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EVALUATING THE ROLE OF GIS AND RS IN DELINEATING BIOLOGICALLY SENSITIVE ZONES AT KARACHI COAST: A CASE STUDY OF TASMAN OIL SPILL

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ABSTRACT

A disaster is generally sudden whether natural or man-made and requires prompt action. Combination of GIS and RS technologies in the world leading towards the emergence of GIS based Environmental Sensitivity Index (ESI). This provides the ecologist and resource managers necessary information and data to take timely decisions for any ecological/environmental response. This paper examines the benefits of GIS and RS, specifically for the Least Developing Countries (LDCs), as the technological subset often aggravates the situations due to delayed actions and wrong assessment of the damages thus resulting in loss of most productive/sensitive coastal zones. This has happened in 2003 when 31000 tons of light crude oil was spilled by Tasman Spirit in the Arabian Sea near the port of Karachi, Pakistan causing massive ecological and environmental damages. This study demonstrates how the GIS and RS help in synthesis and integration of the data of various research studies. It also aims at predicting the pattern and the pathway of any potential damages to the most sensitive coastal areas/ecosystems, before and after any disaster, considering Tasman Spirit case studies delineating the Biologically sensitive zones with the help of the ESI model which is based on five main factors: Shoreline Slope Exposure to waves, Wind Direction, Socioeconomic Exposure and Biological Productivity (flora, fauna and habitats) and developed for the first time for the coastal areas of Pakistan for this research study.

Keywords: ESI, GIS, Oil Spill, Biologically Sensitive Zones, Ecosystem

INTRODUCTION

The growth of the human environment globally has been escorted by industrialization. Oil is the leading requisite of different nations due to which the process of oil transportation is elicited. In bulk transportation of oil from supplier location to demand location engage severe threats in terms of accidents which results in environmental damages. The current remoteness of producers in places where oil assets lie and the places of the consumers along with the exhaustive use of oil all over the world has resulted in the development of increasingly complex sea transportation (Connolly and O'Rourke, 2003).

Coastal ecosystem is a complex and vibrant system having a chain relationship and multifaceted network of interaction with other environmental entities. Environmental changes either from anthropogenic source or from natural and acute pollution situation may intimidate ecosystems (Eggen et al. 2004). The aftermath of these effects depends on the pliability and the state of the ecosystem (Harwell and Gentile, 2006). Over the years there are numerous oil spill incidents reported globally.

Oil pollution is one of the key environmental problems and is important to address. There are two leading oil tanker routes passing through the Arabian Sea, having potency to trigger the factor of environmental pollution. In recent history, oil spills around the globe are very common creating extensive damages to the environment. In this perspective, similar calamity occurred when an oil tanker Tasman Spirit carrying 67,535 tons of light crude oil got grounded while attempting to enter the Karachi port of Pakistan on 27th July 2003 and broke into two pieces on 14th August 2003. It instigated widespread damages to an area of more than 2000 sq km off Shore and approximately 16 Km along the coastline due to massive spillage of 31,000 tons of light crude oil out of which approximately 30% to 40% evaporated according to Environment Impact Evaluation Committee (EIEC) preliminary report (EIEC, 2003)and was carried to the adjoining residential coastal areas where these hazardous substances were inhaled and absorbed, by living and non living species and things. The oil ruin the coastal environment including marine life, mangroves community, wildlife refuges and critical habitats.

The affected coastal belt is connected with the densely populated area with diverse aquatic ecosystems; comprising both flora and fauna prominently mangrove forests (*Avicenna marina*) and other important plant species. In addition Olive Ridley Sea turtles habitats, dolphins and several species of fish are the noteworthy entities of this region. Biological diversification of this region includes phytoplankton like thecate dinoflagllates, centric diatoms, *Ceratuim sp*. and *Nocilluca Scintillans*, *Gonyaulax polyedrea*, *G. polygramma* and *G. monocantha* etc. Zooplanktons are also distributed all over the coast of Pakistan including calanoid copepods, lucifers and chaetognaths etc. This enriched region was badly hit by Tasman oil spill and impacted over the 16km belt of

Karachi beaches, thus triggering different health, socio-economic and environmental issues amongst the population of adjoining areas and marine life.

Fig. 1. Satellite image of coastal area , Karachi, Pakistan. The specific Study Area is marked with the inset square.

The Problem

In handling oil spills a primary concern is to identify the effects of oil in different eco-systems under different settings (Krishnan, 1995). Sensitivity mapping has a vital role in detecting this risk in a geographic area. The use of sensitivity mapping for oil spills has a long history. Initially (Strong and Semple, 1986) work to identify the use of GIS for oil spill management. Their work encompasses the absences of non-computerized environmental databases for oil spill controlling. They also outlined how a geographical database can be used for oil spill response and eventuality planning. The work of Dicks and Wright (1989), has explored the linkage of databases to maps. It is also noteworthy to mention the work of Jensen et al(1990) at this point who proposed the incorporation of GIS and remote sensing for sensitivity mapping. These initial works reinforced the benefits of assimilating GIS for oil spill risk assessment. The ability to link diverse data from many sources to produce new information is vital in resolving some of the spatial problems present during oil spills (Krishnan, 1995).

An estimated 11,000 tons of highly toxic volatile organic compounds (VOCs) were released in the air from this oil spill. The worst oil impacted areas of Karachi Coast included the most popular recreational beaches of Clifton and DHA Beaches covering about 16 km coastline.

The oil-spill severely damaged the marine ecosystem due to the coastal waters pollution at Karachi Harbor, Clifton and DHA coasts up to the western coast of Bundal Island. As a direct short term impact of Tasman Spirit Oil-spill, large scale mortalities of benthic fauna and fauna including commercial fish, crabs, shellfish, and other marine organisms were methodically documented by the National Resource Damage Assessment (NRDA) team in their report of a joint venture of Pakistan Environment Protection Agency (PEPA) and United Nation Development Program (UNDP), Islamabad (NRDA, 2004).

Serious negative impacts were recorded on the birds, mammals and turtles and mangroves in the oil impacted zone. Although many isolated studies were conducted to evaluate the environmental impact of Tasman Spirit, however, these were not able to evaluate the collective risk and long term effects of this accident due to discontinuation of any further investigation in this direction as proposed by several stakeholders and researchers at the time of spillage specifically due to missing GIS based ESI or any other databank for Karachi coastal areas of Pakistan.

The major objectives of this study include:

Assessment of the extent of the damage due to Tasman Spirit Oil Spill using GIS and RS techniques;

- Delineation of biological sensitive zone and extent of impacts;
- Spill Trajectory mapping.

Significance of GIS and RS in Oil Spill Mapping

There are three major causes of oil spill which are in the form of, accidents, operations and possible deliberate actions, irrespective of the reasons of an oil spill, the negative impacts are mostly multifaceted on environment, aquatic species, humans and related economy of the affected coastal areas. If the spill is result of oil transportation via sea or deep waters and is close to coastal localities, GIS delivers an active, user-friendly edge to search a variety of diverse attributes and physical information from a spill; chiefly, it offers the combination of apparatus to speed up decision making and more precisely enumerate offshore spill size and the trajectory. GIS is an authoritative tool for the modeling, monitoring and mitigation measures against an oil spill hazards. It is effectively used for the modeling of sensitive environments for ranking of clean-up activities. GIS is helpful in integrating and arranging data of multiple sources into simplified maps integrating the ability to work as powerful and effective tool for monitoring oil spill hazards.

Remote sensing is defined as the process or technique of obtaining information about anything without being in contact with it. Remote sensing tools are important for the development of maps which help in the precise demarcation of coastlines and detailed landforms. The collection of suitable remote sensing data and valid digital image processing techniques contains a compromise between costs and mapping capabilities, including coverage area, and spatial resolution (Green, 2000). Remote sensing has fundamental importance in risk mapping, there are numerous causes of hazards to the environment and to society and some of them are initiated from human actions (Smith and Petley, 2009). Remote Sensing has enough potential for the detection of oil spills and facilitate in prevention planning, pollution treatment and restoration.

In this study remote sensing support in extracting information about the physiognomies of shoreline, active coastal ecosystem, water quality, land use, oil plume, temporal variation etc. Optical (visible, infrared sensors and ultraviolet sensors) or radar are the sensors operated in this study to detect oil spill, Sensors mostly used in detecting the oil spill are explained in Table-1. LANDSAT platform and RADARSAT-1 is used in this study for monitoring the impact of oil spill at Karachi coast in 2003. The highlighted part in the following table represents the sensors used in this study.

MATERIALS AND METHODS

Various methods got involved in order to achieve the above-mentioned goals, and to explore and attain these objectives in a relevant manner, it was essential to plot the flora and fauna of the study area as well as to delineate the extent of damages. To achieve the task combination of GIS and RS became important aid to structure the study. As extensive land use change and burden on natural resources (World Resource Institute, 2005) put the coastal zone at risk of technological and other hazards. Areas near Karachi port are ecologically and humanly populated. These areas were badly affected by the Tasman oil spill, thus on the contrary to the National Oceanic and Atmospheric Administration (NOAA) sensitivity index (NOAA, 2002; Petersen, 2002), the sensitivity index of the Karachi coast is developed with some modifications, with the help of GIS as an important tool for modeling the oil spill hazards thus helping in understanding dynamics of coastal hazards. The methodology of this study is based on steps given in Fig.2.

Development of Base Map

A base map is the indispensable requirement for designing any GIS model, development of base map is accomplished by going through the different procedures, and first most important requirement for the development of base map is the raster or image data sources which are the timeline for getting the different temporal observations. for this study the Quick bird, LANDSAT, and RADARSAT imageries are used for the development of base map incorporated with the different hard copy maps that are scanned and geometrically corrected through different software including ERDASs Imagine a software for digital image processing, as purchasing of digital imagery cost a lot, Therefore selection of Images is done by considering this fact and open source imageries are used for base mapping.

Development of AOI (Area of Interest)

Satellite imagery tiles are not up to the exact mark of the study area because of its definite tile size mostly study area is lying within the smaller extent of the imagery so to overcome this image subset is developed which helps in targeting the relevant area of interest subset development is done by various method includes the clipping of an image based on the extent of another theme, as well as in ERDAS imagine the subset is developed by using the subset application based on area of interest file.

Table 1.Characteristics of some available sensors for Oil Spill Management.
(Source: Andrade, and Szlafsztein, 2012; Jha et al., 2008)

	SENSORS	PLATFORM		SPATIAL RESOLUTION (M)	OVER-PASS FREQUENCY (DAYS)	IMAGERY AREA	APPLICATION
Radar	SAR	Space bome	Ers-2	30	3,35and 136days	100 km	Identify large offshore spills and coastal environments- strategic planning and monitoring
	SAR		Radarset-1	8-100	24days	45-500 km	
	SLAR	Airbome	Airplane	10-50	As required	60-80	Detect and identify the polluter, the extent and type of oil spill and cleaning necessity environmental mapping strategic and tactical planning
	SAR		Airplane	1-10	As required	-	
Optical	MSS,TM,ETM,ETM+	Space bome	Landsat5 Landsat6 Landsat7	15-120	16 days	183-185 km	Detect oil if the weather condition is good and discriminate false positives; identify and mapping environment strategic and tactical planning
	HRV		Spot-2 Spot-3	10-20	26days	60x60/100km	
	CCD		Cbers-1; Cbers-2	20	26days	113km	Detect oil spill if weather conditions are good; identify and mapping environment strategic and tactical planning
	IRMSS		Cbers-1; Cbers-2	80-160	26days	120km	Detect oil spill if weather conditions are good; capable to detect thermal surface differentiations- strategic and tactical planning
	WFI		Cbers-1; Cbers-2	260	5days	890km	Detect oil spill if weather conditions are good; monitoring; ; identify and mapping environment strategic and tactical planning
	VIDEO CAMERA	Airbome	Airplane	Altitude dependent	As required	-	Oil spill and coastal environment documentation. The infrared sensor for measuring the thickness of oil slicks operational planning
	STILL CAMERA		Airplane	Altitude dependent	As required	-	

Geometric Corrections

It is the method of transforming the satellite image a raw form of random coordinate system into map projection (geographic) coordinate system, the pixels of the image are aligned and fit into real world map co-ordinates. images are geometrically distorted because of several reasons like it is because of the mechanical or optical imperfection of the sensor, earth's rotation during the period of image acquisition may also effect, Atmospheric effects, curvature of earth surface etc due to these inherently geometric distortions satellite imageries are not perfect for any geo-scientific analysis, data fusion and overlay of different layers and images, composite map development making measurement is not possible until it is geometrically corrected.

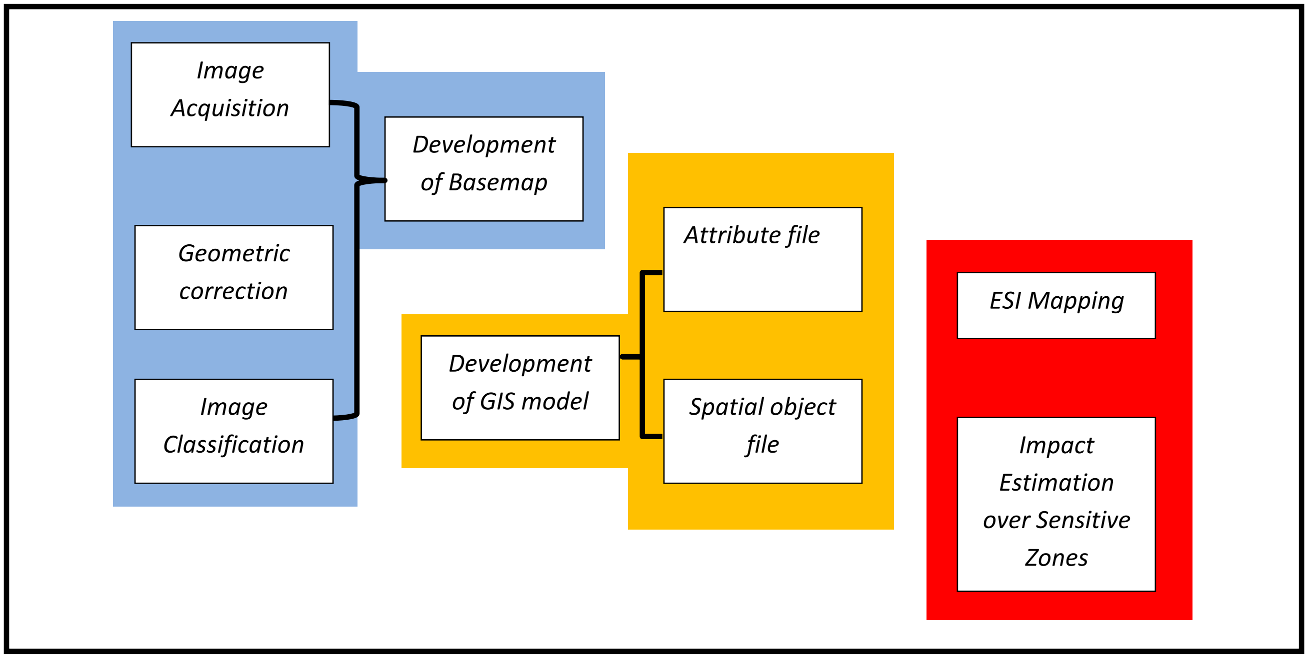

Fig. 2. Methodology Model used for ESI mapping and impact assessment of this Study.

Image Enhancement

Satellite imageries contains the noise and needs the image enhancement for better visibility and spectral response numerous image enhancement techniques respond in different methods, choice depends on the objectives to acquire image enhanced by using different methods depends upon which characteristic of the image is to enhanced like ERDAS image provides several methods and techniques of image enhancement including radiometric enhancement, spectral enhancement and spatial enhancement in this study brightness and contrast adjustment, Histogram equalization, Resolution merge technique and Gaussian filter is applied so that the image visibility is enhanced to an extent of interpretation (Fig.3a and 3b).

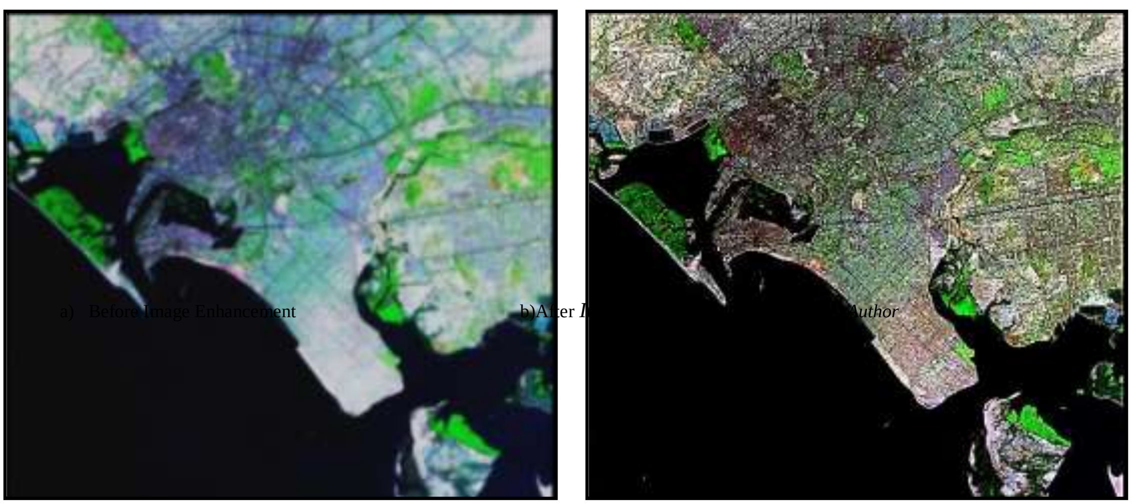

Fig. 3. Satellite Image of Karachi Coast : *a)* Before Image Enhancement and *b*) After Image Enhancement.

Development of GIS Model

GIS represents the data in three ways; Point, Line, Polygon (Spatial Object file) and incorporation of attribute information. Digitized vector layers are integrated with attribute information collected through survey and other sources in order to accomplish the mapping task

Shoreline Habitats Classification

Shoreline habitat classification is one of the significant components of the study. Major factors for sensitivity ranking include shoreline exposure, biological productivity, nearby human settlement, slope, wind direction and geological settings etc. Data is processed for shoreline habitat classification for which acquired SRTM DEM 30 m is processed for getting the contours lines with attributes of elevation which helps in understanding the surface, cultural and physical layers are obtained by on screen digitization from satellite images and analogue maps which were scanned. Before digitization all the images are geo-referenced using Affine Transformation and ground truth points from the topographic map. The detailed method of processing the data is as follows.

Usage of Radar

In this study Radar data is also used for the extraction of plume and affected zone information. Radar is an active sensor and operates in a radio wave region (1m – 104m), for coastal environment SAR is a powerful tool for mapping and helps in providing information about the appearance and the submergence of the coast (Filho *et al*., 2009). Radar dataset is useful for mapping oil spill (ERS1, 2. RADARSAT, JERS) while optical satellite imageries do have some limitations and does not have enough potential as compared to SAR data for oil spill mapping and detection (Fingas and Brown, 2000). The fusion of these two sets helps in achieving the relevant goals in this study.

Spill Trajectory Mapping

It is one of the mandatory requirements that the potential geographic zone is delineated which is impacted by the Tasman oil spill, by using the space born data set (Fig. 4),and integrating it with the oceanographic information like water current pattern and wind pattern etc.

Biological Affected Zone Mapping

After delineating the trajectory biologically impacted areas are mapped into which a collective mapping is done for both flora and fauna for this a remote sensing dataset and techniques are used by integrating it with GPS survey data.

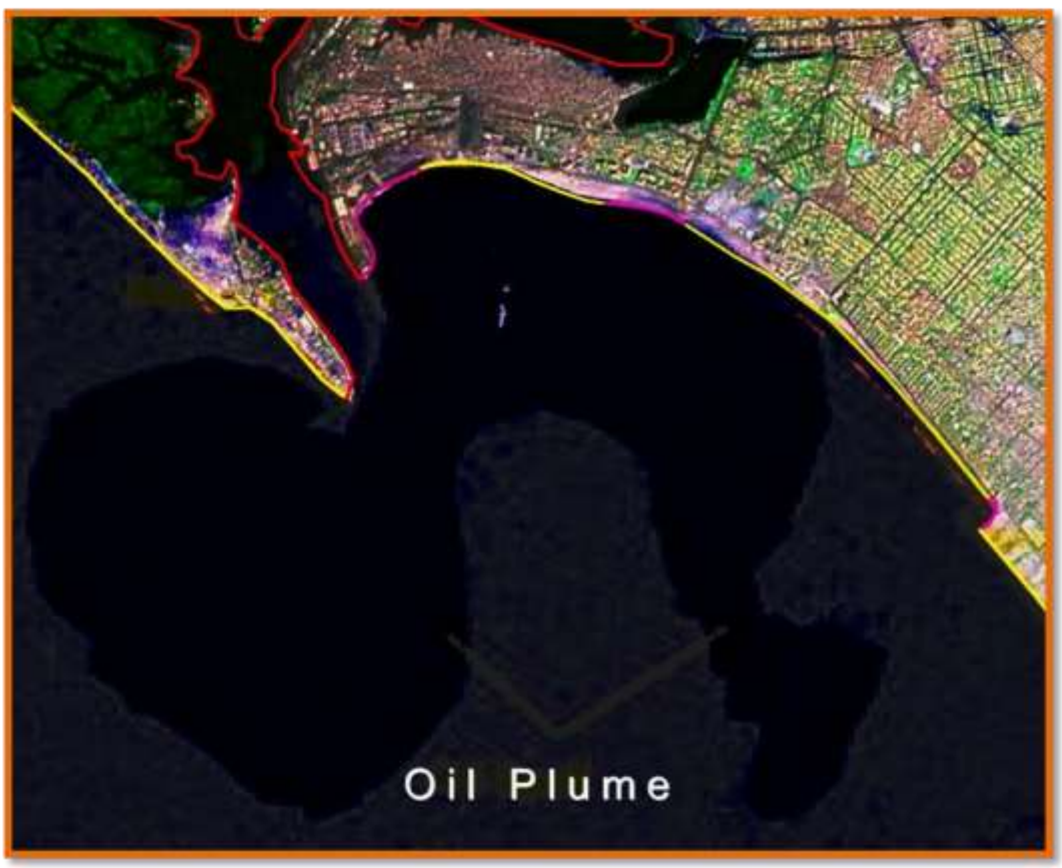

Fig. 4. Oil Plume along Karachi Coast after Tasman Spirit Oil Spill.

RESULTS AND DISCUSSION

Relative Environmental Sensitivity Index(RESI) Mapping

RESI is developed by executing the factorial mapping of the study area. These factorial maps include Shoreline slope, Exposure to waves and wind direction, Socio-economic exposure mapping and biological productivity mapping which includes both flora and fauna(Fig. 5). The first yield is the ESI Map which represents the classification of shoreline with respect to the corresponding factors which has been developed for the first time under this study in Pakistan for any of its coastal areas.

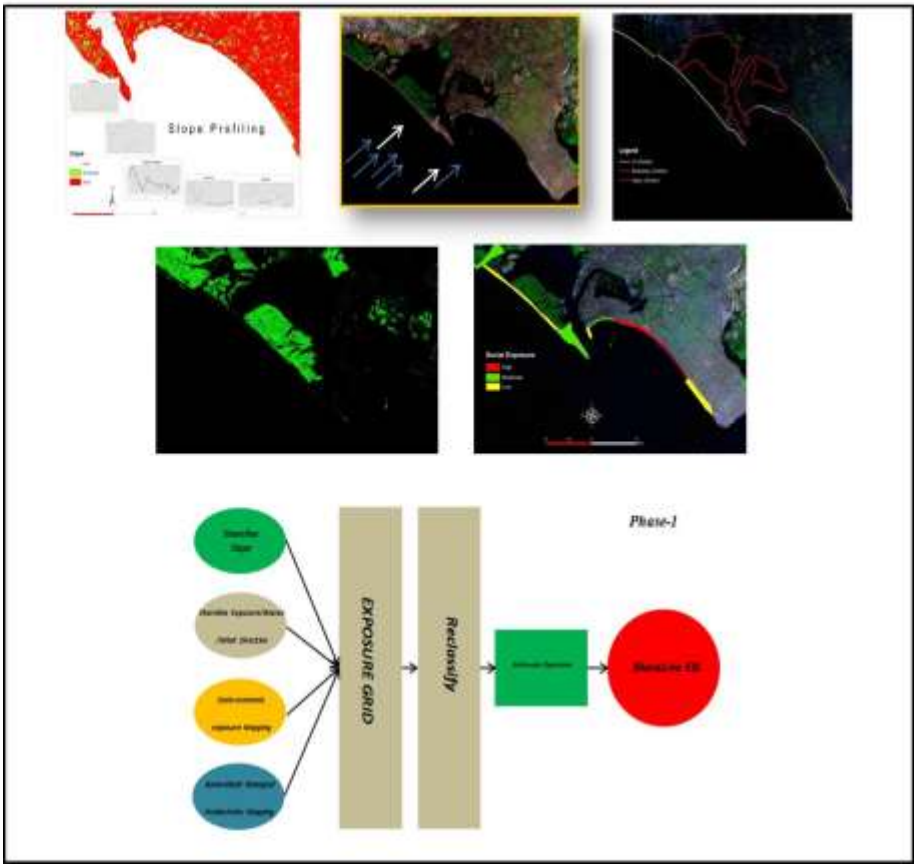

Fig. 5. Schematic diagram depicting Methodology used for Relative Environmental Sensitivity Index (RESI) Mapping for Oil Spill Impact Study.

Spill Trajectory Mapping:

Spill trajectory mapping is one of the prior tasks in order to estimate the impact of Tasman oil spill. For this to achieve RADARSAT data of 19th Aug 2003 (Fig. 6) is used which is enhanced by using the ERDAS Imagine image processing software. This helped in calculating the accurate covered area of the plume (Fig. 7) as well in identifying the level of interaction to the different sites of Karachi coast in terms of distance point of view. The distance from the spill location is calculated from the different sites on the coast using the schematics distance method technique which helps in identifying the nearby areas of the coast to spill location (Fig.8). This linear distance ranges from 1 to 16 Km in which three risk classes are generated, where 1 to 6 km rank as high risk class, 7 to 10 rank as moderate while 11 to 16 rank as low risk most of the mangroves community are in moderate and low risk zone while the major turtle nesting sites are also not directly influenced by this spill while few zones of mangroves are under severe impact after this spill in addition the turtle moving trajectory to that nesting site of Sand spit and Hawkes Bay was under attack by Tasman oil spill, severely impacted areas include the few portion of DHA, Clifton, KPT which are also in monsoon wind direction where the oil fume blasting situation also occurs, which replaces the substrate with the oil layer from where the different birds and other fauna takes food. The air was heavily polluted after the spillage and this impact is catalyzed by the specific monsoon winds huge amount of volatile organic compounds were introduced to the coastal environment of Karachi. The severely impacted areas were from Ibrahim Hydri to Shireen Jinnah colony to Village restaurant, and up to Korangi 11/2, the pungent odor was reported throughout the zone, this pungent odor was reported by the residents and visitors within a distance of upto 1.35 km from the beach area. Shireen Jinnah colony, Seaview and Clifton were the most impacted areas where the workers, picnickers vendors and residents all got exposed to the heavy volatile organic compounds. Some of the basic reasons Tasman Spirit Oil Spill may be ranked amongst the few most disastrous spillages, in the seas across the globe with respect to the damages caused to the environment and the coastal population apart from the technical facts and figures as discussed in the succeeding evidences are:

- The heavy spillage of some 31000 tons of light crude oil in less than 2 KM from the coast line.
- The oil containing the dreadful carcinogenic agents in the form of VOCs was carried to the thickly populated coastal area beaches due to the vigorous waves and wind actions in that direction.
- The continued exposure of the coastal population to such an adverse condition for a period of no less than a month forcing them to inhale the dreadful carcinogenic agents for a very long period.

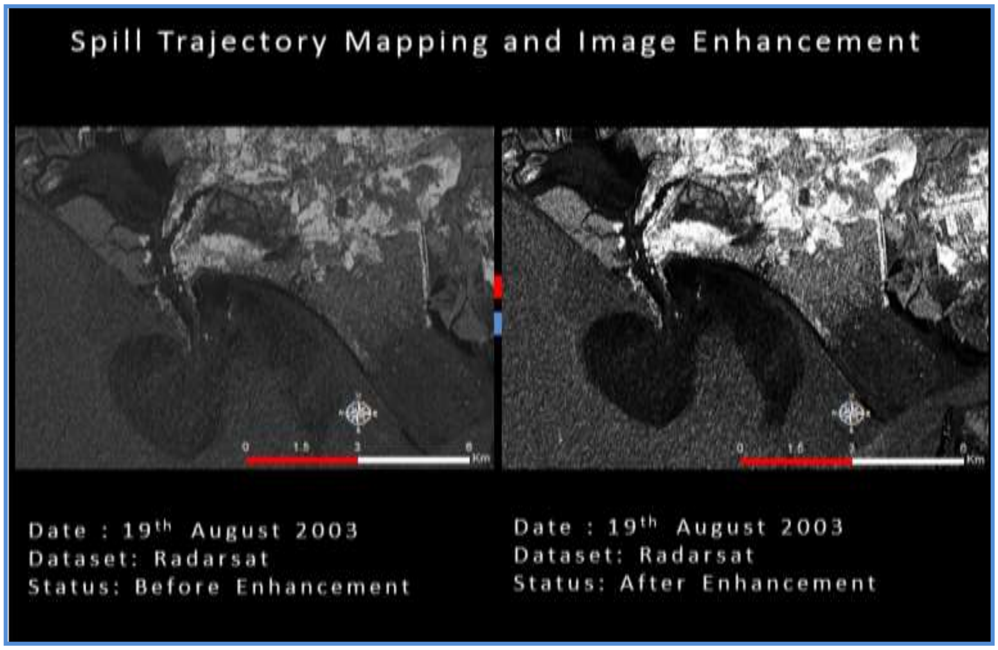

Fig. 6. Radarsat Image of 19th Aug 2003 for Tasman Oil Spill.

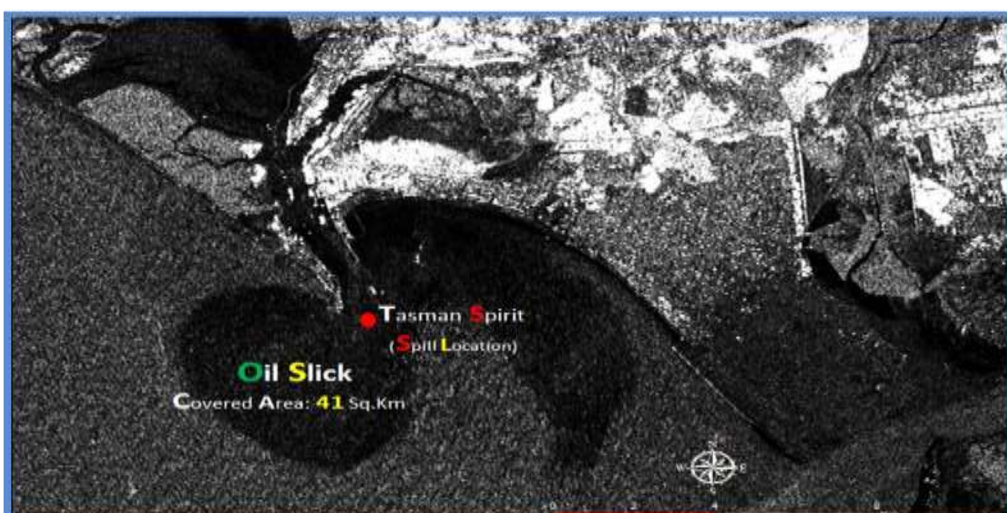

Fig. 7. Enhanced Image of Radarsat Image of 19th Aug 2003 showing area covered by oil plume from Tasman Spirit Oil Spill.

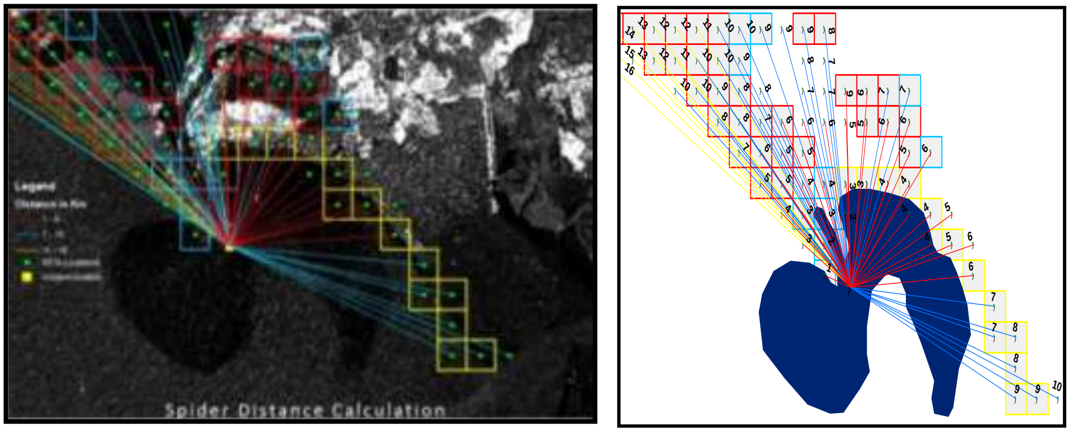

Fig. 8. Schematics distance method technique (Spider Distance Calculation) used to identify vulnerable areas of the coast to spill location on the coast.

Spider distance calculation method helped in analyzing the incident distance relationship. On the basis of incident location and its distance from the coastline the impact of spill is classified by considering the a general hypothesis that greater the distance from the spill location lesser will be the impact the red lines in the above figure demonstrating the high risk areas because of their closeness to the spill location similarly blue lines shows the moderately affected geographical areas while yellow respond to less impacted zone.

Delineation of Biological Sensitive Zone

In order to delineate the composite sensitive zones it was necessary to delineate the factorial maps of all the identified field of study area, amongst which biological sensitive zoning was one of the most important parameter to achieve equally space grid as shown in Figure 9. This map was overlaid on the acquired satellite imagery and surveyed results. Thus resulted in extracting the different sensitive zones which are classified as High Moderate and Low, in red, blue and yellow colors respectively on the map. The Highly biologically sensitive zone can be seen in the west of study area under the red grids, where *Avicenna marina* and other type of mangrove community exist in bulk serving as breeding grounds for different species.

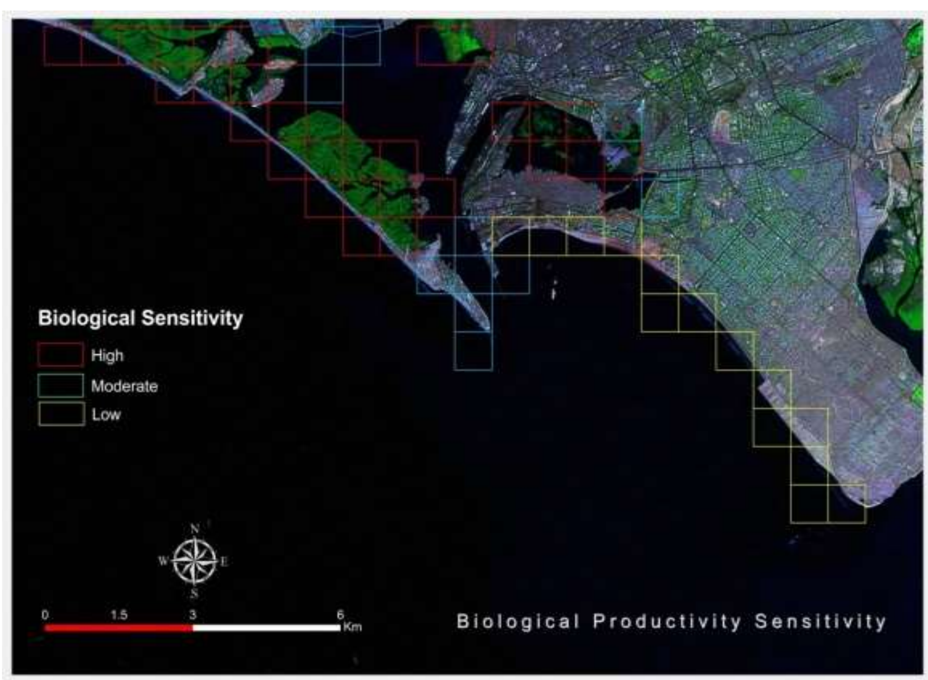

Fig. 9. Biological Productivity Sensitivity along south coast of Karachi (Source: Aurthor).

The red zones are representing the high sensitive area in terms of biological point of view while this sensitive zone is also close to the incident location as shown in spider distance analysis. The monsoon period is vital and considered as the breeding season of many marine and marine-related species, inflow of fresh water in this zone helps in reducing the salinity while also introduces the phyto and zoo planktons, and collectively this zone serves as a significant ecological site. Some of mangrove fish species are found during survey like *Clupeiformes, Cypriniformes, Anguiliformes, Perciformes, Beloniformes, Mugiliformes* etc. Vital signs of Mullets, Snappers Cuttlefish, Crabs, Flounders and bivalves are found during the survey. While indigenous species of mangroves *Avicenna marina* and *Rhizophora mucronata* are quite dominant. The high sensitive zone (Fig. 9) is composed of sparse and dense mangroves, Tidal mud flats, terrestrial vegetation, saline ponds in back water, salt pans and dry land. The saline ponds attracted the migratory birds some of the species noted in several studies. Tasman Spill seriously injured that rich natural biological zone which not only affected the above mentioned flora but also impacted over the migratory birds.

Conclusion

This Study evaluated the benefits of GIS and RS Technology, specifically for the Least Developing Countries (LDCs), as the technological subset to assess the damages in case of oil spill emergencies. Tasman Spirit Oil Spill 2003 was assessed, monitored and evaluated for environmental damages through the degree of impacts over the Environmentally Sensitive Areas (ESA) and developing a composite relative sensitivity index RSI. This study demonstrates how the GIS and RS help in synthesis and integration of the data of various research studies. The development several maps on plume spot, land use information, habitat information, Flora and fauna information, slope and coastal segmentation ,demographic structure etc. done within ESI mapping of the study area for delineation of the most to least sensitive zones. This study has contributed in highlighting the significance of the technological support for developing proper response strategies for oil spill response and establishing a GIS Database for understanding and responding to environmental disasters.

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