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Phytosociological analysis in disturbed zone of the Gatumba mining area, Ngororero district, Rwanda

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Abstract

The Gatumba mining area is one among the zones disturbed by the mining activities in Ngororero district, west of Rwanda. The aim of the study was to investigate the plant community, to indentify plant species and describe the vegetation of the Gatumba mining area and to suggest species that can be used for rehabilitation of the disturbed area. The floristic data were analysed in accordance with the Braun-Blanquet procedures, Jaccard similarity index and Shannon index for the plant diversity analysis. A total of 35 families were recorded with 83 genera, and 103 species (31 monocotyledones, 68 dicotyledones, 1 gymnosperm and 3 pteridophytes). The most represented family was Poaceae with 19,6% species, followed by Asteraceae with 15% species. These two families are known to colonize disturbed areas and usually demonstrate adaptation to unfavorable conditions. The results showed that the vegetation was diversified and heterogeneous and four plant communities collectively made by a mixture of shrubby and grassy vegetation. The dominant species are annual, related to human activity. Indigenous species have disappeared in the area which demonstrates the negative impact of the mining and agricultural activity on the plant community of the area. The species *Tithonia diversifolia*, *Sesbania sesban* and *Crotalaria dewildemaniana* were found to be the most indicated for rehabilitation of the disturbed area.

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Introduction

Rwanda is a small country (26,338 km²), located within the centre of the Albertine Rift, in the western arm of the Africa' s Rift Valley, which is considered to be the highest in species richness in Africa and makes the country ideal for focus on issues of conservation (REMA, 2009). Rwanda shelters 2,150 plant species known today; the number of plant species found in this country is far from being totally fully identified and new species are still being discovered. Rwanda's natural vegetation is regional mosaic comprising Guineo-Congolese and Sudanese vegetation types which includes savannah with grasses, bushes and trees; mountain rain forests and mountain meadows; forest galleries, swamps and aquatic vegetation (MINITERE and ISAR, 2007).

Rwanda constitutes the Eastern limit for plants from the Guineo-Congolian region. An example is the *Thonningia sanguinea* VAHL. (Balanophoraceae), which is widespread in Western and central Africa, and is found in Cyamudongo forest, in the Western part of Rwanda (REMA, 2009). Plants from the Afromontane region are confined to higher altitudes, such as the orchid *Disa robusta* found in Nyungwe forest (REMA, 2009). The East African Savannah elements comprise the Zambezian floral region, and most of these plants are found in Akagera National Park and its surroundings (Fischer and Killmann, 2007). Some species found all over the country in Rwanda include *Ficus thonningii BLUME*, *Euphorbia tirucalli L.*, *Erythrina abyssinica* LAM. ex A. RICH., *Vernonia amygdalina* DELILE, *Dracaena afromontana* MILDBR.. These plant species have been traditionally planted around the households since long time ago in Rwanda. The country is currently covered by 21% of forests in total (MINAGRI, 2012). Total vegetation area continues to decline in Rwanda because of human activities including agriculture, mining and urbanization.

Mining has caused significant land erosion and severe pollution of rivers and streams surrounding the area and destroyed the local vegetation. Moreover, the increase in price of Coltan Tantalum in the international market has resulted in an overexploitation of Gatumba mining zone. As a consequence, natural vegetation cover was removed and top soil washed away, exposing bare soil or rock which reduced available land for cultivation in a highly populated region (Byiringiro and Biryabarema, 2008).

This current study regards to the effect of coltan excavation on vegetation in Gatumba mining area and possible ways to mitigate by using local plant species.

Previous study of the vegetation in the vicinity of the Gatumba mining area (Ndabaneze *et al.*, 2008) showed that native vegetation had almost disappeared in that area and has been replaced by other local and exotic plant species such as *Lantana camara L.* The mine spoils are colonized by natural vegetation or used for cultivation of annual crops and small-scaled farming systems have been developed.

In the framework of the national policy on environment conservation there is a need to systematically rehabilitate all the areas disturbed by the mining and quarries exploitation by using local plant species among others. To undertake such important activity in the Gatumba mining zone a survey of the vegetation was necessary in order to help in selecting plant species that can be recommended to be used in the rehabilitation process.

The study aims to evaluate the impact of the mining activity on the plant communities in the study area and identify plant species that easily grow in that particular area. Hence, according to the plant species found the study will guide the management decisions in selecting plant species that are the most suitable for the rehabilitation process of the disturbed area.

Materials and methods

The study area

The study area covered the Gatumba mining zone. Administratively, it is located in Ngororero district, Western province, Rwanda. With regards to the coordinates of Gatumba mining area, it is bounded by the following coordinates: latitude 1°53' and 1°56' S; 29°37' and 29°40' E. The study area covers an area of about 12 km². It is found in two cells of Gatumba sector, namely Cyome and Ruhanga cells, which are administrative subunits of sectors and subunits of a district.

Topography and soils at Gatumba mining area

The typical Soil Reference Groups (WRB, 2006) identified the types of soils found in the investigated area of Gatumba mining as technosol, greysol, cambic-fluvisol, fluvisol, luvisol, umbrisol, lixisol and leptosol. The soils of the Gatumba mining area are typical soils of the tropical highlands of Rwanda. They are relatively young, flat grounded, influenced by landslides and soil flushing, containing non-weathered material and often characterised by higher soil fertility than lowland soils (FAOSTAT, 2007).

Climate of the study area

Ngororero District is characterized by a tropical climate with an average annual temperature of 18°C but this varies with altitude (Table 1).

Ngororero district has a bimodal rainfall pattern with short rains from October to December and long rains from March to June. At an average altitude of 1700 m asl, the annual mean precipitation in the Gatumba mining area amounts to 1200 mm. The Gatumba area receives rain throughout the year, with the maximum precipitation in March and minimum in July. The year 2010 had slightly more rain than 2009 (Fig. 1).

Transect methods

The phytosociological study was conducted by using the transect method (Troupin, 1966) due to the apparent heterogeneity of the vegetation in the study area. In total, four sites (Ruhanga, Birambo, Mpare and Rwasare) were investigated comprising 20 transects. Each transect was 50m long and plots of 4m² were placed at every 10m along the selected transect. The sampling sites were selected according to historical and present mining activities, plant communities, and archived photographs of mining. The selection of transect orientation was guided by the floristic heterogeneity and the plant physiognomy encountered on ground. For each of the 20 transects selected the type of soil was identified according to the Soil Reference Groups (Table 2).

Plant species were identified according to Troupin (1978, 1982, 1985 and 1988). Local names were provided by local population in the field and were also helpful for plant identification.

Data processing

From the transect method used for plant sampling, each plant was assigned a coefficient of Abundance-Dominance (AD). This coefficient is the average percentage of the surface covered by the individual plant species present in a sampled site. Estimation of average surface covered by plant species and allocation of AD coefficient were done according to Braun-Blanquet (1934) cited in Troupin (1966) (Table 3). The medium of coverage classes is considered to be the most significant but it gives a very big importance to the elevated surface coverage. This method has the merit of being operational on the data obtained on the ground over the other methods developed by van der Maarel (1975) which has the higher scale value.

In order to analyse plant communities, the following phyto-sociological parameters were calculated (Troupin, 1966):

1) Presence (*P*) represents the presence or absence of a plant species along a transect;
2) Frequency (*F*) is the presence rate of plant species along transects and is given by the following formula:

$$F = \frac{P}{N} \times 100$$

where N is the number of sampling points (relevés).
3) Relative frequency (*RF*) is the percentage rate of the frequency of one plant species compared to the total frequencies of plant species of a transect, and it is calculated using the formula in below:

$$RF = \frac{F}{\sum F} \times 100$$

4) Dominance (*D*) is the sum of all medium coverage for each plant species within the transect. The relative dominance (RD) is the percentage rate of the dominance of one plant species compared to the total dominance of all species within transect and is calculated as:

$$RD = \frac{D}{\sum D} \times 100$$

5) Frequency- dominance (*FD*) is the sum of relative dominance and relative frequency.

6) Performance index (φ) is the dominance of a species along a transect which is calculated according to the following formula:

$$\varphi = \frac{FD}{\sum FD} \times 100$$

Different transects were compared to assess the similarity and dissimilarity of plant sample sets based on Jaccard similarity index (J) (Jaccard, 1908) calculated by the formula:

$$J_{i,j} = \frac{a}{a+b+c}$$

where *i* and *j* are a set of two transects, *a* is the number of plant species present in the two transects, *b* is the number of plant species present only in the first transect, and *c* is the number of plant species present only in the second transect.

The Jaccard coefficients were calculated using Multivariate Statistical Package (MVSP) (Kovach, 1993) and displayed on horizontal axis of different dendrograms. According to Gillet (2000), the value of Jaccard similarity index varies from 0 (very dissimilar vegetation) to 1 (very similar). If J is <0.5, the vegetation investigated is heterogeneous and if it is >0.5, the vegetation is homogeneous.

Shannon diversity index (*H*) (1948) was used to measure the diversity in categorical order. It was calculated using the following formula:

$$H = -\sum_{i=1}^{s}(P_i \times \log 10 Pi)$$

where P_i is the fraction of the entire population made up of species *i*, and s is the number of species encountered on site. After using MVSP for Shannon diversity index calculation, the H values of the indices were typically compared to ½ $\log_{10}$ N, where N represents the total number of plant species found in a given site. When the H value is higher than the ½ $\log_{10}$ N, the studied vegetation is considered as diversified.

Results

From a total of 20 transects selected, 103 plant species were collected and grouped into 83 genera and 35 families, dominantly representing flowering plants, including 31 monocotyledons and 68 dicotyledons (Fig. 2, Table 4). Among the monocotyledons the dominant family was Poaceae, with 19.6% of total species collected while for the dicotyledons, the dominant family was Asteraceae, with 15% of total species collected in the study area. Rare non-flowering plants were also found, and they include gymnosperms and pteridophytes representing 1% and 3%, respectively. From the overall number of plant species found on the study site, Ruhanga site has the largest number of plant species (77), followed by Mpare site (44) and Birambo site (40), while the lowest numbers of plant species was found at Rwasare site (36).

Table 1. Monthly temperatures (in °C) of Ngororero District, adapted from data of Gisenyi meteorological center (2010).

Months/ Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
2009	19.8	19.5	20.2	19.9	20.1	20.2	19.9	21.1	20.9	20.4	19.9	20	20.16
2010	20.6	21.1	20.6	20.3	20.8	20.1	20	21.3	20.2	20.1	20	20.1	20.43

Floristic analysis per site

For each site investigated in study area, a number of dominant plant species were found, based on the above-mentioned list and using the performance index as a criterium. Performance index was calculated for each plant in each transect at every site and this allowed to determine dominant plant species for each site (Fig. 3).

Table 2. Transects location and respective soil types.

Site	Transects	Soil types
Ruhanga	T1	Technosol
	T12	Technosol
	T2	Technosol
	T13	Technosol
	T3	Technosol
	T14	Technosol
	T4	Technosol
	T15	Technosol
	T5	Lixisol
	T16	Cambic-Fluvisol
Birambo	T10	Fluvisol
	T20	Fluvisol
	T9	Fluvisol
	T19	Fluvisol
Rwasare	T8	Fluvisol
	T11	Fluvisol
Mpare	T7 T17	Fluvisol Fluvisol
	T11	Cambic-Fluvisol
Birambo	T6	Fluvisol

In Ruhanga site (Fig 3a) *Digitaria abyssinica* dominates herbaceous stratum with performance index of 45.5% values. It is followed by *Digitaria velutina* with 33.5% and *Crotalaria dewildemaniana* with 26.7%. The vegetation of Ruhanga site can be defined as a plant association of shrubby-grassland dominated by *Digitaria abyssinica, Digitaria velutina, Lantana camara, Crotalaria dewildemaniana,* and *Sesbania sesban*

It was also observed that the Ruhanga soil is very disturbed by mining and other human activities and its Technosol soil type is covered by poor vegetation. At this site during the study, the mining activities were still going on for extraction of coltan and other minerals. The extraction of mineral was done on steep slope which facilitated the movement of soil as land slide

In Mpare site (Fig 3b) the vegetation was dominated by *Digitaria abyssinica* with the performance index equivalent to 36.1%, followed by *Digitaria velutina* with 15.2%, *Erythrina abyssinica* (14.7%) and *Ageratum conyzoides* L with 11.4%. Thus, the vegetation of Mpare site can be defined as a shrubby-grassland made by an association dominated by *Digitaria abyssinica, Erythrina abyssinica* and *Ageratum conyzoides*. The type of soil found in Mpare was fluvisol with influence of water flow from Ruhanga mining site.

Table 3. Medium coverage of the Abundance-Dominance coefficients.

Abundance-Dominance (AD) coefficient Braun-Blanquet (1934)	Range in coverage (%)	Medium coverage (%)
5	100-75	87.5
4	75-50	62.5
3	50-25	37.5
2	25-5	15
1	<5	2.5
+	Low coverage	0.2
r	one individual	0.1

Rwasare site (Fig 3c) the vegetation was dominated by *Erythrina abyssinica* with 14.7% followed by *Ageratum conyzoides* with performance index of 12.2%. The herbaceous stratum was represented by

Digitaria abyssinica. Thus, the vegetation of Rwasare site can be defined as a shrubby-grassland made of association of *Ageratum conyzoides, Erythrina abyssinica, Bambusa vulgaris* and *Digitaria abyssinica*. The soil type found in this site was fluvisol due to its richness in limon and other sediments characterizing this type of soil.

In Birambo site (Fig 3d) *Cyperus papyrus* dominates with a performance index of 44.5%. The next dominant plant species were *Leersia hexandra, Polygonum pulchrum* and *Bridelia micrantha* with performance indices of 35.3%, 29.2% and 16.1% respectively. The vegetation of Birambo site can be defined as a shrubby-grassland made *of Cyperus papyrus, Leersia hexandra*, and *Polygonum pulchrum* association. The soil was a fluvisol, which was very rich in humus brought by affluent streams of Nyabarongo River.

Table 4. Families, genera and species of plants collected in Gatumba mining area.

Families	Species	Genera number	Species Number
Dicotyledons			
Acanthaceae	*Acanthus pubescens (OLIVER) ENGL.*	2	3
	Acanthus repens OLIVER		
	Dyschoriste trichocalyx (OLIVER) LINDAU		
Amaranthaceae	*Achyranthes aspera L.*	1	1
Anacardiaceae	*Mangifera indica L.*	1	1
Apiaceae	*Centella asiatica (L.)URBAN)*	1	1
Araliaceae	*Polyscias fulva (HIERN) HARMS*	1	1
Asteraceae	*Ageratum conyzoides L.*	12	15
	Aspilia kotschyi (SCHULTZ-BIP. ex. HOCHST.) OLIVER		
	Bidens grantii (OLIVER) SHERFF		
	Bidens pilosa L.		
	Bothriocline longipes OLIVER et HIERN.		
	Conyza welwitschii (S. MOORE) WILD.		
	Crassocephalum vitellinum (BENTH.) S.MOORE.		
	Gynura scandens O. HOFFM.		
	Helichrysum globosum SCHULTZ-BIP. ex A. RICH.		
	Helichrysum mechoianum P. BEAUV		
	Helichrysum newll OLIVER et HIERN.		
	Microglossa pyrifolia (LAM.) KUNTZE		
	Tithonia diversifolia (HEMSLEY) A.GRAY.		
	Galisonga parviflora CAV.		
	Vernonia amygdalina DELILE		
Balsaminaceae	*Impatiens burtonii HOCHST.f.*	1	2
	Impatiens bequaertii DE WILD.		
Convolvuulaceae	*Ipomoea batatas (L.) LAM.*	2	2
	Ipomoea cairica (L.) SWEET		
Euphorbiaceae	*Acalypha racemosa WALLICH. et BAILLON*	4	5
	Bridelia brideliifolia (PAX.) FEDDE		
	Bridelia micrantha (HOCHST.) BAILLON		
	Euphorbia tirucalli L.		
	Manihot esculenta CRANTZ		

Fabaceae	*Cassia singueanna DELILE*	10	12
	Rhynchosia minima (L.) DC.		
	Caesalpinia decapetala (ROTH) ALSTON		
	Crotalaria dewildemaniana WILCZEK		
	Crotalaria recta A. RICH.		
	Desmodium intortum (MILL.) URB.		
	Eriosema montanum BAKER f.		
	Erythrina abyssinica LAM. Ex A. RICH.		
	Indigofera arrecta HOCHST. ex A. RICH.		
	Rhynchosia luteola (HIERN.) SCHUMANN		
	Sesbania sesban (L.) MERRILL var nubica CHIOV.		
	Tephrosia pumila (LAM.) PERSON		
Flacourtiaceae	*Dasylepsis racemosa OLIVER*	1	1
Lamiaceae	*Hoslundia opposita VAHL.*	2	2
	Leonotis nepetaefolia (R.BR.) ALTON f.		
Malvaceae	*Triumfetta cordifolia A. RICH.*		
	Hibiscus ludwigii ECKLON et ZEYHER.	2	3
	Hibiscus noldeae BAK. f.		
Melastomataceae	*Dissotis ruandensis ENGL.*	1	1
Myrtaceae	*Psidium guajava L.*	2	2
	Eucalyptus ficifolia F.J.MUELL		
Myricaceae	*Myrica silicifolia HOCHST. ex A. RICH.*	1	1
Myrsinaceae	*Maesa lanceolata FORSSKAL.*	1	1
Onagraceae	*Ludwigia abyssinica A. RICH.*	1	1
Oxalidaceae	*Biophytum petersianum KLOTZSCH*	2	2
	Oxalis latifolia KUNTH		
Passifloraceae	*Passiflora edulis SIMS.*	1	2
	Passiflora ligularis JUSS.		
Phytolaccaceae	*Phytolacca dodecandra L'HERIT.*	1	1
Polygonaceae	*Polygonum pulchrum BLUME*	1	1
Rosaceae	*Rubus rigidus SMITH.*	1	1
Rubiaceae	*Spermacoce princeae (SCHUMANN) VERDC.*	1	1
Verbanaceae	*Clerodendrum myricoides (HOCHST.) R.BR. ex VATKE*	2	3
	Clerodendrum rotundifolium OLIVER		
	Lantana camara L.		
Monocotyledons			
Agavaceae	*Dracaena afromontana MILDBR.*	2	2
	Sensevieria dawei STAPF.		
Araceae	*Colocasia esculenta (L.) SCHOTT*	1	1
Cyperaceae	*Cyperus distans L.f.*	2	6
	Cyperus latifolius POIRET		
	Cyperus papyrus L.		
	Cyperus pseudoleptocladus KUEK.		
	Cyperus rigidifolius STEUDEL		
	Lipocarpha chinensis (OSBECK)J. KERN		
Commelinaceae	*Commelina benghalensis L.*	1	1
Musaceae	*Musa sapientum L.*	1	1
Poaceae	*Bambusa vulgaris SCHREDER*	16	20

	Brachiaria semiundulata (HOCHST. ex A. RICH) STAPF		
	Cynodon nlemfuensis VANDERYST		
	Digitaria abyssinica (HOCHST. ex A. RCH.) STAPF		
	Digitaria velutina (FORSSAKAL) P. BEAUV.		
	Eragrostis exasperata PETER.		
	Euleusine indica (L.) GAERTN.		
	Hyparrhenia collina (PILG) STAPF		
	Hyparrhenia filipendula (HOCHST. ex STEUDEL) STAPF		
	Hyparrhenia rufa (NEES)STAFF		
	Imperata cylindrica (L.)BEAUV.		
	Leersia hexandra SWARTZ		
	Melinis minutiflora P.BEAUV.		
	Panicum chionachne MEZ		
	Paspalum conjugatum FLUEGGE		
	Paspalum scrobiculatum L.		
	Pennisetum purpureum SCHUM.		
	Rhynchelytum repens (WILLD.) C.E. HUBB.		
	Sporobolus pyramidalis P. BEAUV.		
	Zea mays L.		
Non-flowering plants			
Pteridaceae	*Nephrolepis cordiofolia L.*	2	2
	Pteridium aquilinum (L.)KUHN		
Selaginellaceae	*Selaginella* sp.	1	1
Cupressacae	*Cupressus* sp.	1	1

For the overall vegetation of Gatumba mining area couple of transects have been correlated in order to analyse their similarities or dissimilarities. This relationship between transects was highlighted by Jaccard similarity indices. The vegetation with lower value of Jaccard index of 0.5 was classified as heterogeneous, while the one which had a value equal or higher than 0.5 was classified as homogeneous Gillet (2000). In twenty transects combined from all four sites, the dendrogram (Fig. 4) shows that Jaccard coefficients for some couples of transects (T5-T9, T4-T8 and T12-T14) are higher than 0.5 values. The remaining couples of transects present Jaccard coefficients which are less than 0.5, demonstrating dissimilarity. Thus, the flora of Gatumba mining area is heterogeneous.

An overall calculation of the Shannon diversity indices for the four sites was done to evaluate the diversity of Gatumba flora as a whole. The threshold value for the 103 plant species identified in the whole Gatumba area is ½ $\log_{10}103$= 1,004. All transects except T2 and T20 possess the Shonnon index values that are higher than 1,004 (Fig. 5), which indicates that the flora of Gatumba mining area is diversified in general.

Discussion

Phytosociological analysis showed that the study area is mainly cultivated and four plant communities characterize the area which is dominated by grasses and to a lesser spatial extent, by shrubs. Those categories of plant communities include dicotyledons (66%) with 68 plant species, monocotyledons (30%) with 31 plant species, pteridophytes (3%) and gymnosperms (1%). Ndabaneze *et al.* (2008) found the same categories of plants although their respective frequencies are relatively different from those found in the current study. In this study, the ratio of monocotyledons to dicotyledons is 1/2.2.

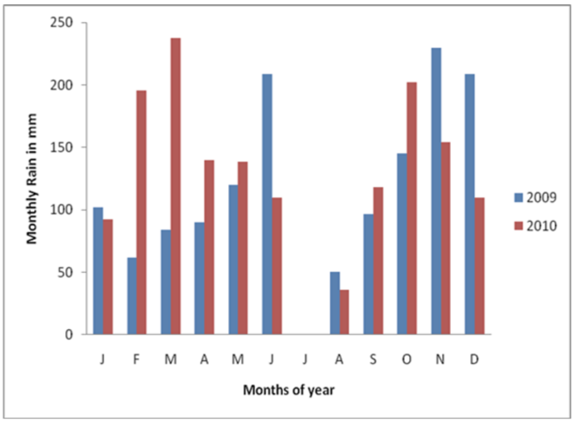

Fig. 1. Monthly rainfall of Ngororero District (adapted from data of Gisenyi meteorological center (2010).

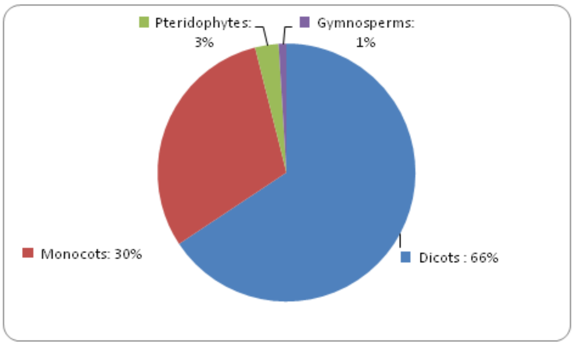

Fig. 2. Distribution of plant categories found in Gatumba mining area.

The natural vegetation in the area which was a forest as reported by Ndabaneze *et al.* (2008), has disappeared and is today represented by very few indigenous species like *Polyscias fulva*. According to the performance index of the species in different sites, dominant species which characterize the plant communities in the study area differ from one site to another. This is probably due to the types of soil but also to the degree of disturbance by the human activities. Most of the species identified are annual and their establishment is in close relation with human activities including mining and agriculture. The study revealed that the investigated site is a highly disturbed area. This is manifested by the mixture of dominant plant families which are characteristic of disturbed environments. In fact, Asteraceae family was found to be dominant (15%) among dicotyledons while Poaceae was found to be dominant among monocotyledons (19.6%). According to Ye *et al.* (2008) Gramineae and Compositae manifest universal high tolerances and adaptations to unfavorable conditions. The Poaceae family was also reported by Shu *et al.* (2005) to be one of the colonizing vegetation in mine tailings with high metal concentration and low fertility.

Among the identified plant species, we found *Lantana camara* L., and *Tithonia diversifolia* which are invasive plant species. As Gatumba mining site undergoes an increasing concentration in metal elements, this may modify the natural soil composition and helps in the colonization by new plant species. This has been confirmed by Knops *et al.* (1999) when they observed that contaminated soils were more exposed to colonization by invasive plant species easily propagated by birds and with ability to grow on different types of soil due to loss of local biodiversity.

Jaccard similarity indices calculated for Gatumba vegetation were less than 0.5, which characterise heterogeneous vegetation. This coefficient of 0.5 has been discussed by Gillet (2000) to distinguish heterogeneous from homogeneous vegetation. Such heterogeneous status demonstrates the dissimilarity between the transects selected in the area, and may be due to the variability of the types of soil and to the degree of soil degradation caused by mining activities, other human activities and other factors such as soil erosion. Furthermore, the high values of the Shannon diversity index for most transects indicate that the flora in Gatumba mining area is diversified with a large number of species that are relatively evenly distributed.

Among the plant species growing in the area under investigation *Tithonia diversifolia, Sesbania sesban* and *Crotalaria dewildemaniana* can be recommended to be cultivated for rehabilitation. Though those plants species do not exhibit the highest performance index in the area they can produce biomass in a short period. Moreover, *Crotalaria dewildemaniana* and *Sesbania sesban* are able to fix nitrogen and are useful fodder. Thus the above mentioned species are good candidate species to be cultivated for mine reclamation where mining activity has been completed

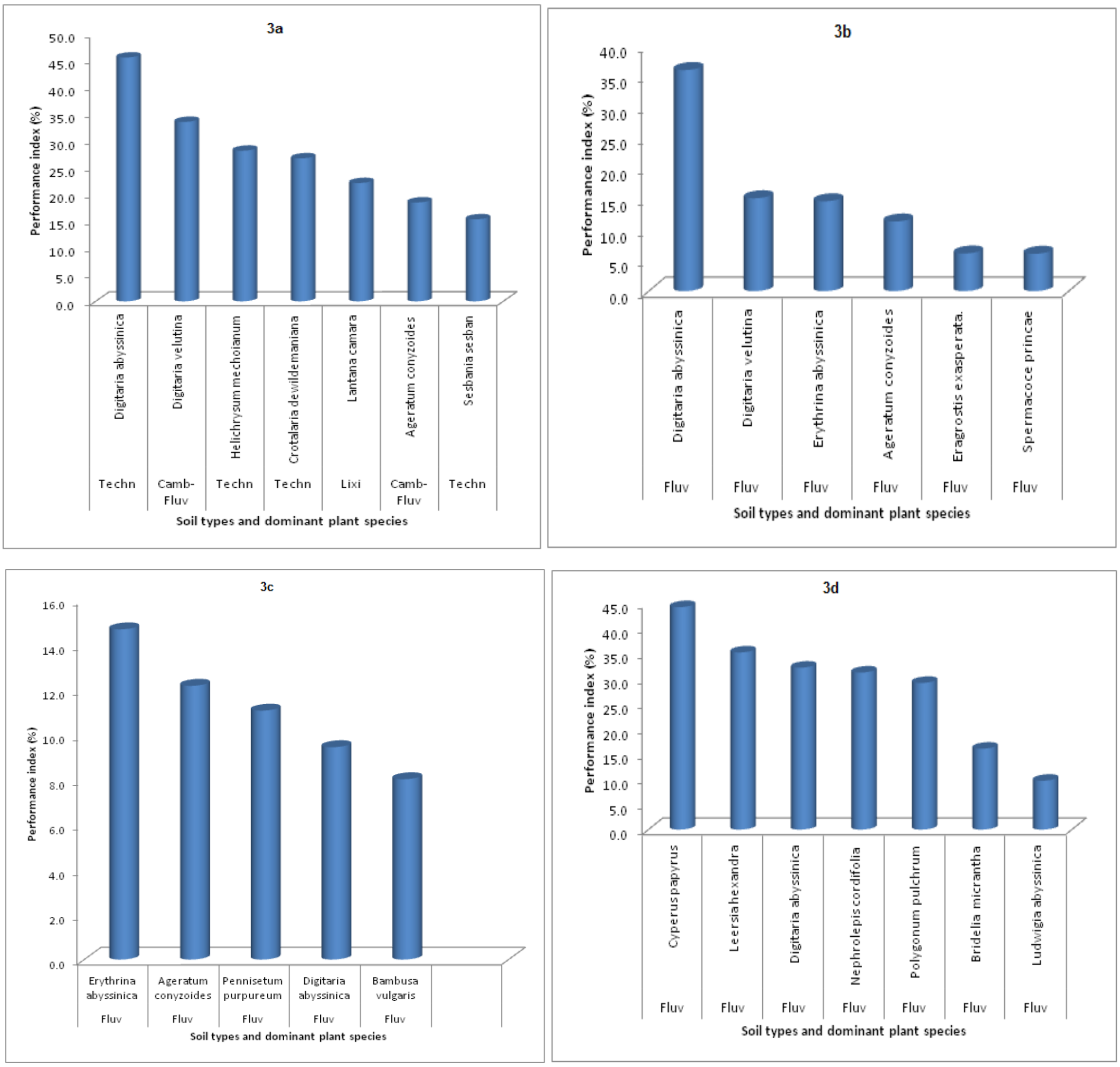

Fig. 3. Performance indices of dominant plant species in four sites according to their respective soil types (Fluv: fluvisol, Camb-fluv: cambic-fluvisol, Lixi: lixisol). **a:** Ruhanga site, **b:** Mpare site, **c**: Rwasare site and **d:** Birambo site.

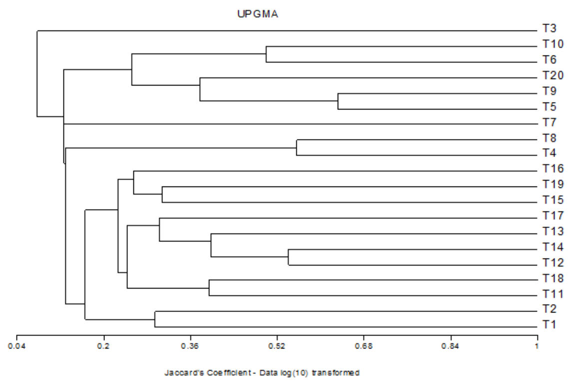

Fig. 4. Dendrogram of 20 transects of Gatumba mining area. (T: represents transects).

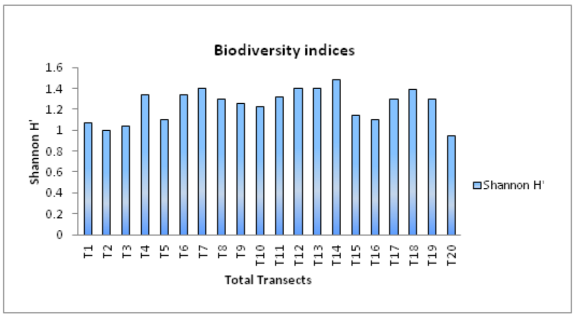

Fig. 5. Shannon diversity indices for all transects of the study area.

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Appendix 2. Absence or presence of plant species in all transects of the study area.

Plant species	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
Acalypha racemosa	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Acanthus pubescens	0	0	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	1	0	0
Acanthus repens	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
Achyranthes aspera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Ageratum conyzoides	1	0	0	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1
Antherotomma naudinii	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aspilla kotschyi	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Bambusa vulgaris	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0
Bidens grantii	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	1	0
Bidens pilosa	0	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0	1	0	0	0
Biophytum petersianum	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
Bothriocline longipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Brachiaria semiundula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0
Bridelia micrantha	0	0	0	1	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0
Bridelia brideliifolia	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0
Caesalpina decapetala	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Cassia singueans	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0
Centella asiatica	1	1	1	0	1	0	0	0	1	0	0	1	1	1	0	0	1	0	0	0
Clerodendrum myricoides	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Clerodendrum rotundifolium	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0
Colocasia esculenta	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
Commelina benghalensis	0	0	0	0	1	1	0	0	1	1	1	1	1	1	0	0	0	1	1	1
Conyza wewitschii	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crassocephalum vitellinum	1	1	0	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0

Crotalaria arrecta	0	0	1	0	0	0	0	0	0	0	0
Crotalaria dewildemaniana	0	0	1	0	0	0	0	0	0	0	0
Cupressus sp	0	0	0	1	0	0	0	1	1	0	0
Cynodon nlemfuensis	0	0	0	0	0	0	0	0	0	0	1
Cyperus distans	0	0	0	0	0	0	0	0	0	0	0
Cyperus latifolia	0	0	0	0	1	0	0	1	0	0	0
Cyperus papyrus	0	0	0	0	1	1	0	0	1	1	0
Cyperus pseudoleptocladus	0	0	0	0	0	0	0	0	0	0	0
Cyperus rigidifolius	0	0	0	0	0	0	0	0	0	1	0
Dasylepsis racemosa	0	0	0	0	0	0	1	0	0	0	1
Desmodium intortum	0	0	0	1	0	0	0	1	0	0	0
Digitaria abyssinica	1	1	1	1	1	1	0	1	1	0	1
Digitaria velutina	0	0	0	0	0	0	1	0	0	0	0
Dissotis ruandensis	0	0	0	0	0	0	0	0	0	0	0
Dracoena afromontana	0	0	0	0	0	1	0	0	0	1	0
Dyschoriste trichocalyx	0	0	0	0	1	1	0	0	1	1	1
Eleusine indica	0	0	0	0	0	0	0	0	0	0	1
Eragrostis exasperata	0	0	0	0	0	0	1	0	0		
Eriosema montanum	0	0	1	0	0	0	0	0	0		
Erythrina abyssinica	0	0	0	1	0	0	1	1	0		
Eucalyptus filifolia	0	0	0	0	0	0	0	0	1	0	0
Euphorbia tirucalli	0	0	0	0	0	1	0	0	0	0	0
Galinsoga parviflora	0	0	0	0	0	0	0	0	0	0	0
Gynura scandens	0	0	0	0	0	0	0	0	0	0	1
Helichrysum globosum	0	0	0	0	0	0	1	0	0	0	0
Helichrysum mechoianum	1	0	0	1	0	0	0	1			
Helichrysum newll	0	0	0	0	0	0	0	0			
Hibiscus ludwigii	0	0	0	0	0	0	1	0			

Hibiscus noldeae	0	0	1	0	0	0	0	0	0	0	*Passiflora edulis*	0	0	00	00	0	0	0	0	0	00	10	0	0	0	1
Hoslundia opposita	1	0	0	1	0	0	0	0	0	0	*Passiflora ligularis*	1	1	10	00	0	0	1	0	0	00	00	1	1	0	0
Hyparrhenia collina	0	1	0	0	0	0	0	0	0	0	*Pennisetum purpureum*	1	1	10	00	0	0	1	0	1	00	00	1	1	0	1
Hyparrhenia filipendula	0	0	0	0	0	1	0	0	0	1	*Phytolacca dodecandra*	0	0	00	00	0	1	1	0	0	00	10	0	0	0	0
Hyparrhenia rufa	0	1	0	0	0	0	0	0	0	0	*Polygonum pulchrum*	0	0	00	00	0	0	0	0	1	01	11	0	1	0	1
Impatiens bequartii	0	0	0	0	0	0	0	0	0	0	*Polyscias fulva*	1	0	00	00	0	0	0	0	0	00	00	1	0	1	0
Impatiens burtonii	0	0	0	0	0	0	0	0	0	0	*Psidium guajava*	0	0	00	00	0	0	0	1	0	01	10	0	0	0	0
Imperata cylindrica	0	0	0	0	0	0	0	1	0	0	*Pteridium aquilinum*	0	0	00	00	0	0	0	0	0	00	10	0	1	1	1
Indigofera arrecta	0	0	1	0	0	0	0	0	0	0	*Rhynchelytrum repens*	0	0	00	00	0	0	1	0	0	10	00	1	0	0	0
Ipomoea batatas	1	0	0	0	0	1	0	0	0	0	*Rhynchosia luteola*	1	1	00	00	0	1	0	1	0	00	00	0	0	0	0
Ipomoea cairica	0	0	0	0	0	0	1	0	0	0	*Rhynchosia minima*	1	1	00	01	0	1	0	1	0	00	00	0	0	0	0
Lantana camara	0	0	0	1	0	0	1	1	0	0	*Rubus rigidus*	0	0	00	00	0	0	1	0	0	01	00	1	1	1	0
Leersia hexandra	0	0	0	0	1	1	0	0	1	1	*Selaginella sp*	1	0	00	00	0	0	0	0	0	10	01	0	0	0	0
Leonotis nepetaefolia	0	0	0	0	0	0	1	0	0	1	*Senseviera dawei*	0	0	00	00	0	0	1	1	0	10	00	1	0	0	0
Lipocarpha chinensis	0	0	0	0	0	0	0	0	1	0	*Sesbania sesban*	0	0	00	00	1	0	0	0	0	10	01	0	0	0	0
Ludwigia abyssinica	0	0	0	0	1	0	1	0	1	1	*Spermacoce princae*	0	0	00	00	0	0	0	0	0	00	01	0	1		
Maesa lanceolata	0	0	0	0	0	0	1	0	0	0	*Sporobolus pyramidalis*	0	0	00	10	0	0	0	0	0	00	00	0	0		
Mangifera indica	0	0	0	0	0	1	0	0	0	1	*Tephrosia pumila*	0	0	00	00	0	0	0	0	0	00	00	0	0		
Manihot esculenta	0	0	0	0	0	1	1	0	0	0	*Tithonia diversifolia*	1	0	00	00	0	1	0	0	0	00	00	0	0	0	0
Melinis minutiflora	1	1	0	0	0	0	1	1	0	0	*Triumfetta cordifolia*	1	1	10	01	0	1	1	1	1	01	00	1	1	1	1
Microglossa pyrifolia	0	0	0	0	0	0	0	0	0	0	*Vernonia amygdalina*	0	0	00	00	1	0	1	0	0	01	00	0	0	0	0
Musa sapientum	0	0	0	0	0	1	0	0	0	1	*Zea mays* 0 0	0	0	00	00	0	0	0	0	0	00	00	0	0	0	0

Myrica salicifolia	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
Nephrolepis cordifolia	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0
Oxalis latifolia	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	1	0	0	0	0
Panicum chionachne	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
Paspalum conjugatum	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paspalum scrobiculatum	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0