Biodiesel resources assessment and evaluation of the production capacity from Salicornia plant in Golestan Province, North-East Iran

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Abstract: Biofuel products from halophytic plants are valuable due to their high oil content and growth on non-productive, salt-affected lands. The northern part of Golestan Province has high potential for bio-fuel production from salt-tolerant plants such as Salicornia bigelovii (oilseed halophyte) due to its water and soil properties. In this research, the suitable locations for growingSalicornia plant in Golestan Province were defined based on suitability analysis. By this analysis, the suitable area for cultivation and total amount of producible biodiesel were evaluated. In this regard, the principal parameters were defined and the suitable areas were specified by spatial superposition of these layers, using Geographical Information System (GIS). The Index Overlay model was applied for data combination in suitability analysis. The results showed that the most suitable lands for growing Salicornia, are located in the North-West part of Golestan Province with an area of 2365km2, corresponding to about 12% of the total study area. The total amount of producible biodiesel of this area is estimated to be 201.143 million liters per year.

Keywords: Bioenergy, Biofuel, Site selection, GIS, Salicornia

1. Introduction

Energy plays a very important role in any production process. In general, energy sources are classified as renewable and non-renewable. Recently, factors such as global warming, higher energy demand and declining reserve of fossil fuel have led to the initiation of a worldwide movement towards replacing fossil fuels with renewable energy sources. Bioenergy is one of the renewable energies with minimum environmental impact in terms of greenhouse gas emissions [1], and can be applied for both heat and power generation. The main sources of biomass are biological materials from different types of plants (terrestrial and aquatic), agricultural waste, urban sewage and animal waste [1]. Biodiesel is derived from renewable biomass such as vegetable oil, animal fat, and cooking oil [2-5]. Oilseed is a halophyte (salt-tolerant plants), having a biomass with high potential for liquid biofuels production and high resistance to saline soils [4, 5]. Oilseed halophytes such as *Salicornia bigelovii*, have unusual fatty acids which can be used as liquid biofuel in industrial applications [6, 7]. The selection of suitable land for the planting of oil crops is the first step to sustainable production of bio-fuels. Geographical information system (GIS) has been used to evaluate the potential of bioenergy resources.

Many studies have been conducted on the assessment of renewable energy resources, using a GIS based methodology [8-14]. Moreover, appropriate locations for planting the desired plants as bioenergy resources can be estimated using

GIS as the Decision Support System (DSS) tool. Potential assessment of biomasses based on the GIS methodology conducted by Höhn et al. [15] in southern Finland showed that GIS was used to identify appropriate sites for biogas plants. Falasca et al. [16] investigated to determine lands with potential to grow *Salicornia bigelovii*; as a plant with high oil content for biodiesel production in Argentina. They classified sites into various categories such as optimal, very suitable, suitable, marginal and non-suitable lands, according to the overlapping of temperature and rainfall maps. Sidiras [17] used a GIS based application to investigate the spatial and temporal variations of biodiesel production units in Greece. Niblick et al. [18] evaluated the potential of bio-fuel crop production on urban marginal lands. They obtained the amount of available urban marginal lands in Pittsburgh, Pennsylvania using a GIS framework. According to the obtained results; 3500 ha of unused urban marginal land was suitable for bio-fuel cultivation. They concluded that these lands can be used to produce up to 129,000 liters of sunflower biodiesel per year. Hiloidhari et al. [19] evaluated the availability of straw and its demand in tea drying factories using GIS. Their research revealed that straw biomass can economically substitute coal as a source of thermal energy. In their research, Zhang et al. [20], identified the Upper Peninsula of Michigan as a suitable location for the production of bio-fuel. They developed a GIS based integration method with total transportation cost model. The village in Baraga County was defined as the optimal location for a facility to convert forest biomass to biofuel. Beccali et al. [21] investigated the technical and economic possibility of using biomass for bioenergy production in Sicily. Digital data layers such as land use, transportation facilities, urban cartography, regional territorial planning, terrain digital model, lithology, type of climate, civil and industrial users collected and integrated the use of GIS integration methodology as a DSS.

Water and soil salinity are the two main challenges facing agriculture in Iran. Generally, there are several reasons such as low rainfall, high rate of evaporation, improper irrigation practices and drainage, which lead to desertification. These areas have high potential for growing oilseed halophytes [22]. Kohan et al. [23] studied the soil and water content of lands in Golestan Province (North-East of Iran) and the result showed that the saline lands of the province have high potential for biodiesel production. The study also recognized about 20 species of salt-tolerant plants, growing in the province as seeds having oil rich content and applicability. They offered that Salicornia, *Phragmites australis* and Suaeda plant species should be cultivated for biodiesel production in this province because of their resistance to high soil salinity, to enable high productivity, easy production and implant, compatibility with existing water and soil conditions, high lipid and carbohydrate compounds and higher oil contents for biodiesel production.

In this research work, Golestan Province was chosen due to the high rate of water evaporation, high saline content in lands and the low vegetation cover. Also, among the desired oil plants for biofuel production, Salicornia was selected because it is a common halophyte plant with high oil content. The site selection for planting Salicornia in Golestan Province was done using a GIS. The GIS discarding and classifying integration methods were used for mapping and defining the spatial availability of suitable lands for Salicornia plant. The focus of this research is the assessment of Salicornia cultivation on agriculturally poor lands of Golestan Province, which prevents desertification and provides economic benefits to the local people.

2- Study area and its characteristics

The study area (Golestan Province) is located in the northeast of Iran with latitude 36º30´ and 38º15´N and longitude 54º and 56º30´E. This province has a land mass of 20380 km^2 [24] and is one of the most important provinces from an agricultural point of view, because of the availability of a wide range of fertile lands. A general location map of Golestan Province is shown in Figure 1. Elevation range in this area is from -298 m to 3820 m a.s.l and increases from north to south. Digital Elevation Model (DEM) and distribution of topographic slopes in Golestan Province is presented in Figure 1.

Golestan Province has a variety of climate conditions from humid to arid. The south band of this province has humid climate and is covered by high density forests and croplands whilst the north band has semi-arid and arid climate condition [24]. The land use map of the study area is shown in Figure 2. As can be seen in the map, the farmlands in Golestan Province are located in three climates including semi-arid, humid and semi humid. Therefore, fundamental differences can be observed in the quantity of rainfall, evaporation, infiltration, runoff and other hydrologic factors in the province. The annual precipitation is around 700 mm/year in the south and 200 mm/year in the north of the study area. In general, the average annual rainfall (shown in Figure 3) is 450 mm/year in the province, which is 80% higher than the average rainfall in the country. The average annual evaporation rate is about 2000 mm/year in the north and 800 mm/year in the southern part of the province [25].

The northern half of the province has vast saline lands. In summer and fall, because of the higher rate of evaporation, the soil is always arid and the color of soil becomes white because of movement of salt to the surface. In winter and fall, the salinity of the soil reduces because of leaching. Figure 4 shows the soil salinity based on the Electrical conductivity (EC). As shown in this figure, the saline areas are spread mostly in the Torkaman plain at the east of the province and bank of Gomishan, Enche and Daneshmand lakes. The result of soil sample analysis is shown in Table 1. In these areas, only salt-tolerant plants are able to grow [23]. Thus, the northern half of the province has high potential for biodiesel production from salt-tolerant plants.

In Golestan Province, 114 salt-tolerant species were identified and among them, 20 species could be used as a biodiesel resources with economic benefits [23]. Salicornia, *Phragmites australis* and Suaeda plant species are more appropriate for biodiesel production due to their resistance to salinity, high productive capacity, easy cultivation, their compatibility with existing water and soil condition in the area. These plants are known to contain high lipid and carbohydrate compounds in elevated oil percent [23]. In this study, Salicornia plants are selected as species for biodiesel production.

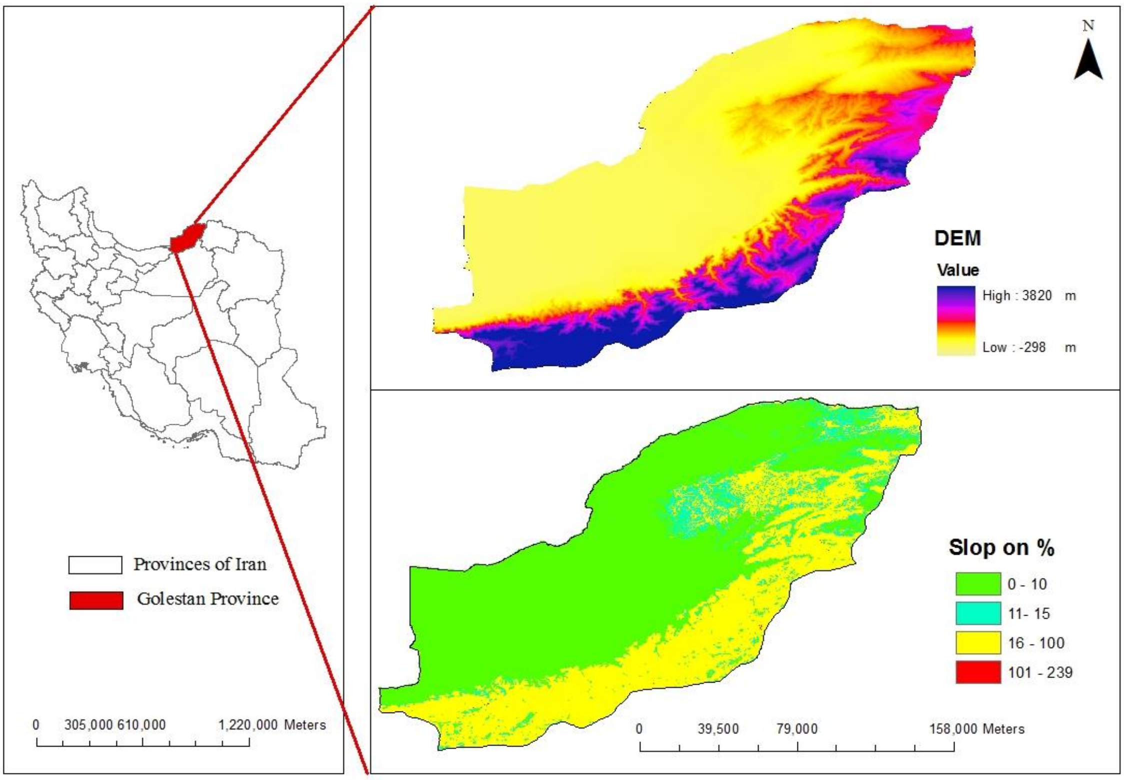

Figure 1 Location map of Golestan province in northeast of Iran, digital elevation and slope maps

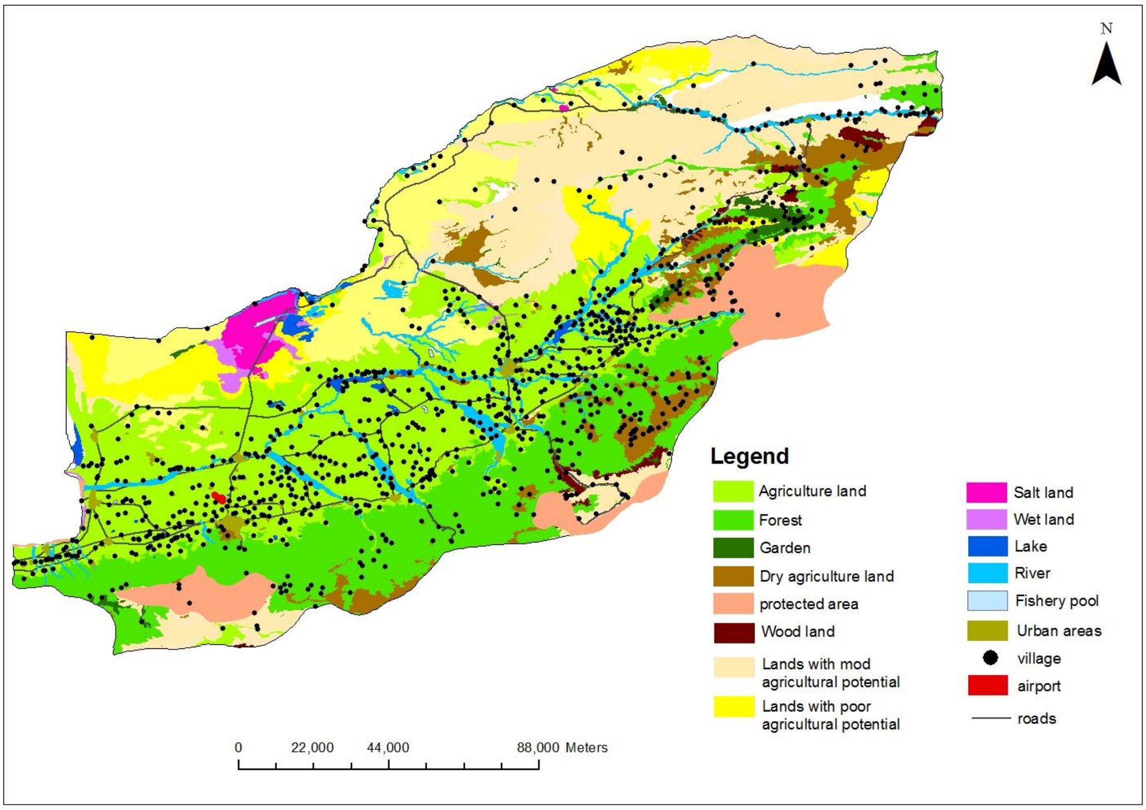

Figure 2 Land use map of Golestam province

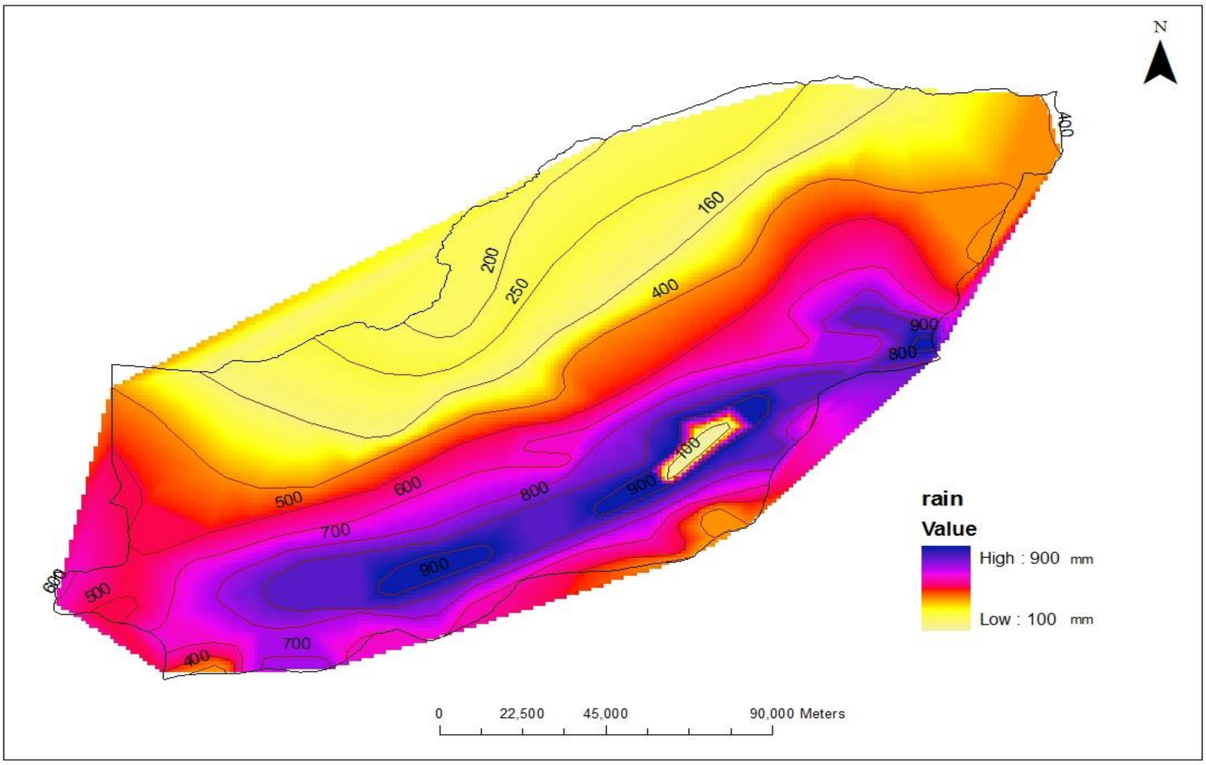

Figure 3. Annual average rainfall (mm/y)

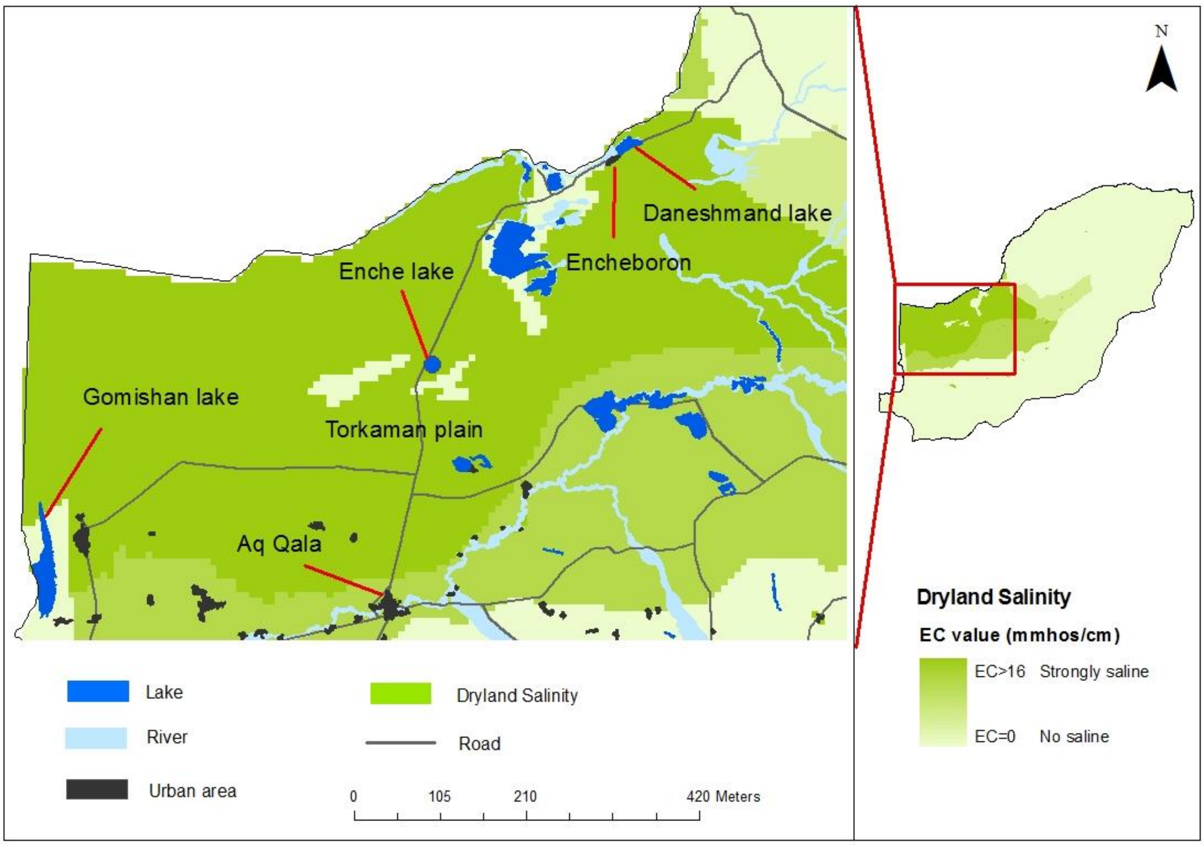

Figure 4. Soil salinity map of the study area

Table1: Level of acidity, electrical conductivity and concentration of sodium in soil of regions [23]

location	Na (mEq/L)	EC (mmhos/cm)	pH
Bank of Daneshmand lake	3203	22.6	7.94
Bank of Enche lake	4961	22	8.2
Bank of Gomishan lake	5809	70	7.55
Tangli	6105	72.8	7.14
Dashli boroon	3553	11.8	8.34

3- Characteristics of Salicornia plant

Salicornia bigelovii Torr is a halophyte species that belongs to the Chenopodiaceae family, which can be produced by seawater agriculture and they survive implantation in arid regions through irrigation with saline water. Areas with saline conditions such as saline semi-deserts, mangrove swamps, marshes and sloughs, and seashores are the most suitable areas for growing Salicornia [26]. This plant is a leafless, succulent, small-seeded, annual salt-marsh plant and can be used as food, forage and oilseed crops [27,28]. It is also a potential oilseed and a promising carbon sequestration plant; and its oil content is similar to sunflower oil in fatty acid composition (>70% linoleic acid, a desirable polyunsaturated oil for human consumption). The seed of *Salicornia bigelovii* contains 26 to 33% of oil, and 35% protein with a salt content of less than 3% [6, 7and 29]. *Salicornia bigelovii* may grow in soil with electrical conductivity and annual rainfall ranges from 12.2 to 22 mmhos/cm[30] and 80 - 300 mm/year [16], respectively. In the U.S. and Europe, this plant is grown for its oil which can be extracted from the seed and refined with conventional oilseed equipment; the taste and texture of this oil is similar to that of olive oil [6]. The plant could be cultivated as a bioenergy crop for producing liquid bio-fuels. The total dry biomass of plants and seed yields that have been produced by halophytes irrigated with hyper-saline seawater (40g/l) are in the range of 10 -20 tons/ ha and 2 tons/ha, respectively [6, 7]. Also, the biodiesel yield of each hectare of this plant (approximately 2.5 acres) is between 850 to 945 liters of BQ-9000 [31].

4- GIS integration model

In this study, all lands were considered and evaluated based on the suitability value for cropping Salicornia and it was used as part of the suitability analysis.

4.1. Evidence layers

According to the previous session some criteria and parameters for the cultivation of Salicornia plant should be considered in the GIS model, which are defined as constraints and factors.

4.1.1. Constraint layers

The built-up areas (settlement), water bodies, protected areas, roads and airports were considered as the constraints, and are shown in Figure 2. In order to protect these areas, buffer distances around them were generated and marked [32]. The constraints or discarding factors and their buffer distances are shown in Table 2 for the different factors.

Built-up areas (settlement)

Built-up areas consist of the village and urban land. Lands near residential and recreational areas should not be cultivated. Legislation prescribes that the cultivation of lands have to be at least 600m away from any village and urban areas (residential quarters) for possible future development [32]. A 600m wide buffer zone was created around the built-up locations.

Hydrographical network (water bodies)

The hydrographical network consist of rivers, lakes and fishery pools. Cultivation of lands should not be done on terrain subject to flooding. In order to comply with environmental regulations, a 500m wide buffer zone was created on hydrographical network features [32].

Protected areas

The protected areas consist of garden, forest and dry farms. There should not be any cultivation near protected areas. According to legislations, it is prohibited to cultivate in protected areas, thus [32], a 500 m wide buffer zone around protected areas was created and applied in the site selection process.

Roads and railways

To prevent and reduce road destruction, transportation problems and accidents, there should be at least a 100 m distance between cultivated farmlands and roads [32]. On both sides of roads and railways (road layer),100 m wide buffer areas were created.

Airports

Airports have particular security regulations and private cultivations should not be close to airports. In order to comply with regulations, a 500 m wide buffer zone was created around airports [32].

Table 2: Constraints considered in growing of biomass plant

Constraint	Safety distance (m)	Description	Reference
Built-up areas (settlement)	600	Residential areas require a surrounding safety area.	[32]
Water bodies	500	Nearness to rivers, lakes, Pools, reservoirs, etc. requires a safety area around the element.	[32]
Protected areas	500	National parks and protected areas need a protective ring.	[32]
Roads and railways	100	Roads require a surrounding safety area	[32]
Airports	500	These sites need a safety area to guarantee	[32]

4.1.2 Categorizing factors (Classifying layers)

The most effective parameters for cultivating Salicornia plant are the topography of the land, salinity of soil and the amount of rainfall, which are considered as factors. The most important categorizing factors and acceptable range for growth of Salicornia plant are shown in Table 3.

Soil quality (dry land salinity)

The rating of soil salinity based on electrical conductivity (EC) is an important factor for the cultivation of Salicornia. In this section, a map was generated showing soil salinity in the study area (Figure 4). Therefore moderately and strongly saline soil classes are more important in the classification of this factor. *Salicornia bigelovii* will grow well in areas where the soil electrical conductivity ranges between 12.2 - 22 mmhos/cm. Therefore, the most suitable sites for the cultivation of *S. bigelovii* are in a moderately saline phase where the electrical conductivity ranges from 8 - 16 mmhos/cm and in a strongly saline phase where electrical conductivity exceeds 16 mmhos/cm.

Land slope

The topography of the area is an important factor for cultivation and productivity. Terrains with steep slopes will need leveling and could create problems for cultivation. To avoid or reduce possible surface disturbances, the cultivation should be in terrain with "almost level" (<5% slope) to "very gently sloping" (6–15% slope). We generated a map showing the topographic slopes in the study area (See Figure1). As a selection criterion, it was decided that areas with slopes greater than 15% would not be appropriate and received higher value.

Rainfall

The other important factor that determines plant growth is rainfall rate. According to the previous section, *S. bigelovii* plant only grows in areas where the annual rainfall ranges are from 80 to 300 mm/year.

Table3: Factors considered in siting Salicornia plant cultivation

Factors	**Type**	**Acceptable range for growth**	**Original data layers**
Soil quality	Environmental	Moderately saline and strongly saline	Salinity of soil
Slope of land	Physiography	Slopes less than 15%	DEM
Rain downfall	Environmental	80mm/y < Range < 300mm/y	Rain

4.2. Suitability analysis and conceptual model

By superimposing the matic maps of specified criteria, we were able to select the "right" or "most appropriate" area on the basis of selection parameters. There are several layers of combination processes such as Boolean logic combination, algebraic combination, index overlay combination, fuzzy logic and vector fuzzy logic combinations. In this research, index overlay model was used for integration of the layers.

Index overlay method superimposed the data layers and integrated all the layers in a single raster layer and quantify the values of each pixel in order to define the best available place for Salicornia cultivation. In this method, each map has a different class, and a different score is given to each class of the map. The output score was calculated directly by applying Eq. (1) [33].

$$V = \frac{\sum W_j * A_j}{\sum A_j} \tag{1}$$

where W_j is the weight of the j^{th} map, and A_j is the score in the j^{th} map.

The workflow diagram describes the stepwise methodology for selecting the site for Salicornia cultivation as illustrated in Figure 5. In order to choose a suitable area, their main features were assigned to one of two datasets, constrain or classifying layers.

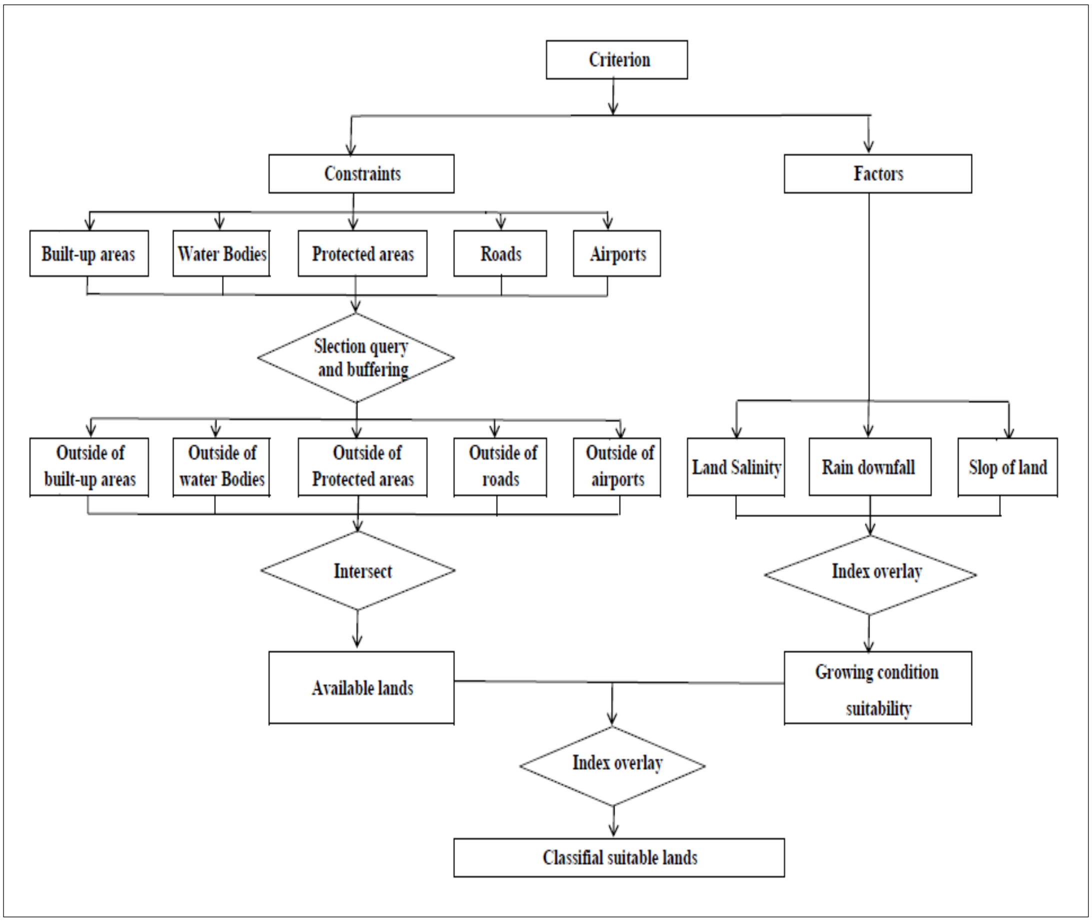

Figure 5. Site selection flowchart for Salicornia cultivation lands.

4.2.1 Constrain layers

Cultivation of Salicornia plant should not be done in prohibited areas, so allowable areas are defined in this study using effective parameters. In section 4.1.1, constrain layer and their buffer distances were described. After creating buffer (safety distances) around features (constraints) using GIS buffer algorithm, the outside areas from constraints layers were specified and these areas by means of the intersect tool in ArcMap were overlaid [33]. The remaining areas were defined as available lands, and are shown in Figure 6.

4.2.2 Classifying layers

Available lands, soil quality (dry land salinity), rainfall and land slope are layer dataset that were classified and weighed in this research, as shown in Table 4. Their classes were valued based on Salicornia plant growth conditions and cultivation requirements. The classification and weight of the parameters are shown in Table 4. Parameters were weighted with regard to their importance to study's goal.

Available lands are allowable area for cultivation of *S. bigelovii*, and were grouped into 3 classes including:

- areas with agriculturally poor land;
- Localities with good agricultural potential;
- Agricultural lands and wood lands.

Class 1 (area with poor agricultural land) is based on the described priority in the introduction, the class 1 type of land has greater priority over the other classes on site selection.

Soil quality (dry land and salinity level) is based on the dryness of the land and the salinity level of the soil is classified into 5 different classes [34]. The most suitable area found for cultivation of *S. bigelovii* are those where the electrical conductivity values are greater than 8 mmhos/cm. Hence, electrical conductivity (EC) with a value that is greater than 8 mmhos/cm has the highest productivity.

Table 4: Classification and evaluation of factors

Factors	Unit	Weight	Classes	Value
Slope of land	Degree	3	0-2	4
			2-5	4
			5-8	3
			8-12	2
			12-15	2
			15-20	1
			20-30	1
			30-65	1
			>65	1
Soil quality (Dry land Salinity)	**(**mmhos/cm)	5	0-2	1
			2-4	2
			4-8	3
			8-16	4
			>16	5
Available lands		1	area with poor agricultural potential	3
			Localities with good agricultural potential	2
			Agriculture lands and wood lands	1
Rainfall	mm/y	1	100-200	2
			200-300	3
			300-900	1

The slopes map is generated from the DEM data layer and were classified into 9 different classes based on the Makhdoom [35] land use classification method. The area with slope less than 15% would be appropriate for the cultivation of *S. bigelovii*. The area with slope less than 15% (<8°) were classified into three priority classes.

The annual rainfall of Golestan Province ranges from 100 to 900 mm/year. The classified rainfall map was developed in three classes and based on appropriate range of rainfall that support the cultivation of *S. bigelovii* plant, a range of 80 to 300 mm/year has the greatest productivity.

Then soil quality (dry land and salinity level), rainfall and land slope layers were overlaid based on the weight(s) assigned to each data layer. The weight(s) show the importance of the data layer in the site selection process. The resulting layer defines the condition suitable for growth. Finally, by overlaying the available land with suitable growing conditions, the classified suitable lands were obtained. The resulting map was categorized based on pixel value to three different suitability classes.

5. Results and discussion

In this section, the vegetation coverage of areas, which are suitable zones for planting Salicornia and production of biodiesel for each zone are presented. Figure 7 illustrates the vegetation coverage of cultivable areas for the entire Golestan Province. The area is about 50% of Golestan Province with 20165 km^2 in area; this vast area is located in the central and northern part of the province. From Figure 7, areas with agriculturally poor land are shown in red, they represent the most suitable areas for growing Salicornia. These lots have an area about 2615 km^2 (26% of allowable areas) and are located in the northern zone of the province (see Table 5). Also in Figure 7, the blue color shows lands with good agricultural potential, located in the northeast zone of the province with an area of about 3402 km^2 (34% of allowable areas). Cultivated marginal lands with greater extension (39% of allowable areas) are shown in green and are located in the central zone of the province; and the wood lands have an area of about 80 km^2 (1% of allowable areas) (see Table 5).

The result of superpositioning of the layers is a thematic map that shows the alternatives by means of suitability intervals for the cultivation of Salicornia plant, from the least to the most suitable case. Figure 8 shows the suitable areas. The most suitable, with the highest values, are indicated in red and the least suitable, with the lowest values, presented in yellow. Table 6 shows the result of superpositioning the layers, its value and category. The intermediate zones or second level with value of 25–35 occupies the largest category. The best area (colored red on the map) is located mostly in the north-west of Golestan close to the bank of Gomishan, Enche and Daneshmand lakes with area of about 2365 km^2 is highly suitable (35-45) for the cultivation of Salicornia plant.

Table 5: Vegetation coverage of allowable lands

Allowable areas	**Area (Km^2)**	**Share**
Area with poor agricultural potential	2615	26%
Localities with good agricultural potential	3402	34%
Agriculture lands	3967	39%
Wood lands	80	1%

The largest area of this zone consists of agriculturally poor land with EC (Electrical Conductivity) greater than 16 mmhos/cm. Level 25-35 (colored in orange on the map) is located mostly in the center and north-east of Golestan, close to the residential zones with an area of about 3990 km^2 and consists of an area with agriculturally poor lands, agriculturally fertile lands and agriculture lands with EC between 2 and 16 mmhos/cm.

The least suitable zone (colored yellow) in the south and east of the province has an area of about 3709 km^2. The majority of this area consists of localities with good agricultural potential and agriculture lands with EC between 2 and 4 mmhos/cm used for agricultural propose. According to section 3, the amount of BQ-9000 biodiesel produced per hectare of *S. bigelovii* cultivated is 850.5 liters. Thus, the amount of biodiesel produced from each zone (liter) is obtained by applying Eq. (2):

$$Q = A * C \quad (2)$$

Where Q is the biodiesel produced; A is the area under farming of each zone and C is the amount of produced BQ-9000 biodiesel which is 850.5 liters per hectare.

Thus total amount of biodiesel produced from suitable land for cultivation with an area of 10064 km^2 is 855942 liters from which 201143 liters was produced from the best land available with an area of 2365 km^2 (level 3), about 339350 liters of it belonged to zone 2 and 315450 liters of it belonged to zone 1 with an area of 3709 km^2 (see Table 6).

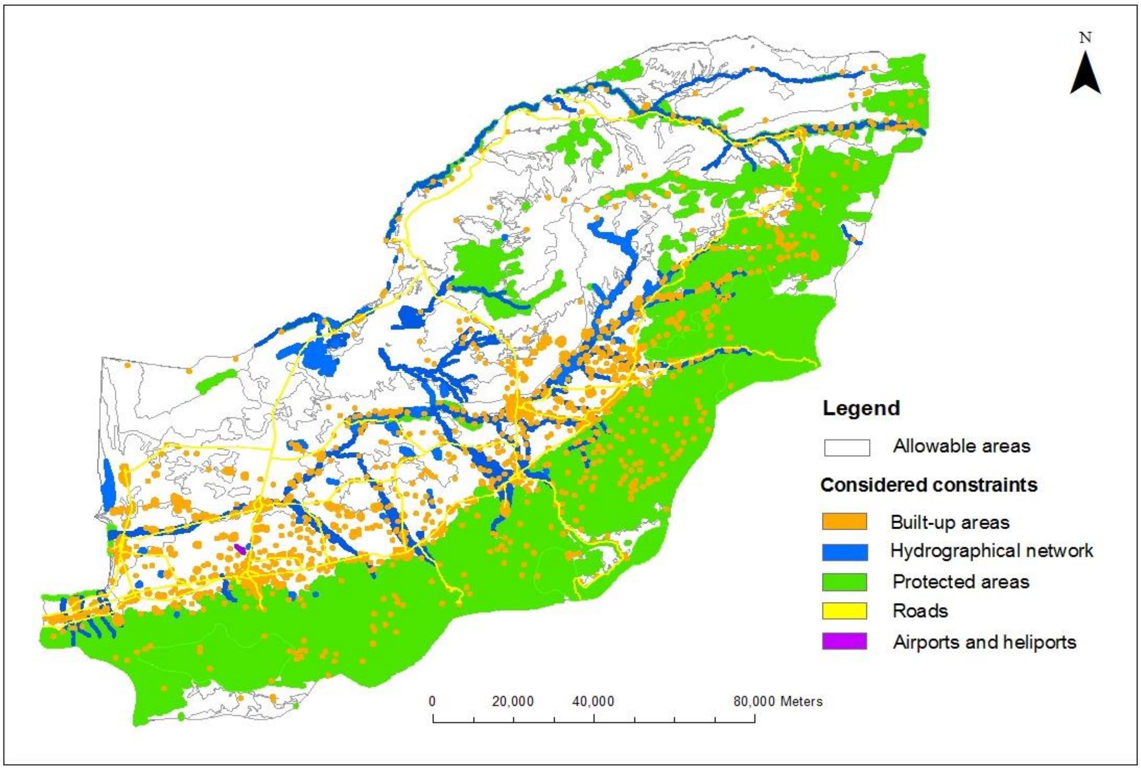

Figure 6. Suitable areas for growing Salicornia (constrains with buffer areas)

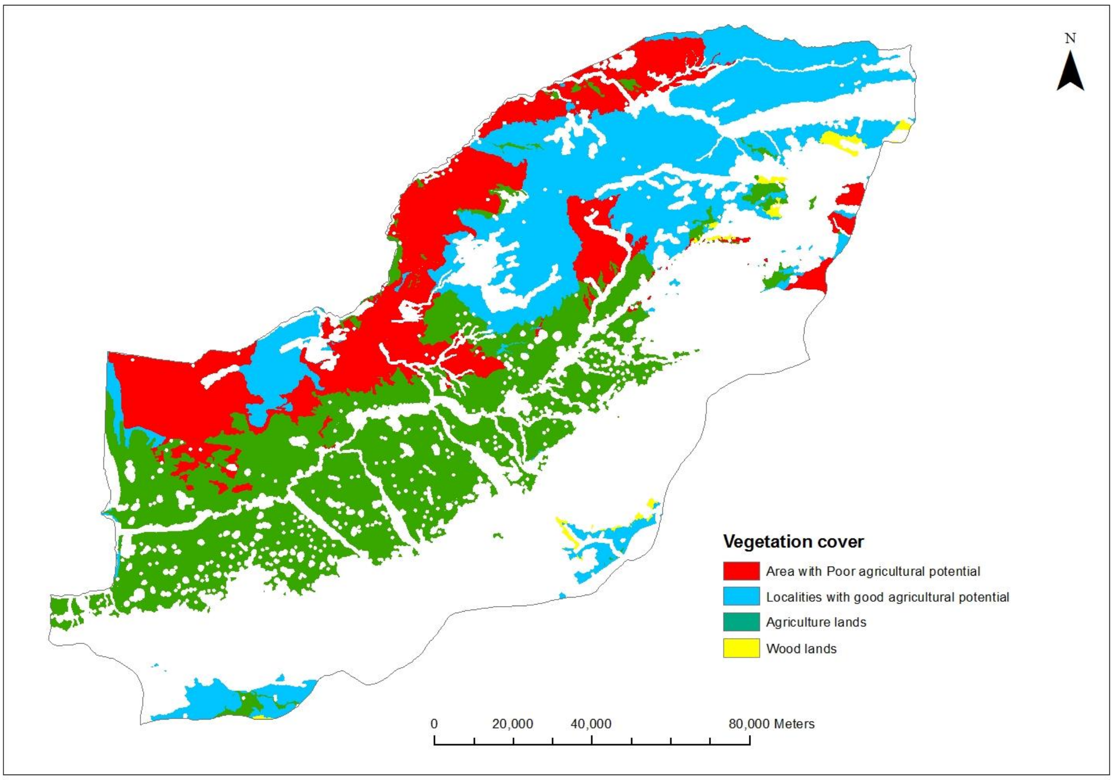

Figure 7. Vegetation coverage of allowable areas

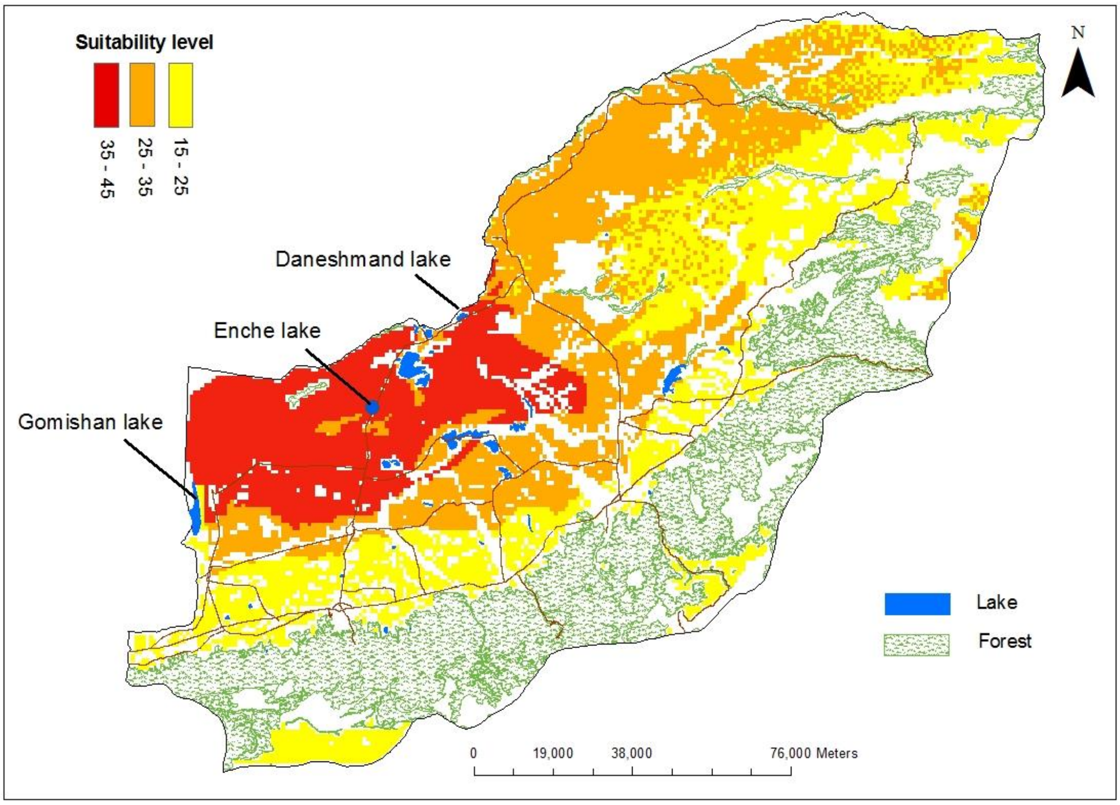

Figure 8. Salicornia plant cultivation suitability map in Golestan province

Table 6: Suitability zones for cropping Salicornia plant and produced biodiesel from each zone

Areas by suitability levels			
Suitability value and level	**Suitability Class**	**Area (Km^2)**	**produced biodiesel (1000 litter)**
(15 – 25) Level 1	Low	3709	315450
(25 – 35) Level 2	Moderate	3990	339350
(35 – 45) Level 3	High	2365	201143

6. Conclusion

Biodiesel has become an economically viable venture both on a subsistence level and on a vast commercial scale, allowing farmers, industries, and villages to attain energy independence. This research has provided a digital based Decision Support System (DSS) method, for the production of feedstock for biodiesel production from the cultivation of Salicornia plant, especially in agriculturally poor land. This will enhance the effectiveness of decision-making on the site selection process. The potential economic viability of biodiesel production from Salicornia plant in Golestan Province in the North-East of Iran was assessed, by identifying potential cultivation locations to explore future spatial distributions of biodiesel sites. The spatial distribution of environmentally viable biodiesel production was determined using a GIS-based sustainability management and site suitability model. The suitability model evaluated the regions in Golestan Province with high Salicornia productivity where potential biodiesel processing plants can be sited to improve economic sustainability of the community. For this aim, four different parameters were selected, according to the growth conditions of the plant. By superimposing these parameter layers, appropriate areas for cultivation of *S. bigelovii* on the basis of effective factors were defined. Index Overlay models were used in the suitability analyses for data analysis and integration. With regard to the results of overlaying layers and summing of the pixels values, 10064 km^2 of land is allowable for the cultivation of the plant from the total area land mass of Golestan Province (20165 km^2). The result showed that 2365 km^2 of the allowable lands are suitable (35-43) for the cultivation of Salicornia plant and these lands are located in the north-west of the province which have agriculturally poor land. The amount of biodiesel produced from the farming of this area is almost 23% (201143 liters) of the total amount of biodiesel produced from allowable areas for the cultivation of *S. bigelovii* (855942 liters).

References

[1] S. H. Yokoyama, Y. Matsumura, *The Asian biomass handbook*. The japan institute of *energy,2008.*

[2] S. Hull, *Wisconsin Sustainable Planting and Harvesting Guidelines for Nonforest Biomass*. Wisconsin Bioenergy Council , 2011.

[3] E. M. Nada, The Manufacture of Biodiesel from the used vegetable oil. Thesis submitted to the *Faculty of Engineering at Kassel and Cairo Universities*, 2001.

[4] Haas Center, *An Evaluation of Biodiesel Production Feasibility in Santa Rosa County*. Haas Center for Business Research and Economic Development, 2005.

[5] J. Crockett, C.L. Peterson, P. Mann, Feasibility Study for Commercial Production of Biodiesel in the Treasure Valley of Idaho. *Universityof Idaho,College of Biological & Agricultural Engineering*, 2006.

[6] R. M. Garcia, Physiological studies of the halophyte Salicornia bigelovii:A potential food and biofule crop for integrated aquaculture- agriculture systems.*The university of Arizona*, 2010.

[7] E. P. Glenn, J.J. Brown, Salt Tolerance and Crop Potential of Halophytes. *Critical Reviews in Plant Sciences*, 1999. 18(2): 227–255.

[8] A. Thomas, A. Bond, K. Hiscock, A GIS based assessment of bioenergy potential in England within existing energy systems. *Biomass and Bioenergy*, 2013; 55: 107–121.

[9] D. Voivontas, D. Assimacopoulos, E.G. Koukios. Aessessment of biomass potential for power production: a GIS based method. *Biomass and Bioenergy*, 2001; 20(2):101–112.

[10] E. Schreurs, T. Voets. T. Thewys, GIS-based assessment of the biomass potential from phytoremediation of contaminated agricultural land in the Campine region in Belgium. *Biomass and Bioenergy*, 2011; 35(10): 4469–4480.

[11] T. Voets, A. Neven, T. Thewys, T. Kuppens, GIS-based location optimization of a biomass conversion plant on contaminated willow in the Campine region (Belgium). *Biomass and Bioenergy*, 2013; 55: 339–349.

[12] M. A. Haddad, P.F. Anderson, A GIS methodology to identify potential corn stover collection locations. *Biomass and Bioenergy*, 2008; 32 (12):1097–1108.

[13] Y. Noorollahi., R. Itoi, H. Fujii, T. Toshiaki, GIS integration model for geothermal exploration and well siting. *Geothermics*, 2008; 37(2): 107-131.

[14] Y. Noorollahi, R. Itoi, H. Fujii, T. Toshiaki, GIS model for geothermal resource exploration in Akita and Iwate prefectures, Northern Japan. *Journal of Computer & Geosciences*, 2006; 33(8): 1008-1021.

[15] J. Höhn, E. Lehtonen, S. Rasi, J. Rintala, A Geographical Information System (GIS) based methodology for determination of potential biomasses and sites for biogas plants in southern Finland. *Applied Energy*, 2014; 113: 1–10.

[16] S. L. Falasca, A. Ulberich, A. Acevedo, Identification of Argentinian saline drylands suitable for growing Salicornia bigelovii for bioenergy. *International Journal of Hydrogen Energy*, 2014; 39 (16): 8682–8689.

[17] D. K. Sidiras, GIS based simulation of the biodiesel penetration in European Union markets: The case of Greece. Biomass and Bioenergy, *21st European Biomass Conference*, 2014, 65: 101–111.

[18] B. Niblick, J.D. Monnell, X. Zhao, A.E. Landis, Using geographic information systems to assess potential biofuel crop production on urban marginal lands. *Applied Energy*, 2013; 103 : 234–242.

[19] M. Hiloidhari, D. Baruah, H. Mahilary, D.C. Baruah, GIS based assessment of rice (Oryza sativa) straw biomass as an alternative fuel for tea (Camellia sinensis L.) drying in Sonitpur district of Assam, India. *Biomass and Bioenergy*, 2012, 44: 160–167.

[20] F. Zhang, D.M. Johnson, J.W. Sutherland, A GIS-based method for identifying the optimal location for a facility to convert forest biomass to biofuel. *Biomass and Bioenergy*, 2011; 35(9): 3951–3961.

[21] M. Beccali, P. Columba, V. D'Alberti, V. Franzitta, Assessment of bioenergy potential in Sicily: A GIS-based support methodology, *Biomass and Bioenergy*, 2009; 33(1) : 79–87.

[22] M. Arab Khedri, D. Nik Kami, E. Farahani, Investigating the application of Salicornia species in forage and oil production. *International Information System for the Agricultural science and technology*, 2008.

[23] E. Kohan Baghikhtarani, A. Abdolzadeh, M.B. Bagherieh, Feasibility study of the biodiesel production from salt tolerance of province Golestan. The first stable development of National Congress, Green Fuel, Esfahan, 2013.

[24] H. Sharifan, S. Alaghmand, Zoning of the 10-Days, Monthly and Annual Rainfall Using GIS: A Case Study on Golestan Province. *Iran Published in: Map Asia*, 2007.

[25] http://www.gsrw.ir. Available on 20/2/2014.

[26] A. J. Davy, G.F. Bishop, C.S.B. Costa, Salicornia L.**(** Salicornia pusilla J. Woods, S. ramosissima J. Woods, S. europaea L., S. obscura P.W. Ball & Tutin, S. nitens P.W. Ball & Tutin, S. fragilis P.W. Ball & Tutin and S. dolichostachya Moss). *Journal of Ecology*, 2001; 89: 681–707.

[27] E. P. Glenn and et.al., Three halophytes for saline-water agriculture: An oilseed, a forage and a grain crop. *Environmental and Experimental Botany*, 2013; 92: 110–121.