INTERNATIONAL JOURNAL OF GEOMATICS AND GEOSCIENCES
Volume 5, No 4, 2015

Research article ISSN 0976 – 4380

Feasibility of applying aviation remote sensing for studying carbon sequestration of mangroves in Pingtung County, Taiwan

Wu-Chou Yu[1], Yi-Ching Fu[1], Shu-Lung Kuo[2]
1. Department of Environ. Engineering & Science, National Pingtung University of Science and Technology, 1, Xuefu Road, Neipu Township, Pingtung County 912, Taiwan,
2. Engineering Consultant, Kelee environmental consultant corporation, 6F.-2, No.288-8, Sinya Road, Kaohsiung City 806, Taiwan
singsuey@ms28.hinet.net

ABSTRACT

The various methods currently available for reducing the emission of the greenhouse gas (CO_2) may not be economically feasible to be implemented by industries or adopted by nations in environmental policies. Taiwan is surrounded by sea with abundant wetland suitable for mangrove growth on the surrounding seashore. If the wetland can be effectively renovated to grow mangrove, the adversely impact caused by CO_2 and CH_4 can be significant alleviated. This alternative is a worthwhile investment on reducing CO_2 emission for Taiwan that is facing a yearly decreasing inland forestry.

In this research, aviation *r*emote sensing images were processed using the ERDAS and ArcGIS software so that the classification of land coverage can be obtained using the Maximum Likelihood Method. Additionally, the NDVI (Normalized Difference Vegetation Index) has also been applied to estimate the quantity of carbon sequestration capability for the Avicennia marina (Forsk.) mangrove growing in the Pingtung region.

The results show that the Pingtong region mangrove has NDVI values between 0.258 and 0.283, which are comparable to the NDVI values between 0.20 and 0.465 as published in literature. The observation indicates the reliability and validity of the aviation remote sensing with high resolution and with near red spectrum experimented in this research for estimating the the Avicennia marina (Forsk.) mangrove growing in this region. The estimated quantity of carbon sequestrated by the mangrove is about 1,461.77 ton.

The capacity of the Avicennia marina (Forsk.) mangrove growing in Pingtung region to sequestrate carbon has a great potential of development and implementation. The results obtained in this research can be used as a basis for policy makers, urban and regional planners, and researchers to deal with future development of cities and their surroundings in regions of highly ecological and environmental sensitivity.

Keyword: mangrove, avicennia marina, remote Sensing, carbon sequestration

1. Introduction

Land suitability evaluation (LSE) is a multicriteria assessment of the land capacity for development based the most desirable factors and their optimal values as defined by experts (Steiner, 1983; Steiner et al., 2000; Collins et al., 2001; Stoms et al., 2002; Marull et al., 2007). Many tools that have proved to be useful for land evaluation are available for carrying out LSE; GIS (geographic information systems) is one of such tools implemented in recent studies (Jankowski, 1995; Wang et al., 2004; Malczewski, 2006; Liu et al., 2007). The incorporation of multicriteria evaluation methods into GIS has emerged as a promising research area attracting many researchers on land planning and management (Bennett, 1997; Wang et al., 2004; Svoray et al., 2005; Verdoodt and Ranst, 2006; Wu et al., 2013). For example, the concept of fuzzy quantifiers was incorporated into the GIS-based land suitability analysis via ordered weighted averaging (OWA) (Malczewski, 2006). A transparent, modular hierarchical system of the Land Suitability Index (LSI) was presented with the objective of delivering Strategic Environmental Assessment (SEA) of developmental land uses for regional planning (Marull et al., 2007). A spatially and temporally explicit multiscale decision support system was demonstrated to reveal the biophysical indicators affecting land use choices of the different stakeholders; these indicators comprised three different environmental assessment tools (Verdoodt and Ranst, 2006; Bolster and Dentz, 2012).

An ever-increasing body of scientific evidence suggests that the anthropogenic release of carbon dioxide (CO_2) has led to a rise in global temperatures over the past several hundred years (Crowley, 2000; Bradley, 2001; Ni et al., 2012). If this theory holds true, unabated release of greenhouse gases will result in global warming that may lead to significant and potential catastrophic alteration of climate, natural hydrological and carbon cycles globally. In an effort to alleviate the possible impact of atmospheric CO_2 on global climate, several strategies are under development to sequester the CO_2 released from stationary and mobile sources (Herzog et al., 1997; U.S. Department of Energy, 1999). These carbon management strategies include: (1) increasing the efficiency of energy conversion; (2) using low-carbon or carbon-free energy sources; and (3) capturing and sequestering anthropogenic CO_2 emissions from large point sources such as coal-fired thermoelectric generation facilities. The third strategy, termed ‘‘CO_2 sequestration”, has gained increased attention in recent years, and would promote continued use of fossil fuels for the generation of electric power by reducing its CO_2 footprint. Terrestrial, geologic, advanced biological processes, and advanced chemical CO_2 sequestration approaches are currently being studied. Each of these options has significant technical and economic hurdles that must be addressed before being considered feasible for full-scale application.

The mangrove plant fresh, which is mostly located at estuaries, is more difficult than land-based forest to be investigated and monitored. Being one of the earliest indicators for climate changes, the mangrove ecological system is easily affected by the changing environmental factors such as increasing atmospheric CO_2, average temperature, mean sea level elevation, and salinity. Hence, the influence of climate changes on global distribution of mangrove and regional ecology is becoming an important topic for the various government agencies and environmental protection groups (Bird, 1995; Woodroffe, 1995). The prediction of global climate toward the end of the 21st century based on the average data collected during 1980~1999 as published in the 2007 UN IPCC climate change report indicates that global warming has caused the atmospheric temperature to increase by 0.74℃ for the last 100 years (1906-2005) to cause obviously increasing frequency and extend of meteorological disasters. In recent years, the improvement of various remote sensing technologies and awaking environmental protection cognizance lead to the tendency of applying remote sensing (RS) for investigating and studying mangrove (Ramsey and Jensen, 1996; Green et al., 1997; Kovacs et al., 2004). Tateda et al. (2005) further used the RS technology to estimate the quantity of carbon sequestered by mangrove. In this research, the aviation multiple spectrum RS technology is used for investigating the NSVI (Normalized Difference Vegetation Index) of mangrove in Pingtung region (Taiwan) in order to estimate its carbon sequestration capacity.

2. Materials and methods

2.1 Region of Study

The mangrove growing in the Kao-Ping (Kaohsiung City and Pingtung County) region is mainly distributed in the area near Donggang Township near Dapeng Bay in Taiwan; the main species is Avicennia marina (Forsk.) Vierh, which is known as Avicennia marina in Mainland China. Based on the results of investigation carried out by Yu (2004), the Kao-Ping mangrove is mainly distributed in Xinyuan Township, Donggang Township, Linbian Township, Jiadong Township, and Fangliao Township. In this research, the ground observation reveals that the above regions have areas with relatively prolific growth of the Avicennia marina (Forsk.) mangrove. Hence, Dapeng Bag (in Donggang Township), Chifong village (Linbian Township) and Singlung Village (Fangliao Township) as shown in Figure 1 have been selected as the sampling and studying sites. The feasibility of applying GeoTaiwan aviation images of the selected site taken during clear days were used for conducting the supervised classification and vegetation index analysis for the Avicennia marina (Forsk.) mangrove in order to estimate its carbon sequestration capacity. The remote sensing images include the ortho-image and near infrared image. Table 1 shows the basic information of these images.

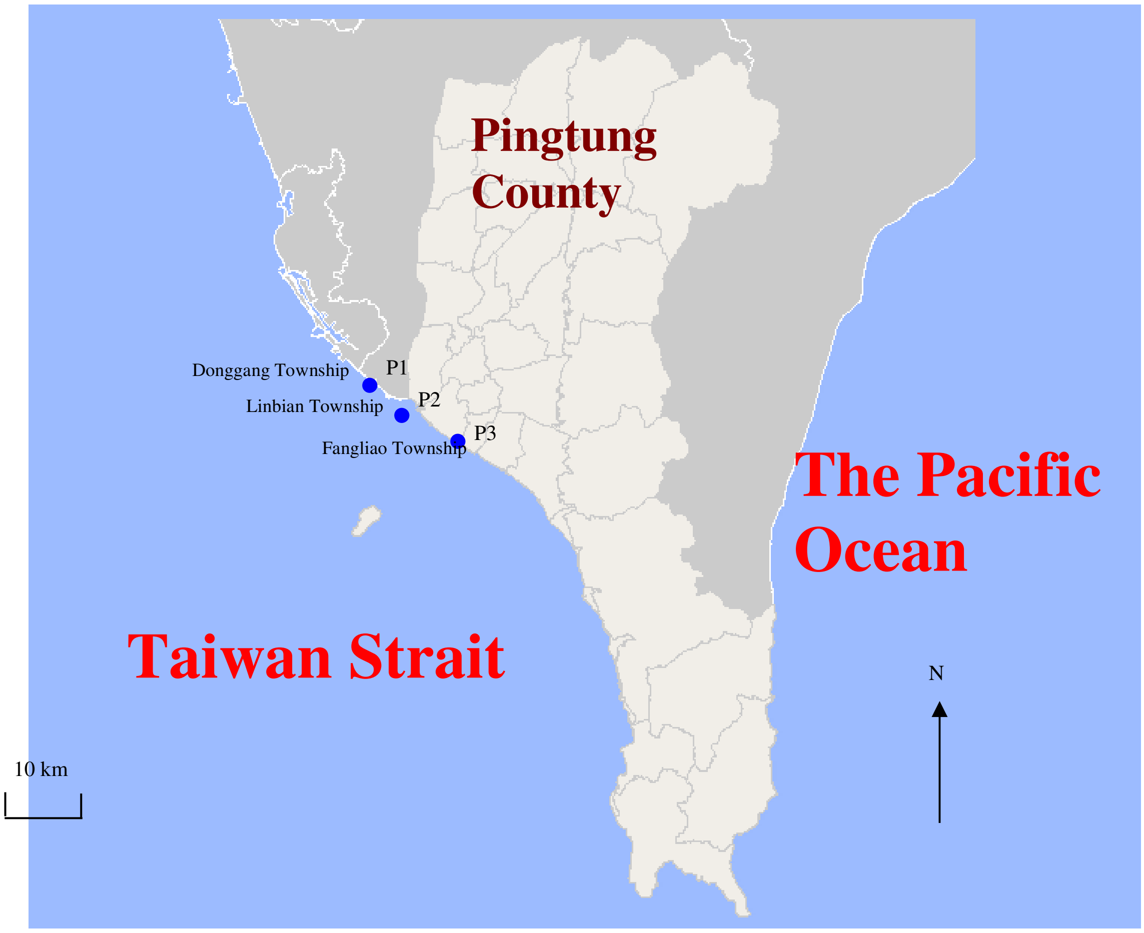

Figure 1: Satallite image showing locations of the sites selected for conducting the research of mangrove (P1, P2, P3)

Table 1: Basic Information on the Remote Sensing Image

Type of Remote Sensing	Date of Photographing	Type of Sensor	Vertical Resolution (m)	
			P	MS
GeoTaiwan	2006/05/09, 2007/03/04	MS & P*	0.2	0.2

MS: Multi-Spectral Sensor, P: Panchromatic Sensor

2.1 Analytical Tools and methods

The aviation remote sensing images were manipulated and analyzed using the ArcGIS 9.2 and ERDAS IMAGINE 8.6 software. The Maximum Likelihood Method available in ERDAS IMAGINE 8.6 was used to classify the ground coverage into 6 categories , i.e. Water, Building 1, 2, and 3, Road and Paved Surface, The Avicennia marina (Forsk.) mangrove, Trees and Grassland as shown in Table 2.

Table 2: Classification of the Ground Cover of the Studying Sites

Category	Code	Species
Water	1	Ocean, River and Ditch
Building 1, 2, and 3	2	House and Shelter
Paved Surface	3	Road, Dike and Concrete Surface
Sand and Pebble	4	Sand and Pebble
Mangrove	5	The Avicennia marina (Forsk.) mangrove
Tree and Grassland	6	Tree, Grassland, Weed

3. Results and discussion

3.1 Analyses of NDVI

Table 3 lists the Error Matrix for Evaluating the Accuracy of Classifying the RS Image and the analyses of the classification accuracy. The overall accuracy is as high as 83.3% with Kappa value of 0.80, which is higher than 0.75 for good correlation (Landis and Koch, 1977), so that the results of surface classification are highly reliable.

Table 3: Error Matrix for Evaluating the Accuracy of Classifying the RS (Remote Sensing) Image.

Classification Data Code	Reference Data Code						Row Total	Classification Data Total	Prod. Ace (%)	User Ace (%)	Omission Error	Commission Error
	1	2	3	4	5	6						
1	8	0	0	0	0	2	10	10	88.89	80.00	11.11	20.00
2	0	8	1	1	0	0	10	10	80.00	80.00	20.00	20.00

3	0	1	9	0	0	0	10	10	81.82	90.00	18.18	10.00
4	0	1	1	8	0	0	10	10	88.89	80.00	11.11	20.00
5	0	0	0	0	9	1	10	10	90.00	90.00	10.00	10.00
6	1	0	0	0	1	8	10	10	72.73	80.00	27.27	20.00
Total	9	10	11	9	10	11	60	60				

1=Water, 2=Building, 3=Road & Concrete-surface, 4=Sand & Rock, 5=Mangrove, 6=Tree & Grassland. Overall Classification Accuracy= 83.3%, Overall Kappa Statistics= 0.80

The objective of this research is to evaluate the feasibility of using the RS technology to evaluate the carbon sequestration capability of mangrove. The mangrove growth in the study areas conforms to urban forest that is defined as the grove growing in densely populated regions. Hence, the tree growth is limited and controlled by anthropogenic factors such as land use so that the artificially planted and natural growing trees form a closely related ecological system. The formula proposed by Lai (2007) for estimating the carbon sequestration by urban forest in metropolitan Kaohsiung expressed as Carbon=56.228 · $e^{(NDVI \cdot 5.058)}$ was used to evaluate the average NDVI value and carbon sequestration based on the RS information collected at 200 sites at the three selected sites. The average NDVI and carbon sequestration are listed in Table 4 in which the mangrove area is the geometric average of the surveyed areas.

Table 4: Average NDVI value and estimated carbon sequestration for Various Townships in the study Area.

Study Region	Total mangrove area (ha)	Average NDVI	estimated carbon sequestration per unit area(ton/ha)	(ton) Total carbon sequestrated
P1	3.14	0.283	235.29	738.82
P2	3.02	0.268	218.10	658.67
P3	0.31	0.258	207.34	64.28
Total	6.47			1,461.77

Note: Carbon=56.228 · $e^{(NDVI \cdot 5.058)}$, ton / Pixel , R^2=0.55.

The estimated NDVI values for the three study areas are between 0.258 and 0.283. The field observation made in this research during the period between October 2007 and June 2008 shows no growth of the Avicennia marina (Forsk.) mangrove at Xinyuan Township whereas the total area of the Avicennia marina (Forsk.) mangrove growth at Jiadong Township is only 0.17 ha with most of the trees cut down. Hence, the carbon sequestration capacities of these two townships are not included in the above estimation. The total carbon sequestration capacity of the mangrove area in Pingtung region is 1461.77 ton.

The equation used for estimating the carbon sequestration was originally developed based on the average carbon absorbed by fish farms that are different from the evergreen tree species found in urban forest. Additionally, the original equation does not consider the tree-related factors, e.g. species, plant density, canopy coverage, tree height, and tree trunk diameter, among the many others. The RS method uses the NDVI as the major biological parameter for estimating the carbon sequestered by plant; the NDVI value may change due to differences in the response of leaves to near infrared or red light. Hence, the results based on the RS method are affected by the mangrove density, canopy coverage, tree height, and trunk diameter as well environmental conditions such as atmospheric temperature. Therefore, variations of these factors will affect the results by overestimating, underestimating, or confusing the final results.

4. Factors affecting the carbon sequestration

The possible cause of variations in the estimated carbon sequestration is further explained in the follows:

1. The original carbon sequestration estimation equation is based on the SPOT satellite RS images whereas the aviation RS images were used in this research. The difference between the sensor specifications for satellite and aviation RS leads to the possibility that constants used in the equation may not represent the true correlation between NDVI and carbon sequestration.
2. The water body surrounding the mangrove forestry may reflect light through the void among leaves to interfere with the spectra of the light shone on mangrove plant surface. Additionally, the atmospheric humidity and brightness may also lower the accuracy of NDVI extraction.
3. The RS images were obtained at the end of spring and the beginning of summer when the Avicennia marina (Forsk.) mangrove has not reached the maximum photosynthetic rate. Hence, the mangrove shows lower NDVI values (0.258～0.283） than other the NDVI values (0.2~0.465) reported in literature for other mangrove forestry. Both Jiadong Township and Fangliao Township have low mangrove area and show some residual mangrove tree stumps after being cut down causing low leave area to reduce the biological light reflection and hence the reducing NDVI value.

Most of the Avicennia marina (Forsk.) mangrove being studied in this research grow along water drainage channels; the tress are easily cut down and removed during the period when the images were taken. Hence, the NDVI value obtained in this research is between the NDVI values for mangrove forestry with medium and high plant densities as reported by Satyanarayan (2001).

The mangrove plants found in the Pingtong region are distributed near embankment, bay shore, and fish farm bank forming stripe-shaped community, which is different from the group communities for mangrove plants growing in estuaries. Therefore, when sensors with insufficient resolution are used, they are easily interfered by light reflected from objects other than mangrove trees so that the accuracy of measuring biological parameters and classifying ground surface coverage are adversely affected.

The NDVI values reported by Satyanarayan (2001) obtained with IRS-1C LISS3 satellite RS images on mangrove forestry growing on Eastern Indian seashore is between 0.20 and 0.40.

Wang (2006) used the SOPT satellite images to study the mangrove forest in the Tamsui River Mangrove Ecological Protection Region, and reported NDVI value being changed from 0.265 in 1994 to 0.465 in 2005. Hirose *et al*. (2004) used the Landsat satellite images to study the mangrove plant in Vietnam Can Gio Mangrove Ecological Protection Region to obtain a threshold NDVI value of 0.3. In this research, the estimated NDVI values are between 0.258 and 0.283, which conform to the values reported by the above three researchers. Hence, the aviation RS method is a potentially feasible for estimating the carbon sequestration.

5. Conclusion

The aviation RS method has been used in this research to conduct the classification of surface coverage for the selected study areas, and to evaluate the carbon sequestration for mangrove growing in the Pingtong region. Based on GeoTaiwan aviation images, the total carbon sequestration quantity is estimated to be 1,461.77 tons. However, because of limited research time and equipment, the traditional method of using the biological quantity or on-site measured plant photosynthesis for estimating the mangrove carbon sequestration capacity in order to check the validity of the RS-based results has not been carried out. Only the feasibility of using the RS method has been covered in this paper.

The aforementioned discussion reveals that if an adequate resolution is selected, and complete visible and near infrared light spectra are covered, the RS method is feasible to obtain reliable results on evaluating the Avicennia marina (Forsk.) mangrove. For addressing the unique characteristics of the Avicennia marina (Forsk.) mangrove growing in the Pingtong region such as bushy growth in a long and narrow clustering area, RS images with high resolution, e.g. those obtained using aviation RS or the ISONOS or QUICKBIRD satellites launched after September 1999 will be appropriate. Additionally, the RS should cover visible light (especially red and green light spectra) and near infrared spectra.

This RS research was carried out during the period around the end of spring and beginning of summer that is close to the wet season (May through November) in Taiwan. Most mangrove trees growing in storm drainage channels and near dikes have been cleared during the wet season because they may interfere with discharging of flood water. The on-site investigation was conducted during autumn and winter when mangrove trees grow prolifically. Hence, the estimated quantity of carbon sequestration based on RS information collected during the wet season is lower than the actual carbon sequestration capacity of the mangrove in the study areas.

Although the Avicennia marina (Forsk.) mangrove trees are often cut down, they grow prolifically near Pingtung seashore indicating that the plant has adapted to the local environment. In the future, the government may have the policy to encourage private sectors to plant the Avicennia marina (Forsk.) mangrove in Dapeng Bay and abandoned fish farms along the seashore for achieving carbon sequestration, end-of-the-pipe treatment of wastewater, and environmental beautification in addition to providing educational function, promoting tourism, and accumulating assets for economic benefits from carbon exchange.

6. References

1. Bennett, D.A., (1997), A framework for the integration of geographical information systems and model base management, International Journal of Geographical Information Science, 11(4), pp 337-357.

2. Bolster, D., and Dentz, M., (2012), Anomalous dispersion in chemically heterogeneous media induced by long range correlations, J. Fluid Mech., 695(3), pp 366-373.

3. Bradley, R.S., (2001), Many citations support global warming trend, Science, 292(5524), pp 2011.

4. Collins, M.G., Steiner, F.R., and Rushman, M. J., (2001), Land-use suitability analysis in the United States: Historical development and promising technological achievements, Environmental Management, 28(5), pp 611-621.

5. Crowley T.J., (2000), Causes of climate change over the past 1,000 years, Science, 289(5477), pp 270-277.

6. Green, E.P., Mumby, P.J., Alaisdair, E.J., Clark, C.D., and Ellis, A.C., (1997), Estimating leaf area index of mangroves from satellite data, Aquatic Bot., 58(6), pp 11-19.

7. Herzog, H., Drake, E., and Adams, J.E., (1997), CO_2 capture, reuse, and storage technologies for mitigating global climate change: A white paper: Final report, DOE contract DE-AF22-96PC01257, Washington, DC: DOE.

8. Hirose K., Syoji, M., Hang, H.T.M., Anh, N.H., Triet, T., and Nam, V.N., (2004), Satellite data application for mangrove management, International Symposium on Geoinformatics for Spatial Infrastructure Development in Earth and Allied Sciences, Vietnam.

9. Jankowski, P., (1995), Integrating geographical information systems and multiple criteria decision making methods, international journal geographical information systems, 9(3), pp 251-273.

10. Kovacs, J.M., Flores-Verdugo, F., Wang, J., and Aspden, L.P., (2004), Estimating leaf area index of a degraded mangrove forest using high spatial resolution satellite data, Aquatic Botany, 80(5), pp 13-22.

11. Lai, S.Y., (2008), Application of remote sensing on urban forest carbon sequestration evaluation in Kaoshiung City, The Master's Thesis of Forestry Research Institute. National Pingtung University of Science and Technology, Pingtung, Taiwan. (in Chinese).

12. Landis, J.R., and Koch, G.G., (1997), the measurement of observer agreement for categorical data, Biometrics 33(1), pp 159-174.

13. Liu, Y., Lv, X.J., Qin, X.S., and Guo, H.C., (2007), An integrated GIS-based analysis system for land-use management of lake areas in urban fringe, Land scale Urban Planning, 82(4), pp 233-246.

14. Malczewski, J., (2006), ordered weighted averaging with fuzzy quantifiers: GIS-based multicriteria evaluation for land-use suitability analysis, Int. J. Appl. Earth Observation Geoinformation, 8(4), pp 270-277.

15. Marull, J., Pino, J., Mallarach, J., and Cordobill, M., (2007), Land suitability index for strategic environmental assessment in metropolitan areas, Land scale Urban Planning, 81(3), pp 200-212.

16. Ni, Q.W., Wang, L., Zheng, B.H., and Sivakumar, M., (2012), Evolutionary algorithm for water storage forecasting response to climate change with small data sets: The wolonghu wetland, China, Environmental Engineering Science, 29(8), pp 814-820.

17. Ramsey, E., and Jensen, J.R., (1996), remote sensing of mangrove wetlands: Relating canopy spectra to site-specific data, Photogrammetric Engineering and Remote Sensing, 62(8), pp 939-948.

18. Satyanarayana, B., Thierry, B., Seen, D. L., Raman, A. V., and Muthusankar, G., (2001), remote sensing in mangrove rresearch-relationship between vegetation indices and dendrometric parameters: a case for coringa, east coast of INDIA. Proceeding ACRS 2001 - 22nd Asian Conference on Remote Sensing, Singapore, 1(3), pp 567-574.

19. Steiner, F., (1983), Resource suitability: Methods for analysis. Environmental Management, 7(5), pp 401-420.

20. Steiner, F., McSherry, L., and Cohen, J., (2000), Land suitability analysis for the Upper Gila River Watershed, Landsc. Urban Plann., 50(4), pp 199-214.

21. Stoms, D., McDonald, J.M., and Davis, F., (2002), Fuzzy assessment of land suitability for scientific research reserves, Environ. Manage, 29(8), pp 545-558.

22. Svoray, T., Bar, P., and Bannet, T., (2005), Urban land-use allocation in a mediterranean ecotone: Habitat heterogeneity model incorporated in a GIS using a multi-criteria mechanism, Land scale Urban Planning, 72(4), pp 337-351.

23. Tateda, Y., Imamura, M., and Ishi, T., (2005), Estimation of CO_2 sequestration rate by mangrove ecosystem, Harmonization of Energy and Environment, 12(4), pp 32-40.

24. United States Department of Energy, (1999), Report. DOE/SC/FE-1, Carbon sequestration research and development, Washington, DC: DOE.

25. Verdoodt, A., and Ranst, E.V., (2006), Environmental assessment tools for multi-scale land resources information systems: A case study of Rwanda, Agri. Agriculture, Ecosystems & Environment – Journal, 114(2-4), pp 170-184.

26. Wang, X.H., Sheng, Y., and Huang, G.H., (2004), Land allocation based on integrated GIS-optimization modeling at a watershed level, Land scale Urban Planning, 66(2), pp 61-74.

27. Wu, L., Long, T.Y., and Cooper, W.J., (2012), Temporal and spatial simulation of adsorbed nitrogen and phosphorus nonpoint source pollution load in Xiaojiang watershed of three gorges reservoir area, China, Environmental Engineering Science, 29(4), pp 238-247.

28. Ye, F.R., (2004), A survey on the composition and distribution of mangroves in Kaohsiung and Pingdong Area, The Master's Thesis of Department of Biological Sciences, Nationl SunYat-Sen University, Kaohsiung, Taiwan. (in Chinese).