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Dynamics and socio-environmental impacts of mopane worm harvesting in rural communities in Zimbabwe: prospects for climate-smart approaches

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Rural communities in parts of Botswana, Namibia, South Africa, and Zimbabwe rely heavily on mopane worms (*imbrasia belina*) as a livelihood, particularly during times when the households have limited livelihood options. While mopane worms are a vital source of protein and income for rural communities, climate change and variability are putting the sustainability of this vital natural resource under threat. As such, a critical evaluation of the harvesting methods and the associated dynamics is necessary to establish ways of sustaining this resource. This study thus sought to examine the existing mopane worm harvesting practices and evaluate their viability in the wake of climate change and variability. The study focused on Garanyemba Ward 13 of Gwanda District in south-western Zimbabwe. It assessed the harvesting practices and their impact on the environment and the sustainability of mopane worm populations. A qualitative research approach involving participant observation, focus group discussions, and interviews was employed. The findings show that the harvesting of mopane worms in the area was achieved predominantly through climbing up or shaking the trees, plucking worms from branches, and gathering worms that would otherwise be crawling on the ground. Socio-environmental impacts of the existing methods of harvesting revealed include vegetation damage leading to decreased mopane woodland densities, the emergence of squatter communities during outbreak times and the associated land pollution. The study concludes that the influx of foreign harvesters, which eventually exposed the habitat of mopane worms over-harvesting was attributed to limited institutional control. The study recommends control of harvesters by strick enforcement of regulatory frameworks, adherence to selective harvesting to ensure the preservation of worms for future production.

KEYWORDS

mopane worms, rural communities, sustainable resource utilization, traditional harvesting methods, climate-sensitive approaches, Zimbabwe

1 Introduction

Harvesting mopane worms (*imbrasia belina*) is one of the key nature-based livelihoods for several rural communities in southern Africa (Makhado et al., 2014; Baiyegunhi and Oppong, 2016). Mopane worms occur in warm areas with high concentrations of mopane trees. There are two primary seasons for mopane worms in a year, which are April and May, then December and January. Mopane worms are the caterpillars of the anomalous emperor moth, which almost exclusively feed on the mopane tree (*colophospermum*). They are also known as *amacimbi* in the local Ndebele language or *madora* in the Shona language. Mopane worms are valuable not only as a source of income for underprivileged rural women, but also as a source of wholesome food for both rural and urban households. Rural households have historically harvested mopane worms for subsistence purposes, thus contributing significantly to their diets.

Although many studies on mopane worms in Zimbabwe and other parts of Southern Africa have been done, there has not been much research on the sustainability of the collection methods employed. There is a need for studies looking at sustainable methods of mopane worm harvesting. It is against this background that this research seeks to assess the dynamics of the mopane worm harvesting practices and the social and ecological impacts of the existing harvesting practices; in order to recommend climate-sensitive harvesting techniques.

2 Desk-top studies

Mopane worms are important resources that have a significant impact on rural economics and nutrition in mopane forest areas (Ghazoul, 2006). They are the caterpillars of the anomalous emperor moth (*imbrasia belina*), which almost exclusively feeds on the mopane tree (*colophospermum*). Rural households have historically harvested mopane worms for subsistence purposes, and although this has never been properly evaluated, it is believed that mopane worms contribute significantly to rural diets (Manditsera et al., 2022).

Mopane woodland is predominant in the subtropical savanna ecosystems of Southern Africa between latitudes 15^{0}S and 25^{0}S. According to estimations from Makhado et al. (2014), mopane woodland makes up between 30 and 35% of Southern Africa's 1.5 million square kilometers of savanna. The mopane tree grows in hot, dry valley bottoms and nearby plains, in Southern Angola, Northern Namibia, Botswana Zimbabwe, central and southern Mozambique, the Luangwa Valley in Zambia, central Malawi, and northern South Africa (Makhado et al., 2014). Mopane woodlands occur in places with annual rainfall ranging from 400 to 800 mm (Burke, 2006).

2.1 Knowledge of the mopane worm reproductive cycle is important

Knowledge of the reproductive cycle of the mopane worm is crucial for the proper timing of harvesting (Sekonya et al., 2020). The cycle begins with the egg stage. The female moth lays eggs on the leaves of mopane trees. These eggs are small and typically laid in clusters. Once the eggs hatch, larvae emerge. The larvae are what is commonly referred to as mopane worms. During this stage, the larvae feed voraciously on the leaves of the mopane tree, growing rapidly in size (Sekonya et al., 2020). After a period of feeding and growth, the larvae enter the pupal stage. At this point, they burrow into the soil to undergo metamorphosis. Inside their cocoons, they transform into adult moths. The final stage of the mopane worm's life cycle is the adult moth stage. Once the metamorphosis is complete, adult moths emerge from their cocoons (Sekonya et al., 2020). They mate and lay eggs to start the cycle anew. To ensure sustainable harvesting of mopane worms without disturbing their life cycle, it is crucial to consider the timing. The ideal time for harvesting mopane worms is during their larval stage before they enter the pupal stage. This ensures that a portion of the population can continue to mature into adult moths and sustain the population for the future.

2.2 Mopane harvesting in Zimbabwe

Zimbabwe is one of many nations with extremely rich biodiversity that supports local communities' livelihoods (Thompson and Chishakwe, 2011; Chigonda, 2018). According to Frost (2005), mopane worms, are a significant source of both food and income at a time when many households have limited options for a living. The nation's failing economy and high unemployment rate have also boosted the gathering of mopane worms. Additionally, the spiraling inflation has driven up the cost of food in Zimbabwe to the point where mopane worms have become a cheaper alternative source of protein in most places (Stack et al., 2003).

In the Gwanda District, mopane worms constitute a significant source of food and income for the local communities and beyond. The mopane worms in Gwanda district are an open-access resource since there is no restricted access. As such, mopane worms are subject to the challenges of open access resources, including unsustainable exploitation and extinction threats (Gondo et al., 2010) Studies carried out in Zimbabwe on mopane worm harvesting revealed a decreasing prevalence of the worms. This was observed around Mwenezi, Chiredzi, and the lower Save Valley (Potgieter et al., 2006; Gondo et al., 2010). In the light of the above observations, the present study sought to investigate the mopane worm harvesting methods and practices and the prospects for adopting methods that promote continued exostence of this resource under climate change.

Literature reveals that people frequently travel long distances to harvesting places and camp there for several days since mopane worm harvesting outbreaks can be unpredictable (Shen et al., 2023). The resultant informal settlements have adverse impacts on the health of the local ecosystems (Dube and Dube, 2010), People typically flock to the outbreak sites during the December and April harvesting seasons and competition for mopane worms and excessive harvestingtends to cause the resource to dwindle (Shen et al., 2023). Sometimes the velds are burned during on-site mopane worm processing thereby reducing the velds' ability to support grazing animals which negatively affects nearby villagers. As such, action is required to ensure the sustainability of the mopane worm and the associated velds (Shen et al., 2023). to The present study ought to generate evidence to make appropriate recommendations in this regard.

2.3 Climate-sensitive approaches to mopane worm harvesting

Climate-sensitive methods of harvesting mopane worms consider how possible changes in the climate may affect the distribution and

availability of mopane trees as well as the worm population. Such strategies seek to guarantee the resource's long-term viability while reducing the detrimental effects of climate change on the environment (Chikodzi et al., 2013). To spot changes in distribution, abundance, and trends, adaptive management entails ongoing observation and evaluation of the mopane worm population and its surroundings. This information allows management tactics to be modified to preserve the resource's sustainability. Managers can make sure that harvesting levels do not go above ecological thresholds by determining indicators like the bare minimum of mopane trees needed to sustain a healthy worm population (Kerley et al., 2003). This strategy guarantees the resource's long-term availability while promoting the health of the ecosystem. In a study by Kerley et al. (2003) of the association between mopane trees and worm populations in the Kruger National Park in South Africa it was revealed that to keep the worm population alive, there needed to be a minimum of 5–10 mature mopane trees per hectare. Research also points to the importance of observing ecological thresholds to maintain sustainable ecosystem management and make wise decisions on conservation initiatives (Downing et al., 1997).

3 Methodology

3.1 Study area description

Garanyemba Ward 13 is located in Gwanda District (Latitude: 21° 29′ 59.99" S Longitude: 29° 29′ 59.99″ E) in Matabeleland South province in southwesten Zimbabwe (Figure 1). The district is characterized by a varied topography, which includes hilly and semi-arid areas. The town of Gwanda, which is the administrative headquarters of the district is the major economic and administrative hub for the area.

The region falls within a semi-arid climate zone characterized by distinct wet and dry seasons. The rainfall pattern in this area is typically bimodal, with the long rainy season occurring from November to March and the short rainy season from October to November. The average annual rainfall in the region ranges between 400 mm to 600 mm, with variations from year to year (Food and Agriculture Organisation, 2006). During the summer months, which coincide with the rainy season, temperatures can reach highs of around 30–35 degrees Celsius. In contrast, winter months are cooler, with temperatures dropping to around 10–15 degrees Celsius at night (Nyathi and Dube, 2020). The dominant vegetation types include savannah grasslands, thornveld, and scrubland. The savannah grasslands are common in areas with slightly higher rainfall and consist of grass species such as red grasses, star grasses, and finger grasses (Dube and Phiri, 2013). These grasslands support grazing activities for livestock rearing, which is a significant economic activity in the region. According to Ghazoul (2006), thornveld vegetation is found in drier areas and consists of acacia trees, shrubs adapted to arid conditions, and mopane woodland. The area supports a diverse array of flora and fauna, with the mopane tree being a keystone species that plays a crucial role in shaping the ecosystem.

Garanyemba ward 13 is a communal settlement comprising 8 villages, with a population of 7,984 (3,756 males, 4,228 females), 1917 households, and an average household size of 4.8 (Population and Housing Census Report, 2022). The ward has well-maintained roads and a conveniently accessible clinic that is perfect for clinical evaluations.

3.2 Data collection

A case study research design was adopted to allow the study of complex social phenomena in their natural settings (Yin, 2009). This research approach enabled a thorough examination of the intricate dimensions in the unique setting of Ward 13. A mixed methods research approach combining qualitative and quantitative approaches to collect and analyze data was used (Creswell and Tashakkori, 2007). Information was obtained from multiple sourcesincluding focus group discussions (FGDS), observations, and key informant interviews.

The target participants comprised of local harvesters, community leaders, and other stakeholders. Residents from local villages were chosen by stratified random sampling to take part in the study. Dividing the population of harvesters into strata based on specifics ensures that each subgroup is adequately represented in the sample. This approach helped to capture the diversity within the population and provided a more accurate representation of the entire community. By ensuring that each stratum is represented in the sample, this method could reduce sampling variability and increase the reliability of the study results. Use of stratified random sampling enabled the comparison of different subgroups within the population. In the context of studying mopane worm harvesting methods, this approach helped to identify variations in practices, impacts, or perceptions across villages or demographic groups, providing valuable insights for developing targeted interventions.

Key informants including a ward councilor, a local member of parliament, and officials from the Gwanda Rural District Council (RDC) were chosen through purposive sampling. The use of purposive sampling to select key informants was preferred due to its ability to capture specialized knowledge, ensure representativeness, and optimize resource efficiency. By targeting individuals with direct experience in mopane worm harvesting practices, the research could gather detailed insights that are crucial for developing approaches for sustainable resource management in rural communities. Interview questions were presented to key informants to gather data on various aspects of mopane worm harvesting, including the frequency of harvesting activities, the number of households involved, the number of mopane worms harvested, and the methods used for harvesting.

A total of 200 local villagers participated in focus group discussions (FGDs), with 10 members from each village. The councilor's division of the ward into villages helped in the formation of these groups. To target harvesters in operation during the two mopane worm outbreak seasons, the FGDs were held in December and April. Finding out people's ideas, thoughts, and feelings concerning the harvesting procedures followed was made easier with the use of focus group discussions (Krueger and Casey, 2000). was Attempts were made to foster an environment where focus groups participants felt at ease disclosing their concerns, fears, and suggestions.

3.3 Data analysis

The NVIVO program was used to facilitate the analysis of the collected data. Thematic coding was used to group the data collected from focus group discussions and interviews. The data was categorized into themes including harvesting and processing methods, socio-environmental impacts, and harvesting best practices.

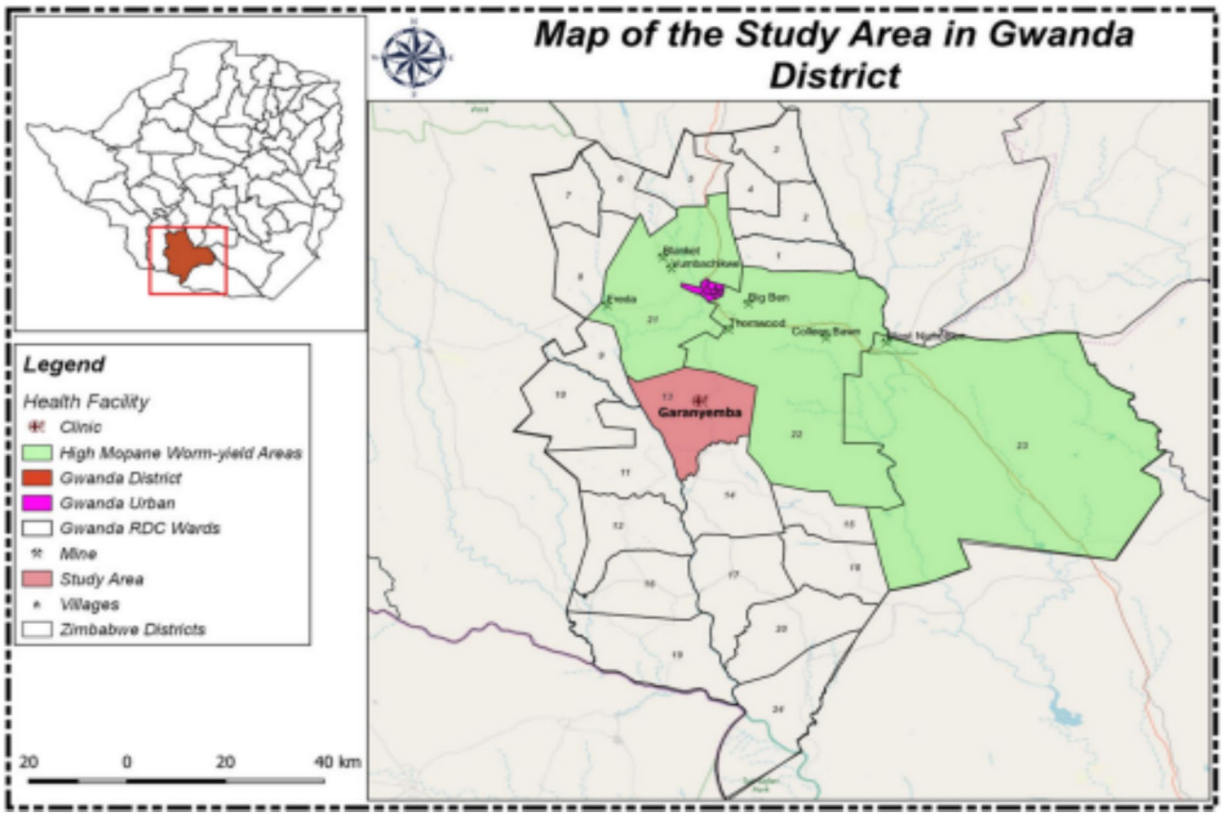

FIGURE 1
Location of Garanyemba Ward 13 (Source: Ndlovu et al., 2021).

4 Results and discussion

The Garanyemba ward presented a specific cultural and physical context for mopane worm collection practices. These practices are limited to specific places and populations and by focusing on this ward, the research gained comprehensive insights into the practices and knowledge related to mopane worm collection.

4.1 Composition of mopane worm harvesters

The study revealed that mixed-age groups of both genders participated in the gathering and processing of mopane worms (Table 1). Men's participation was quite low (10%) compared to women and children who made up (90%) of the participants. This result compares fairly well with findings from the study done by Stack et al. (2003) in Gwanda and Mwenezi districts where only about 5% of males participated in the harvesting activities. The explanation for this finding is that mopane worm harvesting was traditionally regarded as a women's activity (Stack et al., 2003). However, the 10% observed in this study could imply an increase in men's participation in this traditionally women-dominated activity. The increase in male participation could be attributed to several factors. For instance, a high level of unemployment in the country, of about 11.47% (Labor Force Survey Q1 2024). Further, some traditional livelihoods for men are no longer viable due to the threat of climate change and variability (Ndlovu et al., 2020) Thus the business of mopane worms becomes a promising alternative livelihood.

A notable observation from the study was the high level of involvement of children below the age of 12 years, both boys and girls in mopane worm harvesting. This could be an indication of the pervasive presence of children in the workforce. These results confirm the findings by Mangoma and Bourdillon (2001) that in rural areas it is usual for youngsters to assist their parents with routine chores and productive activities from an early age. This study established that the December and April mopane worm harvest periods fall within the school holidays in the country, hence, it is an ideal opportunity for parents to get assistance from their children.

It was also revealed that not every household in the ward participated in collecting mopane worms. Some households did not participate due to religious beliefs which prohibited the consumption and/or handling of mopane worms. As regards socio-economic classes, the study revealed that people from all socio-economic classes participated in the mopane worm collection. Local villagers indicated that mopane worms were not just collected by the poorest households. It was established that wealthier households tended to purchase mopane worms from local collectors for both personal consumption and reselling. The results also showed that the harvesters were a mix of local villagers and people from outside Gwanda. While some participants expressed reluctance to divulge their origins, others revealed that they had traveled from as far as Beitbridge (about 200 km away), Zvishavane (180 km), Kadoma (390 km), Kwekwe (320 km), Mberengwa (226 km), and Bulawayo (127 km), thus, they traveled from various parts of the

TABLE 1 Composition of mopane worm harvesters by gender and age Garanyemba study area, Gwanda.

	Adults over 20 yrs		Youth 13–19 Yrs		Children 12 Yrs and below	
Mopane worm activities	Male *N* = 11	Female *N* = 105	Male *N* = 6	Female *N* = 54	Male *N* = 4	Female *N* = 20
Collection	11	105	6	54	4	20
Processing	5	105	2	49	2	18

country, well beyond the study area. This finding resonates with the observations by Gondo et al. (2010) in Matobo and Bulilima Mangwe districts (also in Matabeleland South Province), which revealed that people occasionally traveled long distances to the epidemic sites and often spent several days camping there while harvesting mopane worms.

4.2 Observed mopane worm harvesting practices and methods

It was observed that mopane worms, typically in their fifth instar stage and the final stage before pupation, were being picked from the ground and the trees. Mopane worms that are picked up from the ground just before they pupate typically have less food that has been digested in their stomachs, making them easier to handle as they are somehow stiff. Additionally, observations revealed that some mopane worms were harvested from the trees while they were still feeding, necessitating rigorous processing to eliminate any remaining undigested material from their stomach.

During fieldwork, no better technological tools were found other than the use of gloves to shield hands from sharp spines during collection and degutting. To remove the mopane worms from the trees, harvesters grasped them by one end, either the head or the back, and gently pulled them apart to remove them from the branches. It was observed that mopane worms were disemboweled by hand-squeezing them to release the guts when harvesting. About half of the harvesters wore gloves, and 20% wrapped strips of fabric around their fingers, particularly their thumbs. Some participants reported that due to the high cost of gloves, not all collectors could afford them. Individuals who could not afford commercial gloves attempted to reduce the agony caused by sharp spines by employing self-made protection (plastic or fabric strips), rolling bottles or using sticks to crush the mopane worms.

It was revealed during focus group discussions that some harvesters (particularly those who harvested for trading) also used a different method that involved placing mopane worms in a pit, covering it with hot coals, and letting the heat build-up causing the worms' intestinal contents to be expelled. Before cooking, mopane worms should ideally be rinsed with water after degutting. These harvesters believed that by gathering in this manner, they would catch many worms faster.

The harvesters also disclosed that they participated in activities that are typical of traditional harvesters, such as shaking or climbing trees, bending tree branches, "plucking" worms off short trees, and gathering worms that are crawling on the ground (Figure 2). More than 80% of the harvesters said that they manually selected the worms by bending the branches of infected trees, gathering from short trees where the worms were easily accessible, and gathering from the ground the worms that were large enough and prepared to pupate. The harvesters emphasized that these methods were the simplest and fastest for gathering the worms. Given that this technique has been documented in other research as a response to an increase in harvesters (Gullan et al., 2005), it was fascinating to see that some harvesters did not break tree branches. Although there are now more harvesters in this area, there are no longer the same "shortcuts." Surprisingly, both the local and the immigrant harvesters admitted that they refrained from breaking tree branches because they were aware of the negative effects that would follow, such as the reduction or even extinction of mopane worms. The harvesters who shook the trees indicated that mature worms do not adhere to tree branches as securely as young ones do, which makes them more likely to fall when the tree is shaken. Nevertheless, it appeared that very few harvesters were aware of this; more accurately, their phobia of lizards and snakes prevented them from employing this harvesting technique.

It was learned that local harvesters carried the worms for processing at home since they resided near gathering places. Immigrant collectors who traveled from other places to the outbreak sites did the processing in the collection areas. In areas with limited water resources, mopane worms are prepared without prior washing. Mopane worms could be prpeared in a variety of ways, according to harvesters, but the two most popular methods are (a) roasting over a bed of hot coals and then sun drying and (b) boiling in salty water and sun-drying.

The nature of technical innovations that collectors were likely to embrace is affected by the common practice of processing in collection locations. Light equipment was more appealing than large, cumbersome equipment that is difficult to transport. This confirms the oservations by Gashe and Mpuchane (1996) that simpler methods are often used by the majority of mopane worm harvesters in Southern African nations, including Zimbabwe, Botswana, and South Africa.

4.3 Socio-environmental impacts of mopane worm harvesting

The findings of this study revealed that the sustainability of the mopane worms was under threat due to several factors including increased exploitation, and decreased selective harvesting. One of the participants expressed,

> *'During the harvest time, too many people from outside this village flock to this place to such an extent that we the locals find it difficult to harvest. Some come driving their cars while some use public transport. This whole village is usually full of harvesters'.*

As indicated in the above quote, several people visited the area, thus increasing pressure on the mopane woodland resource thereby overwhelming the receiving community.

4.3.1 Deforestation

A major environmental issue perceived by key informants who included traditional leaders was the decline in mopane tree density.

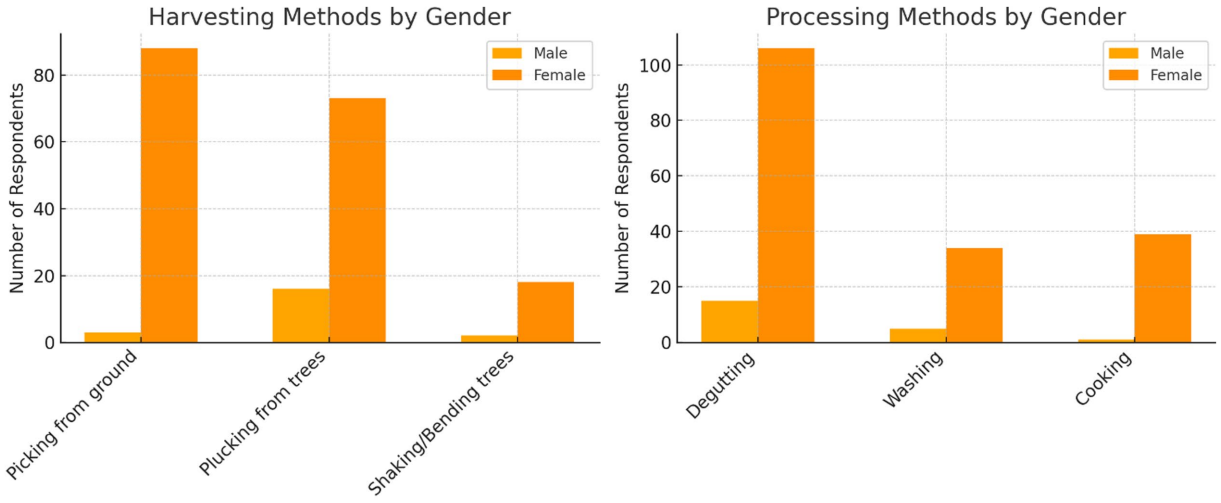

FIGURE 2
Harvesting and processing methods used.

The debarking and the collection of branches and trunks associated with mopane harvesting and processing, and for firewood and construction purposes were observed. Such practices could lead to the dwindling in numbers of the mopane trees and can negatively impact on the availability of the worms in the long run, as observed by Illgner and Nel (2000). On the contrary, Gullan et al. (2005) argue that the years of reduced mopane worm outbreaks are associated with climate-induced drought rather than with unsustainable harvesting of the resource. Further studies on the impact of climate change are needed to verify this argument in the case of Garanyemba ward.

Perceptions indicated that the loss of vegetative cover was not due to mopane harvesting *per se* but also due to increased demand for firewood. One headman had this to say:

> *'Due to the high cost of electricity as well as increased load-shedding in Gwanda town, many urban dwellers have resorted to the use of alternative forms of energy such as firewood and usually come to our village to get firewood. Mopane trees are at risk because of their capacity to produce charcoal'.*

This statement shows that urbanites could also be contributing to deforestation through their demand for firewood from the study area, is fairly close to Gwanda town (about 30 km),

4.3.2 Depletion of mopane worms

Results from this study have indicated that the depletion of mopane worms in Garanyemba Ward 13 was an anticipated challenge considering the increasing demand for worms, and the inefficient management system. The harvesting methods were based mainly on traditional knowledge systems. Traditional knowledge may not provide a sustainable harvesting strategy in the absence of a quantitative database, monitoring system, or sound biological knowledge (Maviya and Gumbo, 2005). It was also revealed that mopane moths had disappeared in some areas they traditionally were visible and this was attributed to factors such as unsustainable harvesting and prolonged droughts. Literature confirms these as important factors. Other contributory factors include soil type, predators, browse quality, and the decline of mopane woodlands (Marais, 1996; Styles, 1996). Table 2 shows the contributing factors identified in this study and the averages of the scores given by the respondents for each particular factor.

The depletion of these mopane worms especially in areas nearby the villages was causing social tensions and conflicts among the villagers and harvesters as they competed for the limited resource. As a result some villagers resorted to traveling to other wards for mopani worm harvesting (Figure 3). Some local villagers perceived that excessive demand for the mopane worms would eventually lead to the extinction of the resource in their neighborhood.

4.3.3 Mushrooming of informal settlements

The outbreak of mopane worms can be sporadic, causing people to travel considerable distances to the outbreak areas and camp there for several days while harvesting. Hence there has been an emergence of informal settlements at outbreak sites in recent years (Stack et al., 2003). The environmental impacts of informal settlements during the harvest of mopane worms included deforestation, land pollution, and rampant veld fires. The field observations made in the informal settlements during the harvesting season in April and December 2022 revealed that informal shelters themselves were made from mopane tree poles taken from the surroundings and strong plastic covers. However, some harvesters brought their modern camping tents. As the number of harvesters and informal settlements continued to increase, the destruction of mopane worm habitat also increased. Some mopane trees were destroyed by harvesters in their quest to get all the worms even from the top branches. Figure 4 shows the perceived environmental impacts of informal settlements in outbreak areas.

A common finding from the focus group discussions held during this study was that the local harvesters attributed the disappearance of mopane worms around their villages to the increasing number of immigrant harvesters. When asked to comment on the impact of the informal settlements on harvesting, one of the local harvesters said,

> *'Most of the harvesters in the informal settlements are young and inexperienced, thus they cannot tell whether the worm is ready for harvest or not. They just harvest every worm they come across, whether big or small, everything is collected for sale in their places of permanent residences'.*

Despite the perceived decline in the mopane worms and habitats, about 80% of the harvesters confirmed that they were still visiting the same areas for harvesting. Factors such as proximity to the village, absence of institutional or regulatory hurdles, and negligible costs to reach and access the harvesting areas were cited as the reasons for the choice to utilize the same harvesting areas that they historically used.

4.3.4 Environmental pollution

Environmental officers from the Environmental Management Agency (EMA) which is the legal body that oversees the environmental laws in the country, and the local Rural District Council raised land pollution as another environmental issue in the mopane worm outbreak sites. Observations during this study confirmed this phenomenon around the camping sites of the immigrant harvesters. Stray papers, empty bottles, and mostly baby diapers were being dumped in the area, especially around temporary shelters.

TABLE 2 Factors contributing to mopane worm depletion.

Contributing factors	Averaged impact level (on a 1–5 scale)
Unsustainable harvesting	5
Effects of droughts	4
Soil type	3
Rainfall	4
Predators	3
Browse quality	4
Decline of mopane woodlands	5

4.4 Best practices and sustainable methods of harvesting mopane worms

About 85% of the adult participants in this study understood the importance of leaving some larvae to pupate instead of harvesting all the larvae. The participants expressed knowledge of the crucial aspects of management necessary for mopane moths to continue to live in sufficient numbers to enable recurring outbreaks of mopane worms. The following expression by one of the harvesters emphasizes the importance of sufficient feed for the worms:

> *'Food plants are necessary for the mopane worms to grow and feed on. There should be enough fifth-instar mopane worms so that they can pupate and give rise to the following generation of adult moths. The pupae, however, must not be disturbed'.*

Concern over the observance of sustainability principles was noted. About 15% of the adult harvesters claimed that the commercialization of mopane worms made it impossible to gather sustainably because outsiders do not observe sustainability principles. One of the key informants noted:

> *"In certain places, individuals dig up and gather the pupae, mostly during dry spells. Such actions are often motivated by hunger experienced especially by poor families".*

The participants were generally aware that unsustainable practices should not be carried out since they endangered the availability of adult mopane worms in future. As a conservation measure, participants in focus groups suggested that in a given year, the harvesters should choose not to collect mopane worms from certain wooded areas, allowing the larvae to pupate there. Thus, is a form of rotational harvesting is expected to allow undisturbed reproduction and relates to rotational grazing strategy which is often applied in rangelands to allow restoration of pastures and biodiversity (McDonald et al., 2019). Participants generally felt that for this strategy to succeed strong local institutional mechanisms were required to enforce compliance, and that strong commitment was

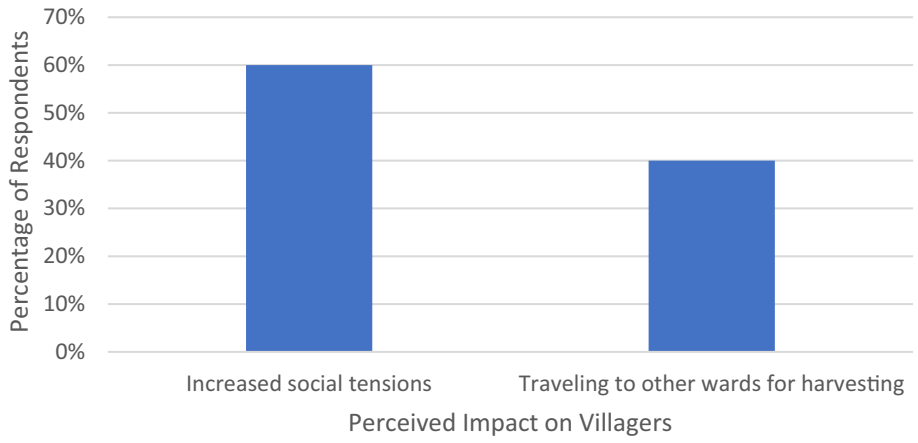

FIGURE 3
Perceived impacts of increased demand for mopane worms.

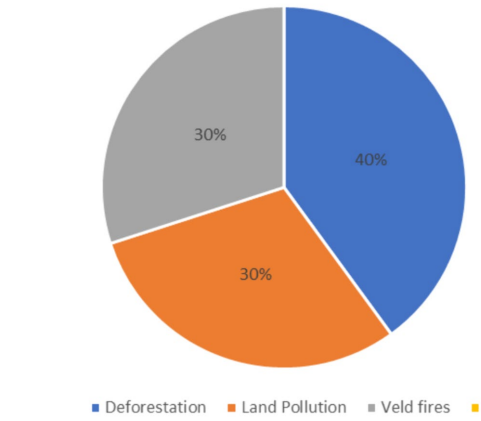

FIGURE 4
Perceived environmental impacts of informal settlements in outbreak areas.

required from every member of the community. However, Without any significant scientific evidence it can be difficult to determine sustainable harvest levels and prioritize conservation strategies (Wickens, 1991; Zuidema, 2000).

Another suggested strategy was to ban activities that devastate forests and mopane trees. The villagers confirmed the need for relatively safe locations for female moths to deposit their eggs and for the larvae to develop into healthy adults after hatching. One of the harvesters said:

> *"We need to agree as a ward to leave some areas untouched so that we allow the female moths to lay their eggs and develop into lavae without any disturbance, The councillor and village heads should assist us to achieve this goal by coming up with stringent rules and fines to those found trespassing in those areas".*

Particpants generally understood that since mopane trees are the primary food source for the larvae, the trees should be in abundance. Particpants highlighted the need to stop certain practices for the community to continue experiencing significant mopane outbreaks yearly. The practices included damaging trees and branches when gathering mopane worms, clearing substantial tracts of mopane woodland, and failure to control veld fires.

All of the participants agreed that one of the sustainable measures that needed to be implemented was the control of mopane worm harvesters. The problematic issue of weak or nonexistent regulatory frameworks surfaced in nearly all of the FDGs that were held. Garanyemba area experienced an unregulated collection of mopane worms, with large numbers of harvesters from outside the outbreak areas. According to the Gwanda RDC, bylaws were in place to control access for the locals to get maximum benefit from this natural resource. However, there were challenges with the implementation of the bylaws.

An extract from the Gwanda RDC by-laws on mopane worms read:

> *'No person is allowed to harvest, collect or pick for sale or commercially trade in amacimbi, fruits or other forest produce in the council area, except in terms of a permit issued in terms of the Communal Forest Produce Act (Chapter 19:04) and under the following conditions'.*
>
> *'Any person who is involved in commercial exploitation or collection for sale of forest products is required to notify the Council in writing: provided the Council shall always seek ways of ensuring that the local inhabitants shall be given preference in accessing forest produce than people from other areas outside the Councilarea and Council may regulate or impose a fee for access'* (Gwanda Rural District Council, 2023) By-laws, 2023, Forest Produce Section 19.1 pg. 1,526.

The phrase above makes it very clear that the by-laws expressly forbid those who would engage in the commercial gathering of mopane worms. This creates a window or a loophole whereby anyone could still visit the locations of the outbreaks and gather as long as they did not sell from the field, yet they could sell from homes after processing, which made it difficult to monitor or control. The by-laws were not explicit regarding the council's stance on immigrant harvesters. Traditional leaders highlighted that some of the immigrant harvesters would come as though visiting their relatives in the local villages but endup gathering mopane worms and then return to their homes after the outbreak season ends. This made the situation complicated and difficult to control. The fact that some local villagers were hosting outsiders as relatives and that the existing by-laws were not strict enough were seen by traditional authorities as major sources of the challenges. Because of this, a large number of people continued to flock to the Garanyemba ward during outbreaks, resulting in unsustainable harvesting practices. In light of the above observations, local harvesters recommended that the RDC should investigate the matter of fines, possible deterrents, and ways to improve enforcement of bylaws.

4.5 Prospects for climate-smart mopane worm harvesting methods and potential benefits

It has been noted that mopane worms, are a traditional delicacy in Southern Africa and play a significant role in the region's food security and economy (Nemadodzi et al., 2023). As climate change continues to impact the environment, the mopane worm habitats and reproductive cycle are under threat. There is a growing need to develop climate-smart harvesting methods to ensure sustainable utilization of the mopane worms. Several strategies may be suggested to enhance the ecological and socio-economic benefits to the local communities and beyond. Table 3 summarizes some suggested adaptation strategies.

The adoption of *Internet of Things (IoT)* is a potential strategy to track and monitor mopane worm populations and can inform appropriate and timely intervention measures (Wang and Bu, 2022). With increases in internet coverage anticipated from the launch of more satellites rural communities are expected to have better internet connectivity at more affordable rates (Yaacoub and Alouini, 2020). Use of other real-time monitoring strategies can be considered as a way to ensure that sustainable harvesting methods are adhered to. *Real-time monitoring* can provide valuable

TABLE 3 Summary of potential adaptation strategies.

Strategy	Benefit
Monitoring systems (IoT)	Ensures sustainable harvesting practices through population tracking
Remote sensing and GIS	Enhances decision-making for sustainable harvesting
Incorporating traditional knowledge	Preserves cultural heritage and ensures sustainable use
Climate-resilient farming practices (agroforestry)	Maintains healthy mopane tree populations, improves farm productivity, and enhances ecosystem resilience
Controlled harvesting (cooler parts of the day)	Reduces stress on worms, minimizes mortality rates, and prevents overexploitation
Community-based management systems	Empowers local communities in decision-making and enforcement of regulations

insights into population trends, habitat conditions, and the impact of human activities on mopane worm populations, ultimately contributing to the conservation of this natural resource (Gubbi et al., 2013). By setting quotas and regulations based on scientific data, it is possible to prevent overexploitation of this resource. Remote sensing and geographic information systems (GIS) can aid in mapping mopane worm habitats and monitoring population dynamics (Miller and Rogan, 2007). Using this data-driven approach can enhance decision-making for sustainable harvesting.

Promoting *traditional knowledge and* harvesting *practices* can help preserve cultural heritage while ensuring the sustainable use of mopane worms (Moller et al., 2004). Indigenous knowledge often includes insights on when and how to harvest, in harmony with nature. By integrating these traditional practices into modern harvesting techniques, it is possible to maintain the delicate balance between resource utilization and preservation for future generations (Berkes et al., 2000; Zinhiva and Chitakira, 2017).

Encouraging *climate-resilient farming practices*, such as agroforestry or sustainable land management, can contribute to maintaining healthy mopane tree populations, which are crucial for the survival of mopane worms (Chitakira et al., 2015; Taillandier et al., 2023). Apart from improving farm productivity, agroforestry and sustainable land management systems can contribute to ecosystem resilience, including maintaining healthy mopane tree populations.

Controlled harvesting should be considered. Harvesting could be done only during the cooler parts of the day to reduce stress on the worms and minimize mortality rates (Maviya and Gumbo, 2005). This implies that harvesting should be avoided during conditions such as heat waves. Rotational harvesting could be adopted to allow rest periods (during which no harvesting takes place) for outbreak areas to recover and prevent overexploitation. The rest periods could be agreed upon by the local communities and possibly some by-laws can be generated through the support of the local authorities and the EMA. As noted by Baiyegunhi et al. (2015), it is important to establish community-based management systems where local communities have control over harvesting practices and can enforce regulations. Local communities should be involved in decision-making processes to ensure that harvesting practices align with their needs and values (Jones and Erdmann, 2013).

Agroforestry practices that integrate mopane trees into farming systems, can enhance the resilience of ecosystems to climate change (Taillandier et al., 2023). This strategy can provide additional benefits such as improved soil fertility and increased water retention which are important for adaption to climate change and variability.

Climate-smart harvesting methods can help preserve biodiversity by ensuring the sustainable management of mopane worm populations and their natural habitats. By adapting harvesting practices to the changing environmental conditions, communities can build resilience to the impacts of climate change and ensure the long-term availability of mopane worms as a valuable resource.

5 Conclusion

This study has confirmed earlier findings that women and children make up the majority of mopane worm harvesters, and has highlighted that the proportion of men participating in this business could have increased. It was shown that local villagers as well as immigrant harvesters from various socio-economic classes participated in mopane worm gathering. Conventional harvesting techniques were employed, such as shaking branches, bending or climbing trees, pulling worms from branches, and collecting worms from the ground. Relatively few harvesters utilized gloves or formal personal protective equipment. Handmade protection including fabric or plastic strips was utilized more often. The study revealed a perceived decrease in mopane tree density in the area associated with unsustainable harvesting practices. Destruction of mopane habitat was seen as a cause for the disappearance of mopane worms in some areas of the ward. Land pollution and uncontrolled veld fires in the mopani worm outbreak areas associated with the growing number of informal settlements by immigrant harvesters were environmental issues of concern. Measures should be taken jointly by the local authorities and villagers to control the harvesting habits as well as the number of immigrant harvesters. Based on an examination of the existing regulatory frameworks, the study recommends strengthening the cooperation between traditional authorities and government institutions in documenting and enforcing sustainable mopane worm harvesting regulations. Integrating scientific knowledge with traditional knowledge and practices related to mopane worm harvesting can provide insights for developing strategies that support the sustainable utilization of this natural resource while safeguarding the ecological balance. The study recommends implementation of monitoring programs to track the health of the mopane worm population and to inform harvesting control measures to adopt. Further research is necessary for a better understanding of the impact of climate change on mopane worm populations in specific contexts such as the Garanyemba area.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

The studies involving humans were approved by GWANDA Rural District Council and Traditional leaders. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Ethical approval was not required for the study involving animals in accordance with the local legislation and institutional requirements because the mopane worms were not disturbed or touched at all, the study only focussed on their harvesting. Harvesting practices by people was the focus of the study hence approval was sought from community leaders and the local authority.

Author contributions

SD: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft. MC: Conceptualization, Data curation, Formal analysis, Funding acquisition, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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