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ASSESSMENT OF THE ROLE OF GUM ARABIC PRODUCERS' ASSOCIATIONS (GAPAS) IN REHABILITATION OF GUM ARABIC BELT: CASE OF NORTH AND WEST KORDOFAN STATES, SUDAN

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Abstract

The research aimed to investigate the involvement of Gum Arabic Producers' Associations (GAPAs) in the rehabilitation of the gum Arabic belt in North and West Kordofan States, Sudan. Data were collected through social surveys of household heads, interviews, and observations, as well as remote sensing images from 1998, 2009, and 2020. Secondary data were obtained from different literature sources. The data were analysed using SPSS and ERDAS software. The results of the social survey showed that the establishment of GAPAs coincided with an increase in gum-producing trees, but GAPAs did not directly contribute to the rehabilitation process. Instead, the rehabilitation efforts were carried out through collaborations between the Forests National Corporation (FNC), multi-donor projects, and GAPAs. The remote sensing results showed changes in vegetation cover over the study period, with an increase in dense, moderate, and sparse vegetation cover classes. The research concluded that GAPAs have a significant impact on the enhancement of vegetation cover. External institutions played a role in the restocking of gum trees. It was recommended that GAPAs be strengthened through capacity building and the adoption of technology to improve gum production. FNC should encourage micro-financial institutions to support rehabilitation projects, utilise mapping to protect the gum gardens, and monitor the rehabilitation processes.

Keywords*: Assessment; Rehabilitation; Gum Arabic belt; Remote sensing; Gum Arabic Producers Associations (GAPAs); Contribution; Sudan*

Introduction

The total area of forests in Africa decreased from 705 million hectares in 1990 to 624 million hectares in 2015. The drivers of deforestation and degradation are attributed to natural and human causes. Droughts, fires, storms, and diseases are examples of the natural causes, while human activities include clearing for agricultural practices, overexploitation of timber harvests, expansion of settlement areas, and development of infrastructure. Adopting participatory forest management and raising awareness to mobilise communities' participation and forest financing are common strategies and practices used for the rehabilitation and restoration of degraded forests [1-4].

[5] reported that Sudan has been engaged in activities related to afforestation and reforestation since 1911. The achievements of programmes of afforestation and reforestation

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implemented by FNC have been changed annually based on the availability of sources, which include external sistance. Likewise, stated that in the early 1980s, FAO introduced a programme for establishing tree plantations in some parts of Sudan with the participation of local communities [6]. Then the idea was adopted by a few other NGOs. The bulk of the gum Arabic resource base is in the semi-arid region and low-rain forest savannah between latitudes 10° and 17°N. Gum Arabic production is mainly practiced in traditional rain-fed agriculture zones [7, 8]. Due to its location and values, the gum belt has a suitable environment that allows many NGOs to accomplish their objective of tree rehabilitation.

Since the 1980s, gum Arabic Belt has accommodated NGOs and multi-donor projects that work in the rehabilitation of gum Arabic Belt. During 1980–1995, UNSO funded the three phases of the Restocking of Gum Arabic Belt Project (RGABP) in North Kordofan State. In the third phase of the project and to strengthen gum producers, twenty GAPAs emerged in Umrawaba Locality, North Kordofan State, in 1992 [9], with the main objectives of improving the financial returns for gum producers and maximising the production of gum Arabic, reducing the dependence on the traditional financial system "Sheil", and ensuring sustainable production of gum Arabic [9, 10].

Since the first formal establishment, there have been 20 GAPAs during the project's life span. After the phase-over of the project in 1995, the FNC has assumed responsibility for the establishment of GAPAs across the gum belt [9]. Most of the studies of GAPAs attempted to determine the role of GAPAs in the production and marketing of gum Arabic, while there was no study conducted to address the issue of the sustainability of gum production. Therefore, the aim of this paper is to assess the role of GAPAs in the rehabilitation of the gum Arabic belt.

Conceptual framework

Rehabilitation is defined as the process of supporting the restoration and management of a degraded ecosystem, including its structure and function, to a close estimation of its status prior to its disturbance [1]. It is also defined as the reestablishment of productivity and some, but not necessarily all, of originally existing plant and animal species. For ecological or economic reasons, a new forest may emerge to include some species that did not exist in the original forest. Over time, the protection and ecological services functions of the original forest may be reestablished [11]. However, community participation has a positive impact on increasing the planted forestland annually because of increasing reforestation programmes, afforestation activities, and other forest rehabilitation and restoration strategies [12, 13]. Rehabilitation of forest cover must start with the understanding that forests, woodlands, and trees are renewable resources, and then the nature of deforestation and degradation should be considered [14]. Different countries have been practicing rehabilitation strategies to reduce the rate of deforestation. There are no general solutions and strategies since these will vary with the region and will change over time. Effective implementation is essential, including stakeholder participation, the development of management plans, monitoring, and enforcement [15].

For investigating the role GAPAs play in the rehabilitation of the gum Arabic belt, the paper discussed the rehabilitation process based on two scenarios: direct rehabilitation through plantations or indirect rehabilitation through support for the provision of inputs and production. The conceptual framework is developed based on the above scenarios to assess the role of GAPAs in the rehabilitation of the gum Arabic belt (Fig. 1). The rehabilitation process is centralised in the black box of the framework. The right pillar of the conceptual framework was used to identify the stakeholders who are responsible for or contribute to the rehabilitation process of gum Arabic belts, while the scenarios of rehabilitation (direct and indirect) of gum belts were described in the left site column. GAPAs, which originate from the individual producers (mainly responsible bodies of rehabilitation), were in the middle of the stakeholders'

chain because the other responsible bodies of rehabilitation first emerged from the GAPAs and supported them to achieve their objectives.

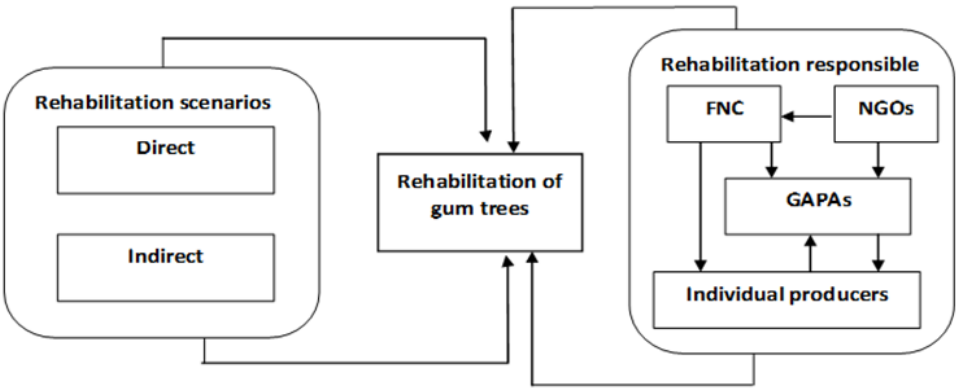

Fig. 1. Conceptual framework to assess the role of GAPAs in the rehabilitation of gum belt

Material and methods

Description of the study area

The study was conducted in North and West Kordofan states, which are located within the arid zone of central Sudan and in the central part of the Arabic belt. The two states are characterised as vulnerable areas suffering from degradation and desertification processes. The two states witnessed the initiation of NGOs interventions to rehabilitate the gum Arabic belt, as well as the introduction of GAPAs. North Kordofan State is in a semi-arid zone with an area of 190,840km^2, and the population was estimated at 2.92 million in 2008, while West Kordofan State extends from low rainfall savanna to high rainfall and hill catena with an area of 144,00km^2 [16, 17]. The people of the two states rely on the integration of agricultural crops, animal production, and gum Arabic production from Acacia Senegal as their main sources of livelihood [9].

Data collection instrument, sampling techniques and data analysis

To achieve the objective of the study, a combination of social survey and remote sensing methods were deployed. Secondary data were obtained from relevant literature, government and NGO documents, and scientific publications. While the primary data were collected through social surveys, 338 HHH gum producers were interviewed, 42 interviews with GAPAs' committees, and GAPAs' questionnaires. Key informants' interviews were also used for triangulation of findings. The social survey data were collected from 14 GAPAs, and the selection of the HHH respondents was based on the random sampling technique. On the other hand, non-probability sampling techniques were applied to select the respondents in the other methods (GAPAs' committees' interviews using the total account and using the purposive and/or snowball methods for the key informants). The social survey data was analysed through the statistical package for social sciences software (SPSS version 25).

For identifying the Land Use Land Cover (LU/LC) changes, remotely sensed data was used, where satellite images were chosen from the Landsat sensors. These images were clear of cloud cover and freely downloaded from the United States Geological Survey website (GloVis) at the paths of 174, 175 and 176 and rows 50 and 51. Consequently, three Landsat images were used with a spatial resolution of 30m (Table 1); Landsat 5 and Landsat 8 (OLI_TIRS) images were downloaded for the years 1998, 2009 and 2020. Landsat images were selected purposefully because of their geographical coverage and temporal availability. As well as the relation between the years of selected images and the importance decisions related to GAPAs,

where the first image of 1998 was six years after the formal establishment of GAPAs, while the image of 2009 was selected to put four years' distance since the government's decision of 2005 to adopt the intervention idea in all the production states in the country.

Table 1. Utilized Landsat Images in Determining Forest Cover Change

Satellite/Sensor	Pass/Raw	Data of acquisition	Spatial resolution	Selected bands
Landsat TM	174/50/51 175/50/51 176/50/51	30/11/1998	30 m	1, 2, 3, 4
Landsat TM	174/50/51 175/50/51 176/50/51	23/11/2009	30 m	1, 2, 3, 4
Landsat OLI	174/50/51 175/50/51 176/50/51	19/11/2020	30 m, 15m	2, 3, 5, 7

Source: (GloVis, 1998; 2009; 2020)

The satellite data used in this study and other information items were analysed with ERDAS Imagine 2014 and ArcMap 10.7, where images were preprocessed through radiometric and geometric correction, image enhancement, and supervised classification of LULC with the aid of a GPS device. In addition to that, Microsoft Excel 2016 was used in computing the LU/LC changes, showing their percentages and change rates in the study area. The summary of the methodology and research procedures is depicted in figure 2.

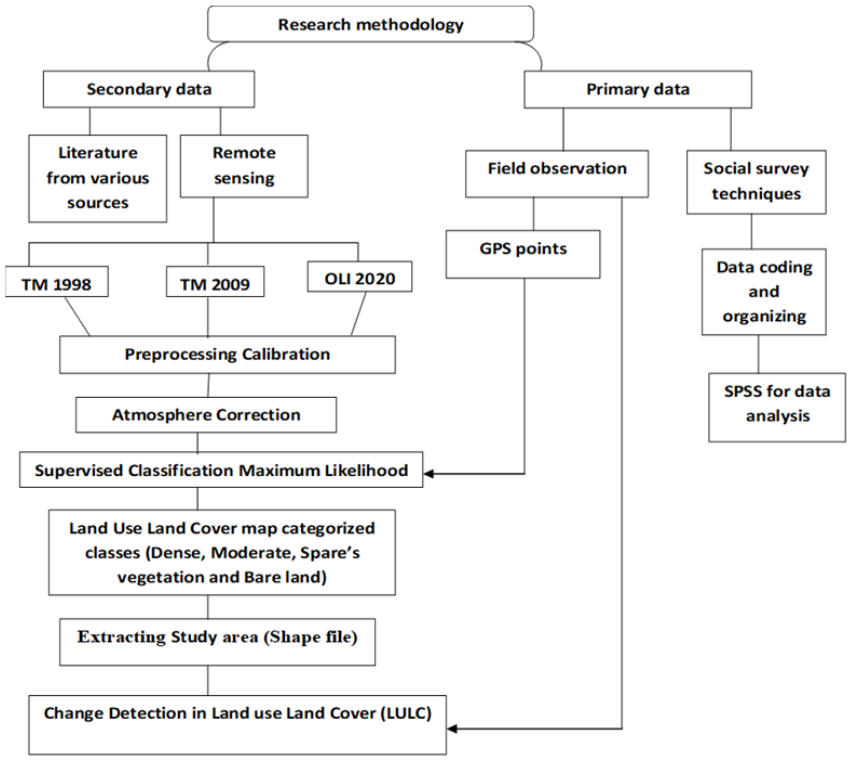

Fig. 2. Flowchart of schematic representation of the research methodology

Results and discussion

Social survey analysis

Table 2 shows the characteristics of the HHHs in the study area. The average age of HHH in the study area was above 45 years, which means they have good experience with gum production, with an average family size of 7-8 members in the study area. The age of the HHH and family size are important parameters for skilled labour for gum production and farming activities. These findings are in line with those of [18, 19], who stated that the number of family members will contribute to the provision of more labour for home horticulture, which could result in more variety species in home garden agroforestry practices. The results concur with those of [20], who reported that smallholders rely more on family members as labour for the production of food, medicine, fuel, and fibre than other capital.

The inheritance system was the dominant land tenure in Alkhowi and Shiekan localities, while 20.8% of the respondents in Umrawaba locality purchased their lands to secure a livelihood. With regards to the production system, in Shiekan Locality, there are three common production systems (traditional agroforestry, semi-mechanised cultivation, and shifting cultivation) that are practiced (Table 2). While in Alkhowi, gum producers relied on traditional agroforestry, this was mainly because of the remoteness of their areas from the urban cities where finance and markets are accessible. This result agrees with [21], who stated farmers who adopted the traditional gum Arabic agroforestry system are characterised by less commercialization, access to finance, less fragmented land, more education, high gum prices at gates, being located at a remote distance from the markets, and having more years of experience with gum production.

Table 2. Socioeconomic and gum production resources characteristics of the HHHs

Attributed		Locality		
		Alkhowi	Shiekan	Umrawaba
Age (year)	Mean	45.5	48.6	50.1
	SD	13.3	13.3	10.6
Family size	Mean	8	7	8
	SD	3	3	3
Land tenure system (%)	Title holder	8.4	13.2	20.8
	Rented	2.2	2.1	5.4
	Sharing cropping	1.7	2.2	10.9
	Inheritance	87.1	81.4	63.1
	land release	0.7	1	0
Agricultural production systems (%)	Traditional agroforestry	100	40.0	0
	Semi-mechanized	0	12.7	0
	Shifting cultivation	0	47.3	100
Crops rotation (%)	Between	16.3	24.5	17.1
	Separated	74.3	65.7	64.5
	Both	9.4	9.8	18.4
GAPAs type (%)	Marketing	83.5	81.9	81.3
	Production	16.5	14.8	16.6
	Both	0	3.3	2.2

The findings in table 2 also revealed that the main production rotation is the bush follow system; farmers relied on the block design to plant gum trees separately from other agricultural crops. These findings disagree with [22], who confirmed the critical importance of farm size and size of inherited land for the initial adoption of gum production, particularly with the long-term rotation of the plantation (20–25 years), only farmers with large holdings and stable ownership will be able to adopt gum agroforestry systems. Concerning the GAPAs type, the majority of the respondents stated that GAPAs were formed to deal with the marketing of gum products.

The findings in Table 3 show the stoking density of Hashab (trees per ha) in the study area. The majority of the respondents (90.1%) in the study area confirmed that the average gum tree density in their gum garden is 200 trees or less per ha. In Alkhowi locality, 20.4% of the respondents asserted that the stocking density is more than 200 trees per ha (with an average of 280 ± 60 trees per ha). This result agrees with [23], who revealed in their results that 245 trees per ha are found in pure stands of Hashab trees with an average gum Arabic production of 450 grammes per tree.

Farmers that own more than 150 trees per ha are found in GAPAs that depend on gum production as one of the main sources of their livelihood or in GAPAs with external support interventions. The high tree numbers in Alkhowi and Umrawaba are mainly due to the high returns from gum per unit area as a result of the high stocking density, or the highest price, as well as the production systems that are practiced in the two localities. This result concurs with [23, 24], who stated that the density of Hashab trees varies from one stand to another due to the various forms of management practices. Gum Arabic trees under reserved forests can reach up to 450 trees per ha, while the density of gum trees in private gardens ranges at least between 100 and 125 trees per ha, whereas the high average can reach 625 trees per ha [23].

Table 3. The stocking density of Hashab trees in the study area

Locality	Perception of the respondents on the stocking density Trees/ha (%)				Average stocking density (Trees/ha)				
	<50	50-100	101-200	>200		<50	50-100	101-200	>200
Alkhowi	16.7	29.7	33.2	20.4	Mean	30	62	134	280
					SD	10	10	29	60
Sheikan	62.3	20.2	15.0	2.5	Mean	24	64	135	213
					SD	12	12	21	0
Umrawaba	81.7	11.4	0.0	6.9	Mean	30	59	0	284
					SD	7	9	0	0
Mean	53.6	20.4	16.1	9.9					

Figure 3 shows the status of Hashab trees in the study area. About 83.6% of the respondents in the study area stated that the stocking density of Hashab trees in their gum gardens increased, and they verified this increase in stocking density for regeneration and protection. Contrarily, some farmers asserted that there is a decline in Hashab stocking density due to fire and illegal felling. About 91.6% of the respondents indicated the prevalence of three age groups (young, mature, and old trees), particularly in Umrawaba Locality. However, there are still some farmers in Shiekan Locality with no Hashab trees in their gardens. The increment in the Hashab density can be attributed to raising gum prices and to the rehabilitation of gum Arabic belt programmes that were carried out by NGOs.

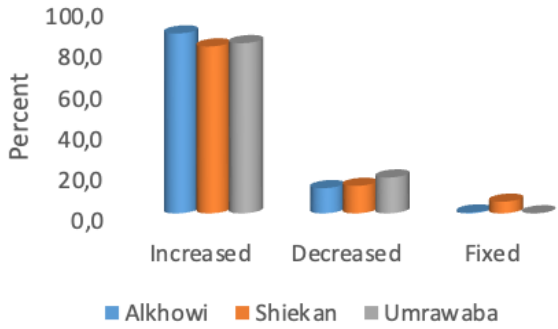

Fig. 3. Hashab trees status in the study area

This result agrees with [17], who clarified that the increase in vegetation cover in North Kordofan state is mainly due to the increase in rainfall and the migration of local people, which is affected by the abundance of farm fields and reduces the pressure of grazing. More so, concluded that one of the main reasons for the establishment of GAPAs is to improve gum trees [25].

The direct role of GAPAs concerning reforestation and afforestation programmes

Increase the gum area after GAPAs adoption

Table 4 presents the gum production in the study area. The findings indicated that gum producers in Umwaraba Locality were keen to increase their land through the purchase of land or shifting cultivation compared to producers in the other two localities. However, the total gum production land resource in Umrawaba remains less than that in the other two localities, where the gum production land resource in Alkhowi locality was the highest among the study areas. The average gum production resource land was one of the main assets and natural capital that hindered the livelihood of gum producers, where gum gardens were characterised as small-scale farms. This finding agrees with [26], who stated that gum Arabic in Sudan is mainly produced by small-scale farmers. More so, [27] reported that local gum Arabic producers in Nigeria are mainly peasant farmers.

Table 4. Gum Arabic land area

Attributes	Increase gum area after GAPAs adoption (%)			Total land area (ha)		
	Yes	Yes, but not too much	No	Mean	SD	Range
Alkhowi	24.3	4.2	71.5	66.3	86.9	0.75 - 450
Shiekan	30.9	5.0	64.1	20.4	27.7	1.50 - 225
Umrawaba	75.6	4.2	20.2	26.3	23.6	3.75 - 120
Mean	43.6	4.5	51.9			

Initiatives techniques to improve gum production, and the role of GAPAs

The gum producers in the study area confirmed that there are several techniques for improving gum production (Table 5). About 34.8% of producers stated that the main technique adopted to improve gum production is the expansion of gum plantations, particularly in Umrawaba Locality, where 58.2% confirmed the same finding. The production and marketing of gum Arabic in the study area are practices based on indigenous knowledge and are mainly based on the individual efforts of the producers, which are influenced by the socio-economic characteristics of the producers. While the adoption level of innovation and its forms that are applied in the production and marketing of gum Arabic is basically associated with external interventions. The results agree with the statement of [28, 29], who stated that smallholders in east sub-Saharan Africa rely on agroforestry innovation as an option to cope with climate change.

Table 5. Ideas to improve the production of gum Arabic and the role of GAPAs

Locality	Ideas to improve the production of gum Arabic (%)					Role of GAPAs (%)
	Use improved seeds	Tapping more trees	Increase the gum plantations	Tapping in suitable time	Protect the gum trees	
Alkhowi	10.8	25.9	23.1	12.9	27.3	1.0
Shiekan	45.2	12.6	23.1	3.0	16.0	13.3
Umrawaba	4.0	30.4	58.2	5.7	1.7	0
Mean	20.0	23.0	34.8	7.2	15.0	7.2

With regards to the role of GAPAs in introducing innovation in Table 5, gum producers in Umrawaba rely on their own indigenous experience to increase the gum plantations, while 13.3% of the respondents in Shiekan declared that they rely on GAPAs to introduce ideas to

improve gum production. The findings are in line with those of Anania and [30], who stated that cooperative membership leads to the adoption of modern inputs, increased intensification, increased commercialization of farm produce, and higher revenue and farm income. GAPAs are passive and do not have significant roles in enhancing the production of gum Arabic because of the misunderstanding of their members about their roles towards their GAPAs. This result disagrees with that of [31, 32] in Ethiopia and with [33] in Kenya, who stated that households who were living inside the forest previously and closer to the forest organised themselves into groups, associations, or cooperatives for forest management, and accordingly, their result indicates a strong relationship between forest cooperatives and community participation in forest management and rehabilitation practices.

Changes after joined the GAPAs

Table 6 shows the changes that farmers have seen since the adoption of the GAPA intervention. About 70.8% of the respondents stated that there has not been any change since they joined GAPAs. However, gum producers who face changes have ascertained that there have been several positive changes since the establishment of GAPAs. Among these changes, increase the Hashab stocking density (the main change). However, 21.9% of the producers in Umrawaba Locality declared an increase in income from gum Arabic as a main change. Other changes included a lifestyle change, the provision of credit, increased production, and an increase in gum prices. The changes that gum producers enjoyed occurred in areas where GAPAs have received external support. The finding is in line with that of [34], who stated that cooperatives that receive governmental support usually have strong economic status. While the findings contradicted those of [31, 35], who reported that the intervention of the government in forest management through collective action was mainly based on the interests and needs of local users, indigenous knowledge, and informal institutions, which offer great benefits for sustainable resource utilisation and rehabilitation of degraded forests.

Table 6. Changes since joining of GAPAs

Locality	No change	Increase the crops land	Increase Hashab trees	Provision of service	Tractor machine	Increase income	Other
Alkhowi	95.7	0.7	4.3	0	0	0	1.5
Shiekan	60.2	15.3	15.5	5.3	6.7	3.4	7.3
Umrawaba	56.5	0	14.2	0	0	21.9	18.4
Mean	70.8	5.3	11.3	1.8	2.2	8.4	9.1

The indirect role of GAPAs concerning reforestation and afforestation programmes

Responsibilities of GAPAs towards their memberships

The majority of the respondents (68.7%) stated that GAPAs failed to achieve their objectives by supporting their members with production inputs, as asserted by 93.6% and 65.8% in Alkhowi and Shiekan Localities, respectively. The starting-up stage of GAPAs is mainly attributed to the lack of financial resources and the misunderstanding of the members and executive committees about the cooperatives' principles and values. These results are in line with [36], who stated that chairmen may have a restrictive influence on cooperative development due to their lack of professional knowledge and skills, especially in relation to marketing. More so, most of the youth and women's agricultural cooperatives in the East Cape, South Africa, were found to be at the starting-up stage, which is mainly due to insufficient access to financial services, poor infrastructure facilities, a low level of extension services, and poverty [37]. Moreover, the executive committees of GAPAs in the study area were basically selected on the basis of their social and economic characteristics, whereas they are the local villages' leaders, traders, and other wealth members in society who are not concerned with GAPA's affairs, and due to their position in the village, they represent associations in the higher organisational structure of GAPAs and unions at various administrative levels only for their social status. In this situation, the majority of the GAPAs' officers were not seeking to activate

their GAPAs since they have no leisure time to devote to GAPAs since they are wealthy and donors need support from GAPAs. The findings confirm the argument of [38], who revealed that the initiator of the farmers' cooperative in China could be an influential figure within the village, a person who worked for the government, or a wholesaler of agricultural products.

However, 24.7% of the respondents in Shiekan State stated that GAPAs, in collaboration with external support, provided physical capital to their members (agricultural machines, water tanks, and gum stores), while 36.9% in Umrawaba Locality confirmed that they received financial capital from the Sudan Revitalising Gum Arabic Production and Marketing Project (SRGAPMP) before the tapping season. Therefore, the collaboration partnership between GAPAs in Sheikan and Umrawaba and the external institutions (FNCs, banks, and NGOs) has positively influenced the provision of services and benefits. The finding concurs with [39], who stated that one of the most critical problems confronting the development of agricultural cooperatives is a lack of finance. While the result disagrees with that of [40, 41], who stated that agricultural cooperatives have the potential to supply the required agricultural inputs so that commodities' production will be done timely and consequently enhance productivity and contribute to providing a secured market for small farmers who produce commodities in remote rural areas, Cooperatives can play important roles in raising farm income, improving crop productivity, and reducing production input costs [42, 43].

With regards to financial capital, 44% of the respondents in Umwaraba Locality asserted that they relied on GAPAs as a source of credit. The SRGAPMP collaborated with GAPAs in Umrawaba Locality in 2013 to provide financial and/or physical capital to enhance gum Arabic production and marketing. The financial capital that was provided enhanced the plantations of gum trees in the locality through raising the return from gum Arabic, which encouraged producers to plant and protect their gum trees. Moreover, the respondents verified many justifications behind their dependency on GAPAs to obtain the financial fund. The main reasons behind its preference are its availability and readiness to provide support before the tapping season, in addition to its cheapness compared to other sources. Moreover, GAPAs provide stores for collected gum, which provide the opportunity to dispose of the gum at high prices. This leads to the undercapitalization of GAPAs, which mainly depend on external financing sources. The findings agree with [44], who reported that between 2009 and 2014, the International Fund for Agricultural Development (IFAD) and the Sudan Multi-Donor Trust Fund extended funding and training to 10 associations entirely comprised of female farmers in five Sudanese localities as a way of reviving the tradition of gum harvesting.

Concerning human capital through capacity building, the findings in Table 7 show the lack of training programmes organised by GAPAs. Except for 22.5% and 5% in Umrawaba and Shiekan, respectively, it was confirmed that GAPAs provided training to their members in collaboration with external supports.

Table 7. Perception of the respondents on training provided and by GAPAs

Locality	Existence of the training (%)	Main themes covered by trainings (%)		
		Plantation	Tapping	Others
Alkhowi	0	0	0	0
Shiekan	5	8.5	42.5	49.0
Umrawaba	22.5	9.6	63.3	27.1
Mean	9.2	9.1	52.9	38.1

Since gum producers in the study area are familiar with gum trees, there was a poor programme of training organised to cover the plantation topics, as clarified by less than 10% of the respondents. However, tapping techniques and tools were mentioned as the main issues tackled in the training. Other topics related to management include organisational management practices, improvement of production practices, and storage. The result revealed that the lack of accessibility to training and inadequate meetings is mainly attributed to the absence of external support, as it is influenced by the remoteness of the area, low-skilled human power, a lack of legal requirements, and a financial bottleneck. In addition to that, most of the training programmes were addressed to the executive committees' members rather than others. This

finding agrees with [30], who indicated insufficient education and training as guiding instruments, as typically the boards of directors, committees, and hired staff have priority in training and education, while the rest of the members seldom get a chance to receive education and training. [45] indicated that the majority (72.2%) of the committee members of GAPAs were subjected to training sessions in meeting management, filing systems and book-keeping, accounting procedures, tapping techniques, and ideal gum harvesting.

The environmental situation in the study area is critical due to deforestation, degradation, and climate change, which are detrimental to gum production. Therefore, collaboration between different stakeholders to provide technical support for gum producers through trainings will capacitate producers and contribute to the rehabilitation of the degraded gum Arabic belt areas. As well as capability building to adopt techniques that can be used to compact desertification and deforestation. However, the lack of access to training was mainly due to the absence of external support, a lack of partnership, and a low level of awareness. These factors were influenced by location, a lack of skilled human power, legal requirements, and financial bottlenecks. This result agrees with the recommendation of [46], who stated that the management of natural resources should be more broadly incorporated into the services that farmers' organisations provide to their members for the mitigation of risks associated with environmental degradation and climate change.

Images analysis

Land Use Land Cover results in 2020

Four classes of LULC were detected in the study area by supervised image classification. These classes were: dense vegetation area, moderate dense vegetation, sparse vegetation, and bare land, as shown in Fig. 4. The result of the supervised classification of OLI 2021 showed that in Umrawaba Locality, moderate vegetation dominates the area with 205221.4 ha and represents 55.69%. Followed by sparse vegetation equal to 123615.5 ha (33.54%), while barren land is 754.47 ha (represented by 0.20%). In Sheikan Locality, the dense vegetation area occupied 62978.04 ha, which represents 17.35%. The moderate and sparse vegetation were dominant and represented 58.62% (212726.7ha) and 23.95% (86906.88ha), respectively. Meanwhile, in Alkhowi Locality, the barren land occupied 12.82% (57039.66ha) of the total area of the locality (Figs. 4 and 5).

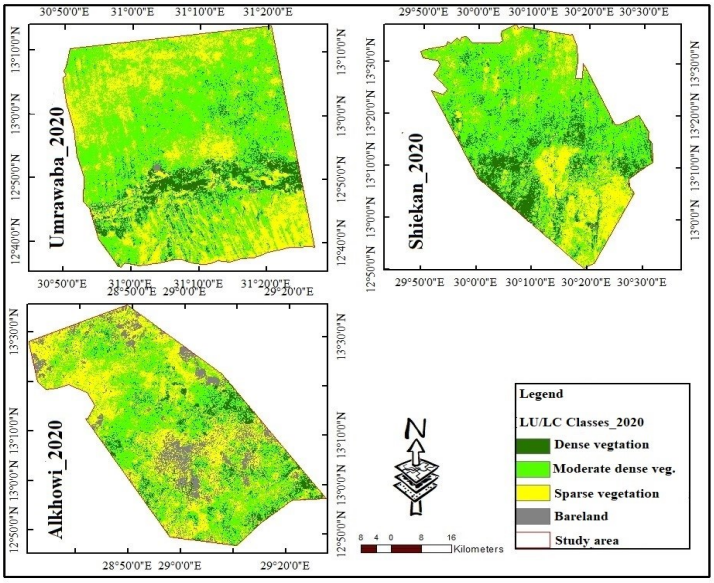

Fig. 4. Supervised classification map of OLI Landsat data 2020

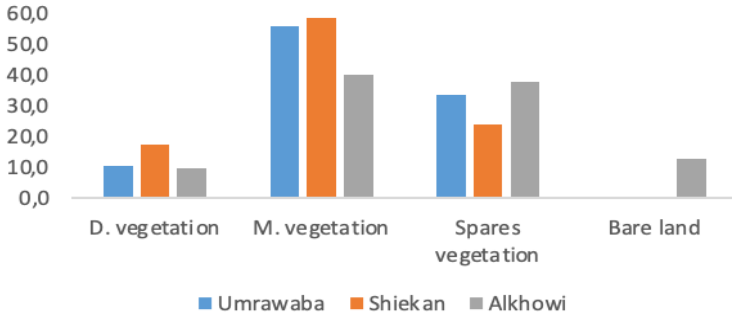

Fig. 5. Distribution of Land Use and Land Cover in the study area (ha) in 2020, Where the D = Dense and M = Moderste

Assessment of LULC change detection

LULC change during 1998-2009

Investigation of classification results (Fig. 6 and Table 8) illustrated that there is a decrease in dense, moderate, and sparse vegetation in the Umrawaba area from 14385.33ha (3.90%), 32515.2ha (8.82%), and 160653.15ha (43.59%) in 1998 to 9628.74ha (2.61%), 17299.98ha (4.69%), and 142083.63ha (38.55%) in 2009, respectively. The bare land increased from 160979.76ha (43.68%) in 1998 to 199526.76ha (54.14%) in 2009. Meanwhile, in Sheikan Locality, there has been an increase in moderate and sparse vegetation from 79236.81ha (21.83%) and 178755.3ha (49.265%) in 1998 to 137970.8ha (38.55%) and 224434.8ha (61.84%) in 2009, respectively. While dense vegetation and bare land decreased from 3742.56ha (1.03%) and 101167.65ha (27.88%) in 1998 to 223.2ha (0.06%) and 272.16ha (0.07%) in 2009, respectively, Moreover, in Alkhowi Locality, there has been an increase in moderate and sparse vegetation from 131429.25ha (29.53%) and 162813.06ha (36.58%) in 1998 to 186265.26ha (41.8%) and 258399.72ha (58.06%) in 2009, respectively. The dense vegetation and bare land decreased from 43199.28ha (9.71%) and 107627.4ha (24.18%) in 1998 to 193.95ha (0.04%) and 209.07ha (0.05%) in 2009, respectively.

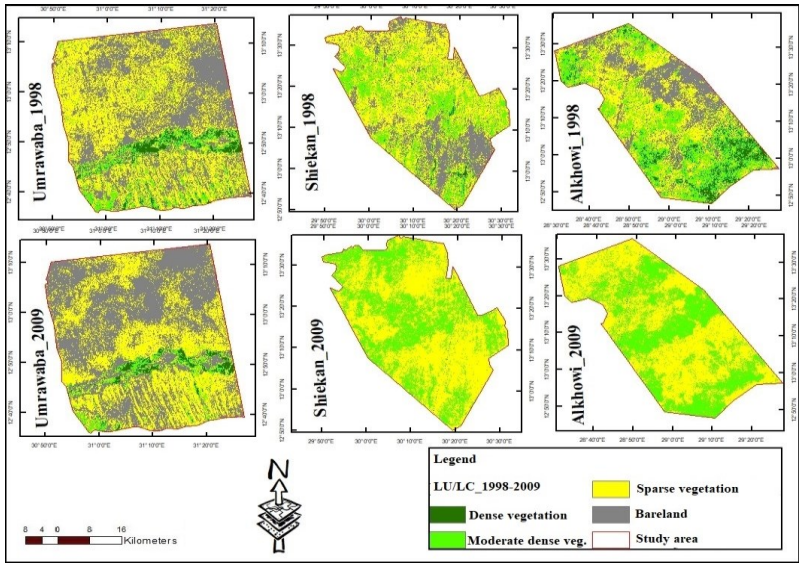

Fig. 6. Classified images of TM 1998 and 2009

Table 8. Distribution of LULC in 1998 and 2009 in the study area

Class name	Area(ha) in 1998	%	Area(ha) in 2009	%
	Umrawaba			
Dense vegetation	14385.33	3.90	9628.74	2.61
Moderate vegetation	32515.2	8.82	17299.98	4.69
Sparse vegetation	160653.15	43.59	142083.63	38.55
Bare land	160979.76	43.68	199526.76	54.14
	Sheikan			
Dense vegetation	3742.56	1.03	223.2	0.06
Moderate vegetation	79236.81	21.83	137970.81	38.02
Sparse vegetation	178755.3	49.26	224434.8	61.84
Bare land	101167.65	27.88	272.16	0.07
	Alkhowi			
Dense vegetation	43199.28	9.71	193.95	0.04
Moderate vegetation	131429.25	29.53	186265.26	41.85
Sparse vegetation	162813.06	36.58	258399.72	58.06
Bare land	107627.4	24.18	209.07	0.05

LULC change during 2009-2020

Figure 7 and Table 9 show that the dense and moderate vegetation in Umrawaba increased from 9628.74ha (2.61%) and 17299.98ha (4.69%) in 2009 to 38940.66ha (10.57%) and 205221.42ha (55.69%) in 2020, respectively. The sparse vegetation and bare land decreased from 142083.63ha (38.55) and 199526.76ha (64.14%) in 1998 to 123615.45ha (33.54%) and 754.47ha (0.20%) in 2020, respectively. Meanwhile, in Sheikan, there is an increase in dense, moderate vegetation and bare land area from 223.2ha (2.61%), 17299.98ha (38.02%), and 199526.76ha (54.14%) in 2009 to 38940.66ha (10.57%), 205221.42ha (55.69%), and 289.71ha (0.08%) in 2020, respectively. The sparse vegetation decreased from 224434.8ha (61.84%) in 2009 to 86906.88ha (23.95%). Moreover, in Alkhowi, there is an increase in dense vegetation and bare land area from 193.95ha (0.04%) and 209.07ha (0.05%) in 2009 to 42744.42ha (9.60%) and 57039.66ha (12.82%) in 2020, respectively. Also, the moderate and sparse vegetation areas declined from 186265.26ha (41.85%) and 258399.72ha (58.06%) in 2009 to 177724.62ha (39.93%) and 167559.21ha (37.65%) in 2020, respectively.

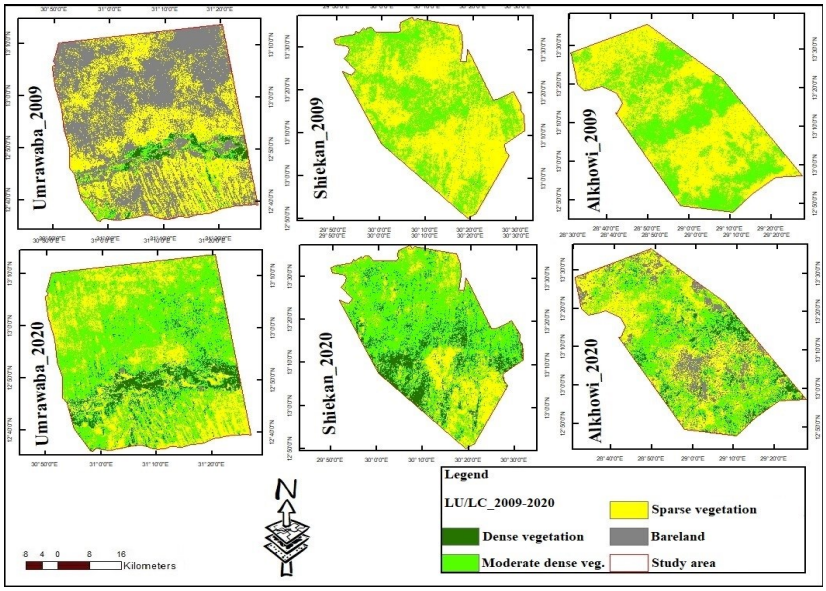

Fig. 7. Classified images of TM 2009 and OLI 2020

Table 9. Distribution of LULC in 2009 and 2020 in the study area

Class name	Area(ha) in 2009	%	Area(ha) in 2020	%
	Umrawaba			
Dense vegetation	9628.74	2.61	38940.66	10.57
Moderate vegetation	17299.98	4.69	205221.42	55.69
Sparse vegetation	142083.63	38.55	123615.45	33.54
Bare land	199526.76	54.14	754.47	0.20
	Sheikan			
Dense vegetation	223.2	0.06	62978.04	17.35
Moderate vegetation	137970.81	38.02	212726.7	58.62
Sparse vegetation	224434.8	61.84	86906.88	23.95
Bare land	272.16	0.07	289.71	0.08
	Alkhowi			
Dense vegetation	193.95	0.04	42744.42	9.60
Moderate vegetation	186265.26	41.85	177724.62	39.93
Sparse vegetation	258399.72	58.06	167559.21	37.65
Bare land	209.07	0.05	57039.66	12.82

Figure 8 and Table 10 display that the dense and moderate vegetation in the Umrawaba area increased from 14385.33ha (3.90%) and 32515.2ha (8.82%) in 1998 to 38940.66ha (10.57%) and 205221.42ha (55.69%) in 2020, respectively. The sparse vegetation and bare land declined from 160653.15ha (43.59) and 160979.76ha (43.68%) in 1998 to 123615.45ha (33.54%) and 754.47ha (0.20%) in 2020, respectively. Meanwhile, in Sheikan, there has been an increase in dense and moderate vegetation areas from 3742.56ha (1.03%) and 79236.81ha (21.83%) in 1998 to 62978.04ha (17.35%) and 212726.7ha (58.62%) in 2020, respectively. The sparse vegetation and bare land decreased from 178755.3ha (49.26%) and 101167.65ha (27.88%) in 2009 to 86906.88ha (23.95%) and 289.71ha (0.08%) in 2020. Moreover, in Alkhowi, there is a decrease in dense vegetation and bare land area from 43199.28ha (9.71%) and 107627.4ha (24.18%) in 1998 to 42744.4ha (9.60%) and 57039.66 ha (12.82%) in 2020, respectively. So, the moderate and sparse vegetation increased from 131429.25ha (29.53%) and 162813.06ha (36.58%) in 1998 to 177724. 62ha (39.93%) and 167559.21ha (37.65%) in 2020, respectively.

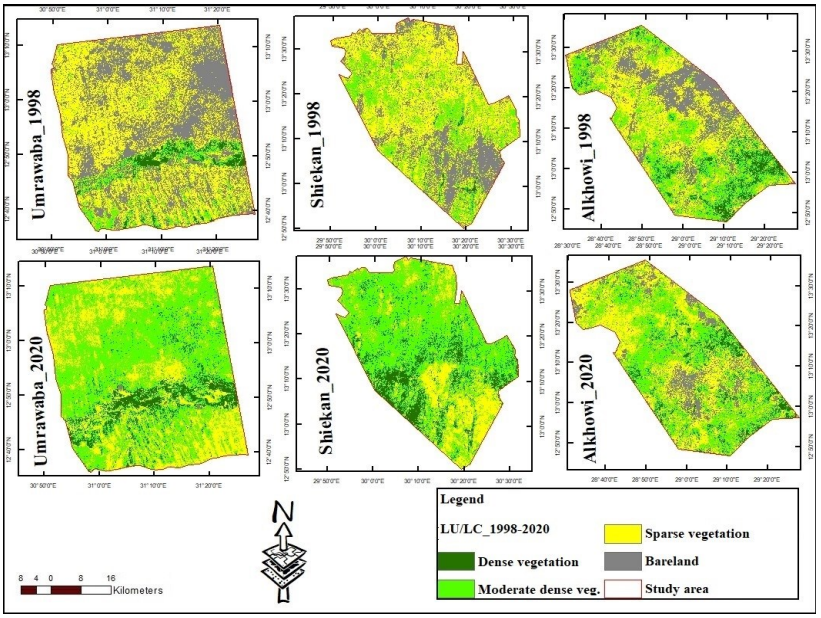

Fig. 8. Classified images of TM 1998 and OLI 2020

Table 10. Distribution of LULC in 1998 and 2020 in the study area

Class name	Area(ha) in 1998	%	Area(ha) in 2020	%
Umrawaba				
Dense vegetation	14385.33	3.90	38940.66	10.57
Moderate vegetation	32515.2	8.82	205221.42	55.69
Sparse vegetation	160653.15	43.59	123615.45	33.54
Bare land	160979.76	43.68	754.47	0.20
Sheikan				
Dense vegetation	3742.56	1.03	62978.04	17.35
Moderate vegetation	79236.81	21.83	212726.7	58.62
Sparse vegetation	178755.3	49.26	86906.88	23.95
Bare land	101167.65	27.88	289.71	0.08
Alkhowi				
Dense vegetation	43199.28	9.71	42744.42	9.60
Moderate vegetation	131429.25	29.53	177724.62	39.93
Sparse vegetation	162813.06	36.58	167559.21	37.65
Bare land	107627.4	24.18	57039.66	12.82

Comparative results

Both the social survey and remote sensing results confirmed the increase in dense and moderate vegetation cover in the study area between 1998 and 2020. Since the formal establishment of GAPAs, there has been an increase in vegetation cover, especially in Umrawaba and Shiekan localities. This is mainly attributed to the incentive of high gum Arabic prices that were offered in collaboration with external institutions and to the implementation of rehabilitation programmes through NGOs intervention projects that financed and supported gum producers through their GAPAs. The findings confirmed the statement of [25, 47, 48], who stated the establishment of GAPAs was mainly for the development of rural areas and gum producers, improving gum Arabic trees, and promoting gum production and marketing. However, the result of the 2009 image revealed that gum Hashab density in Umrawaba Locality decreased in the study area as a result of economic sanctions, price fluctuations, market accessibility, and crop production instability. This result concurs with the argument of [49], who concluded that the gum Arabic producer's cooperative societies in Sudan have positively contributed to settling the household members of gum producers in North Kordofan State, although these societies have not had any impact on the improvement of gum Arabic production and marketing.

Although the highest gum Arabic production was found in Alkhowi Locality, it is witnessing an increase in the total bare land. This may have been attributed to the low intensity of gum production where it's located in a remote area, which had a negative influence on the price at the village gate, the type of market in which producers market their gum products (relying on the local market at the village or nearby villages), poor infrastructure, and a lack of external supports. Therefore, gum producers, to accomplish their needs, relied on other sources of livelihood. The other justification for increased bare land may be due to the movement of the gum belt towards the south as an effect of climate change. Even though gum producers in the locality were organised into GAPAs, they failed to be pioneers for improving gum production and marketing through collective action activities. The findings agree with the statement that there are various factors that influence the management and rehabilitation of forests through collective action [31, 50]. Contrary to this, the findings disagree with [51], who stated that to address the challenge of the forest degradation rate, various strategies for forest rehabilitation and restoration could be practiced through community involvement. A participatory forest management strategy was applied to organise farmers into groups for sustainable management and rehabilitation of the degraded forests. These organisations create a set of rules and regulations, a motivation mechanism for property rights, and encourage external support

through which the local community is stimulated to participate in the rehabilitation of degraded forest activities.

Conclusions

The study concluded that the reforestation and afforestation programmes are mainly reliant on the intervention and support of external institutions through the implementation of various projects. Although the keenness of gum producers to adapt strategies for rehabilitation of Hashab trees was very low, Gum Arabic producers in Alkhowi locality are keen to conserve their gum gardens as they rely on gum Arabic as a cash crop that is produced in the off-season. Since the 1980s, many NGOs have implemented and financed projects that have contributed to the reforestation and afforestation of Hashab trees. The establishment of GAPAs in Sudan has made a slight direct and indirect contribution to the rehabilitation of Hashab tress through collaboration with external intuitions. The main contributions of GAPAs are the provision of production inputs (seeds, seedlings, finances, and tools), marketing the gum Arabic, and training sessions. In Alkhowi Locality, gum producers are mainly relying on the traditional agroforestry system; therefore, moderate, and sparse vegetation cover classes are common in this area. The study recommended strengthening the role of GAPAs in the rehabilitation of the gum Arabic belt through capacity-building programmes to develop effective and capable organisational structures. Formulate policies and laws to ensure the protection and management of gum trees and gum Arabic. Create smart partnerships to enhance the production and marketing of gum Arabic.

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