

Predict Location(s) of *Apis dorsata* Nesting Sites Using Remote Sensing and Geographic Information System in Melaleuca Forest

¹M.M. Saberioon, ¹M. Mardan, ²L. Nordin, ³M.S. Alias and ⁴A. Gholizadeh

¹Department of Agriculture Technology, Faculty of Agriculture,

²Departments of Civil Engineering, Faculty of Engineering,

³Department of Forest Production, Faculty of Forestry,

⁴Department of Biology and Agricultural Engineering, Faculty of Engineering,
University Putra Malaysia, 43400, Serdang, Selangor, Malaysia

Abstract: Problem statement: The Asiatic Giant honeybees (*Apis dorsata*) are seasonally abounded throughout the upland and lowland rainforests in South East Asia. The colonies of *A. dorsata* are found to nest in aggregates on tall bee trees (tree emergent) in the open, as well as, nesting singly in concealed locations when nesting low, especially in the submerged forest of *Melaleuca cajuputi* as in the vast hectare of Melaleuca forest along the coastal areas of Terengganu. The trunk and branches of the Melaleuca trees are almost upright and the bark are papery and loose that it is unsuitable to serve as nesting support for *A. dorsata*. Therefore, other trees with sloping branches in the vicinity of the Melaleuca forest are chosen as nesting supports for the *A. dorsata* colonies. *Melaleuca cajuputi* and *Acacia auriculiformis* trees are major sources of nectar and pollen for *A. dorsata*. **Approach:** A pilot study were conducted to determine the vegetation distribution area of *Melaleuca cajuputi* and *Acacia auriculiformis*, colony distribution and density *Apis dorsata* colonies using the remote-sensing and field survey by GPS hand held in the submerged Melaleuca forest around the village of Gong Beris, Marang district, Terengganu (Upper left 5°2'19.223"N, 103°10'4.092"E and lower down 4°53'42.31"N, 103°22'37.90"E). **Result:** Based on the map and field survey, it is clear that almost all *Apis dorsata* nesting sites were located in the *Acacia auriculiformis* areas *Melaleuca cajuputi* is mostly using by *Apis dorsata* as source of nectar and pollen in Marang district, Malaysia **Conclusion:** The outcome on the distribution area and feral colonies nesting sites will be used to propose the locating of possible *A. dorsata* nesting sites and understand better nesting behavior of *Apis dorsata* to improvement searching ability for honey hunters in Marang district.

Key words: *Apis dorsata*, honey hunters, remote sensing, GIS, Melaleuca, Marang, Malaysia

INTRODUCTION

Throughout the range of Southeast Asia, upland to lowland forests, giant honey bees (*Apis dorsata*) are found to build their nests in aggregates on tall bee trees, as well as nesting singly in concealed locations when nesting low. From 13000 BC, based on a rock painting, nests of *Apis dorsata* at Asia and Southeast of Asia have been exploited to produce the bulk of honey and wax and being traded for ages. In Malaysia, professional honey collectors or Honey Hunters whom using traditional techniques, are collecting honey from *Apis dorsata* colonies in ages. Honey hunters have to climb steep cliffs or ascend tall "bee trees" by hand-made ladders during the darkness of the night then kept away with smoke and cut away the comb completely for collecting honey. This

technique is a very strenuous, laborious and demanding job (Mardan, 1989; Othman, 1997).

In low land rainforest along the coastal corridor of Kelantan and North Terengganu, *Melaleuca cajuputi* (*Gelam*) and *Acacia auriculiformis* (*Acacia*) are the two dominant trees which are major sources of nectar and pollen for giant honey bee (*Apis dorsata*) (Kiew and Muid, 1991). The honey from these trees has strong flavor and weak density. It granulates quickly, with grain varying from fine creamy to coarse brown and dark if more than moderate heat is used during extraction, straining or packing; on the other hand, the trunk and branches of the Melaleuca trees are almost upright and the bark are papery and loose that it is unsuitable to serve as nesting support for *A. dorsata*. Therefore, other smooth barked trees with sloping

Corresponding Author: M.M. Saberioon, Department of Agriculture Technology, Faculty of Agriculture,
University Putra Malaysia, 43400, UPM, Serdang Selangor, Malaysia

branches in the vicinity of the Melaleuca forest are chosen as nesting supports for the *A dorsata* colonies.

Honey from Giant honey bees provides significant supplementary income source to the local people in Marang district. Furthermore, it is important to predict the locations of nesting by *Apis dorsata* to improve searching ability honey hunters in forest. One of the suitable techniques to understand and predict *Apis dorsata* nesting behavior is mapping distribution of vegetation in Melaleuca forest and surveys the *Apis dorsata* bee trees in forest.

The Manual (traditional) mapping method to measure and inventories the vegetation coverage of the Melaleuca forest will take a long time and cost. Better means are needed for land use inventory. In many of the developed countries and some of developing countries, Remote Sensing (RS) and Geographic Information System (GIS) are widely used to provide up-to-date information (Luney and Dill, 1970). Recent advances in RS and GIS technology have become cost effective and affordable, by virtue of the following reasons: (a) satellite images are sufficiently accurate and reliable, (b) changes over time can be identified, (c) computers have the power to rapidly process large quantities of data and (d) object-oriented GIS provide enormous flexibility in storing and analyzing any type of data, providing decision support modeling for effective management (Buchan, 1997).

RS technology is particularly useful tool to produce a broadly consistent database at spatial, spectral and temporal resolution which is useful for forest. As well, RS data can be made effective and economical for periodic preparation of accurate inventories and also for managing and monitoring forests. Different techniques are available for differentiating and mapping forest units. Studying large area, data can be processed in an automated way; for thematic mapping, images are visually interpreted, enabling the forestry experts to use their knowledge and experience (Lillesand and Kiefer, 1994)

The majority of studies used satellite RS to map forest types defined on the basis of structural and bioclimatic attributes related to the degree of canopy closure. Roy *et al.* (1991); Saxena *et al.* (1992) and Liu *et al.* (2008) explored forest type identification using remotely sensed data by both visual interpretation and supervised classification techniques. An analysis of the cost effectiveness of these techniques revealed the latter to be more economical. Other studies have concentrated on purely digital classification techniques with refinements to increase the accuracy of classifications (Sudhakar *et al.*, 1996; Tuia and Camps-Valls, 2008; Dixon and Candade, 2008). Classification

accuracy may also be increased through the use of contextual and ancillary information, such as historical land use information, site characteristics (i.e., topography) and geobotanical relationships (Brondizio *et al.*, 1996; Paradella *et al.*, 1994; Trivedi *et al.*, 2006; Tuomisto *et al.*, 1994). The additional technique to improve accuracy and also replace information which missed by clouds and shadow of clouds is fusion technique (Hall, 1992; Chen *et al.*, 2007).

Some studies have been conducted to use RS in forest and forest management. Sulong *et al.* (2002) was used Landsat and aerial photography to mapping mangrove in Kemaman district, Terengganu state and Lim *et al.* (2009) explored RS to mapping high spatial land cover in Mebok Estuary, Penang, Malaysia. Rebelo *et al.* (2007) investigated RS and GIS for inventory of wetlands by mapping and change detection in Seri Lanka. Jussof and Pathan (2009) utilized airborne hyperspectral sensing for mapping individual oil palm trees with high accuracy RS technique which can guide researchers to make plan for oil palms forest as one of the economical sources in Malaysia (Rebelo *et al.*, 2007).

GIS is associated with basic term, geography and information system. The literal interpretation of geography is "writing about earth". Write about the Earth, geographic deals with the spatial relationship of land with man (Chandra and Ghosh, 2006). A key tool in studying the spatial relationships is the map which is a graphical property of spatial relationships and phenomena over a small segment of the Earth or the entire Earth. On the other hand, an information system is a chain of operations which consists of from planning the observation to using the observation-derived information in some decision making process (Brondizio *et al.*, 1996).

In that regard, it is important to know the geographic information such as vegetation distribution area of *Melaleuca cajuputi* and *Acacia auriculiformis* as two main sources of nectar and pollen for *Apis dorsata* colonies in Marang district. Also the location and distribution of the colonies in order to determine the density of colonies were used to create a map which can be helpful to understand nesting behavior and predict high possibility locations of nesting sites by *Apis dorsata* to produce more and matured honey at appropriate time for improving honey products on either the quality on the quantity in Melaleuca forest.

This study sheds light on using remote sensing and geographic information system to understand and predict *Apis dorsata* nesting behavior in Marang district, Terengganu state of Malaysia.

MATERIALS AND METHODS

Study area: This study was conducted in Marang district, located in the state of Terengganu at the northern east of Peninsular Malaysia (Fig. 1); between upper left of 5°01'N, 103°11'E and lower right of 4° 50' N, 103° 24'E. The district's topography consists of the South China Sea coast, peat swamps, hills and plains. The sub-

districts of Rusila, Pulau Kerengga and Merchang lie on the coast with sandy plains gradually giving way to hills in the interior. The Jerong sub-district is mainly hilly, while the sub-districts of Bukit Payong and Alor Limbat consist of rolling plains and peat swamps. The dominant trees species in this area are Mangrove, *Melaleuca*, *Acacia*, Rubber and Coconut trees.



Fig. 1: Study area
254

Image data: Spot-5 image in Multispectral mode with 10 meter resolution and 10×10 m pixel size was used for this current inventory. The image had been taken at 03/05/2007 that was near to field truthing so as to minimize the influence of time on landscape elements (Pohl and Van Genderen, 1998).

Preprocessing: Before image processing based on Richard and Jia (2006) bands 3, 2 and 1 (NIR, Red and Green) which known as False Color Composition (FCC) in order to extract useful information from the optimal band combination with linear enhancement was selected as suitable preprocessing to classify and identify various land cover map in this study area.

Image processing: In order to extract the information from RS data, especially from multispectral RS data, land use/land cover classification based on statistical pattern recognition techniques which applied to multispectral RS data is one of the most often used methods (Narumalani *et al.*, 2002). Digital image classification uses the spectral information represented by the digital numbers in one or more spectral bands and attempts to classify each individual pixel based on this spectral information.

In either case, classification approaches try to assign all pixels in the image to particular classes or themes. In this research 5 classes were determined based on objectives of study. The classes were (i) *Melaleuca cajuputi* trees (ii) *Acacia auriculiform* trees (iii) Water bodies (iv) Non-vegetation areas (v) Cloud/Haze/Shadow. Some parts of maps were covered by cloud in SPOT-5 images that caused cloud be the last class in this part.

For mapping study area into 5 classes, Maximum Likelihood Classification (MLC) algorithm was chosen and performed as one of the powerful algorithms among different supervised classification. Supervised classification and delineation of the study area were based on the name assigned to class according to identification done by ground check, visual interpretation and the homogeneous signature represented by the classes.

Field survey: Acquisition of ground data for this study was conducted in two different periods based on the study objectives. First field data was conducted in August 2008. *In situ* data was collected from 25 sites from which 15 sites were dominated by *Melaleuca cajuputi* (*Gelam*) and 10 sites were selected from *Acacia auriculiformis* (*Acacia*) distribution. The locations were determined and recorded by GPS Juno™ ST handheld which is one of the products of Trimble

Company with accuracy of 2.5-5 m to collect coordinate point.

The second field data acquisition was conducted from January to April 2009 to determine *Apis dorsata* nesting sites. In this part all coordinates from nesting sites of *Apis dorsata* colonies were procured by honey hunters using the GPS Garmin 60CX with an accuracy of 7-10 m. All coordinate data of latitudes and longitudes (WGS84) were then converted to Malaysian Rectified Skew Orthomorphic (RSO) using GPS Pathfinder Office 2.90.

Spatialmap: *Melaleuca cajuputi* and *Acacia auriculiformis* distribution which derived from SPOT-5 classified image was converted from raster to vector and transferred as a layer to Arc/GIS 9.2. Other layers were integrated inclusive distribution of *Apis dorsata* nesting sites, access paths such as roads and rivers which derived from digital cartographic maps with 1:25000 scales were gathered and overlaid each other on ArcGIS v 9.2.

To determine forage range and searching ability, buffer function in ArcGIS v 9.2 was used in two distances, 1 km for forage range and 1 kilometer for searching ability as base on motorbike parking points.

RESULTS

Figure 2 shows the output of MLC classification with 91.98% overall accuracy and 0.8635 Kappa coefficient. The performance of MLC technique on SPOT-5 image based on ground truthing was analyzed statistically, visually and graphically (Table 1). The statistical results show that *Melaleuca cajuputi* is the most dominant species in Marang district in Terengganu state.

Thirty three points were collected as nesting sites by using GPS hand held in study area. All coordinate positions were converted and transferred as a layer to the map (Fig. 3). Based on *Apis dorsata* nesting sites and Spot-5 image classification, proportion of *Apis dorsata* nesting sites and locations was determined (Table 2). From total 32 nesting sites, about 17 nesting sites were located in *Acacia auriculiformis* trees which have witnessed 185 combs. In *Melaleuca cajuputi* only 10 nesting sites with 158 combs was observed in field survey. To add more, 6 nesting sites were located in other vegetation areas with about 7 combs (Fig. 4). According to Dyer and Seeley (1991) the foraging range of *Apis dorsata* is within 500-1000 m consequently, buffer with 1000 m was created for each nesting sites to show the forage rang of *Apis dorsata* in Marang district (Fig. 5).

Table 1: Statistical result of Maximum Likelihood Classification (MLC) of SPOT-5 image

Class code	Description	Pixel	Area (ha)	Percent
1.	<i>Melaleuca cajuputi</i> (Gelang)	7606173	76,061.73	61.72
2.	<i>Acacia auriculiformis</i> (Acacia)	2448432	24,484.32	19.87
3.	Non-vegetation	999176	9,991.760	8.11
4.	Water bodies	220347	2,203.470	1.15
5.	Cloud/haze/shadow	1049186	10,491.86	1.79
6.	Unsupervised	0	0	0.00
	Total	12323314	123,233.14	100.00

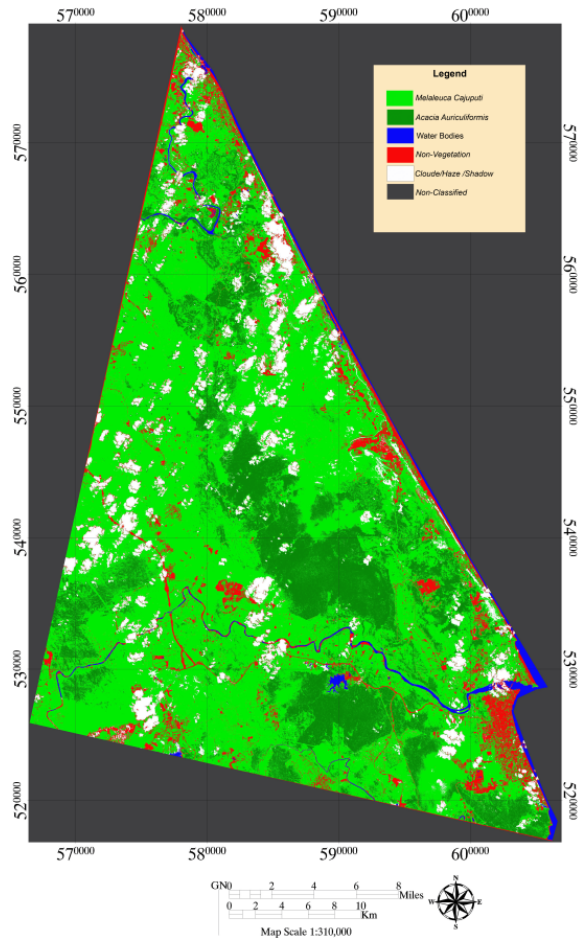


Fig. 2: Maximum Likelihood Classification (MLC) Result from SPOT-5 Image, for marang, Terengganu

DISCUSSION

Based on the map and field survey, it is clear that almost all *Apis dorsata* nesting sites were located in the *Acacia auriculiformis* areas. It means that *Apis dorsata* construct their nests on the branches of *Acacia auriculiformis* trees branches for nesting support. The branch and trunk of *Melaleuca cajuputi* are too upright to serve as nesting support.

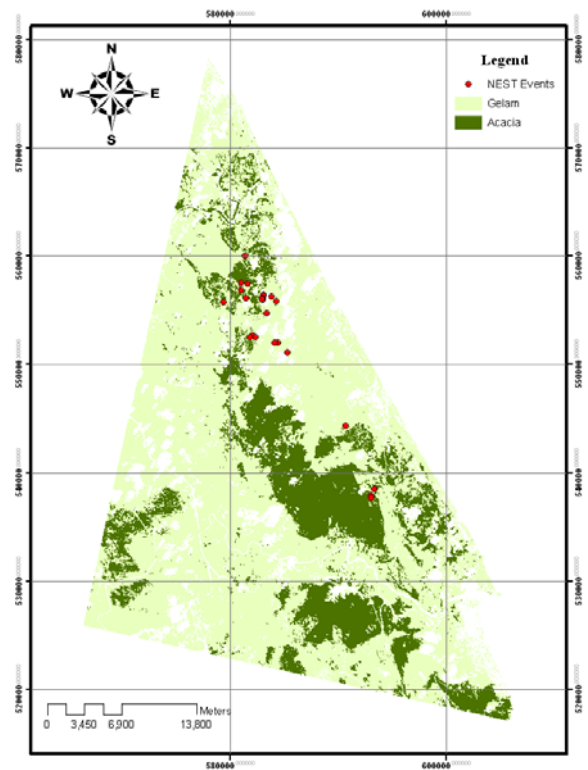


Fig. 3: Distribution of *Apis dorsata*'s nesting sites in Marang district, Malaysia

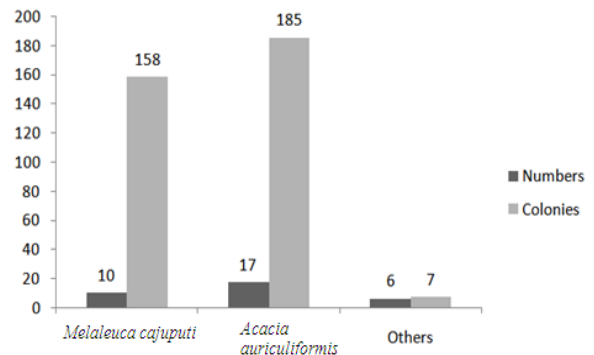


Fig. 4: proportion number of *Apis dorsata* combs and colonies in Marang district, Malaysia

Table 2: *Apis dorsata* nesting sites distribution data in Marang district

Code	Coordinate x	Coordinate y	NC	Location
1.	581075.12	557498.23	1	<i>Acacia auriculiformis</i>
2.	581476.68	560048.02	1	<i>Acacia auriculiformis</i>
3.	581536.67	556103.28	50	<i>Melaleuca cajuputi</i>
4.	582095.83	552662.23	100	<i>Acacia auriculiformis</i>
5.	590707.35	544311.77	1	<i>Melaleuca cajuputi</i>
6.	585361.07	551090.93	1	<i>Melaleuca cajuputi</i>
7.	581651.14	557439.59	1	<i>Acacia auriculiformis</i>
8.	581108.79	556896.12	1	<i>Acacia auriculiformis</i>
9.	583409.25	554716.91	1	Other
10.	584449.37	551973.10	1	<i>Melaleuca cajuputi</i>
11.	584303.09	555828.73	1	<i>Melaleuca cajuputi</i>
12.	581892.46	552511.80	100	<i>Melaleuca cajuputi</i>
13.	582379.28	552542.33	1	<i>Melaleuca cajuputi</i>
14.	579459.98	555793.86	50	<i>Acacia auriculiformis</i>
15.	584212.23	551979.28	1	<i>Melaleuca cajuputi</i>
16.	593358.41	538489.08	1	<i>Acacia auriculiformis</i>
17.	593108.59	537899.25	1	<i>Acacia auriculiformis</i>
18.	593090.00	537711.90	1	<i>Acacia auriculiformis</i>
19.	583129.56	556412.94	1	Other
20.	583132.63	556317.61	2	Other
21.	583095.50	556114.89	1	Other
22.	583083.15	556010.49	1	Other
23.	583015.41	556065.82	1	Other
24.	583905.88	556283.56	1	<i>Melaleuca cajuputi</i>
25.	576381.47	560296.06	1	<i>Acacia auriculiformis</i>
26.	576255.06	560117.95	1	<i>Acacia auriculiformis</i>
27.	591019.69	539095.12	2	<i>Acacia auriculiformis</i>
28.	590652.92	538738.92	1	<i>Acacia auriculiformis</i>
29.	578737.27	558374.87	20	<i>Acacia auriculiformis</i>
30.	578937.39	558242.62	1	<i>Acacia auriculiformis</i>
31.	578453.71	558196.83	1	<i>Acacia auriculiformis</i>
32.	578937.19	557791.05	1	<i>Acacia auriculiformis</i>
33.	578622.81	557388.73	1	<i>Melaleuca cajuputi</i>

(NC): Number of combs

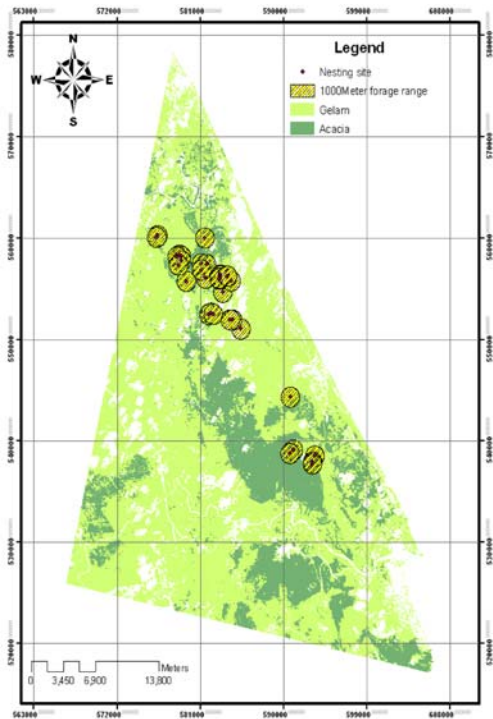


Fig. 5: The 1000 m forage range for *Apis dorsata* in Marang district, Malaysia

It can be concluded that *Apis dorsata* cannot construct the nest on *Melaleuca cajuputi* trees, so it has to nest on the available branches of *Acacia auriculiformis*. It was assumed that it is related to shape and form of this plant species.

Based on this study it can be understood that *Melaleuca cajuputi* is mostly used by *Apis dorsata* as source of nectar and pollen in Marang district, Malaysia. Similar to the studies by Mardan (2007), *Apis dorsata* prefer to use *Melaleuca cajuputi* trees as source of pollen and nectar.

CONCLUSION

This study was conducted to examine application of remote sensing and geographic information system to understand nesting behavior of *Apis dorsata* in Marang district, Malaysia. Also, it is going to prepare map to indicate possible locations of *Apis dorsata* nesting sites for honey hunting in study area based on basic requirements of *Apis dorsata* for nesting such as *Acacia auriculiformis* as nesting trees and *Melaleuca cajuputi* as source of nectar and pollen. Our results depicted that the *Apis dorsata* is prefer nesting on *Acacia auriculiformis* rather than *Melaleuca cajuputi*.

ACKNOWLEDGEMENT

This study has been financed by Yayasan DiRaja Sultan Mizan and also Malaysia Remote Sensing Agency and it is appreciated.

REFERENCES

- Brondizio, E., E. Moran, P. Mausel and Y. Wu, 1996. Land cover in the Amazon estuary: Linking of the thematic mapper with botanical and historical data. *Photogram. Eng. Remote Sens.*, 62: 921-929. DOI: 0099-1112/96/6208
- Buchan, P., 1997. Satellite imagery for regulatory control. *Modern agriculture. J. Site-Specif. Crop Manage.*, 1: 20-23.
- Chandra, A.M. and S.K. Ghosh, 2006. *Remote Sensing and Geographic Information System*. Alpha Science, Oxford, ISBN: 1842652788, pp: 298.
- Chen, S., H. Su, R. Zhang and T. Tian, 2007. Fusing remote sensing images using à trous wavelet transform and empirical mode decomposition. *Patt. Recogn. Lett.*, 29: 330-342 DOI: 10.1016/j.patrec.2007.10.013
- Dixon, B. and N. Candade, 2008. Multispectral landuse classification using neural networks and supports vector machines: One or the other, or both. *Int. J. Remote Sens.*, 29: 1185-1206. DOI: 10.1080/01431160701294661
- Dyer, F.C. and T.D. Seeley, 1991. Dance dialects and foraging range in three Asian honey bee species. *Behav. Ecol. Sociobiol.*, 28: 227-233. DOI: 10.1007/BF00175094
- Hall, D.L., 1992. *Mathematical Techniques in Multisensor Data Fusion*. Artech House Inc., Norwood, ISBN: 1580533353, pp: 301.
- Jussof, K. and M. Pathan, 2009. Mapping of individual oil palm trees using airborne hyperspectral sensing: An overview. *Applied Phys. Res.*, 1: 15-30.
- Kiew, R. and M. Muid, 1991. *Beekeeping in Malaysia: Pollen Atlas*. Malaysian Beekeeping Research and Development Team, ISBN: 967-960-023-8, pp: 186
- Lillesand, T.M. and R.W. Kiefer, 1994. *Remote Sensing and Image Interpretation*. 3rd Edn., Wiley, New York, ISBN: 978-0471255154, pp: 750.
- Lim, H.S., M.Z. MatJafri and K. Abdullah, 2009. High spatial resolution land cover mapping using remotely sensed image. *Modern Applied sci.*, 3: 82-91.
- Liu, K., X. Li, X. Shi and S. Wang, 2008. Monitoring mangrove forest changes using remote sensing and GIS data with decision-tree learning. *Wetlands*, 28: 336-346. DOI: 10.1672/06-91.1
- Luney, P.R.H.W. and J. Dill, 1970. Uses, Potentialities and Needs in Agriculture and Forestry. In: *Remote Sensing with Special Reference to Agriculture and Forestry*, National Research Council (Ed.). National Academies Press, Washington, DC., pp: 1-34.
- Mardan, M., 1989. Some aspects of honey collection from colonies of *Apis dorsata* in Peninsular Malaysia. *Proceeding of the 4th the International Conference on Apiculture Tropical Climates*, (ATC'89), Cairo, Egypt, pp: 442-448.
- Mardan, M., 2007. More about Malaysia bees and bee trees. *Bees Dev.*, 83: 7-9.
- Narumalani, S., J.T. Haldy and J.R. Jensen, 2002. *Information Extraction from Remotely Sensed Data*. Taylor and Francis, New York, ISBN: 0748409246, pp: 623.
- Othman, M.S.H., 1997. Promoting beekeeping as a potential trump card in a drive to conserve selected pockets of *Melaleuca (Gelam)* forest in Peninsular Malaysia. *Proceeding of the International Conference on Tropical Bees and the Environment*, Oct. 1997, University Putra Malaysia, Malaysia, pp: 214-222.
- Paradella, W.R., M.F.F. Da-Silva, N. De and A. Rosa, 1994. A geobotanical approach to the tropical rain forest environment of the carajás mineral province (Amazon region, Brazil), based on digital tm-Landsat and Dem data. *Int. J. Remote Sens.*, 15: 1633-1648. DOI: 10.1080/01431169408954196
- Pohl, C. and J.L. Van Genderen, 1998. Multisensor image fusion in remote sensing: Concepts, methods and applications. *Int. J. Remote Sens.*, 19: 823-854.
- Rebelo, L.M., C.M. Finlayson and N. Nagabhatla, 2007. Remote sensing and GIS for wetland inventory, mapping and change analysis. *J. Environ. Manage.*, 90: 2144-2153. DOI: 10.1016/j.jenvman.2007.06.027
- Richard, J.A. and X. Jia, 2006. *Remote Sensing Digital Image Analysis: An Introduction*. Birkhauser, Switzerland, ISBN: 3540251286, pp: 439.
- Roy, R.S., B.K. Ranganath, P.G. Diwakar, T.P.S. Vohra and S.K. Bhan *et al.*, 1991. Tropical forest type mapping and monitoring using remote sensing. *Int. J. Remote Sens.*, 12: 2205-2225. DOI: 10.1080/01431169108955253
- Saxena, K.G., A.K. Tiwari, M.C. Porwal and A.R.R. Menon, 1992. Vegetation maps, mapping needs and scope of digital processing of landsat thematic mapper data in tropical region of South-West India. *Int. J. Remote Sens.*, 13: 2017-213. DOI: 10.1080/01431169208904250

- Sudhakar, S., S. Sengupta, I.V. Ramanaa, A.K. Raha and B.K. Bardham *et al.*, 1996. Forest cover mapping of west Bengal with special reference to North Bengal using IRS-1B satellite LISS ii data. *Int. J. Remote Sens.*, 17: 29-42. DOI: 10.1080/01431169608948985
- Sulong, I., H. Lokman, K. Tarmizi and A. Ismail, 2002. Mangrove mapping using landsat imagery and aerial photography: Kemaman district, Terengganu, Malaysia. *Environ. Dev. Sustain.*, 4: 135-152. DOI: 10.1023/A:1020844620215
- Trivedi, R.K., L.P. Chourasia and D.K. Singh, 2006. Application of remote sensing in the study of geo environmental aspects of Rajghat dam project. *J. Ind. Soc. Remote Sens.*, 34: 309-317. DOI: 10.1007/BF02990659
- Tuia, D. and G. Camps-Valls, 2008. Semi-supervised Remote Sensing Image Classification with Cluster Kernels. *IEEE Geosci. Remote Sens. Lett.*, 6: 224-228. DOI: 10.1109/LGRS.2008.2010275
- Tuomisto, H., A. Linna and R. Kallioila, 1994. Use of digitally processed satellite images in studies of tropical rain forest vegetation. *Int. J. Remote Sens.*, 15: 1595-1610. DOI: 10.1080/01431169408954194