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SPATIAL DISTRIBUTION OF THE INVASIVE PLANT *VERNONANTHURA POLYANTHES* ACROSS LAND COVER TYPES OF CHIKUKWA COMMUNITY IN CHIMANIMANI DISTRICT, ZIMBABWE

Abstract: Understanding species spatial distribution and invasiveness is vital in assessing its potential impacts to the ecosystem and livelihoods of communities affected. Due to climate change, invasion by alien woody species particularly, in mountain ranges bordering Zimbabwe and Mozambique, is increasing with potential impacts indicating significant loss of biodiversity on affected areas. The distribution of the invasive plant *Vernonanthura polyanthes* is poorly documented in eastern highlands of Zimbabwe, an area important for food production and endemic plants and animals. This study mapped the spatial distribution of *V. polyanthes* and predicted its invasion hotspots across various land cover types of Chikukwa, Ward 10, Chimanimani district of Zimbabwe. Chikukwa being in proximity to the Zimbabwe-Mozambique boarder, *V. polyanthes* is rapidly spreading into different land covers of Chikukwa thereby affecting livelihood of this community. Supervised land cover classification was used to develop the land cover types. Vegetation attributes (species abundance, diversity, evenness, height and diameter at breast height) were assessed on 30 sampling plots which were randomly selected across the land cover categories. The Normalised Difference Vegetation Index (NDVI) was used for vegetation assessments and predict invasion hotspots for *V. polyanthes*. This study shows that forest and shrub land had higher vegetation diversity compared to other land covers. The *V. polyanthes* formed the most densely populated patches, and 26.3% of Chikukwa is regarded as its hotspot areas. Intervention strategies in Chikukwa are therefore recommended based on the identified hotspots for *V. polyanthes*.

Keywords: *Vernonanthura polyanthes*, Land cover types, Spatial distribution

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Introduction

Invasive Alien Species (IAS) continue to have profound ecological, social and economic effects at national, regional and global scales (Marbuah et al., 2014). Global economic costs have increased in recent years by a great magnitude, recording hundreds of billions in 2020 (Cuthbert et al., 2021). Gwate et al. 2023, predicted that due to climate change, mountain escarpments in Africa are increasingly being invaded by invasive alien woody species. Africa, having many countries reliant on agro-based economies, has recorded huge economic impacts from IAS. For example, recent studies estimated annual cost from IAS to African agriculture sector to be USD 3.66 billion and 99% of the costs were related to yield losses, reductions in livestock derived income and IAS management costs (Eschen et al., 2021; Pratt et al., 2017). Zimbabwe has not been spared from the problems of IAS and over the years the country has experienced challenges with a number of species affecting aquatic (e.g. water hyacinth (Maroyi, 2012)) and terrestrial habitats (e.g. *Lantana camara* (Dube et al., 2017)). For example, *Lantana camara* was attributed to the loss of livestock worth USD$7920/year in Bulilima and Gwanda districts (Dube et al., 2017). The invasive plant *Vernonanthura polyanthes* (Timberlake, 2017) has been recorded in the eastern highlands has not received attention from researchers although its spread is threatening local peoples livelihoods and ecosystem integrity.

The *V. polyanthes* is a native tree to Brazil but was introduced to Southern Africa, in Sussundenga (Mozambique) in the early 1990s and it spread and established in the eastern highlands of Zimbabwe around 1997 (Sukhorukov et al., 2017). The Environmental Management Authority (EMA) of Zimbabwe conducted a survey to assess the establishment and rate of spread of *V. polyanthes* in various communities of Manicaland and declared the nature of *V. polyanthes* as invasive (EMA, 2018) and a community livelihood threat (Timberlake, 2017). Due to the small size of fields in communal areas, IAS may be posing great threats to the livelihoods of people living in communal areas. Communities that bare more prone to such risks are the agro-based ones, such as the Chikukwa communal area in Ward 10 of Chimanimani district, Zimbabwe. People in Chikukwa have raised complains on the encroachment and rapid establishment of *V. polyanthes* in various land covers including cropland, plantation and grazing land among others. In Chikukwa, establishment of *V. polyanthes* in cultivated lands has also been blamed by for poor crop yields, increased labour and effort to control the plant (Sukhorukov et al., 2017) and displacement of native vegetation in other land covers (Timberlake et al., 2016). The Chikukwa area, being close to the Chimanimani National Park, the rapid establishment of *V. polyanthes* in Chikukwa poses a serious risk of spreading into the national park. As a result, this may affect the rich biodiversity in Chimanimani National Park, hence the need to understand the establishment of this invasive species in areas such as Chikukwa.

This study seeks to determine the spatial land cover variation and map the spatial distribution of the invasive *V. polyanthes* and as well predict invasion hotspots across various land cover types of Chikukwa. The research also assesses woody species diversity in land covers of Chikukwa. The study hypothesises that areas in Chikukwa with high invasion levels of *V. polyanthes* have low plant diversity and there is variation in dominance of invasive *V. polyanthes* across land covers of Chikukwa. The outcome of this research seeks to inform policy, authorities and small holder land users in Chikukwa on intervention and prioritization of remedial strategies for monitoring and control of the invasive *V. polyanthes*.

Materials and methods

Location of study area. The study was conducted in Chikukwa, Ward 10, Chimanimani District in the eastern highlands of Zimbabwe. It is located about 32º55'E, 19º42'S covering an area of 16 km^2 in extent (Figure 1). Chikukwa straddles its boarders against the Chimanimani National Park in the east. Chikukwa area experiences annual mean temperatures ranging from a minimum of 9ºC to a maximum of 25ºC and receive average rainfall of above 1000mm per year (Timberlake et al., 2016). The topography of the area is characterized by highly rugged terrain with the highest mountain ranges and the lower valleys. Altitude rises to above 2000 m on the highest mountain ranges and drops to 1000m above sea level in low lying valley areas (Nyelele et al., 2014). Being situated near the Indian Ocean, Chikukwa area is prone to effects of recurring tropical cyclones from the Mozambique Channel.

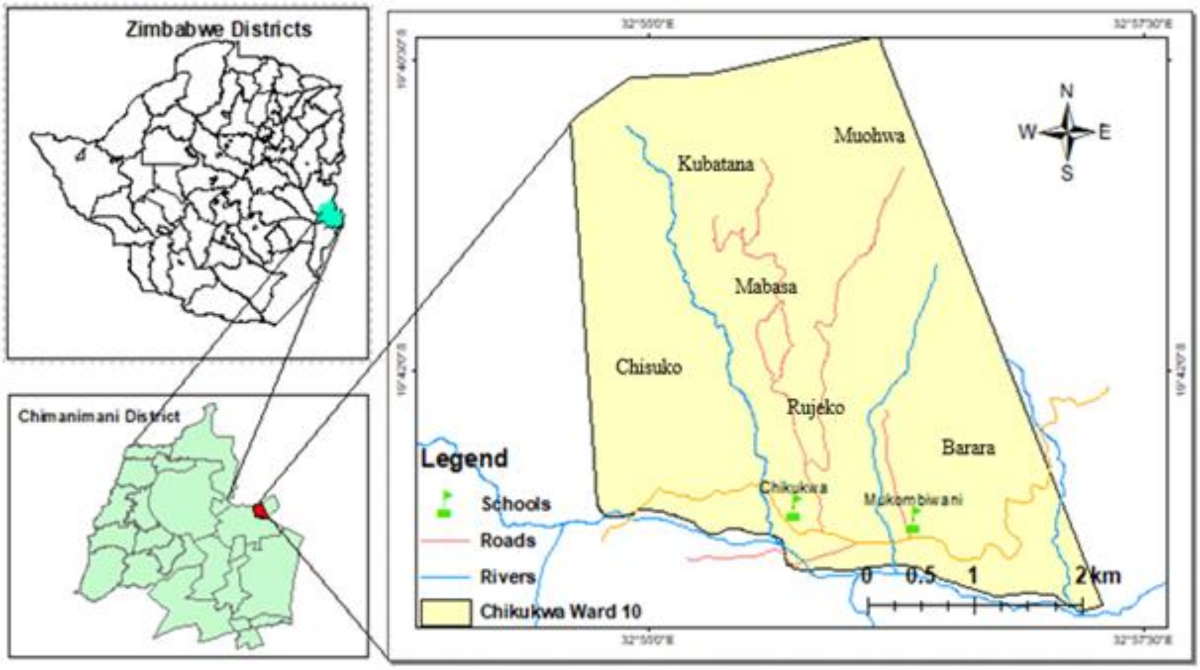

Figure 1. Study area map of Chikukwa Ward 10, in Chimanimani District, eastern Zimbabwe
Source: Own study

Vegetation and soil characteristics. The Chikukwa area has a diverse vegetation as described by Timberlake (2016), ranging from montane forests, grasslands to exotic trees of pine and eucalyptus plantations being a distinct feature shaping the terrain. The vegetation of Chimanimani mountains and surrounding areas is provided by Phipps & Goodier (2011). Chikukwa has fynbos-like vegetation which is mostly sub-montane and montane grassland, and includes a proportion of spaced natural forests. Forest and shrub land dominate the study area and are mostly found in the mountainous areas of Chikukwa. The least land cover category in Chikukwa is water and marsh land referred to as wetland areas reserved for production of *Colocasia esculenta* (Taro root) by the Chikukwa community. On highlands, the soils are deep and infertile due to nutrients leaching (Timberlake et al., 2016) and soils in lowlands are highly productive since they are derived from dolerite are deep, red and clay which are highly productive (Ngarakana & Kativu, 2018).

Sampling design. A stratified random sampling technique was used to demarcate the study area into strata according to the land cover types. Land cover classification from maximum likelihood classifier resulted in five land cover types of Chikukwa namely; forest and shrub land, grassland, water and marshy, cultivation and settlement. Ground truthing was done to validate the identified land cover types. A systematic sampling method was used to generate a total of 30 random sampling points for the purpose of measuring woody vegetation diversity. Six sampling points were spatially distributed across each land cover category for purposes of detailed field-based measurement of woody species diversity.

Data collection. Image processing for land cover classification. The land cover map was generated using supervised classification (Kaul & Sopan, 2012). Cloud free images from Landsat 8 Operational Land Imager (OLI), were obtained for the dry month of May 2023. According to Kaul and Sopan (2012), Landsat images are of high resolution (30m) and are suitable for land cover classification. The maximum likelihood classifier algorithm was chosen due to its robustness (Gómez et al., 2016). Five major land cover classes were developed and these were cultivation; forest and shrub; grassland; settlements as well as water and marshes. Accuracy assessment for the classified map was done through the use of the Confusion matrix in the Integrated Land and Water Information System (ILWIS) software as recommended by Xie et al. (2010). A total of 42 ground control points were obtained during field surveys (using a handheld Global Positioning System receiver) and for accuracy assessment.

Data collection. Determination of woody species diversity in Chikukwa. A preliminary survey was done to map of current invasion of *V. polyanthes* in Chikukwa. Using the results from the supervised classification of land covers, stratified random sampling was used to establish sampling quadrants (20x30m in size) to identify and assess woody species characteristics. Sampling quadrants were set at least 100m from each other (Mebrat et al., 2014). All the plants (trees and shrubs) in the quadrats were identified with the help of experienced botanists. Trees were defined according to criteria used by Gandiwa and Kativu (2009), as rooted, woody, self-supporting plants that are 3m or more in height with one or a few definite trunks whereas shrubs were defined as rooted, woody, self-supporting, multi-stemmed or single stemmed plants greater than 1m but less than 3m in height. For each tree or shrub which was observed in the quadrat, plant height, diameter at breast height (dbh) and crown size were assessed.

Data collection. NDVI classification and determination of hotspots for *V. polyanthes.* The NDVI classification was based on use of Landsat (8 OLI) satellite images to determine vegetation classes (Ahmed, 2016). Images were downloaded from GloVis website (www.glovis.usgs.gov). The May 2023 images generated from cloud free geo-corrected Landsat 8 Operational Land Imager were obtained on 29 May 2023. The 8 OLI images have a spatial resolution of 30m and spectral band 4 (0.64-0.67 μm) and band 5 (0.85-0.88 μm) used for NDVI vegetation assessments. The Integrated Land and Water Information System (ILWIS) software was used to process the NDVI ratios and output values. The NDVI values were then used in vegetation classification. Vegetation classes were based on classification by used by Hashim et al (2019) and NDVI threshold values were classified as non-vegetation, low vegetation and high vegetation (Hashim et al., 2019). According to Hashim et al. (2019), non-vegetation class of bare areas and also water surfaces are presented by low values, low vegetation class including grassland is represented by moderate values and high vegetation class represent forest and shrubs. NDVI vegetation output was used to predict and classify the Chikukwa area into high, moderate and low hotspot areas of *V. polyanthes*.

Data analysis and presentation. The proportion of land occupied by each land cover type was calculated and presented as a table. For each quadrat, the vegetation Shannon diversity, evenness, density and species frequency were computed. The relative dominance, relative density, relative frequency and the Importance Value Index (IVI) were computed at land cover scale as follows:

Relative dominance = (total basal area for a species/total basal area of all species) x 100.

Relative density = (number of individuals of a species/total number of individuals) x 100.

Relative frequency = (frequency of a species/sum of all frequencies) x 100.

IVI = relative dominance + relative density + relative frequency.

The Analysis of Variance (ANOVA) was used to test for significant differences diversity measurements across different land cover types. Variation in percentage dominance, density and frequency by *V. polyanthes* were presented as a table. To determine invasion hotspots, NDVI vegetation output values were used to predict and classify the Chikukwa area into high, medium and low hot spot areas of *V. polyanthes*. Spatial maps were also used for analysis of variation in land covers and vegetation assessments in Chikukwa.

Results and discussion

Land covers for Chikukwa. The resultant land cover classification is illustrated as a map in Figure 2, with five distinct land cover types (cultivation; forest and shrub; grassland; settlement; and water and marshes) developed for Chikukwa (Table 1). The overall accuracy for the classification was 72.8%, suggesting high and acceptable accuracy in the land cover classification according to Xie et al. (2010). The maximum likelihood classifier algorithm classified Chikukwa into the distinct land cover types shown on the map (Figure 2).

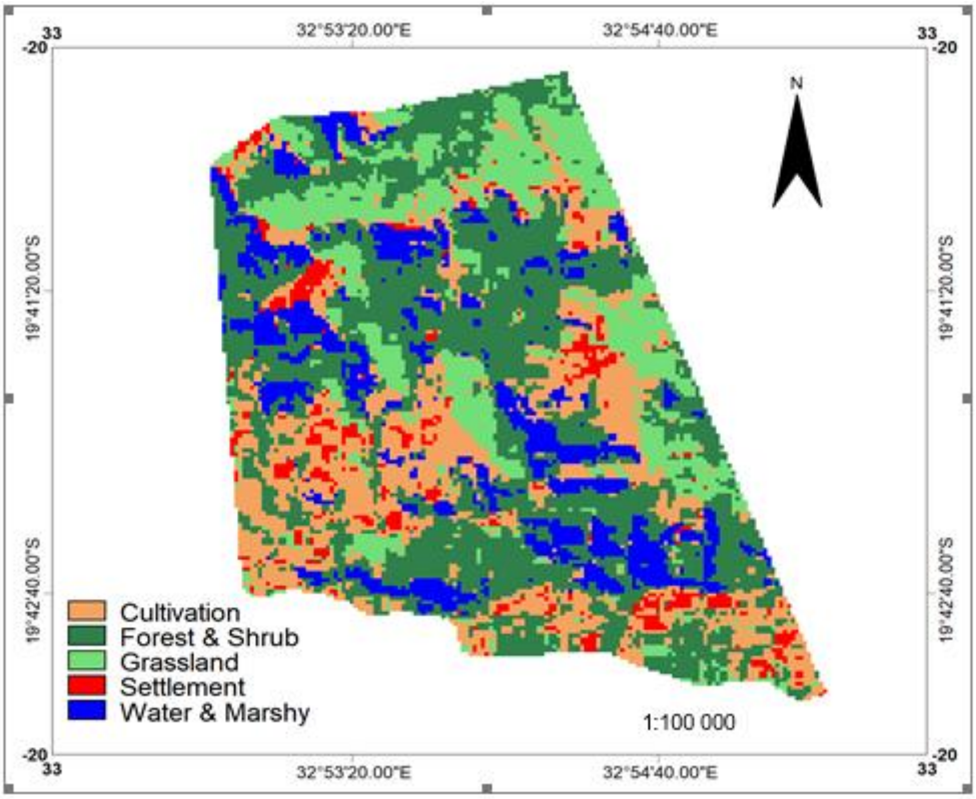

Figure 2. Map showing land cover types for Chikukwa which was developed using remotely sensed data from Landsat (8 OLI) on tile image accessed on 29 May 2023
Source: Own study

Table 1. Areal coverage for different land cover types in Chikukwa

Land cover type	Area (km^2)	Area expressed as a %
Forest and shrub	8.1	49.9
Cultivation	4.3	26.7
Settlement	3.0	18.5
Grassland	0.6	3.4
Water and Mashes	0.3	1.5

Source: Own study

This work has shown that Forest and shrub occupy a greater proportion of the Chikukwa community, accounting for 49.9% (8.1 km^2). Timberlake et al. (2016) also reported similar findings that most of the eastern part of Chimanimani are characterised by highly rugged terrain with Afromontane forests being the dominant vegetation type shaping the terrain. In Chikukwa, more vegetation cover is also found in the mountainous terrain. Natural trees and shrubs dominate the terrain however, pine plantations are also a characteristic feature of the mountainous terrain. Natural disturbances such as Cyclone Idai which hit the area in the year 2018 have left bare areas and invasive species such as *V. polyanthes* encroaching in these bare lands. Cultivation land was also found to be a distinct land cover accounting for 26.7% (4.3 km^2) of the total area in Chikukwa ward 10. This result is not surprising since Chikukwa is a communal area and cultivation of the land forms the basis of community livelihood. Similar findings have also been reported in other studies elsewhere in Chimanimani indicating that most communities in this area engage in production of field crops and is the main livelihood option (Timberlake et al., 2016). Chikukwa area being an agro-based community, farmers complained about increased labour and effort in controlling the establishment of *V. polyanthes* in agriculture land and this result concurred with the EMA 2018 report on *V. polyanthes*. Settlements covered about 18.5% of the study area and this result indicate that Chikukwa has a considerable population. The households are concentrated and the main contributing factor being the terrain which is dominantly a rugged and sloppy terrain.

Species composition and diversity of Chikukwa. A total of 38 woody species representing 24 families were found in Chikukwa. Table 2, summaries the characteristics of woody species in the five main land cover types of Chikukwa.

Table 2. Composition and structural characteristics of woody species in Chikukwa

	Land cover type				
Diversity measure	Forest & shrub	Grassland	Cultivation	Settlement	Water & marshy
Number of families	20	13	7	4	11
Number of species	35	23	7	9	14
Average stem density/ha	1098	346	253	178	212
Average dbh (cm)	5.14	3.13	2.52	2.72	3.34
Mean height (m)	6.04	5.08	5.43	4.76	5.22
Mean Shannon index (H)	2.77	2.29	0.66	0.94	1.12
Mean Evenness	0.79	0.78	0.34	0.41	0.64

Source: Own study

Woody species abundance and their IVIs. The *V. polyanthes* was the most dominant and densely populated woody species in most land covers of Chikukwa except in grasslands were *A. antunesiana* was the most dominant species. The invasive plant *V. polyanthes* is the species with highest IVI across all land covers in Chikukwa. Woody species with the highest importance value index across land covers of Chikukwa are shown on Table 3.

Table 3. Woody species in Chikukwa which has been ranked according to Importance Value Index (IVI)

Land cover type	**Species**	**Relative dominance (%)**	**Relative density (%)**	**Relative Frequency (%)**	**IVI/300**
Forest and shrub	*V. polyanthes*	24.41	16.42	8.75	51.58
	V. kirkiana	11.79	13.71	7.5	33.03
	A. gummifera	15.99	3.71	7.5	27.20
	S. ornata	1.68	9.4	7.5	18.58
	F. sur	1.68	8.0	3.75	13.43
Grassland	*A. antunesiana*	24.63	4.0	5.45	34.08
	F. burkei	25.32	1.71	3.64	30.67
	V. polyanthes	19.00	2.57	5.45	27.02
	G. buchananii	19.34	1.42	3.64	24.40
	V. apiculata	16.87	1.71	3.64	22.22
Cultivation	*V. polyanthes*	8.42	37.14	10.0	55.56
	S. smilacaceae	1.26	2.0	3.75	7.01
	E. tereticornis	1.61	1.14	2.5	5.25
	R. communis	1.12	0.85	2.5	4.47
	S. incanum	0.63	1.14	2.5	4.27
Settlement	*V. polyanthes*	16.82	24.63	8.0	49.45
	P. americana	21.61	8.43	4.5	34.54
	R. communis	11.36	0.67	2.75	14.78
	D. caffra	5.47	2.5	2.75	10.72
	M. esculenta	5.62	1.18	2.75	9.55
Water & Marshes	*V. polyanthes*	12.45	14.41	7.2	34.06
	S. ornata	5.34	3.40	3.82	12.56
	E. abyssinica	4.62	2.32	3.82	10.76
	C. esculenta	2.12	0.87	3.82	6.81
	S. betaceum	2.47	1.75	2.22	6.44

Source: Own study

The vegetation diversity values obtained in this study fall between 0.66 and 2.77. This suggest that the area has medium to high diversity, according to standards elsewhere (Mebrat et al., 2014). In Chikukwa high biodiversity was in forest and shrub areas

(Shannon 2.77). This result is not surprising and compares well with similar studies carried out elsewhere in the eastern highlands in Mozambique side of Zomba forest with Shannon-Weiner diversity of 3.2. In the evergreen forest of Zomba, Timberlake *et al.* (2016) recorded more than 50 families of woody species. This relatively high species richness could be attributed to the proximity of the forests sharing boundaries with Chimanimani National Park with high protection status (Timberlake, 2017). Cultivation land had low diversity of 0.66 due to removal of woody species and weedy plants to create space for growing of crops particularly in Mabasa, Kwayedza and Rujeko village where crop production is a dominant activity. However, opening up of crop land if accompanied by deforestation activities, has been identified in other researches as a key component in providing opportunities for biological invasion (Fleming et al., 2018; Hejda et al., 2009; Hoffmann & Broadhurst, 2016; Shackleton et al., 2020). This has been the case for Chikukwa where cultivation land had the highest percentage relative density (37.1%) and dominance (8.4%) of the invasive *V. polyanthes*. In Mabasa village, *V. polyanthes* was densely populated in crop fields and field margins. In Rujeko village, *V. polyanthes* was densely populated on field margins and foot path margins. The results from this study also further show that grasslands of Chikukwa, particularly in the Chisuko grazing area, had *V. polyanthes* relatively dominant (i.e. 19%) showing that the invasive plant has also established in areas that were predominantly grasses. In addition, the grasslands in Chikukwa are comparable to schists grasslands elsewhere in Chimanimani (Clark et al., 2014; Timberlake, 2017).

NDVI vegetation classification. The NDVI output values ranged from -0.20 to 0.3, high values indicate the high vegetation like trees and shrubs, while moderate value represents low vegetation like grasses and low values represent non-vegetation including water and marshy areas (Table 4). Figure 3 shows the result of Chikukwa vegetation mapping where red indicates high vegetation, green for low vegetation and blue for non-vegetation area.

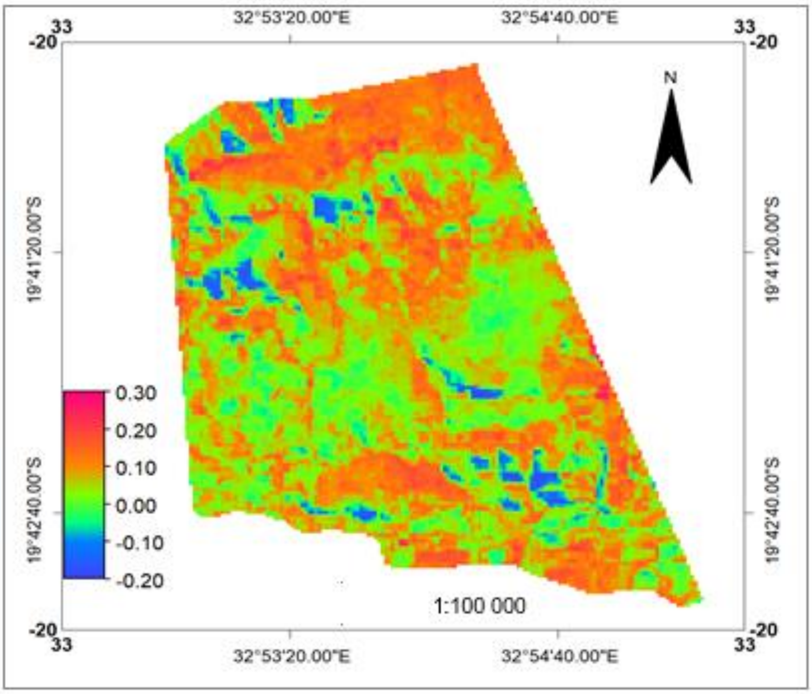

Figure 3. Map showing NDVI values for vegetation in Chikukwa which was developed using remotely sensed data from Landsat (8 OLI), the tile image was accessed on 29 May 2023
Source: Own study

Table 4. Vegetation classes and NDVI threshold values for Chikukwa

Vegetation Classes	Description	NDVI Value
Non-Vegetation	Settlement, water and marshes	-0.20 to < -0.10
Low Vegetation	Grassland, cultivation	-0.10 to < 0.10
High Vegetation	Forest and shrub	0.1 to 0.3

Source: Own study

Hot spot areas for *V. polyanthes* in Chikukwa. The *V. polyanthes* high prone areas are illustrated in red, moderate (yellow) and low (green) as shown in Figure 4. The overall accuracy of the hotspot areas map was found to be 70.8% which is regarded as highly accuracy in validation, hence acceptable. The proportional area coverages of hot spot areas were calculated and coverage for high prone areas was 4.2 km^2, moderate prone areas covered 9.4km^2 and low prone areas covered 2.4km^2.

The hotspot area map for *V. polyanthes* shows that the extreme Northern part (Muohwa area), areas in Kubatana, Mabasa and South-East (Barara area) have more concentrated hotspots for *V. polyanthes*. Moderate and low prone areas are around Chisuko and the central part of Chikukwa (around Rujeko area). This study established that low NDVI values correspond to water and marshy areas in Chikukwa along the Munaka and Musapa rivers as well as other wetland areas, moderate NDVI values corresponded to schist grasslands of Chikukwa mostly found on flat mountain tops. The areas with high NDVI values were those with high vegetation densities. Hotspot areas of *V. polyanthes* has shown that land covers such as the forest and shrub in mountain areas of Muohwa and Kubatana as well as areas around Barara are more prone to invasion by *V. polyanthes* as indicated by a red colour on the hotspot map (Figure 4).

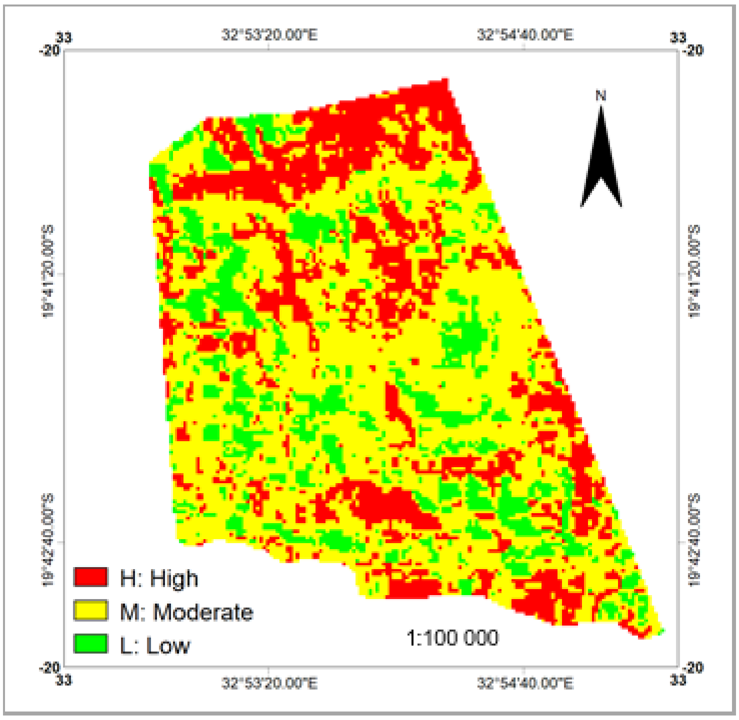

Figure 4. Map of predicted hotspot areas for *V. polyanthes* in Chikukwa which was developed using remotely sensed data from Landsat (8 OLI) from a tile image accessed on 29 May 2023
Source: Own study

This area covers about 26.3% of Chikukwa (4.2km^2). Due to high density of *V. polyanthes* in these high prone areas, this poses threat to native woody species mainly in forest and shrub land. Moderately prone areas constituted about 58.6% (9.4km^2) and most of these areas are around Chisuko, Mabasa and Rujeko areas. Moderate prone areas indicate a considerable threat to agriculture land for Chikukwa through increased labour and effort to control the invasive plant. Low prone areas for *V. polyanthes* covers 15.1% (2.4km^2) and these are mainly areas on mountain tops, areas around Chisuko and water and marshy areas of Chikukwa. Comparing with other similar studies, Timberlake (2017) reported the establishment of *V. polyanthes* in isolated areas of the Chimanimani national park and Sukhorukov (2017) also report that the plant was found along road margins and disturbed areas. However, the current spatial distribution of *V. polyanthes* indicate that the plant has further spread into adjacent areas of Chimanimani National Park including Chikukwa area, where the plant is now dominating in different land covers particularly in forest and shrub, cultivation and settlement where it has not been reported to have established. Therefore, the invasive plant *V. polyanthes* has since become a livelihood threat to the community. On the other hand, the abundance of *V. polyanthes* in Chikukwa also presents an opportunity to explore the medicinal properties of the plant and also abundant terminal heads and inflorescence presence an opportunity for beekeeping farmers in Chikukwa to improve production of honey and enhance income.

Diversity measures across land cover categories. There were significant differences for diversity measures across mainland uses for parameters: abundance, stem density and diversity ($p<0.05$). There were significantly higher evenness values for forest and shrub, compared to other land cover types; grassland, cultivation, settlement and water and marshes. More specifically, in the mean height (Mean = 5.14, SD= 1.37, P = 0.002) was significantly lower than mean Evenness (Mean=0.79, SD = 0.48, P=0.05). The DBH was also significantly higher in Forest and shrub compared to other four land covers and average DBH (Mean = 6.02, SD = 0.79, P = 0.045). The pairwise comparison of the means revealed significant differences between mean DBH and the other two diversity measures ($p<0.05$).

Conclusions

Environmental authorities responsible for Chikukwa should be informed on their intervention strategies based on the identified hotspots for *V. polyanthes* and discriminately apply intervention methods on targeted areas. Densely infested areas can be targeted. Areas such as Kubatana, Mabasa and areas around Muohwa have more hotspots therefore, they can be the primary target areas in eradicating and controlling the spread of *V. polyanthes* in Chikukwa. Use of mechanical and physical control techniques such as cutting using tools can be used on densely infested areas and the stabbing technique is recommended on less infested areas. These techniques can be extremely specific, minimizing damage to desirable plants and animals, but they are generally labour and time intensive. Further research should assess the impact of *V. polyanthes* on livelihood of the people of Chikukwa community. In addition, further research studies should also focus on the effect of *V. polyanthes* to the soil microbiota to better understand its influence to soil nutrients and the growth of other plants.

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