

# **Application of Remote Sensing and GIS for Locating Suitable Mangrove Plantation Sites Along the Saudi Arabian Red Sea Coast**

## **Principal Investigators:**

Dr. Ayman S. H. Aguib  
Civil Engineering Department  
King Saud University- Al Riyadh  
College of Engineering  
P.O. 800 A.C. 11421

Dr. Dhafer Al Garni  
Civil Engineering Department  
King Saud University- Al Riyadh  
College of Engineering  
P.O. 800 A.C. 11421

## **Consultant:**

Dr. Scot E. Smith  
Geomatics Program  
School of Forest Resources and Conservation  
University of Florida  
Gainesville, Florida USA

## **Summary**

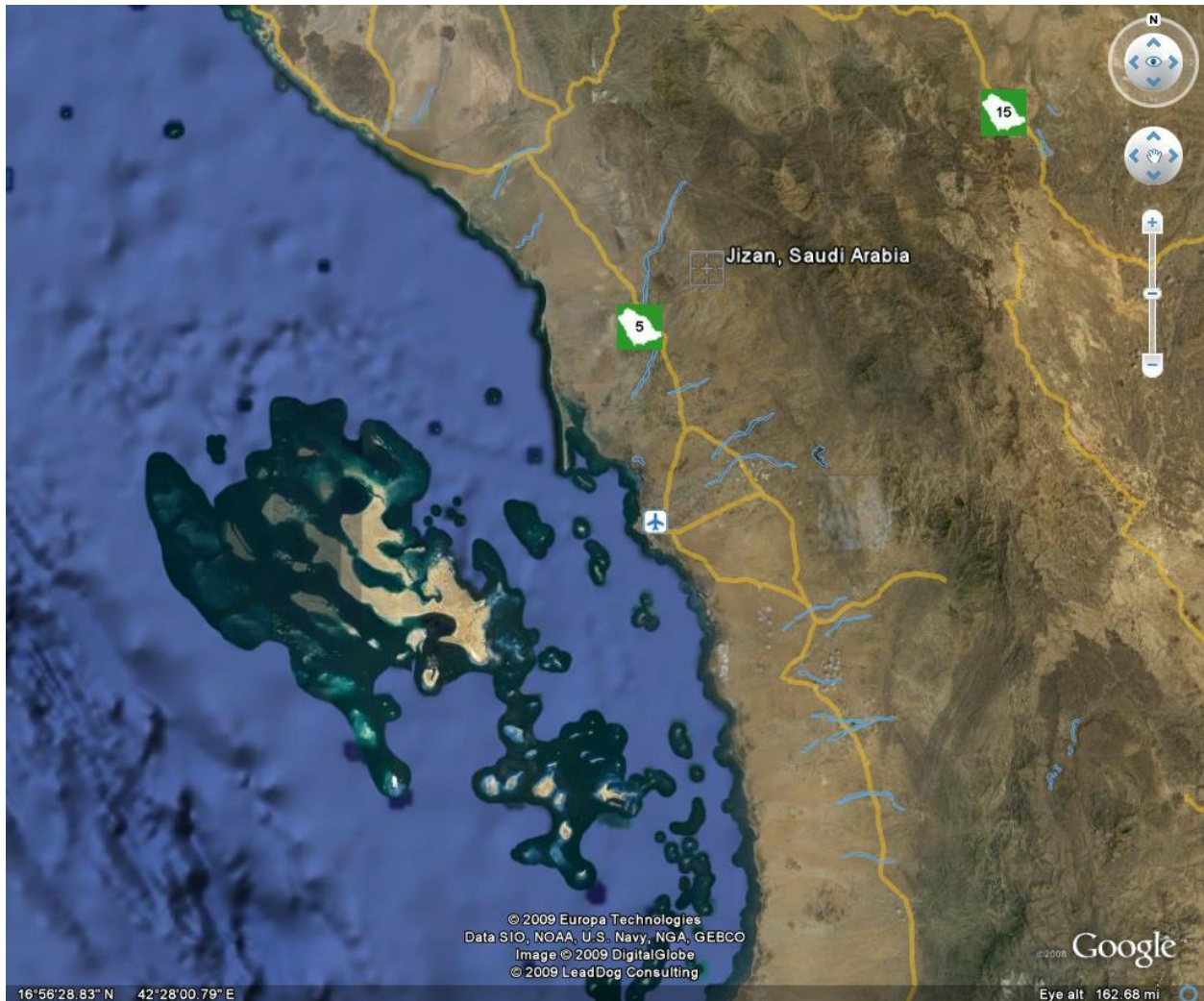
Mangroves play a vital ecological role in supporting the surrounding environment. They are natural nursing grounds for hundreds of aquatic species, including economically important fish and shellfish. Mangroves play an important role in controlling erosion and protecting the coastline. Along the Red Sea coast in Saudi Arabia, mangrove stands are widely distributed and frequently hundreds of kilometers apart. The size and the number of mangrove stands have been reduced and many of the stands have been destroyed. Therefore, it is necessary to conserve the existing stands and establish mangrove plantations where they can potentially thrive. This proposal describes a method to locate suitable sites for mangrove plantations along the south Saudi Arabian Red Sea coast based on the geological setting of the area. Geological characteristics such as soil type, geomorphology and discharge of drainage effluents were

considered as primary sitting criteria. Satellite imagery and digital elevation models (DEM) will be interpreted to determine some of the parameters.

## **INTRODUCTION**

This proposal aims at providing a scientific approach to identifying suitable sites for mangrove plantation establishment along the Saudi Arabia Red Sea coast. Mangroves occur in sparse, but natural, formation along the Saudi Arabian Red Sea coast. Many more mangrove stands existed, but have been destroyed by factors such as overgrazing by Bedouins who use the trees as a fuel and, more recently, by development.

The zone to be studies is centered on the city of Jizan ((جيزان)) shown in Figure 1. Jizan has great tourism potential owing to the abundance of near-shore coral reefs, natural mangroves and beautiful oasis. The Farasan Islands which as 40 km from Jizan, are a protected series of coral islands and are habitat to endangered species of many animals. Jizan has grown from a village of fewer than 10,000 people in 1978 to over 100,000 by 2008 and so care must be taken to protect the mangroves from development.



**Figure 1. Satellite Image of Study Area**

In this proposal, areas suitable for mangrove plantations along the Saudi Arabian Red Sea coast will be identified. This proposal demonstrates how remote sensing and geographic information systems can be used to identify suitable locations to establish mangrove plantations along the Saudi Arabian Red Sea coast. We will limit our study to physical factors necessary for successful mangrove plantation development since (1) the land in question is owned by the Saudi Arabian government and (2) the land is undeveloped. Therefore, there will be no issues with respect to existing land use or ownership. If a site is found to be physically well suited for mangroves, it can be developed without legal constraints.

In this proposal, we describe the approach we used to locate the best sites along the Saudi Arabian Red Sea coast for mangrove plantations. We will then implement the method and show the results.

## 2. PROJECT OBJECTIVES

1. Map existing mangroves along Saudi Arabian Red Sea coast using remote sensing
2. Collect data (soil type, slope, water temperature, etc.) relevant to suitability for growing mangroves
3. Do a GIS analysis of site suitability for the southern Saudi Arabian Red Sea coast
4. Identify sites that are good candidates for mangrove plantation establishment

## 3. LITERATURE REVIEW

Mangrove forests are one of the most biodiversity wetland ecosystems on earth (Lugo et al 1974). Mangrove stands are the home for many unique species of birds and fish. Mangroves provide food and wood for local communities, stabilize coastlines and provide barriers from high waves.

Mangrove forests once lined three-quarters of the world's tropical coasts. Today less than half remain and they are rapidly disappearing (Tomlinson 1986). Indonesia, a country of more than 13,000 islands, possesses the most mangrove forestland of any country, but they are in decline. Brazil and Australia also have extensive mangrove habitats. The groves in Australia are protected and stable, whereas the Brazilian mangroves are declining (Dittmar et al 2006).

In the Red Sea, the extent of mangroves has been declining due to the impacts of unplanned coastal development with only about 10 km<sup>2</sup> remaining off the coast of Saudi Arabia (Hussain et al 1993). In Saudi Arabia, more than 40 percent of the coastline has been infilled and 50 percent of the mangroves lost (Ellison 1999).

More than 530 species of plants and animals have been recorded among mangroves and sea grasses in the Red Sea. These mangroves and sea grass beds support production of 2 million kg of fish annually. Oil and domestic, urban, and industrial pollutants are a problem in several parts of the Saudi Arabian Red Sea coast, although effects on ecosystem structure and function are generally not well known. The coastal zone is fast becoming the repository for solid wastes. Major ecological problems have arisen from loss/degradation of productive coastal habitats, caused by landfill, dredging, and sedimentation (Khalil 2004).

A study on using remote sensing and GIS for locating good sites for establishing mangrove plantations along the Egyptian Red Sea Coast was done by El Monsef and Smith (2008). Their study showed that a number of previously unknown sites had excellent potential for establishing mangrove plantations.

Many other studies have used remote sensing for mapping mangroves and location suitable sites for mangrove plantations including Azlan et al (2009), Coleman et al (2008), Fromard et al (2004), Green et al 1998, Howari et al (2009), Ramsey et al (2009), Vaiphasa (2000).

There have been many studies on site suitability for establishing mangrove plantations (Macintosh et al 2002). Ren et al (2008), Vayda et al (1999), Walters (2000). In each of these cases, the same basic criteria necessary for successful establishment of a mangrove plantation were the same as those identified in this proposal (near-shore water salinity, near-shore water temperature, tidal and wave energy, soil type, stability and renovation potential and flooding possibility).

## **4. DESCRIPTION OF THE PROPOSED WORK**

### **4.1 Approach, tasks and phases**

#### **Approach**

According to Bhat and Suleiman (2004), the critical factors that determine whether a site is suitable or unsuitable for mangrove plantation development are: near-shore water salinity, near-shore water temperature, tidal and wave energy, soil type, stability and renovation potential and flooding possibility.

The range of suitable values for these factors is:

*Water temperature: 22-34 degrees C*

*Water salinity: 3.6% - 3.8%*

*pH: 6.8-7.2*

*Dissolved Oxygen: 6.0 – 7.6 mg/l*

*Transparency: very high*

*Flood potential: low*

*Wave and Tide energy: low*

*Soil Type: Sandy to sandy loam*

*Stability: high*

*Renovation potential: high*

Which these environmental boundaries in mind, our **approach** will be to determine where on the southern Saudi Arabian Red Sea coast these environmental requirements are met.

### **4.2 Research Methodology**

**Water Temperature:** Data from the U.S. National Oceanographic and Atmospheric Administration (NOAA) on the average year-round near-shore sea temperature and salinity for the near-shore zone in the study area will be obtained. Water temperature (surface) will be derived from NOAA's Advanced Very High Resolution Radiometer (AVHRR) satellite which is

accurate to within 0.5 degrees C. *Avicenna marina*, the dominant mangroves species naturally found in the Red Sea coast requires relatively warm water (Teas 1984).

***Air Temperature:*** Mangroves can tolerate air temperature as low as 19 degrees C for short periods of time and as high as 24 degrees C (Teas 1984). They thrive in the 28 degree to 30 degree temperature range (Odum et al 1982). Data on air temperature for the study area will be obtained from the World Weather Organization.

### ***Salinity pH, dissolved oxygen and transparency determination***

Mangrove trees are relatively tolerant of salt, pH, dissolved oxygen and low transparency. For example, they are able to withstand salt concentrations of up to 3.9 percent for up to 6 percent months of the year and thrive in concentrations of about 3.6 percent (Schmitz 2006).

Near-shore salinity and other water quality factors will be derived from field sampling. Surface and sub-surface water samples will be collected at Jizan and 300 km south and 300 km north. Salinity will be determined *in-situ* and in a laboratory. The analysis will include measurement for: salinity, pH, dissolved oxygen and transparency.

### ***Basins Flash Flood Potential determination***

The software River Tools (version 3.5) will be used to define the drainage network of the study area using USGS 7.5 minute (30- by 30-m data spacing) Digital Elevation Models (DEM's). The USGS 7.5-minute DEM cast on Universal Transverse Mercator (UTM) projection.

A Landsat Thematic Mapper panchromatic band image will be used to check and correct the drainage network produced by River Tools.

The software package River Tools generates a Grid showing the drainage patterns of a basin as well as tables of the following variables. Using ArcGIS software the Grid will be converted into shapefile. The shapefile will be used to determine the order of each individual segment of the basin and its length, basin length, basin shape, drainage density, stream frequency, and bifurcation ratio. These factors in addition to basin slope that determined using DEM are critical in determining an area's proneness to flash flooding.

***Basin length*** is the length measured along the principal flow path from the watershed outlet to the basin boundary. It is a measure of the travel time of water through the basin.

***Basin shape*** indicates the path runoff will travel through various parts of the basin and where the runoff will discharge from the outlet. For example, a circular watershed would result in runoff from various parts of the watershed reaching the outlet at the same time. This situation increases the possibility of a flash flood.

On the other hand, an elliptical watershed having the outlet at one end of the major axis and having the same area as the circular watershed would cause the runoff to be spread out over time, thus producing a smaller flood peak than the circular watershed. Basin shapes were estimated by determining basin circularity ration ( $F_c$ ) and basin elongation ratio ( $R_e$ ) (Strahler 1983):

$$F_c = P/(4\pi A)^{0.5}$$

Where,  $P$  and  $A$  are the perimeter and area of the watershed, respectively.

$$R_e = 2/L_m (A/\pi)^{0.5}$$

Where,  $L_m$  is the maximum length of the basin parallel to the principal drainage lines and  $A$  is area of the watershed.

**Drainage density** and **stream frequency** are the total length and total number of the entire stream segments in a drainage basin divided by the total area of the drainage basin. High drainage density or/and stream frequency of a basin indicates a rapid storm response and consequently high probability to form a flash flood (Strahler 1983)

**Bifurcation ratio** is the ratio of the number of streams of any order to the number of streams of the next highest order. The lower bifurcation ratio indicates a circular basin with high flood potentiality and visa a versa. In order to determine the bifurcation ratio, the steam order will be determined for the entire segment in each basin using the Horton Law (Eash, 2007):

$$R_b = \left[ \sum_{n=1}^{I-1} S_n / S_{(n+1)} \right] / (I - 1)$$

Where:

$I$  = basin order

$S_n$  = number of segments of order  $n$

$R_b$  = bifurcation ratio

**Basin slope** is the average slope of a basin and is the most important variable affecting the momentum, speed and concentration of runoff. The possibility of starting a runoff event increases with increasing slope.

### **Soil Type, Stability and Renovation Potential determination**

Mangroves grow best in soil with high sand content, low silt and clay fractions and low calcium carbonate content (Bhat and Suleiman, 2004). The characteristic of the soil adjacent to the Saudi Arabian Red Sea coast is a function primarily of the type of local exposed rock and soil transported from the basins that drained to the Red Sea.

In order to assess the capability of each basin with respect to soil we will evaluate the following variables:

### Factors affecting soil formation and renovation

- Lineament intensity
- Drainage density
- Area of exposed rocks and their mineral composition

### Factors affecting transportation of soil

- Basin order
- Basin bifurcation ratio
- Drainage density
- Slope

### Factors affecting the soil texture and soil mineral composition

- Mineral composition of exposed rocks

Since suitable soils for mangrove plantation are those with high sand content, low clay and low calcium carbonate content, the formations and rock groups exposed on the surface were ranked based on the mineral composition of their rocks to four ranks (1) very good, (2) good, (3) moderate and (4) poor. For example, granitic rocks were assigned a *moderate* rank because when weathering process affects granite, the erosion products of granite includes sand particles which are composed mainly of quartz and clay derived from the reaction of the feldspar minerals (orthoclase, microcline and albite), with water (granite kaolinization process).

Another example a formation composed mostly of calcium carbonate rocks was ranked *poor* because the pH of the sea water at the site was high and as unsuitable for mangrove growth as water becomes less acidic, calcium carbonate becomes insoluble and accumulates around plant roots which inhibit growth (Hassan and Shabara, 2003).

The *soil suitability factor* (SSF) will be determined for each exposed rock unit within the basin using the following equation:

$$SSF = (EA/BA) + (BO/MBO) + (DD/MDD) + (BR/MBR) + (S/MS) + (LI/MLI) + (LR/MLR)$$

Where:

EA = exposed area

BA = basin area

BO- basin order

MBO = maximum basin order

DD = drainage density

MDD = maximum drainage density

BR = bifurcation ratio

MBR = maximum bifurcation ratio

S = Slope

MS = maximum slope

LI = Lineament Intensity

MLI = maximum lineament intensity  
LR = lithology rank  
MLR = maximum lithology rank

The *soil suitability factor* will be determined for each basin by averaging those of all rock unit exposed within the basin and then re-scaling the entire area in a range of between 1 and 100.

### *Coastal Erosion determination*

Mangrove plantations thrive only in low energy zones where coastal erosion risk is minimal (Kairo, 1995). High wave energy prevents establishment of their propagules, prevents the accumulation of sediments that improves growth, and is difficult for their shallow root systems to adjust to. In order to identify these zones along the Saudi Arabian Red Sea Coast, a three-dimension model of the study area will be constructed by superimposing a panchromatic Landsat thematic mapper image over a DEM. The three-dimension model helps us to identify sites of moderately sloped deltas, tidal creeks, small bays and channels with wide flat shore and relatively extended off-shore shallow water level.

Although mangrove's can grow in very small patches, it is uneconomical to establish plantations in areas less than 5 hectares. Therefore, we will set a minimum area threshold of 5 ha for "suitable" areas.

### **Tasks**

1. Collect relevant data (satellite imagery and existing information) on mangroves along the Saudi Arabian Red Sea coast.
2. Perform image processing on satellite imagery to map existing mangroves.
3. Perform image processing and GIS steps to develop GIS layers for the relevant physical factors (i.e., slope, soil type, bifurcation ratio, etc.) for the coast north and south of Jizan.
4. Build the GIS
5. Perform GIS analysis to select suitable mangrove plantation locations

### **Phases**

1. Data collection
2. Image processing
3. GIS development
4. GIS analysis

### **4.3 Management Plan**

Dr. Ayman Aguib is the project's Principle Investigator and so is in charge of the overall operations of the project.

Map data collection for the area will be the task of the technician under the supervision of CO-Principle Investigator Dr Dhafer who will be responsible for choosing the needed satellite imageries and determine the type of the image and the proper satellite that could give the required information.

Images interpretation and GIS modeling will be done at the University of Florida as they have the required labs and software as well as previous experience of similar study. Also training for using these software will be given to the team person who will follow the application and perform the ground truth requirements at the Kingdom of Saudi Arabia.

D. Scot Smith has performed a similar study to the one proposed in Egypt in 2007. He will advise the project and report directly to Dr. Aguib. Satellite imagery is less expensive to purchase in the USA compared to Saudi Arabia and so part of Dr. Smith's responsibility will be to purchase imagery and get to the project image processing team.

#### 4.4 Project Deliverables (Form RE-DI-6)

##### RELATIONSHIP TO STRATEGIC FRAMEWORK

PROJECT EXPECTED OUTCOMES	STRATEGIC TECHNOLOGY PROGRAM GOALS			PROJECT OBJECTIVE ACHIEVED
	GOAL 1	GOAL 2	GOAL3	
1	Training on searching and collecting data from maps	Data acquisition from satellite images sources	Merging data from different sources	Detailed mapping for existing mangrove
2	Practicing for collecting ground data related to study subject	Applying and adjusting data to ground truth		Collecting ground data that affect mangrove growth
3	Practicing for managing data from different resources to GIS	Experiencing on design models on the basis of GIS capability		Establishing GIS system and modeling for growth criteria
4	Training on analyzing output data	Producing maps that help the goals of the study	Expressing information in suitable and readable outputs	Determining areas that suitable for planting Mangrove

<b>5</b>	Realizing the project target and putting plans for application	Enhancing the benefits of outputs to community	Explain the long term importance of the project for coastline protection and get best benefit from environment characteristics	<b>Putting plan for planting mangrove with determining the reasonable starting areas</b>
----------	--	--	--	--

Form RE- D1-6

## 5. VALUE TO THE KINGDOM

This project is valuable to the Kingdom for the following reasons:

- Mangroves are an important endangered natural resource. They provide an excellent habitat for fish and shrimp and they serve as a filter for pollution. Mangroves also promote the growth of sea grasses and coral. Both sea grass and coral are vital to the Red Sea's ecosystem and both are rapidly disappearing.
- Mangroves are conducive to tourist development. Seaside resorts are usually located in or near mangroves. Mangroves provide shade and also are good protection from wind and waves. Mangroves also provide protection to sea grasses and coral reefs which are important to tourism.
- Mangrove plantations serve as a source of building material. Mangrove is a highly sought-after wood in tropical areas due to its salt resistance and all over the world because of the natural beauty of the wood. Furniture and wood craft making industries are associated with mangrove plantations.

## 6. PROJECT EXECUTION

### 6.1 Current Resources

The Civil Engineering Computer Lab will be used in the stage of collecting data from different sources and prepare it in the format needed for image processing. That task needs performing simple image processing and data base establishment which can be done using KSU Civil Engineering Department resources after updating available software. In addition preparation for field trips for collecting required information as well as ground truth data will be conducted through the research team at KSU.

The University of Florida's Remote Sensing and GIS Laboratory will perform image rectification, pre-processing, classification and post-processing accuracy assessment for the project. It will also do the GIS modeling and develop GIS applications. Since a similar project was conducted in this laboratory for the Red Sea Coast of Egypt in 2007, the modeling protocol already exists.

Training on the image processing and GIS modeling techniques used in the Egyptian mangrove study will be conducted for the KSU research team by Dr. Smith at the University of Florida in the summer of 2009. The training will also include field trips to successful mangrove plantations that have been established in Florida as well as trips to areas where projects have successfully protected coral reefs and seas grass beds.

The image processing software (ERDAS IMAGINE) and GIS software (ArcGIS) are identical at KSU and the University of Florida. Therefore, there will be no compatibility issues with interchanging the products of each laboratory.

Final prints and project reports will be prepared at KSU.

**7. UNDERTAKING OF THE RESEARCH TEAM (Form RE-DI-8)**

<p><b>The research team undertakes that:</b></p> <ol style="list-style-type: none"> <li>1- The text and graphics herein as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision.</li> <li>2- No part of this proposal has been funded by any other source.</li> <li>3- No existing funds are available to the research being proposed from any other source.</li> <li>4- No fund would be sought from any other source if an award is made as a result of this proposal.</li> <li>5- We agree to accept responsibility for the scientific conduct of this project.</li> </ol>		
<b>ROLE</b>	<b>INVESTIGATOR NAME</b>	<b>SIGNATURE</b>
<b>Principal Investigator</b>	<b>Ayman S. Aguib</b>	
<b>CO- PI. 1</b>	<b>Dafer Al Gharni</b>	
<b>CO- PI. 2</b>	<b>Scot E. Smith</b>	
<b>CO- PI. 3</b>		
<b>CO- PI. 4</b>		
<b>CO- PI. 5</b>		

## 8. REFERENCES

- Azlan, N, and R. Othman (2009). “*Monitoring of Mangrove Areas Using Remote Sensing Toward Shoreline Protection*”, Proceedings of GIS Osrava 2009. Malaysia.
- Bhat, N. and M. Suleiman (2004). “*Classification of Soils Supporting Mangrove Plantation in Kuwait*”, Archives of Agronomy and Soil Science, Vol. 50, pp. 535 – 551.
- Coleman, T A. Mana and Y. Twumansi (2008). “*Application of Landsat to Study of Mangrove Ecology Along the Coast of Ghana*”, Journal of the ISPRS, vol. 49, pp. 362-379.
- Dittmar, T., N. Hertkorn, G. Kattner and R. Lara ( 2006 ). “*Mangroves: A Major Source of Dissolved Organic Carbon to the Oceans*”, Global Biogeochemical Cycles Journal, 20, GB1012, doi:10.1029/2005GB002570.
- Eash, D. (2007). “*A Geographic Information System Procedure to Quantify Drainage-Basin Characteristics*” Journal of the American Water Resources Association vol 30, issue 1, pg 1-8.
- El Monsef H. and S. Smith, (2008), “*Site Selection for Mangrove Plantations along the Egyptian Red Sea Coast*”, World Applied Sciences Journal. 3 (7) 740-747.
- Ellison, J. (1999). “*Impacts of Sediment Burial on Mangroves*”, Marine Pollution Bulletin, vol 37, issues 8-12, pp.420-426.
- Fromard, F., C. Vega and C. Proisy, (2004). “*Half a Century of Dynamic Coastal Change Affecting Mangrove Shorelines of French Guiana: A Case Study Based on Remote Sensing Data Analysis and Field Surveys*”. Marine Geology vol 208, issues 2-4, pp.265-280.
- Green, E., C. Clark, P., Mumby and A. Ellis. (1998), *Remote Sensing Techniques for Mangrove Mapping*” International Journal of Remote Sensing , vol 19, no. 5, pp.935-956.
- Hassan El-Banna A. and S. Shabara, (2003), “*Marine Water Quality in the Red Sea*”. U.S. Agency for International Development, Program Support Unit, Egyptian Environmental Policy Program, Hurghada, Egypt
- Howari F., D. Jordan, N. Bouhauche and S. Wyllie-Echeverra, (2009). “*Field and Remote Sensing Assessment of Mangrove Forests and Seagrass Beds in Northwest United Arab Emirates*”, Journal of Coastal Research 25 (1), 48-56.
- Hussain, M and T. Khojat (1993) “*Intertidal and Subtidal Blue-Green Algal Mats of Open and Mangrove Areas in the Farasan Archipelago (Saudi Arabia), Red Sea*. Botanica Marina vol 36, no 5, pp. 377-388
- Kairo J. (1995). “*Artificial Regeneration and Sustainable Yield Management of Mangrove Forests in Gazi Bay, Kenya*”, M.Sc. Thesis, University of Nairobi, Kenya, pp 116.

- Khalil, A. (2004). “*Status of Mangroves in the Red Sea*”, PERSGA Technical Series No. 11, PERSA Jeddah.
- Lugo, A. and S. Sneaker. (1974). “*The Ecology of Mangroves, Annual Review of Ecology and Systematics*”, 5:39-64.
- Macintosh, D., E. Ashton and S. Havanon, (2002) “*Mangrove Rehabilitation and Intertidal Biodiversity*”, Estuarine, Coastal and Shelf Science, Elsevier Publications. 323pp.
- Odum, W., C. McIvor, and T. Smith. (1982). “*The Ecology of the Mangroves of South Florida: A Community Profile*”. U.S. Fish and Wildlife Service, Publication FWS/OBS-81/24, Washington, D.C. 144pp.
- Ramsey, E. and J. Jensen, (1996). *Remote Sensing of Mangrove Wetlands*. Photogrammetric Engineering and Remote Sensing vol. 62, No. 8, pp 939-948.
- Ren, H., S. Jian, H. Lu, Q. Zhang, W. Shen and W. Han (2008) “*Restoration of Mangrove Plantations and Colonisation by Native Species*” Ecological Research, Springer Publishers. vol. 38, no. 3, pp 394-410.
- Schmitz, N., V Anouk, H. Beekman, J. Gitundu and N. Koedam, (2006). “*Influence of a Salinity Gradient on the Vessel Characters of the Mangrove Species Rhizophora mucronata*” . *Annals of Botany* 98: 1321–1330.
- Strahler, A. and A. Strahler. 1983. Modern Physical Geography 2nd Ed. New York: John Wiley & Sons.
- Teas, H. (ed.). (1984). “*Biology and Ecology of Mangroves*”. W. Junk Publishers, The Hague, 188 pp.
- Tomlinson, P.(1986). “*The Botany of Mangroves*”. Cambridge University Press, Cambridge, 413 p.
- Vaiphasa, C. (2009). “*Remote Sensing Techniques for Mangrove Mapping*”, Ph.D. Dissertation, ITC Institute, The Netherlands. 390p.
- Vayda, A, and B. Walters (1999), “*Against Political Ecology*”, Human Ecology Journal, Springer Press, vol. 13, no. 5, p.145-150.
- Walters, B., (2000), “*Local Mangrove Planting in the Philippines are Fisherfolk and Fishpond Effective*”, Restoration Ecology, vol 5, no,12, p.34-40.