</i>	Malvaceae	✓	✓
107.	<i>Sida rhombifolia</i>	Malvaceae	✓	✓
108.	<i>Sida schimperiana</i>	Malvaceae	✓	✓
109.	<i>Solanum incanum</i>	Solanaceae	✓	✓
110.	<i>Stephania abyssinica</i>	Menispermaceae	✓	X
111.	<i>Syzygium guineense</i>	Myrtaceae	✓	✓
112.	<i>Teclea nobilis</i>	Rutaceae	✓	X
113.	<i>Terminalia laxiflora</i>	Combretaceae	✓	X
114.	<i>Trigonella Spp.</i>	Fabaceae	✓	✓
115.	<i>Verbascum sinaiticum</i>	Scrophulariaceae	✓	X
116	<i>Vernonia Spp.</i>	Asteraceae	✓	X

117	<i>Vernonia amalgadina.</i>	Asteraceae	√	X
118	<i>Vernonia auriculifera</i>	Asteraceae	√	X
119	<i>Vernonia schimperi.</i>	Asteraceae	√	X
120	<i>Withania somnifera</i>	Solanaceae	X	√
121.	<i>Xanthium spinosum</i>	Asteraceae	√	X
122.	<i>Xanthium strumarium</i>	Asteraceae	√	X
123.	<i>Ziziphus abyssinica</i>	Rhamnaceae	√	X
124.	<i>Ziziphus spina.christi.</i>	Rhamnaceae	√	√
125.	<i>Zizipus Spp.</i>	Rhamnaceae	√	X

Discussion

Lantana camara affected severely the diversity and composition of invaded flora in the study area. The result of this study indicated that the number plant species, Simpson_1-D index of dominance, Shannon_H index diversity, Margalef's index of species richness, and evenness index were reduced significantly in the *Lantana camara* invaded areas as compared to control. The report of the study by Ghisalberti, (2000), Sharma *et al.*(2005), French et al. (2009) and Nel (2015) indicated that the impacts of *Lantna camara* on native biodiversity is highly marked because of the species' invasive characteristics, such as rapid vegetative growth, aggressive competitive ability, high seed production, and proliferation throughout the year in ideal environmental conditions. In addition, there are allelochemicals present almost in all parts of the plant (Choyal and Sharma,2011).

Besides, the higher value of index of dominance in the invaded areas would be predicted that the communities were homogenous in nature and dominated by a single whereas the lower value of index of dominance for non-invaded floral communities would be indicated that the heterogeneous nature of these communities and the communities were not dominated by a single or few species. Moreover, a low value of the Simpson diversity index in invaded study sites also suggests an area was dominated by a few species, homogenous nature of these communities. For instance, in Mechisho community forest (with the lowest value of Simpson diversity index), only the invader was dominated the community. It could be the result of the high invasion of *Lantana camara*. The study by Melkamu Kifetew (2005), Wambua (2010), Nel (2015) and Firew Bekele (2018) indicated the various impacts of *Latana camara* on the diversity of plants species.

On the other hand, if there are more successful species with no species completely dominating the area, the value of the Simpson diversity index is high (the control) (Barrantes and Sandoval, 2009). The communities were showing more heterogeneity in the un-invaded study areas. A high diversity index of Waleme community forest suggests that the area was not dominated by one or two species rather by large number of species which result a more stable ecosystem as reported by Chatterjee (2015) on the

impact of *Lantana camara* on the diversity of plant species. Waleme area community forest was the least affected by the invasion of *Lantana camara*. This might be due to the soil or other environmental factor limited the expansion of *Lantana camara* when compared to other study areas.

The result of the study by Dobhal et al. (2010) also indicated that *Lantana camara* is a serious threat to all major native shrubs growing along Nayar river of Pauri Garhwal, in Uttarakhand State, Himalaya, Northern India which were affected by speedy blowout and distinctive capacity to seize empty niche. In addition the study by Lwando (2009) also indicated that *Lantana camara* has predominant impact on Plant Diversity in Zambia. Generally, Shannon_H index diversity decreased with the corresponding increase in the Percentage of *Lantana camara*. The result of study by Hejda et al. (2009) also confirmed the impact of IAPs on the species richness, diversity and composition of invaded communities.

As the coverage of *Lantana camara* increased, Species Evenness per study site decreased. Evenness (E) has values between 0 and 1.0, where 1.0 represents a situation in which all species are equally abundant (Nagendra, 2002). The result of this study also confirmed that regression equation and Pearson correlation coefficient indicated the existence of strong negative linear relationship between diversity of plant species and number of *Lantana camara*. It indicated that there was a justification for the existence of great impact of number of *Lantana camara* on diversity of plant species. This study also indicated that plant species diversity in *Lantana camara* invaded areas was low. The tests of association (t-test) indicated that there was significant variation in plant species diversity between the invaded and non-invaded plant community in the study areas (p-value = 0.000069 which is < 0.05). The study by Morton (1994) also indicated numerous impacts of *Lantana camara* invasion on diversity of plant species.

A post-ANOVA test; Tukey's Honest Significant Difference (H.S.D) at 95% means was used to separate the means Pallant (2011). In this study ANOVA and then post-hoc tests/ Tukey HSD was conducted to find out which pair of independent variables (number of *Lantana camara*) are significantly different that had significant impact on diversity of plant species (dependent variables) on invaded plant communities of the study areas. Hence, the majority of pair of independent variables in this study was significantly different.

Furthermore, in this investigation PCA (Ordination) was conducted in order to place the points such that points that are nearby together match to sites that are comparable in species composition and points that are distant apart relate to sites that are unrelated in species composition (Chahouki, 2012). The plots for both invaded and non-invaded sites, the region from the origin for a row (site/plots) implies how much the point differs from the average and the area from the origin for a column (species, variable) implies how much the point increases to that direction. Accordingly, PCA was performed in invaded and non-invaded floral communities in three selected Kebeles to know the correlation between plots and the plant species. If two plots close to each other in ordination they have similar plant species and if two plots have analogous plant species, they have related environment. Two sites extreme away from each other in ordination have unrelated plant species, and perhaps have different environment (Paliy and Shankar, 2016, Oulu, 2016).

The scores acquired from a PCA for species and sites can be used to prepare a bi-plot. Consequently, PCA displayed that the species distribution scheme in association with the specific sites in the invaded and non-invaded study areas. Regarding to the non-invaded floral communities, the first two principal components together accounted for 31.6% of the total variance in data set following by the third principle component. This means that the first principal component is superior for demonstrating the distinction of the diversity of plant communities in the three study Kebeles following by the second and third principal components. Moreover, the PCA biplot axis, indicated the isolation of the common plant species including *Solanum incanum*, *Datura stramonium*, *Amaranthus caudatus*, *Ageratum conyzoides*, *Ziziphus abyssinica*, *Osyris quadripartita*, *Acacia abyssinica*, *Achyranthes* spp., *Stephania abyssinica* and *Acacia saligna* indicating the existence of various plant species which might be due to the suitable environmental condition in non-invaded study sites.

Concerning to the invaded floral communities, majority of the plots were close together which might be revealed that those sites/plots were similar in species diversity and composition. This might be resulted that the reducing diversity levels with increasing cover of the *Lantana camara* (Wekhanya, 2016, Shaheen et al., 2019). On the other hand, plots 52, 53 and 55 were far apart to each other's and from the other plots which might be indicated that those plots were unrelated in species diversity and composition.

The diversity and number of family declined considerably in the *Lantana camara* invaded area (Vardien et al., 2012, Gantayet et al., 2014). Fabaceae, Asteraceae, Malvaceae, Euphorbiaceae and Celastraceae contributed most of species (40.89%) to the total flora in non-invaded study sites. Fabaceae was the dominant family in both invaded and non-invaded study areas. This might be due to the suitable environmental condition to the species in the family and large number of species in this family.

Conclusion

Lantana camara categorized as the dominant IAPS in selected study Kebeles of the study areas that reduced species diversity and composition of various plant species in invaded communities. Information on impact of IAPSs on diversity and composition of any plant community is very important for their management. This invasive species has negative impacts on the indigenous plant and its impacts are projected to increase with time. The problem is however aggravated in the majority of terrestrial habitat. Therefore, a management and control strategy for *Lantana camara* and other IAPSs needs to be instituted. Finally, *Lantana camara* has already been established in the study areas and other parts of the country; therefore, further research is required to ascertain the best control and management strategy.

Declarations

Acknowledgments

The authors are Grateful to Ethiopian Biodiversity Institute (EBI) for financial support during the field work.

Authors' contributions: Both authors contributed to the study formation and design. Material preparation, data collection and analysis were performed by the first author. The first draft of the manuscript was written by the first author. The second author supervised the entire work of this research and edited the subsequent versions of the manuscript. Finally, the second author read and approved the final manuscript.

Funding

This study was supported by Ethiopian Biodiversity Institute (EBI) in the course of the field work.

Availability of data and material

The data analyzed during the current study are available from the corresponding author on reasonable request

Conflicts of Interest

The authors declare no conflict of interest.

Consent for publication

Both authors declare that neither the article nor portions of it have been previously published elsewhere; not under consideration for publication in another journal and both authors also consent to the publication of the manuscript in journal of Biological Invasions.

References

Abiyu Enyew, and Raja, N. (2015). Allelopathic Effect of *Lantana camara* L. Leaf Powder on Germination and Growth Behaviour of Maize, *Zea mays* Linn. and Wheat, *Triticum turgidum* Linn. Cultivars. *Asi. J. of Agri. Sci.*, 7(1), 4-10.

Aravind,N. A., Rao,D., Ganeshaiah, K. N.,Shaanker,R.U., and Poulsen,J. G. (2010). Impact of the invasive plant, *Lantana camara*, on bird assemblages at Malé Mahadeshwara Reserve Forest, South India: *Trop.Ecol.* 51 (25), 325-338.

Barrantes,G. and Sandoval, L. (2009). Conceptual and statistical problems associated with the use of diversity indices in ecology: *Int. J. Trop. Biol.*, 57 (3), 451-460.

Biodiversity Conservation, Environmental Management and Rural Development (BIOCEM-RD) (2016) Ltd. Study to assess the impacts of invasive alien species in natural forests, agro-ecosystems, lakes and wetland ecosystems in Rwanda and develop their management plans. Final report.

Chahouki,M.A.Z. (2012). Classification and Ordination Methods as a Tool for Analyzing of Plant Communities; the world's leading publisher of Open Access books Built by scientists, for scientists;

licensee In Tech. (<http://creativecommons.org/licenses.3.0>). Iran,;1-35.

Chatterjee, R. (2015). Impact of *Lantana camara* in the Indian society: *Int. J. of Envi.*; 4(2), 348-354.

Choyal,R. and Sharma,S.K. (2011). Evaluation of Allelopathic effects of *Lantana camara* (Linn) on regeneration of *Pogonatum aloides* in culture media: *As. J. of Pla. Sci. and Rese.*,1 (3),41-48.

Dobhal, P.K., Kohli, R.K., and Batish, D.R. (2010). Evaluation of the impact of *Lantana camara* L. invasion, on four major woody shrubs, along Nayar river of Pauri Garhwal, in Uttarakhand Himalaya: *Int. J. of Biodiv. and Cons.*;2(7), 155-161.

Dogra, K.S, Kohli, R. K., Sood, S. K., and Dobhal, P.K. (2009). Impact of *Ageratum conyzoides* L. on the diversity and composition of vegetation in the Shivalik hills of Himachal Pradesh (Northwestern Himalaya), India, *Int. J. of Bio. and Con.*,1(4), 135-145.

Firew Bekele (2018). Invasive *Lantana camara* L. Shrub in Ethiopia: Ecology, Threat, and Suggested Management Strategies. *J. of Agric. Sci*, 10 (7), 184-195.

French, G, B.K., Turner, P.J. and Downey, P.O. (2009). Impact threshold for an alien plant invader, *Lantana camara* L., on native plant communities. *Bio. Cons.*, 142: 2631-2641.

Gantayet, P.K., Adhikary, S.P., Lenka, K.C., and Padhy, B. (2014). Allelopathic Impact of *Lantana Camara* on Vegetative Growth and Yield Components of Green Gram (*Phaseolus radiatus*) ;*Int. J. Curr. Microbiol. App. Sci.*;3(7),327-335

Genovesi and Shine, C. (2004). European strategy on IAS Convention on the Conservation of European Wildlife and Habitats (Bern Convention) Nature and environment, No. 137 Council of Europe Publishing French edition: ISBN 92-871-5487-2. Council of Europe Publishing, F-67075.

Ghisalberti, E.L. (2000). Review: *Lantana camara* L. (Verbenaceae). *Fitoterapia. Elsevier Science.*, 71, 467-486.

Global Environment Facility (GEF) (2003). Removing barriers to invasive plant management in Africa. Project document. Glosa (Environmental Facility, United Nations Environmental Program).

Habtam Kefelegn (2015). Invasive Alien Weed Species Impacts on Biodiversity and Socio-Economic Aspect in Ethiopia: A Review. *Int. J. of Sci. and Res.*. 4(10), 2179- 2185.

Hejda, M. Pysek, P. and Jarosík, V. (2009). Impact of invasive plants on the species richness, diversity and composition of invaded communities : British Ecological Society, *J. of Ecol.*, **97, 393–403**

International Union for Conservation of Nature (IUCN) (2009). The Invasive Species Context: general principles. Workshop on biofuel production and invasive species, Wasaa, Nairobi, Kenya.

- Kumar, R., Katiyar, R., Kumar, S., Kumar, T., and Singh, V. (2016). *Lantana camara*: an alien weed, its impact on animal health and strategies to control : *J. of. Exntal. Bio. and Agri. Sci.*, 4(3S) 321_337.
- Lisanework Nigatu, Asresie Hassen, Sharma, J., and Adkins, S.W. (2010). Impact of *Parthenium hysterophorus* on grazing land communities in north-eastern Ethiopia, *Weed Bio. and Manag., J. comp.* 10, 143–152.
- Lwando, C. (2009). Effect of *Lantana camara* on Plant Diversity in Zambia : Russell E. Train Fellows; EFN (Education For Nature) Professional Development Grants; New Fellowship Competition.; 1(1), 1-5.
- Melkamu Kifetew (2005). Impact Assessment on an Invasive Species, *Lantana camara* on Indigenous Species Composition and Socio-economic Environment around Adama and Bishofitu Areas, Ethiopia: A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of Master's Degree in Environmental Science, Addis Ababa.
- Morton, J.F. (1994). Lantana, or a Red Sage (*Lantana camara* L., (Verbenaceae), Notorious weed and Popular Garden Flower; Some Cases of Poisoning in Florida. *J. of. Econ. Bot.*; 48, 259-270.
- Nagendra. H. (2002). Opposite trends in response for the Shannon and Simpson Indices of Landscape diversity., *Appl. Geog.*; 22, 175–186.
- Nel, L. (2015). Effects of a highly invasive plant (*Lantana camara*) on an agricultural flower visitation network: Thesis presented in fulfillment of the requirements for the degree of Master of Science (Conservation Ecology) in the Faculty of AgriSciences (Department of Conservation Ecology and Entomology), Stellenbosch University, the Western Cape province of South Africa.
- Oulu, J.O. (2016). Multivariate Analysis in Ecology; Multivariate Analysis and Ordination <http://cc.oulu.fi/jarioksa/> (Oulu)., 1-47.
- Paini, D.R., Sheppard, A.W., Cook, D.C., De Barro, P.J., Worner, S.P., Thomas, M.B. (2016). Global threat to agriculture from invasive species. *Pro. National Academy of Sciences.* 113 (27), 7575–9.
- Paliy, O. and Shankar, V. (2016). Application of multivariate statistical techniques in microbial ecology; HHS Public Access; *Mol Ecol.*, 25(5), 1032–1057.
- Pallant, J. (2011). SPSS Survival Manual a step by step guide to data analysis using SPSS, 4th edition Cataloguing-in-Publication, National Library of www.librariesaustralia.nla.gov.au., Australia. 148-167.
- Rezene Fessehaie and Taye Tessema (2014). Alien Plant Species Invasions in Ethiopia: Challenges and Responses. Ethiopian Institute of Agricultural Research.
- Sebsebe Demissew and Hedberg, I. (2006). Flora of Ethiopia and Eritrea, formatted with Ventura Publisher, Addis Ababa, Ethiopia, Volume. 5, p. 507.

Shaheen,H., Batool,A., Gillani,S.F., Dar,M.E.I., Habib,T., Aziz,S. (2019). Diversity and Distribution of Invasive Plant Species in Suburban Vegetation of Kashmir Himalayas. *Poli. J.I of .Envi.tal. Stu.* 28(4),1-11.

Sharma,G.P., Raghubanshi,A.S., and Singh, J. S. (2005). *Lantana camara* invasion: An overview Review paper Blackwell Publishing Asia Pty Ltd ,*Weed Bio and Manag*, 5, 157–165.

Vardien, W., Richardson, D.M. , Foxcroft, L.C. , and Thompson, G.D. , Wilson, J.R.U. and Le Roux, J.J. (2012). Review: Invasion dynamics of *Lantana camara* L. (*sensu lato*) in South Africa. *Sout. Afri. J. of Bot.*; 81: 81-94.

Vaughan,S. (2003). Ethnicity and Power in Ethiopia. Ph.D. Thesis, University of Edinburgh, Scotland.

Wambua,J.K. (2010).The distribution, abundance and ecological impacts of invasive plant species at Ol-donyo sabuk national park, Kenya , A thesis submitted in partial fulfillment for the Degree of Master of science in the Biology of Conservation, University of Nairobi, School of Biological Sciences, Nairobi,.

Wekhanya, M. N. (2016). The effect of invasive species *Lantana camara* on soil chemistry at Ol- Donyo Sabuk National park, Kenya, A thesis submitted in partial fulfillment of the requirements for award of the degree of masters of Science (Plant Ecology) in the school of pure and applied sciences, Kenyatta University, Kenya.

[Zebene Asfaw](#) and Agren,G. I. (2007). Farmers' local knowledge and topsoil properties of agroforestry practices in Sidama, Southern Ethiopia. *Agroforestry Systems, An acad. Public..*: 71 (1):35-48.

Figures

Figure 1

Administrative Map of the study area

Figure 2

the Relationship between Simpson_1-D Index of Diversity and Percentage of *Lantana camara* per invaded quadrat ($R^2 = 0.9117$, $p < 0.01$).

Figure 3

the relationship between Percentage of *Lantana camara* and Simpson_1-D Index of Diversity per invaded study Kebele ($R^2 = 0.998$, $p < 0.01$)

Figure 4

The relationship between Percentage of *Lantana camara* and Shannon_H index diversity per invaded quadrat ($R^2 = 0.847$, $p < 0.01$).

Figure 5

the relationship between Percentage of *Lantana camara* and Shannon_H index diversity per invaded study Kebele ($R^2 = 0.999$, $p < 0.01$).

Figure 6

the relationship between Percentage of *Lantana camara* and Species Richness per invaded quadrat ($R^2 = 0.2601$, $p < 0.01$).

Figure 7

the relationship between Percentage of *Lantana camara* and Species Evenness per Study Invaded Kebele ($R^2 = 0.967$, $p < 0.01$).

Figure 8

The relationship between Percentage (coverage) of *Lantana camara* and Evenness of Plants per invaded quadrat ($R^2 = 0.8662$, $p < 0.01$).

Figure 9

the relationship between diversity of plant species and number of *Lantana camara* per quadrat ($R^2 = 0.6168$, $p < 0.01$)

Figure 10

Diversity of Plant species (Y) and number of Lantana camara per invaded plot (X) (Waleme Kebele community forest) ($R^2 = 0.614$, $p < 0.01$)

Diversity of Plant species (Y) and Number of *Lantana camara* per invaded plots (X) (Woze kebele community forest ($R^2 = 0.611$, $p < 0.01$)).

Page 32/34

Figure 14

Photo showing Level of Invasion by *Lantana camara* from Mirab Abaya district (Woze kebele Community forest: - photo taken in April, 2020).