Original article

Determining spatio-temporal distribution of bee forage species of Al-Baha region based on ground inventorying supported with GIS applications and Remote Sensed Satellite Image analysis

Nuru Adgaba [a,*], Ahmed Alghamdi [a], Rachid Sammoud [b], Awraris Shenkute [a], Yilma Tadesse [a], Mahammad J. Ansari [a], Deepak Sharma [a], Colleen Hepburn [c]

[a] Engineer Bagshan Chair for Bee Research, Department of Plant Protection, College of Food and Agricultural Science, King Saud University, P O Box: 1460, Riyadh 11451, Saudi Arabia
[b] College of Computer and Information Sciences, King Saud University, Saudi Arabia
[c] Department of Zoology, Rhodes University, South Africa

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ABSTRACT

In arid zones, the shortage of bee forage is critical and usually compels beekeepers to move their colonies in search of better forages. Identifying and mapping the spatiotemporal distribution of the bee forages over given area is important for better management of bee colonies. In this study honey bee plants in the target areas were inventoried following, ground inventory work supported with GIS applications. The study was conducted on 85 large plots of 50×50 m each. At each plot, data on species name, height, base diameter, crown height, crown diameter has been taken for each plant with their respective geographical positions. The data were stored, and processed using Trimble GPS supported with ArcGIS10 software program. The data were used to estimate the relative frequency, density, abundance and species diversity, species important value index and apicultural value of the species. In addition, Remotely Sensed Satellite Image of the area was obtained and processed using Hopfield Artificial Neural Network techniques. During the study, 182 species from 49 plant families were identified as bee forages of the target area. From the total number of species; shrubs, herbs and trees were accounting for 61%, 27.67%, and 11.53% respectively. Of which *Ziziphus spina-christi*, *Acacia tortilis*, *Acacia origina*, *Acacia asak*, *Lavandula dentata*, and *Hypoestes forskaolii* were the major nectar source plants of the area in their degree of importance. The average vegetation cover values of the study areas were low (<30%) with low Shannon's species diversity indices (H′) of 0.5–1.52 for different sites. Based on the eco-climatological factors and the variations in their flowering period, these major bee forage species were found to form eight distinct spatiotemporal categories which allow beekeepers to migrate their colonies to exploit the resources at different seasons and place. The Remote Sensed Satellite Image analysis confirmed the spatial distribution of the bee forage resources as determined by the ground inventory work. An integrated approach, combining the ground inventory work with GIS and satellite image processing techniques could be an important tool for characterizing and mapping the available bee forage resources leading to their efficient and sustainable utilization.

1. Introduction

The Kingdom of Saudi Arabia extends over two million km[2] land area. Despite its arid climatic conditions, the country consists of diverse ecologies and floras in which more than two thousands of plant species have been recorded (Collenette, 1999; Chaudhary, 2001). As a result, beekeeping is practiced in many areas of the country and it is one of the important income generating activities for rural communities. Despite the presence of diverse number of bee plants, seasonal shortage of bee forage is critical. These conditions force many beekeepers to move their

colonies from place to place (averagely 5 times/year) following the availability of bee forage in different ecologies and seasons (Nuru et al., 2014). This often led to overcrowding of large numbers of bee colonies in a few areas, causing intense competition for bee forage and the subsequent declines of productivity of colonies (Khanbash, 2001; Al-Ghamdi, 2007). However, the type of honey bee plants, their relative abundance, spatial distribution, phenology and their relative values for bees and honey production were not studied and documented.

Honey bee floral resources vary in ecological distribution and in periods of availability according to their flowering times (Chemas and Rico-Gray, 1991). It is therefore, very important to differentiate honey bee plants from the total plants, to map their spatial and temporal distributions and determine their relative values to bees and honey production for every geographical region. Such types of information are important to categorize bee forage plants as useful for colony population build-up and honey production (Partap, 1997).

To identify and inventory honey bee plants; different approaches such as palynological analysis of honey samples, direct observation of foraging bees and analysis of pollen loads and pollen stores in the nest have been used (Amoko, 1997; Hepburn and Jacot-Guillarmod, 1991; Hepbun and Radloff, 1995; Admasu, 2003; Abou-Shaara, 2015a,b). However, these methods only give a general idea as to which plant species the honey bee foragers collected pollen from, and not other co-existing plant species which may flower concurrently and from which resources are also readily available. In recent years, another approach is that of above ground vegetation biomass assessments have been used to estimate the bee forage potentiality of an area. The most common techniques are estimations from field measurements which involve representative sampling following the protocols such as by Kent and Coker (1992), Peichl and Arain (2006), Wulder et al. (2008), or direct measurements like those of Suganuma et al. (2006).

Despite their merits in degree of accuracy and applicability for specific tree species, ground inventory work is highly time and labor intensive and difficult to cover large areas. Peichl and Arain (2007) showed the presence of a strong correlation between spectral information recorded by Remote Sensing of Satellite Images with that of vegetation conditions. In addition Sahoo et al. (2005) used satellite-derived images showing temporal vegetation phenology (green-up and brown-down) to monitor vegetation changes. Several vegetation indices particularly, NDVI reflectance images are most commonly utilized in vegetation analysis (Jarlan et al., 2008). Gould (2000) and Rocchini et al. (2007) have used Remote Sensed Satellite Images to map vegetation cover down to species-level.

However, satellite images in their raw form are not suitable to understand and interpret in a meaningful way and to use them for specific objectives. Therefore, it requires a suitable image segmentation process, which is partitioning of an image into non-overlapping, meaningful and homogenous regions based on their pixel properties (Sammouda et al., 2013). Pixel clustering is one of the effective and efficient techniques used to create homogenous image regions for image segmentation and its aim is to partition the desired clusters with high intra-class similarities (Felzenszwalb and Huttenlocher, 2004). In the satellite image segmentation, the application of the Hopfield Artificial Neural Network (HNN) clustering algorithm technique is reported to be useful to process the images in meaningful homogenous regions (Shi and Mallick, 2000).

Since different tree species become green-up as a result of flushing of leaves at different times, Remote Sensed Satellite Image processing of such changes, supported with GIS based ground inventory work, can be used to analyze the temporal and spatial distribution of bee forage species at different seasons. The aim the current work was to determine the spatiotemporal distribution of honey bee forages of the target areas through detail ground inventory work using GIS applications and supported with Remote Sensed Satellite Image processing techniques.

2. Materials and methods

2.1. Study area

The study was conducted in Al-Baha region, Saudi Arabia (Fig. 1). The region is characterized by diverse physiographic conditions which vary from lowland plains to highland plateaus with altitudinal range of 300–2400 m above sea level. The topography of the region is mainly undulated hills, mountains with strips of fertile valleys. The average relative humidity of the region ranges from 52 to 67%. The rainfall amount is relatively low and varies from 229 to 581 mm/annum. The mean temperature is 22.9 °C.

2.2. Ground inventory

The vegetation composition of the target areas was determined by taking 11 representative study sites (valleys). A total of 85 large sampling plots (50 × 50 m each) (total sampling area of 212,500 m²) were covered. The sampling plots were taken following Kent and Coker (1992), Flombaum and Sala (2007) and Suganuma et al. (2006) protocols. Unlike the previous protocols, we used large sampling plots, because trees and shrubs found very scattered in the study area. For each plot all the necessary informa-
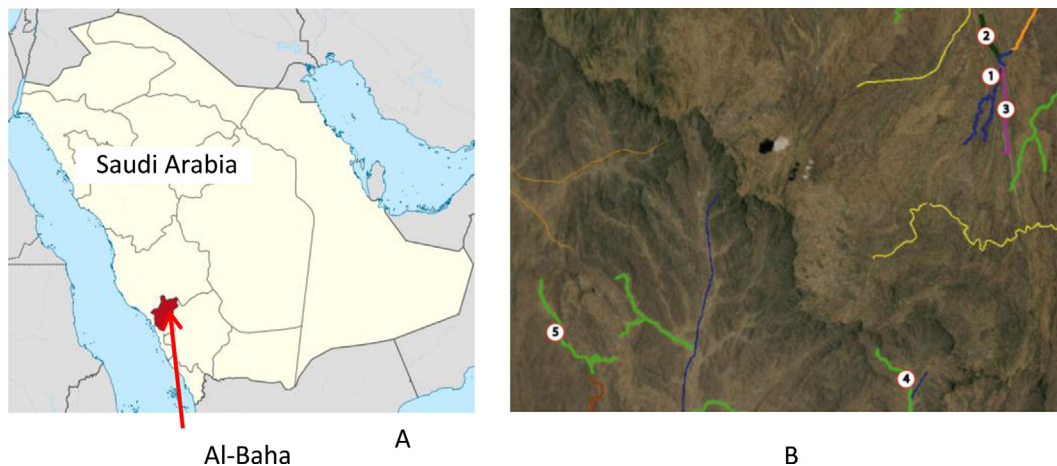

Fig. 1. Map of the studied areas: A = Saudi Arabia, (Al-Baha region); B = specific studied valleys (1 = Majma, 2 = Berha, 3 = Wable, 4 = Alkhatani, 5 = Neera).

tion like: plant species type, height, basal diameter, crown height, crown diameter were taken for each plant with its respective geographical position. The data were entered in Trimble® Juno® 3 series, GPS (USA). To facilitate the data analysis, a database was designed using the ArcGIS-10 software program and used to store, automate and process the entered data. The inventory of honey bee plant species of the target area was conducted by registering all the bee plant species after authentication of the plants as bee forage based on visitation of honey bees to the species for pollen or/and nectar. Voucher specimens were collected of plants for which the species names were unknown, these were sent to the Department of Botany, King Saud University, for identification.

The ground survey data were captured as layers in the database application. The list of entered attributes of each measured tree in each valley was used as vector information to analyze the vegetation condition of the study area. From these data, the relative frequency, relative density, relative abundance, species diversity indices, species important value indices (IVI) and apicultural value (AV) were calculated. The apicultural value of the species was calculated by multiplying the species important value indices with the average nectar sugar amount per plant. The average nectar sugar per plant was determined following Mallick (2000), Kim et al. (2011), Nuru et al. (2012) protocols with some modifications.

2.3. Satellite image processing

To support the ground inventory survey, Remote Sensed Satellite Images (1.0 m resolution) of the study area at different seasons of the year 2013 were obtained from the King Abdulaziz City for Science and Technology Space Research Institute. Processing (color segmentation) of the satellite images was done by assigning (labeling) each pixel with very close features (color, intensity and texture) into only one cluster. This method uses the pixel label to separate objects in the image based on the mean color value of the corresponding cluster in the original satellite image. Each cluster varies from the other depending on spectral information of the forest biomass images recorded by Remote Sensing. Segmentation of the satellite image color was done using the Hopfield Artificial Neural Network (HNN) clustering algorithm technique (Shi and Mallick, 2000). The segmentation was supported with Computer Aided Determination programs using TrueQuant Software application.

2.4. Phenology

Along the inventory of the honey bee forage species their flowering calendar: the onset of flowering, peaking, ending, and total duration of flowering has been recorded by continuous monitoring of the phenology of each species. The monitoring was done at least for two flowering seasons for each plant species.

3. Results and discussion

3.1. Ground inventory

During the survey, 182 plant species were identified as pollen or/and nectar sources for honey bees in the region. The bee forage species were distributed over 49 plant families of which the five families, *Asteraceae, Leguminosae, Lamiaceae, Acanthaceae*, and *Malvaceae* were accounted for the majority (35%) of the total bee forage species of the region. Of the total number of species recorded 111 (61%) were shrubs, 50 (27.67%) herbs and 21 (11.53%) trees. Despite there being less species diversity; trees and shrubs were the major sources of honey in the region, which could be due to their deep rooted nature and their adaptation to low precipitation.

Moreover, trees and shrubs may not be affected equally by intermittent rainfall conditions of the area as for instance annual herbs. Of the total 182 species recorded as bee plants only six species (*Ziziphus spina-christi, Acacia tortilis, Acacia origina, Acacia asak, Lavandula dentata*, and *Hypoestes forskaolii*) serve as major sources of nectar in the region. This is in agreement with previous reports that mentioned only 1.6% of the world's bee plants are the source of most of the world's honeys (Crane, 1990). *Z. spina-christi* was reported as a major honey source plant of eastern Saudi Arabia (Taha, 2015). The importance of having lists of honey bee plants of an area in suitable apiary site selection and cultivating of potential plants for honey bee colonies has been well suggested (Abou-Shaara, 2015a,b).

Species such as *Dipterygium glaucum, Plantago lanceolata, Acacia* spp., *Psiadia punctulata, Rumex* spp. and many grass species are very good sources of pollen for honey bees in the region. In general, pollen source plants are very limited, both in terms of number of species, and their distribution and duration of availability. As a result, brood rearing and colony build-up are very critical to beekeeping in the region. Major reasons for the shortage of pollen could be limited rainfall to support the growth and flowering of annual bee forage species, and the absence of large-scale cultivation of annual crops that serve as additional sources of pollen. Shortage of pollen as a result of extended dry periods and recurrent droughts and subsequent declining of colony performances has been reported in Saudi Arabia (Omar et al., 2013).

The flowering periods of the bee forage plants of the study area were fairly distributed among the different seasons, a higher proportion of flowering takes place in spring (35%) followed by summer (24.4%). Similarly Taha (2015) has reported that high proportion of flowering of bee plants takes place during spring for eastern parts of Saudi Arabia. Some species such as *Z. spina-christi, Acacia etbaica, A. johnwoodii* and *A. asak* have multiple flowering periods. Moreover, plant species such as *Z. spina-christi, A. tortilis* and *Acacia ehrenbergiana* have a wide range of ecological distribution that ranges from 200 to 1750 meters above sea level. As a result, the flowering periods of the same species vary between ecologies.

Generally, the *Acacia* species which are the dominant bee forage species in the areas are spatio-temporally structured in such a way that some *Acacia* species (*A. johnwoodii* and *A. ehrenbergiana*) spatially co-exist but have different flowering seasons. While others such as *A. tortilis* and *A. ehrenbergiana* co-exist and flower concurrently but vary with respect to the time of peak flowering within a season. Furthermore, other *Acacia* species (*A. etbaica, A. johnwoodii* and *A. asak*) are spatially separated in that *A. asak* has been observed to grow mainly in steep rocky escarpments, whereas *A. johnwoodii* grows mainly in the bottoms of valleys or on gently sloping ground with deep soil structure. *A. etbaica* grows on steep slopes or on gently sloping ground, but favoring the eastern aspects of landscape, and does not spatially overlap with other species which flower concurrently.

All of these phenomena may be considered as adaptations by the species to avoid competition for pollinators and minimize heterospecific pollen transfer among related species. Similarly, Stone et al. (1998) recognized similar mechanisms as major contributing factors to the structuring of the flowering of sympatric *Acacia* species in Africa. A mechanism for the minimization of competition for pollinators is believed to be an important force in the structuring of plant communities (Feinsinger et al., 1987). The spatial variation of the *Acacia* species reported to be partially attributed to avoiding completion for pollinators, (Rathcke, 1988). Besides the competition for pollinators; other environmental factors such as physiographic (altitude, soil, slope) and climatic conditions believed to play important role in spatiotemporal distribution of plant species.

Environmental factors, such as variations in the amount of water stored by plants (Borchert, 1994a,b), and changes in temperature (Williams-Linera, 1997) are regarded as important factors involved in phenological variations among some tropical plants. The schematic map of the temporal and spatial distribution of the major nectar and pollen source species of the region are depicted in Fig. 2. This enables beekeepers to harvest honey two times in the same season from the same species.

Generally, flowering periods are very short and intermittent in the region. However, deep rooted trees and shrubs such as Z. spina-christi and many of the Acacia spp. flower, more or less, following regular seasons. However, flowering periods of the majority of annuals, biennials and some perennials, are governed by the onset of rainfall and subsequent soil moisture conditions. As a result, flowering periods' shift from year to year and place to place is highly expected. The effect of rainfall on growth, green up and onset of flowering of plants in different climatic regions have been well documented (Fox, 1990; Abd-ElGhani, 1997; Peñuelas et al., 2002; Borchert, 1994a,b). Moreover, the general spatiotemporal phenological shifts of many plant species as responses to changes in rainfall are also well known (Peñuelas et al., 2004).

Moreover, some plants like A. tortilis and A. ehrenbergiana were observed to flower in dry season, in leafless stages, and secrete considerable amounts of nectar from stored carbohydrates of the previous season (pers. obs. Nuru). However, when rainfall occurs, the plants shift their resource allocation from nectar secretion to vegetative growth (i.e. producing new leaf and vegetative buds) which may lead to declining of nectar secretion and subsequent low honey yield. Partitioning of resources between the vegetative and reproductive functions has been described as a distinct adaptation of plant species found in dry climatic conditions (Singh and Kushwaha, 2006).

According to the vegetation composition analysis, the dominant species in most sites include: Z. spina-christi, A. tortilis, A. ehrenbergiana, A. etbaica, Acacia origena, Acacia johnwoodii and Anisotes

trisulcus contributing for 71.57% of the total studied bee forage coverage of the areas. The distribution of these species was either mixed or pure stands with relatively low species diversity with Shannon's species diversity indices (H′) of 0.5–1.52 for different sites. The average vegetation cover values of the study areas were low (<30%). The relative density, frequency, species important values and relative apiculture values of some major species of the study area are shown in (Table 1). The highest relative frequencies of 0.48, 0.31 and 0.29 were recorded for A. etbaica, A. tortilis Z. spina-christi respectively indicating these species are commonly found in most of the studied plots. The same species have relatively better cover values (Table 1) indicating the species are more dominant in the region.

Causes for sparse vegetation coverage and limited plant diversity of the area could be due to many interrelated factors like: high moisture stress, human interference, recurrent drought, soil erosion, overgrazing, limited efforts toward conservation and rehabilitation. Extensive human interferences and climate changes and subsequent deterioration and continuous decline of many tree species and forest habitats have been reported for the region (Batanouny, 1991; Hall, 2005; El-Juhany, 2009; Hall et al., 2010).

According to the apicultural value estimation, the major plants in order of importance are Z. spina-christi, A. johnwoodii, A. ehrenbergiana, A. tortilis, A. origena and A. etbaica (Table 1). It was found that there was no positive significant correlations ($r = -0.005$, $P = 0.493$, $N = 14$) between IVI value and apicultural value (AV) of the species, which could be because IVI value is mainly related to the timber value while the AV value depends on the number of flowers per plant and nectar sugar amount per flower.

Because of its very intermittent flowering nature; the honey from A. johnwoodii is not commonly exploited in the area. Moreover, despite its high nectar secretion potential, A. ehrenbergiana is also another bee forage plant which is not well exploited for honey production. This may be due to the co-existence and concurrent-flowering of the species with A. tortilis and the more
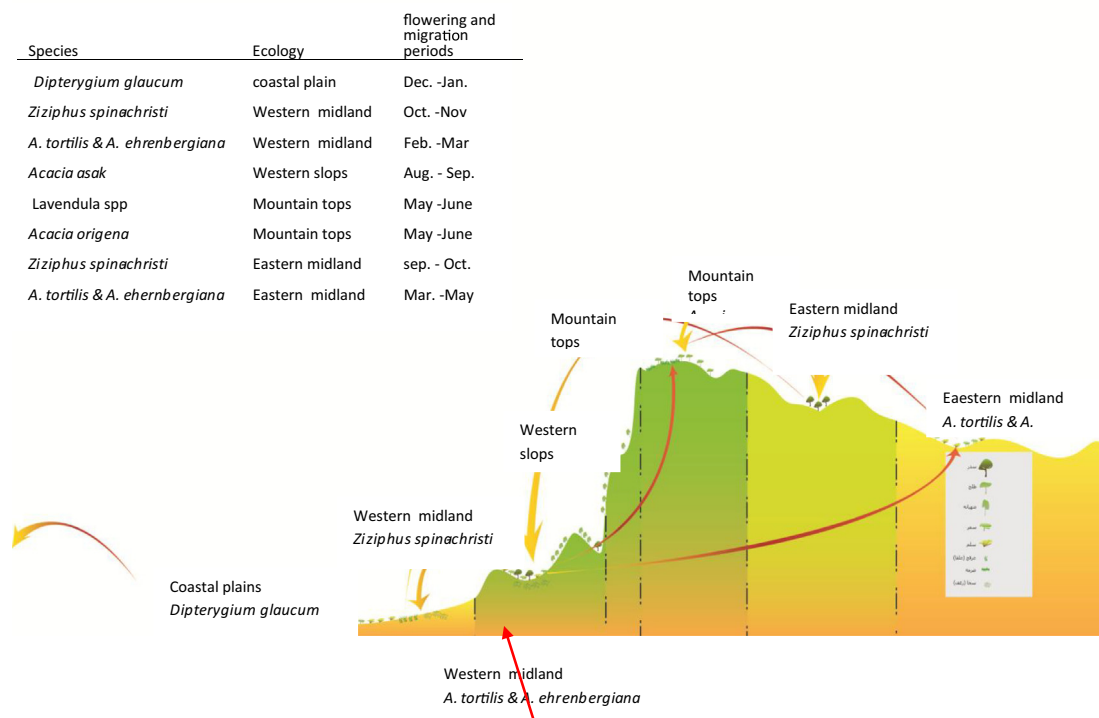
Species	Ecology	flowering and migration periods
Dipterygium glaucum	coastal plain	Dec. -Jan.
Ziziphus spinachristi	Western midland	Oct. -Nov
A. tortilis & A. ehrenbergiana	Western midland	Feb. -Mar
Acacia asak	Western slops	Aug. - Sep.
Lavendula spp	Mountain tops	May -June
Acacia origena	Mountain tops	May -June
Ziziphus spinachristi	Eastern midland	sep. - Oct.
A. tortilis & A. ehernbergiana	Eastern midland	Mar. -May

Mountain tops

Eastern midland
Ziziphus spinachristi

Mountain tops

Eaestern midland
A. tortilis & A.

Western slops

Western midland
Ziziphus spinachristi

Coastal plains
Dipterygium glaucum

Western midland
A. tortilis & A. ehrenbergiana

Fig. 2. Schematic representation of the spatio-temporal distribution of major bee forages of the study area and seasonal colony migration.

Table 1
Species importance and relative apicultural values of some major honey bee plant species of the study area.

Species name	Relative canopy cover/species	Relative density	Relative freq.	Species importance val.(IVI)	Average nectar sugar/tree (kg)	Relative apiculture value
Acacia asak	0.02	0.01	0.03	0.06	0.14	0.01
Acacia ehrenbergiana	0.20	0.21	0.27	0.68	0.55	0.38
Acacia etbaica	0.54	0.76	0.48	1.79	0.13	0.23
Acacia gerrardii	0.05	0.07	0.11	1.55	0.11	0.17
Acacia oerfata	0.01	0.02	0.03	0.06	0.04	0.00
Acacia origena	0.21	0.17	0.19	0.54	0.50	0.27
Acacia johnwoodii	0.11	0.04	0.10	0.26	2.14	0.56
Acacia tortilis	0.45	0.41	0.31	1.16	0.28	0.33
Anisotes trisulcus	0.06	0.25	0.18	0.49	0.11	0.05
Lavandula dentata	0.10	0.49	0.15	0.74	0.12	0.09
Lavandula pubescens	0.11	0.44	0.17	0.81	0.11	0.09
Nepeta deflersiana	0.13	0.22	0.21	0.66	0.12	0.08
Otostegia fruticosa	0.12	0.44	0.12	0.71	0.11	0.08
Z. spina-christii	0.29	0.10	0.29	0.68	6.70	4.52

[*] Apicultural value of the species was calculated by multiplying the species important value index with average nectar sugar amount per tree.

preferences of honey bees toward *A. tortilis* flowers than *A. ehrenbergiana* (pers. obs. Nuru). The low preferences of the honey bees may depend on the morphology of the *A. ehrenbergiana* flowers which consists relatively very dense and longer florets which may reduce the honey bees to access its nectar. The presence of variations in the preferences of honey bees toward different plant species as a result of morphology of flowers and chemistry of nectar has been documented (Cook et al., 2003; Duffield et al., 2008).

The application of GIS system is found to be useful to spatially present the measured plant with their features as layer on the satellite image of the plots Fig. 3. Such spatial presentation of the measured plants with their features in their respective geographical position is useful to monitor the vegetation and land use changes of the studied valleys over the course of time. The importance of application of GIS and Remote Sensed Satellite Image analysis in monitoring vegetation cover changes has been well demonstrated by Lambin and Ehrlich (1997), Shalaby and Tateishi (2007), Abou-Shaara (2013). However it was noticed that slight shifting of the GPS co-ordinates recorded points (plant as object) from the corresponding points from the satellite image (Fig. 3C).

3.2. Satellite image processing

By applying the Hopfield neural network clustering algorithm techniques to the raw satellite images of the area (Fig. 4A); it has been achieved to segment and show the general vegetation cover and distribution of the study area (Fig. 4B, (green)). Using the pixel labels from the satellite images of the vegetation biomass of study area it was possible to further classify the image into two discrete clusters (black and red) (Fig. 4C) based on their mean color values. Finally, we were able to correlate the different cluster colors obtained as a result of segmentations of the satellite image with our GIS based ground inventory records of two co-existing species (*A. tortilis* (black), and *A. ehrenbergiana* (red)) (Fig. 4C), that dominantly grow in the target areas. This color mean value correlation can be used to extrapolate the spatial distribution of the different bee tree species of the target areas. The possibilities of fine tune mapping of vegetation cover to the species level based on appropriate satellite image processing techniques has been well indicated (Gould, 2000; Rocchini et al., 2007; Xie et al., 2008; Sammouda et al., 2013).

This will help estimate area coverage of the different species, the honey production potential and the expected flowering period of the different species and helps to guide migratory beekeepers for successful utilization of the available resources in different times and places. The significance of inventorying of bee forage plants; in suitable apiary site selection, stock level determination and creation of awareness in protecting and conserving of the bee plants species and their general ecosystem have been well documented (Debisa and Admasu, 2009; Taha, 2015).
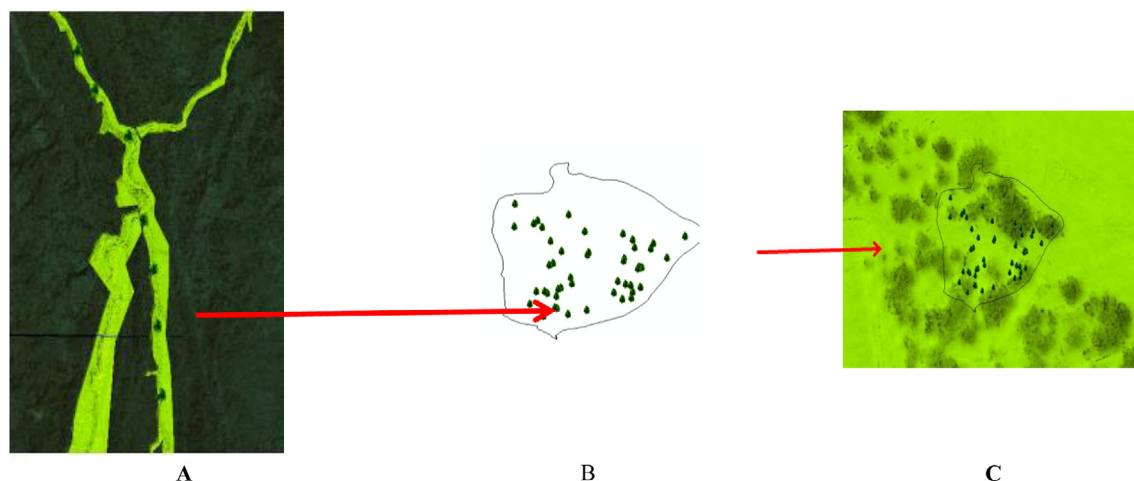

A **B** **C**

Fig. 3. (A), Showing one of the studied valley with its plots as layer on the satellite image of the area; (B) one of the measured plot with trees as points and (C) focuses of the plot features overlapping with the satellite image of the plots.
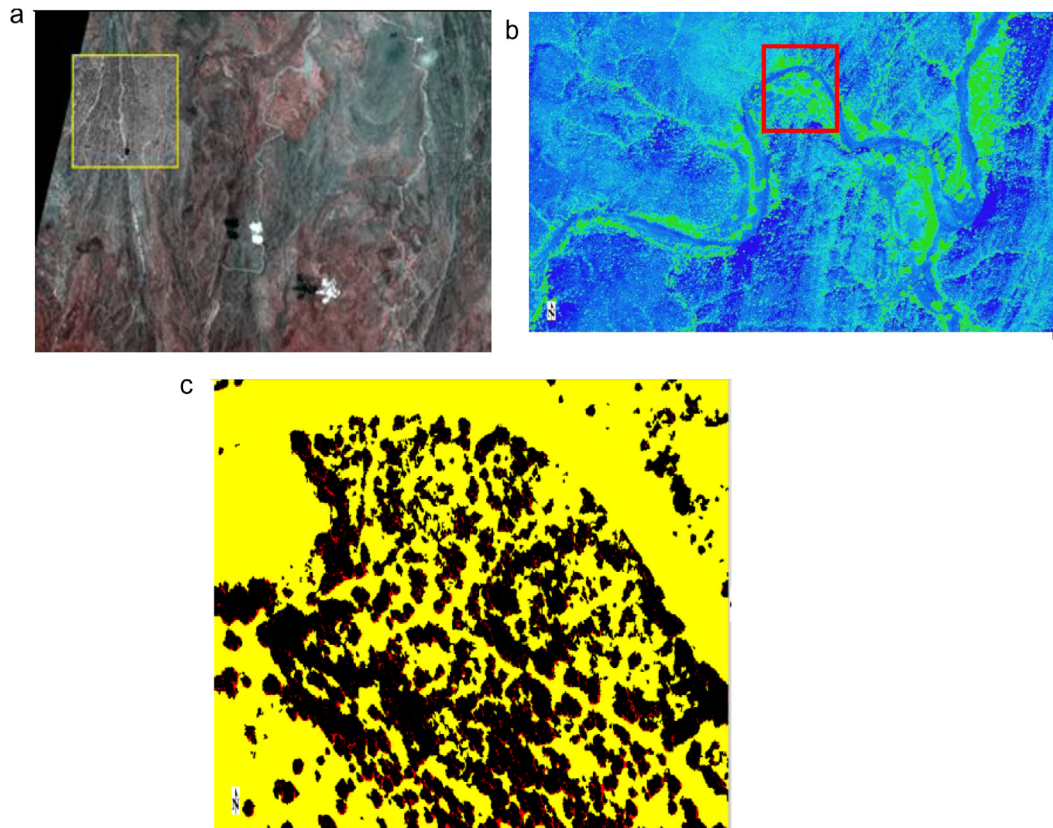
Fig. 4. (A) The satellite image of an area (Valley Alkahatani), (B) the NDVI Filter (color segmentation) result of the zooming part of the marked area in Fig. A, (green color, vegetation coverage); (C) the zoom out of the post Segmentation process of (in Fig. 4B) based on isodata classification techniques with two clusters which represent two species, the red *A. ehrenbergiana* and the black *A. tortilis*.

4. Conclusion

Despite arid conditions of the area very diverse honey bee forages were recorded in the study areas. However the major honey source species are very few and are mainly trees and shrubs. The major bee forage species of the target area have been found to distribute spatiotemporally into eight distinct groups. These allow beekeepers to exploit the resources at different places and seasons. The application of ground inventory work supported with GIS system and analysis of Remote Sensed Satellite Image of vegetation of an area would be better approach to spatially and temporally map the bee forage resource of an area for their efficient utilization.

Acknowledgments

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