Identification of Suitable Sites for Plantation of Biofuel Source *Jatropha C.* using Geospatial Techniques

Muhammad Arslan[1], Arjumand Z. Zaidi[2], Saad Malik[3]
Department of Remote Sensing and Geo-information Science
Institute of Space Technology, P.O. Box 8456, Karachi-75270, Pakistan
1. muhammad.arslan_ncrg05@ist.edu.pk
2. arjumand.zaidi@ist.edu.pk
3. dr.saad@ist.edu.pk

***Abstract*— Wide scale use of fossil fuels in agriculture, transportation, industries and other sectors are not only creating global environmental problems but are also depleting natural resources of energy. In recent years, the value of using environment friendly, as well as, renewable fuels is gaining worldwide attention. Biofuel or bio energy is currently considered as a renewable energy source exhibiting significant growth potential. It contains energy from plants and microalgae. *Jatropha Curcas* (JC) is one of those popular plants that have energy potential. Its seeds contain around 35-45 percentage of oil that can be used as biodiesel. This plant can grow easily and does not require very favorable weather and soil conditions. In this study, geospatial techniques were employed to identify suitable land for JC plantation. Landsat satellite Operational Land Imager (OLI) sensor imageries and Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) were used. Important research parameters, either derived from satellite data or gathered from other sources included bare land, temperature, relative humidity (R. Humidity), rainfall, soil type, land surface elevation and slope. Information regarding bare land, elevation and slope of the area were obtained through satellite image processing. Weather and climate related data were acquired from National Centers for Environmental Prediction (NCEP). The overall goal of this study was to evaluate and propose potential sites suitable for Jatropha C. plantation with required climatic, soil type and terrain parameters using geospatial technologies (remote sensing and geographical information system). Thatta tehsil can be divided into 3 classes of suitability for Jatropha C. plantation; *Most Suitable, Moderate Suitable* and *Less Suitable*. The areas under each category are 1,020.64, 767.58 and 16.34 square kilometers respectively.**

***Index Terms*—Biodiesel, Geospatial, Jatropha Curcas, Thatta Tehsil, Weighted Overlay Analysis**

I. INTRODUCTION

World's energy demand continues to increase with the development of economy and population growth. Use of fossil fuels accounts for many economic and environmental problems including rising fuel price, dwindling energy resources, green house effects leading to global warming and ultimately climate change. In the past decades, biofuels have attained a remarkable importance as the world is struggling to address the ever increasing price of fossil fuels as well as global warming. Adopting renewable energy alternatives will surely reduce global warming [1]. In many developed and developing countries, liquid biofuels like biodiesel, straight vegetable oil (SVO) and ethanol are being explored. According to International Energy Agency (IEA), the global biofuel production of year 2009 reached up to 83 billion liters which is 1.5 percent of the total fuel used in the transportation sector [2].

Biofuels are generally divided into two categories. The first category is called "*First Generation*" and likewise the second one is named as "*Second Generation*" biofuels. This division is based on the processing technology and type of feedstock. The first generation biofuels used seed stocks of agriculture crops such as sugarcane, maize/corn, wheat, sugar beet and others. Since first generation biofuels require food crops for their production, there may be a food security threat associated with their use especially in developing and under developed countries of the world. Second generation biofuels do not require food crops and are extracted from woody oil plants. Since they do not compete with food production on an agriculture land, the risk of food security does not emerge by their use [3]. Jatropha C., a non-edible oil seed plant, is between second generation biofuel plants that is getting prominent attention since the beginning of the 21th century due to its rich non-edible oil content (around 35 to 48 percent) [4, 5]. Originally Jatropha C. was a native plant of South American countries including Mexico, Mesoamerica and few others, but nowadays, it is being cultivated in all tropical regions. In Indian subcontinent, this plant was introduced by the Portuguese traders in the 16th century [6]. The main concern of this study was to propose a methodology for selection of suitable Jatropha C. plantation sites (land) using satellite technology and also to identify suitable sites for its plantation in Thatta tesil. The suitability criteria included climatic, soil type and satellite based parameters discussed, in detail, in the subsequent sections.

A. Advantage of Jatropha Curcas Biofuel

In general, biofuels like other renewable energy sources are environment friendly. Their use is emerging worldwide and expected to grow rapidly in near future. Developed and developing countries have started large scale programs on biofuels [7]. Jatropha Curcas or Jatropha C., a biofuel source selected for this study, also possesses these characteristics.

Some people argue that Jatropha C. has negative environmental and social impacts since its plantation may cause deforestation, displacement of local forest product or food crops and deprivation/alienation of farmers from their lands. It is also said that its water demand may cause depletion of water needed for other important crops to grow [8]. In response to these arguments, it is important to note that Jatropha C. can be planted on bare, degraded, waste or marginal lands which are already declared unsuitable for food crops cultivation and therefore food security is not threaten by its use [9]. Since agriculture land is not required for Jatropha C. plantation, its growth on waste land ensures that it does not take the place of food crops and forest area [10]. A study done in Tanzania has also proved that outgrowth of Jatropha C. does not have negative impact on land access [11]. In Pakistan there is around 45.2 million hectors of marginal land available in Sindh, Punjab and Baluchistan provinces that can be further evaluated as potential sites for plantation of Jatropha C. [12]. As far as depletion of water resources is concerned, Jatropha C., being a drought resistant plant needs low nutrients, low water requirement and less management [9].

B. Energy Need and Biofuel Potential in Pakistan

Pakistan has been blessed with a variety of natural energy options including natural gas and world's largest coal reserves. There are also a number of renewable energy options available for Pakistan including biomass, hydro, wind, solar and tidal powers but unfortunately no effective strategy has yet been set to exploit these resources. Like many non-oil producing developing countries of the world, Pakistan is also facing energy crises nowadays. Agriculture, industrial, domestic, transportation, commercial and other sectors are the major consumers of energy in the country. Pakistan's auto industry is growing at the rate of approximately 25 percent per annum for the last three years. This trend is increasing and more fuel (energy) will be needed in the future [13]. At present, most of the country's economy runs on imported fuel. Pakistan imports different types of energy, mostly oil products to fulfill its need spending huge amount of money (8.8 billion US dollar in 2009-2010). With increase in population, lifestyle standards, infrastructure and industrial developments it is obvious that country's energy demand will definitely increase in near future [14].

Fossil fuels are also responsible for increasing level of greenhouse gases (GHGs) in the atmosphere. Pakistan is emitting 0.43 percent of the world's total GHG emissions [15]. Although, this is not a big amount of emission as compared to developed countries (USA or India), yet it must be reduced. Pakistan has already faced devastating natural disasters in recent past including floods, droughts and wind storm mostly triggered by climate change. Therefore, the search for renewable and environmental friendly fuel is a major political and environmental challenge. Production and usage of biodiesel can minimize the requirement of fossil fuel and environmental and social problems by enhancing environment quality, mitigating GHG emission, promoting rural development and ultimately reducing poverty.

In view of the above issues, Pakistani government took a step forward in the formation of the Alternative Energy Development Board (AEDB). The major scope of this board included the introduction of at least 10 percent biodiesel in the diesel market of Pakistan by 2025 [16].

C. Previous Studies

Jatropha C. has got main attention since the mineral oil crisis of 1970s that made it a recognizable alternate to world's oil resource [17]. Pakistan State Oil (PSO) and Pakistan Agriculture Research Council (PARC) have already taken initiatives in this regard. They are researching on biodiesel from Jatropha oil. They have planted Jatropha C. (trial production) in Karachi. According to Pakistan State Oil (PSO) official source; 7.2 Million liters of Biodiesel (worth approx. PKRS 345 million at PKRS 48/liter of petroleum diesel) will be produced per annum [18]. From views of the local scientists, it is suggested that biodiesel can be produced on marginal/bare land from inedible crops and this can create employment opportunity for the local poor farmers [19]. Many airlines have been flying their aircraft with the biodiesel made partially from Jatropha C. including Continental, Air New Zealand, TAM (Transportes Aéreos Meridionais - Brazil's and Latin America's largest airline) and Japan Airlines [20].

D. Objectives

The primary objectives of this study were to identify suitable land/site for Jatropha C. plantation in and around Thatta tehsil using remote sensing (RS) and geographical information system (GIS) techniques. In order to achieve the primary objective of the study, it was required;

1. To ascertain study parameters that influence Jatropha C. plantation
2. To derive relevant information from satellite data using remote sensing techniques
3. To prepare GIS based maps of suitable sites

E. Justification of Study

Previous researches have been focused on the oil production capacity of Jatropha C. with lesser attention towards site suitability for its cultivation. Moreover, no study has been conducted in Pakistan for this purpose using satellite technology. Studies on Jatropha C. plantation are usually conducted through field surveys [7, 17, 21, 22, 23]. Some studies used climatic data [7, 21, 24, 25, 23, 26, 27] as well as remote sensing and GIS techniques [7, 21, 28] to assess and select potential sites for plantation of Jatropha C. The latest emergence of satellite technology has been very helpful in solving problems related to ground features in an efficient and cost effective manner. Therefore, in the proposed study, Satellite Remote Sensing along with GIS techniques were utilized to identify suitable sites for Jatropha C. plantation in and around Thatta tehsil. In this regard, different climatic and terrain parameters were analyzed along with soil type of the study area to allocate the land suitable for Jatropha C. plantation using remote sensing data and geographical information system techniques.

II. MATERIAL AND METHODS

A. Study Area

Thatta tehsil is one of the nine tehsils of Thatta district. It lies in the Northwest of Thatta district. The geographical location (see fig.1) is from 24.554° N to 25.454° N latitudes and from 67.506° E to 68.359° E longitudes. It is the only tehsil which has around more than 70 percent bare land. According to 1981 census, it had 149,000 and 22,000 rural and urban populations respectively. In 1998 census, 217,000 rural and 37,000 urban populations were recorded [29].

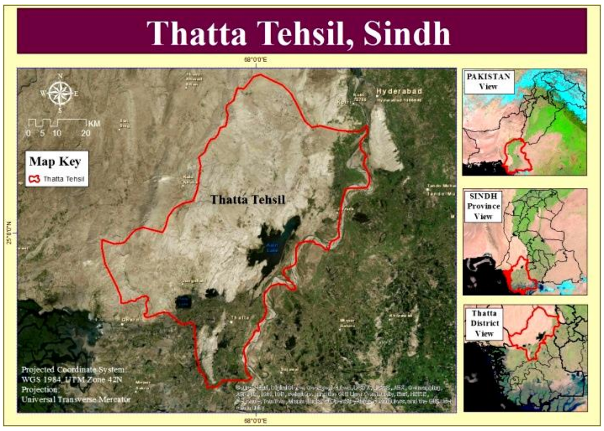

FIGURE 1: STUDY AREA

The weather of Thatta tehsil is relatively warm in summers with average annual temperature ranges between 28 °C and 29 °C (fig. 3). Annual relative humidity (R. Humidity) of Thatta tehsil is around 48-50 percent as shown in fig. 4. Annual precipitation (fig. 5) is recorded at less than 200 mm according to National Centers for Environmental Prediction (NCEP) data [30] and Pakistan Meteorological Department (PMD) records [26]. The major part of the study area is a plain land (figs. 2A and 2B) with maximum elevation of 394 meter (fig. 6). Majority of the land has less than 15 degree slope as presented in fig. 7. Soil composition of the area consists of loamy, gravelly and rocky soils (demonstrated in fig. 8).

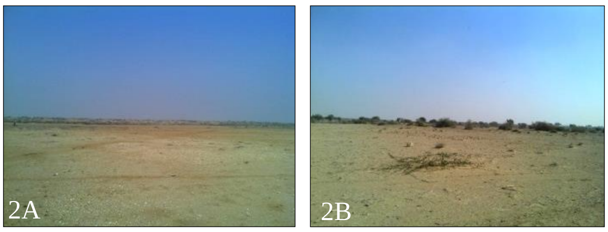

FIGURE 2A AND 2B: SHOWS THE STUDY AREA TERRAIN

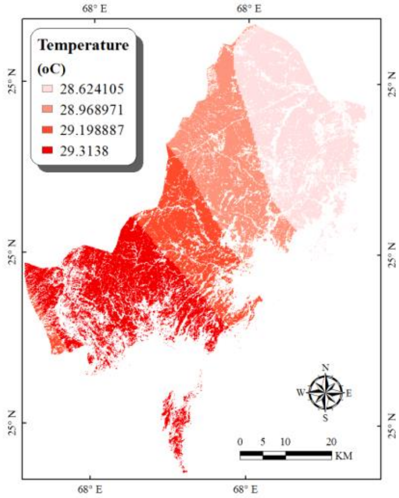

FIGURE 3: TEMPERATURE (IN °C)

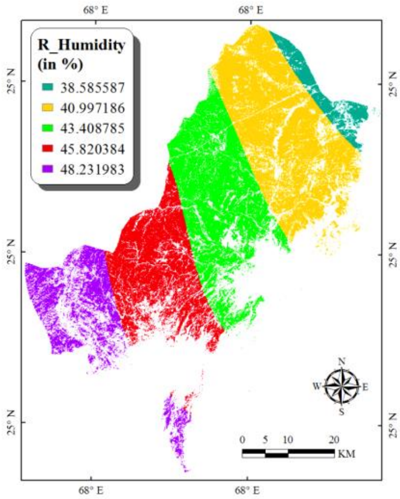

FIGURE 4: RELATIVE HUMIDITY (IN PERCENT)

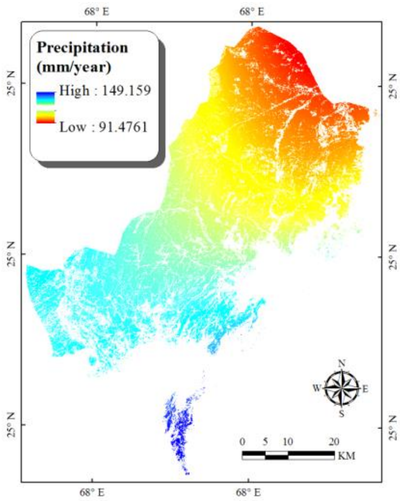

FIGURE 5: PRECIPITATION (IN MM)

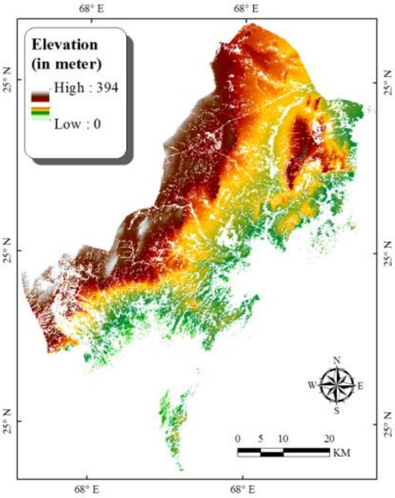

FIGURE 6: ELEVATION (IN METER)

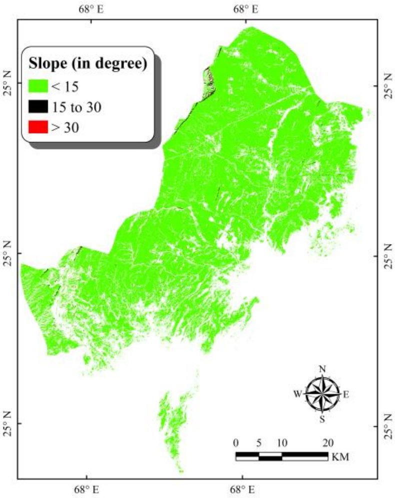

FIGURE 7: SLOPE (IN DEGREE)

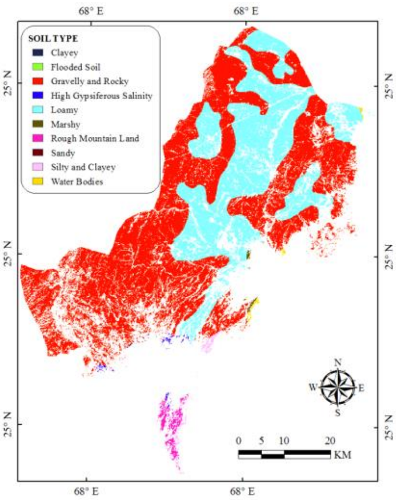

FIGURE 8: SOIL TYPE

B. *Data Sources*

Satellite data used in this study included Landsat-8 Operational Land Imager (OLI) and Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) acquired by the United States Geological Survey (USGS) and freely available from the internet sources. Grid points based climate data (from 1979 to 2013) including precipitation, temperature and relative humidity were downloaded from National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR). The NCEP data are available globally since 1979 at approximately 38 kilometer spatial resolution (shown in fig 9). Study area boundary was acquired from DIVA-GIS in vector format. Soil type data were collected from the Soil Survey of Pakistan and then digitized. Further details of data and data sources are provided in Table: I.

TABLE: I
DATA SOURCES AND DESCRIPTION

S.N.	Data	Description	Sources
1	Landsat-8 Data	30 m resolution	Earth Explorer*
2	SRTM DEM	30 m resolution	Earth Explorer*
3	Study area boundary	Vector layers	DIVA-GIS**
4	Soil Type	Hard Copy	Soil Survey of Pakistan
5	Climate	Grid point data	Global Weather Data for SWAT***

* http://earthexplorer.usgs.gov/, ** http://www.diva-gis.org/gdata
***http://globalweather.tamu.edu/

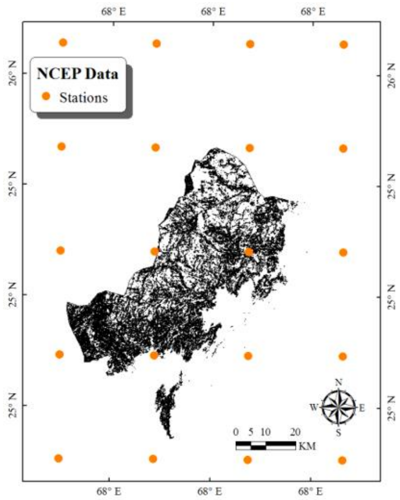

FIGURE 9: NCEP GRID POINT DATA DISTRIBUTION

C. *Site Selection for Jatropha C. Plant*

Every plant responds differently with respect to climate, terrain and soil characteristics. The selection of suitable sites for Jatropha C., in this study, is also based on these characteristics which are described below.

Climate

Nowadays, Jatropha C. is found almost everywhere in the world. It is planted in many regions like Asia, Africa, South America and Oceania [31]. It is sensitive to low temperatures and cannot survive at extreme low or freezing temperatures. Even an annual mean temperature below 15 ^{o}C can significantly reduce its yield. For seed provenance, it should be planted in areas with 17 ^{o}C to 28 ^{o}C mean annual temperatures, however, heat is not as harmful for their growth and Jatropha C., being a thermophyte plant, can tolerate high temperatures [32].

It is observed that 90 percent Jatropha C. plantation is cultivated on the lands where annual precipitation is above

600 mm [33]. For good yield or production purpose, the annual rainfall should be around 900 mm-1200 mm otherwise an alternate irrigation source may be needed [27]. It may, however, grow in regions with annual rainfalls as low as 250 mm provided that a high humidity is present in the air to supplement water deficit [23]. Jatropha C. behaves well in semi-arid conditions and if humidity is high in this environment then Jatropha C. can give better result. Too much rain combined with high humidity, though, is reported to be detrimental for the plant causing root/stem fungus [34].

Terrain

Jatropha C. should not be planted on lands where natural vegetation or agriculture is already present (due to food security issues). Lands with water logging or salinity and urban areas are also not suitable for Jatropha C. plantation. Surface slopes also have an impact and should not exceed 30 degrees because it directly affects the soil erosion, irrigation and drainage [35]. A land that has slope more than 25 or 30 degrees are usually given the least priority because it causes water loss and soil erosion [36]. Jatropha C. can grow on lower altitude from 0 to 500 meter amsl (above mean sea level) [23]. It can also be planted on 1,800 meter amsl high altitude area, although, at high altitudes there may be a risk of frost attack which can stunt the plant's growth [3].

Soil

Jatropha C. plant prefers well drained aerated sandy, gravelly and loamy soils [37]. It cannot grow on clay soil because heavy clay soil hinders the Jatropha C. root formation since water cannot reach to the root level [16]. Soil depth should be at least 45 centimeter to facilitate the penetration of plant root into the deep soil [31]. Selection of hard or rocky land is usually given the least preference for Jatropha C. plantation.

D. *Methodology*

This study included both desktop computer analyses and field observations. Important research parameters of the study area, either derived from satellite data or gathered from other sources, include bare land, temperature, rainfall, relative humidity, soil type, land surface elevation and slope. A field visit was also performed to verify the data acquired from satellite and other resources and to get a general idea about the study area. Local people were also contacted during this visit to get their views about this study. Following were the main steps taken to accomplish the proposed study.

- Landsat-8 satellite (OLI) sensors images of 30 meter spatial resolution (path 152 and row 42 and 43) were downloaded from Earth Explorer website. SRTM 30 meter DEM tiles of the study area were also acquired from the same website that was used in this study to derive slopes.
- Soil type map was obtained from Soil Survey of Pakistan (SSP) in hard copy form.
- Information regarding bare land, elevation and slope of the study area were derived from satellite images. Bare land layer was extracted using bareness index [38] (as mentioned in equation 1 and shown in fig. 10).

Bareness Index (BI) = {(OLI4 + OLI6) – (OLI5)}..(1)

Where OLI4, OLI5 and OLI6 are 4 (red), 5 (near infrared) and 6 (short wave infrared 1) bands of Landsat-8 OLI image respectively.

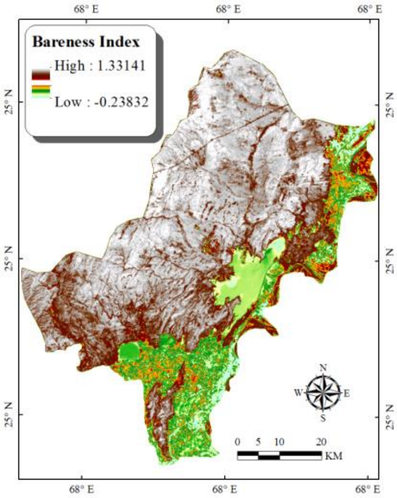

FIGURE 10: BARENESS INDEX SHOWING BARE LAND

- Climate related data were acquired from National Centers for Environmental Prediction (NCEP). NCEP provides climate data on daily basis. NCEP data were further converted into annual averages according to the study requirements. Inverse Distance Weighted (IDW) interpolation technique was used to interpolate the NCEP climate data using ArcMap IDW tool.
- After the pre-processing of all layers, these layers were masked using bare land extent of the study area. The masked layers were then reclassified and resampled at 30 meter spatial resolution in order to perform weighted overlay analysis. Weighted overlay is a GIS-based analysis performed to combine several datasets for generating a new layer based on given criteria. The suitability criteria for all study parameters are defined in Table: II. The final suitability map was developed as a result of the weighted overlay analysis. The primary steps followed for this purpose are described in fig. 11.

METHODOLOGICAL FRAMEWORK CHART

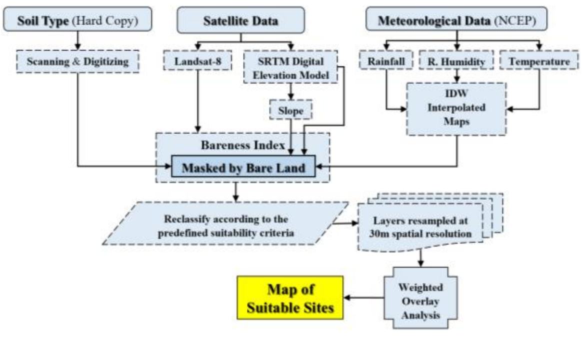

FIGURE 11: METHODOLOGICAL FRAMEWORK

TABLE: II
SUITABILITY CRITERIA FOR JATROPHA CURCAS PLANTATION

S.N.	Parameter	Range/Limitation	Suitability Classes			Data Source	Reference
			More Suitable	Moderate Suitable	Less Suitable		
1	**Slope**	Not exceed 30^o	< 15^o	$15^o – 30^o$	> 30^o	SRTM DEM	[7, 21, 31, 35, , 40]
2	**Elevation**	0-1800m m.s.l.	< 1500 m	1500m - 2100m	< 0 and > 2150	SRTM DEM	[3, 16, 40]
4	**Temperature**	18 ^oC - 28 ^oC	20 ^oC-28 ^oC	17 ^oC-20 ^oC	<17 ^oC and >28 ^oC	NCEP Data	[7, 16 , 24, 31, 33, 39, 40, 41, 42, 43]
5	**Rainfall**	250mm – 3,000mm	1,000mm – 3,000mm	250mm – 1,000mm	< 250mm and >3,000mm	NCEP Data	[24, 40, 43]
6	***Relative Humidity**	Maximum	High	Moderate	Low	NCEP Data	[32, 34]
7	**Soil Type**	Aerated sandy, gravelly, loamy or soil without/a little clay content	Loamy, sandy or gravelly well drained soil	Stony or rocky soil or a little part of clay/salt	Clay soil or water logged	Soil Survey of Pakistan	[16, 31, 40]

Relative humidity suitability criteria is not given in the existing literature review
Source: Expert Knowledge

III. RESULTS AND DISCUSSION

The result is divided into three classes of suitability of land for Jatropha C. plantation in Thatta tehsil. This suitability was computed carefully using weighted overlay analysis based on four study parameters including temperature, relative humidity, soil type and slope.

The final suitability map has divided the Thatta tehsil into three (03) suitability classes for Jatropha C. plantation; *Most Suitable*, *Moderate Suitable* and *Less Suitable*. The areas under these categories are 1,020.64, 767.58 and 16.34 square kilometers respectively (refer. Table: III). A map showing these sites in Thatta tehsil is presented in fig. 12.

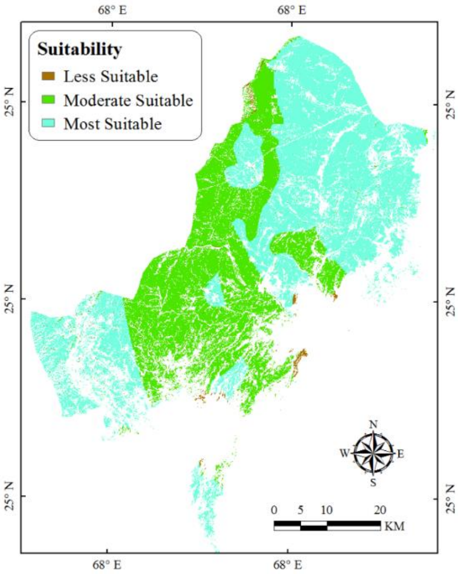

FIGURE 12: SUITABLE SITES FOR JATROPHA C. PLANTATION IN THATTA TEHSIL

Elevation was not included in the analysis because the entire study area came under the most suitable range given by the experts. As far as rainfall layer is concerned, it was also excluded in the overlay analysis because precipitation did not come even under the least suitable category given by the experts. It was presumed, therefore, that the plantation will be supported through any alternate water supply. Pakistan State Oil is also not depending on the precipitation for Jatropha C. plantation owing to its non-availability in the region and utilizing groundwater for this purpose (information gathered through interview).

TABLE: III
AREA-WISE SUITABILITY

S.No.	**Category**	**Area** [Km^2]	**Area** [%]
1	Most Suitable	1,020.64	56.55
2	Moderate Suitable	767.58	42.53
3	Less Suitable	16.34	0.904

IV. CONCLUSION

This research work was done for Jatropha C. plant suitable site selection using meteorological, satellite and soil type data and geospatial techniques at Thatta tehsil, Thatta Sindh. Most of the project activities were based on desk work including internet downloading and processing of data using computers and geospatial software. An alternate approach could have been to gather this data through field measurements that, beyond any doubt, is both time and cost intensive. Therefore, it can be stated with confidence that geospatial tools are more efficient and cost effective to study or analyze similar problems than traditional approaches that involve tedious site surveys involving sophisticated equipment and skilled manpower. Also, many times the sites to be surveyed are not accessible due to unsuitable weather conditions or due to some other reasons that may also cause data gaps or unnecessarily delays in the project execution. Owing to their wide applicability, the utilization of geospatial tools have been increased in recent years and many government agencies, organizations and private sectors are using them for site selection, natural resources management, disaster management, town planning and etc.

To achieve the objectives of the study, GIS layers of elevation, slope, temperature, rainfall, relative humidity and soil were developed using satellite data and geospatial tools. All parameters were found to be favorable except precipitation because Jatropha C. requires more rainfall than what existed in Thatta tehsil. Jatropha C. requires tropical climate in which more than 600 mm or above rainfall is received. The limitation of the site with regards to the water availability should be addressed through alternate water sources. In accordance with the pre-defined suitability ranges of the other parameters, the study site was delineated into three (03) classes; less suitable, moderate suitable and most suitable for Jatropha C. plantation.

The field visit also confirmed the availability of barren land in the study area. It was also revealed that, at present, no such activity related to Jatropha C. plantation or any other biofuel crops is being performed in Thatta tehsil or nearby areas. Therefore, it may be concluded that Jatropha C. plantation for biofuel extraction in Thatta tehsil would not only be beneficial for the economic prosperity of the country but it will also produce job opportunities for the local people of Thatta tehsil without threatening the food security of the region.

In this study, available literature has been reviewed to study site selection criteria. Further studies may include additional parameters like soil chemical characteristics, groundwater table, etc. and more advance GIS tools such as Analytical Hierarchy Process (AHP) overlay analysis and Community Viz (Scenario 360, an arcgis extension) to achieve more precise results.

ACKNOWLEDGMENT

The author is thankful to the supervisors for providing their valuable guidelines and moral support to accomplish this task. National Sugar Crop Research Institute, Thatta, Sindh is also acknowledged here for providing support during field visits. Further, it is also worthwhile to mention Pakistan State Oil (PSO) and Pakistan Agriculture Research Council (PARC) for sharing information regarding prospectus of Jatropha C. in Pakistan.

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