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Performance assessment of newly developed seaweed enhancing index

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Abstract: Seaweeds are regarded as one of the valuable coastal resources because of their usage in human food, cosmetics, and other industrial items. They also play a significant role in providing nourishment, shelter, and breeding grounds for fish and many other sea species. This study introduces a newly developed seaweed enhancing index (SEI) using spectral bands of near-infrared (NIR) and shortwave infrared (SWIR) of Landsat 8 satellite data. The seaweed patches in the coastal waters of Karachi, Pakistan were mapped using SEI, and its performance was compared with other commonly used indices - Normalized Difference Vegetation Index (NDVI) and Floating Algae Index (FAI). The accuracy of the mapping results obtained from SEI, NDVI, and FAI was checked with field verified seaweed locations. The purpose of the field surveys was to validate the results of this study and to evaluate the performance of SEI with NDVI and FAI. The performance of SEI was found better than NDVI and FAI in enhancing submerged patches of the seaweed pixels what other indices failed to do.

Keywords: Floating Algae Index (FAI); Normalized Difference Vegetation Index (NDVI); Remote Sensing; Seaweed Enhancing Index (SEI); Seaweed.

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1. **Introduction**

Benthic maps are significant for management, research, and planning of marine resources. The in-situ sampling is a traditional technique to map benthic habitats, but there exist limitations as more time, and financial resources are required to cover larger spatial areas. Satellite remote sensing is a practical solution for the mapping of the marine environment. Satellite remote sensing is very useful for providing timely and updated information for monitoring high spatial and temporal variations of coastal resources including seaweed stocks [1]. For thematic mapping, habitats are defined as spatially distinct areas where the physical, chemical, and biological characteristics are distinctively different from nearby regions [2]. Seventy different classes and twenty-seven different categories of seaweed are reported from the coastal areas of Pakistan [3]. Ulva fasiata, Chondria tennussima, Sargassum spp, and Valoniopsis pachynema are the most richly found species of seaweeds in this region.

Mapping seaweed resources using conventional methods are capital intensive and time-consuming. Remote sensing (RS) is a useful tool for observing benthic habitats such as submerged aquatic vegetation (SAV), benthic algae, and coral-reef ecosystems. Numerous researchers have tested airborne and spaceborne sensor systems for marine studies [4]. Therefore, the present study was undertaken with the

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following objective: To map seaweed resources along Karachi coast using Remote sensing (RS) and geographical information system (GIS) techniques.

2. Material and methods

2.1. Study area and satellite data

Seaweed resources in Pakistan are still unmapped. The need to preserve and map seaweed sites in the country can be appreciated by realizing the importance of these precious coastal resources. The study sites for the present work are located offshore Hawks bay beach along Sindh coast (Figure 1). These sites were selected through preliminary surveys. The surveys were conducted during February 2014. Several GPS points were recorded on seaweed patches and overlaid on the satellite imagery of the same month (February 26, 2014) and location (Figure 1).

Many researchers have used MODIS, MERIS, and Landsat data to study floating algae and seaweed indices [5], [6], [7] and [8]. MERIS 30m data is available only for few regions of the world. MODIS has a coarser spatial resolution to monitor floating algae seaweed. In MODIS 250m data, not every pixel is algae, so there can be mixed pixels having algae with water [8].

In this study satellite sensors, LANDSAT 8 were used to develop different indices to extract the seaweed area. Besides newly developed SEI, two commonly used bands combinations —Floating Algae Index (FAI) and Normalized Difference Vegetation Index (NDVI, were used to map seaweed patches at study sites. To test the applicability of SEI at other seaweed locations, Landsat 8 imagery of the Central California coast, dated December 12, 2013, was acquired from the Earth Explorer website (http://earthexplorer.usgs.org).

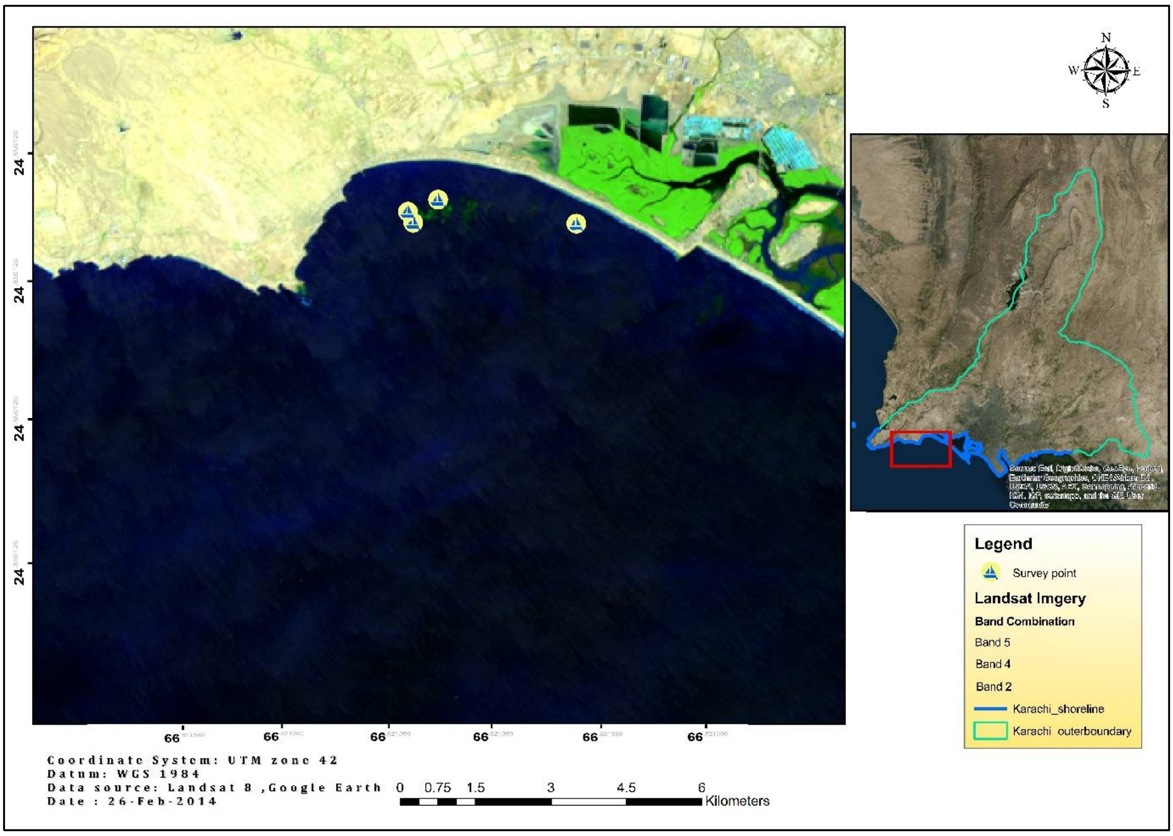

Figure 1. Study Area: Hawks Bay Beach along the Sindh Coast with GPS Points on Seaweed Patches

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2.2. *Methodology*

Figure 2 illustrates the workflow of the study. The subsequent sections also present a detailed description of each step.

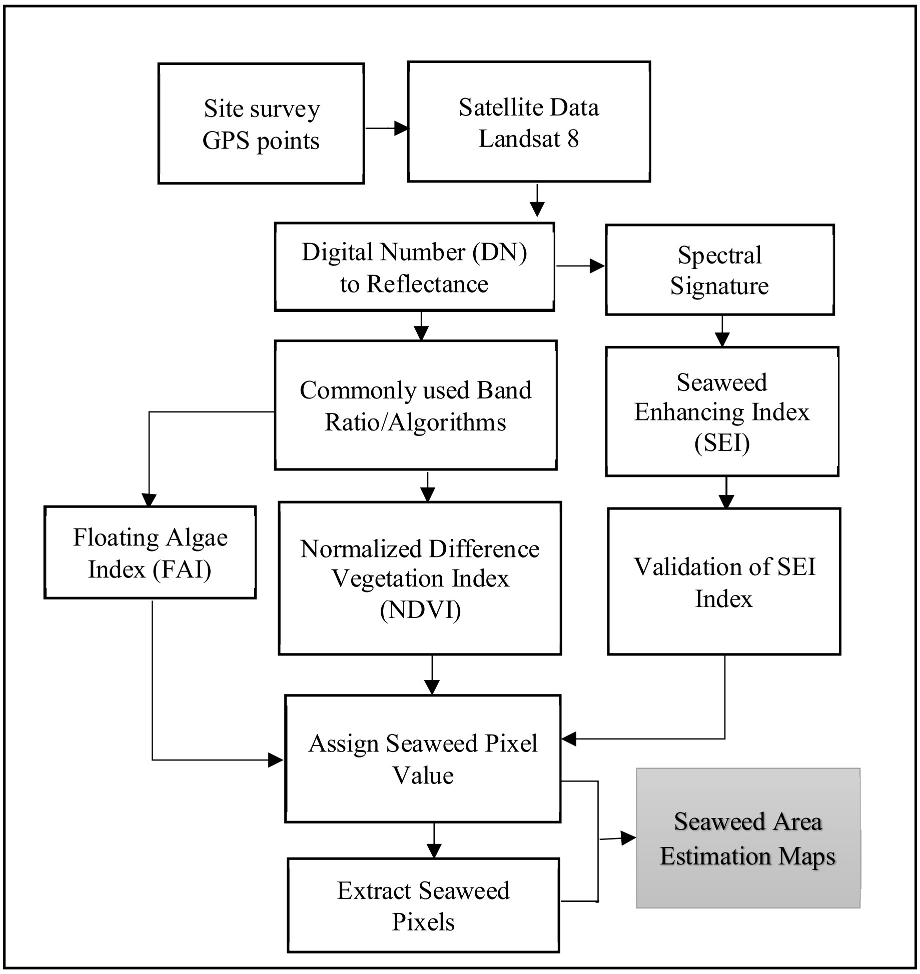

Figure 2. Workflow Diagram

2.2.1. Pre-processing of data

Layer stack of all Landsat 8 bands, except coastal/aerosol and thermal band is done followed by extraction of the region under study. Digital numbers (DN) represents the pixel values of satellite images that need to be converted into reflectance values. For this purpose, first, radiance ($L\lambda$) was calculated using DN (Equation 1). Next, the radiance image was converted into a reflectance image (Equation 2).

$$L\lambda = \frac{LMAX - LMIN}{255} * DN + LMIN \qquad (1)$$

$$\rho\lambda = \pi * L\lambda * \frac{d^2}{ESUN\lambda} * COS\theta s \qquad (2)$$

Where:

$L\lambda$ = Spectral radiance (at-satellite radiance)

LMax = Spectral radiance which scaled to QCALMAX in watts/ (meter squared * ster * µm)
LMin = Spectral radiance which scaled to QCALMIN in watts/ (meter squared * ster * µm)
DN = Digital number
Pλ = Unit less Top of the Atmosphere (TOA) reflectance
D = Earth-Sun distance
Esun λ = Mean solar exoatmospheric irradiances
θs = Solar zenith angle

2.2.2. Band ratios and algorithms

The vegetation spectral indices are used to compare data obtained under changing brightness conditions. However, the traditional vegetation indices may not be very useful to study plants that grow submerged or underwater [5].

Normalized Difference Vegetation Index (NDVI) is a modest quantitative approach to measure the extent of vegetation biomass. NDVI has been frequently used to analyze quantitative estimates of vegetation extent. NDVI is based on Red (R) and Near Infrared (NIR) bands of electromagnetic spectrum. NDVI is defined by Equation 3 [9].

$$NDVI = (NIR - RED)/(NIR + RED) \quad (3)$$

Various studies have used Floating Algae Index (FAI) for mapping floating algae in many aquatic environments. FAI was found capable of discriminating between algae and water pixels, therefore, to map floating algae in oceans, FAI is considered to be an improved index than NDVI and Enhanced Vegetative Index (EVI) [8]. In some papers, FAI has also been used for detecting green tides along coasts. FAI is calculated by Equation 4 [10].

$$FAI = Rrc\,NIR - Rrc\,NIR' \quad (4)$$

Where:

RrcNIR = Baseline reflectance of NIR band
RrcNIR' can be calculated using Equation 4.

$$Rrc\,NIR' = Rrc\,(Red) + (Rrc\,(SWIR) - Rrc\,(Red)) * (\lambda NIR - \lambda Red)/\,(\lambda SWIR - \lambda Red) \quad (5)$$

Where:

Rrc(Red) = Baseline reflectance of Red Band
Rrc (SWIR) = Baseline reflectance of Shortwave Infrared (SWIR) band
λNIR = Wavelength of NIR Band
λRed = Wavelength of Red Band

2.2.3. Spectral signature and development of a new Seaweed Enhancing Index (SEI)

Scientists describe that the variations of spectral signatures in reflected and absorbed electromagnetic radiation at different wavelengths help to identify specific objects, such that the extent of reflectance and absorption depend on the wavelength of electromagnetic radiation for any specified object [11]. Each substrate has a different spectral signature that can be helpful to differentiate it from others and this technique is applicable also in the benthic environment [12]. Spectral characteristics of mangroves, water, and seaweed sites in Landsat 8 image were examined and their spectral signatures were mapped (Figure 3). The spectral signatures show meaningful peaks in NIR and SWIR bands (Bands 5 and 6 of Landsat 8 image) at seaweed locations differentiating water and seaweed pixels. For seaweed pixels, the high peak was observed in NIR band (Band5), whereas, the lowest peak was in the SWIR (Band6) region of the electromagnetic spectrum. Similar to the algorithms used in all other normalized difference indices, these two bands are used to develop a new index for seaweed as presented in Equation 6. It is important to note that a similar trend exists for mangrove as well, and therefore, it is necessary to either mask/remove mangrove area from the study area to avoid misinterpretation of mangrove pixels as seaweed or carefully examine the range of SEI to differentiate between the two substrate categories.

$$Seaweed\ Enhancing\ Index\ (SEI) = \ (NIR - SWIR)/(NIR + SWIR) \quad (6)$$

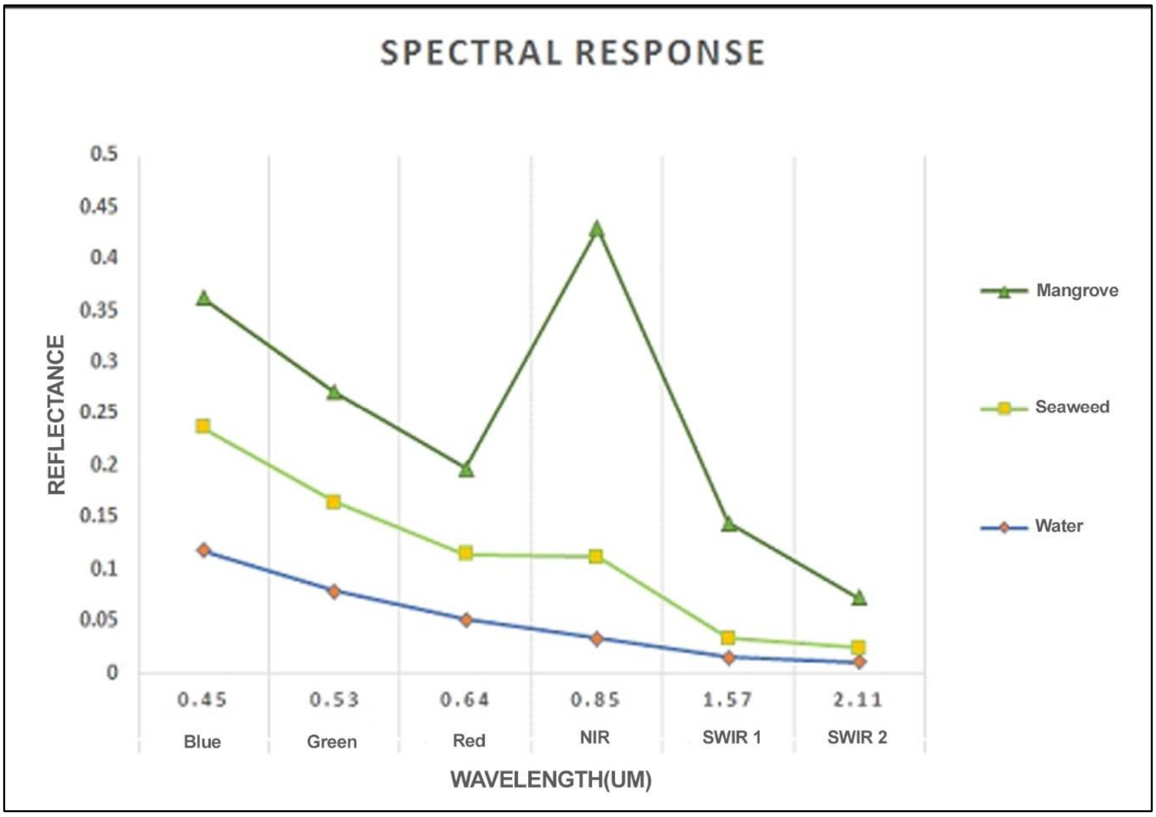

Figure 3. Spectral Response of Seaweed, Mangrove, and Water

2.2.4. Reclassification

Raster images of NDVI, FAI, and SEI were converted into vector data using GIS software. The seaweed class was extracted from each raster. The groups classified as seaweed in all images are used to estimate seaweed area in square kilometer along the Karachi coast.

2.2.5. Validation of Seaweed Enhancing Index (SEI)

The seaweed sites were identified through field surveys and recorded as GPS points. The overlay of GPS points on satellite imagery helped to capture the spectral signature of seaweed and develop SEI index. To test the applicability of the new index, SEI is used on another site with confirmed seaweed patches. Santa Barbara coast, Central California (Figure 9) was chosen for this purpose. NASA earth observatory article verified seaweed locations with field pictures along Central California coast [13, 14]. SEI successfully mapped seaweed along the Santa Barbara coast (Figure 10).

3. Results and discussions

FAI is a good indicator for enhancing phytoplankton bloom and seaweed resources, and it separated algae and water pixel. FAI water pixel values ranged from -0.46 to 0.49 as shown in (Figure 4), whereas, the pixel values for the seaweed area range between 0.09 and 0.01. Maximum and Minimum values of water pixels were 0.01 and -0.46, respectively. The mangrove class range was 0.09 to 0.39 as shown in (Table 1).

Normalized difference vegetation index has been applied to the same image. NDVI values range from -1 to +1 as shown in (Figure 5). The maximum value of seaweed pixel was 0.16, and the minimum value was 0.11. Maximum and minimum water pixel values were 0.011 and -0.1 and mangrove class range was 0.16 to 0.37, respectively, as shown in Table 2.

Figure 4. Floating Algae Index (FAI) from -0.46 to 0.49 (The circle highlights the Seaweed Patches)

Table 1. FAI Range for Seaweed, Mangrove Vegetation, and Water

Class	Pixel value range
Water	-0.46 to 0.01
Seaweed	0.01 to 0.09
Mangrove	0.09 to 0.39

During analysis, it was noticed that both indices, FAI and NDVI, could not capture submerged seaweeds very well. Hu [10] has applied NDVI on MODIS 250m to analyze massive bloom of the floating algae such as Epiactis prolifera in the Yellow Sea [8]. Furthermore, he stated that this method was useful to map floating algae but ranges of NDVI of the algae are sensitive to the environment, and these conditions create complications in visual interpretation analysis. Besides NDVI and FAI, a need for a better index was felt that can also identify submerged seaweed patches.

Figure 5. NDVI ranging from -1 to 1 (A circle is drawn around the Seaweed Patches)

Table 2. NDVI Range for Seaweed, Mangrove Vegetation, and Water

Class	Pixel value range
Water	-0.1 to 0.011
Seaweed	0.11 to 0.16
Mangrove	0.16 to 0.37

Spectral features of each substrate category can be used to differentiate one from other including marine benthic environment [11]. During analysis, it has been noticed that the reflectance values of band 5 (NIR) and band 6 (SWIR) of Landsat 8 show the good response for the seaweed areas as shown in the graph of spectral reflectance signatures (Figure. 3). Based on these two bands a new index was developed for extracting seaweed patches. The newly developed seaweed enhancing index (SEI), showed enhanced larger areas of seaweed resources as compared to NDVI and FAI as shown in (Figure 6). SEI for seaweed pixels has a value range from 0.011 to 0.16. Maximum and minimum values of the water pixels range from 0.011 to -1, whereas, the mangrove pixel values range from 0.16 to 0.374 as presented in Table 3. This newly developed index was found better than FAI and NDVI by extracting submerged patches in addition to surface floating seaweeds.

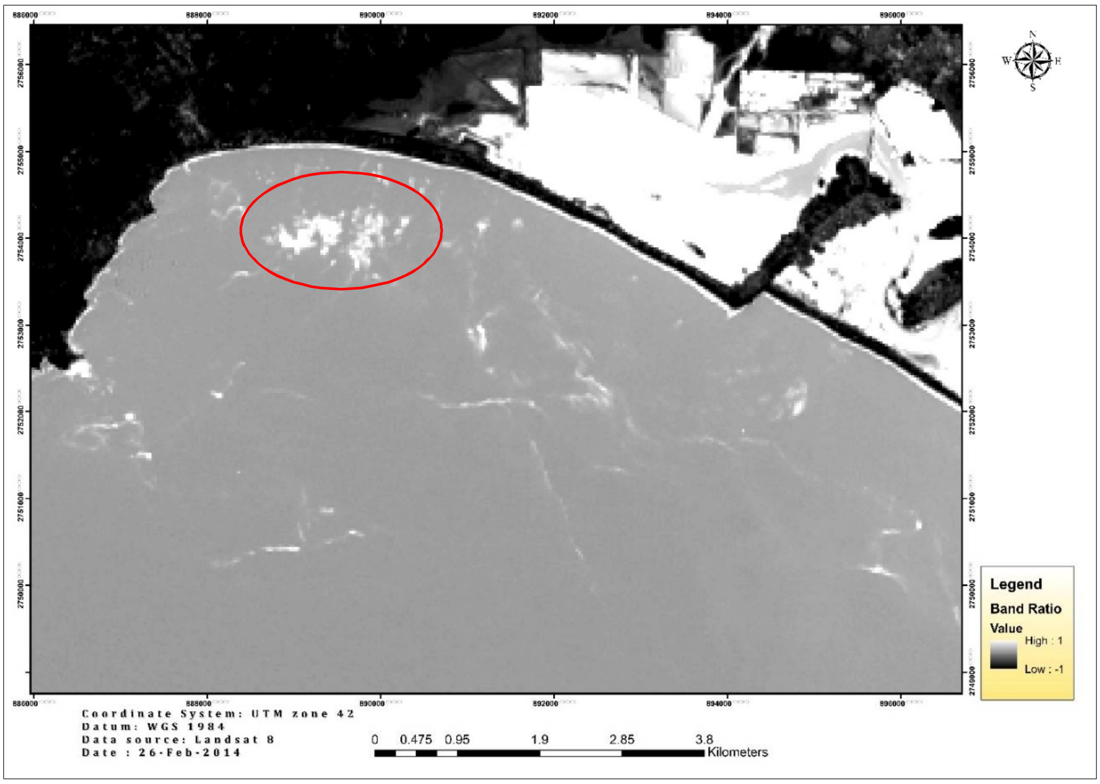

Figure 6. SEI with Values Ranging from -1 to 1 (A Circle is drawn to highlight Seaweed Patches)

Table 3: SEI Range for Seaweed, Mangrove Vegetation, and Water

Class	**Pixel value range**
Water	-1 to 0.011
Seaweed	0.011 to 0.16
Mangrove	0.16 to 0.374

Finally, GIS tools were applied to FAI, NDVI, and SEI images to classify seaweed area into low, medium, and, dense seaweed classes (Figure. 7). Area of each seaweed class was estimated. In Figure 7, red color shows low, blue shows medium and green indicates dense seaweed areas.

In FAI image, low, medium, and high seaweed areas are 0.4473 km^2, 0.1728 km^2, and 0.045 km^2, respectively. In NDVI image, low, medium, and high seaweed areas were found to be 0.4545 km^2, 0.198 km^2, and 0.0603 km^2, respectively. In SEI image, the coverage of low, medium, and high seaweed area is 1.0962 km^2, 0.392 km^2, and 0.1296 km^2, respectively. Figure 8 shows a graphical representation of area estimation.

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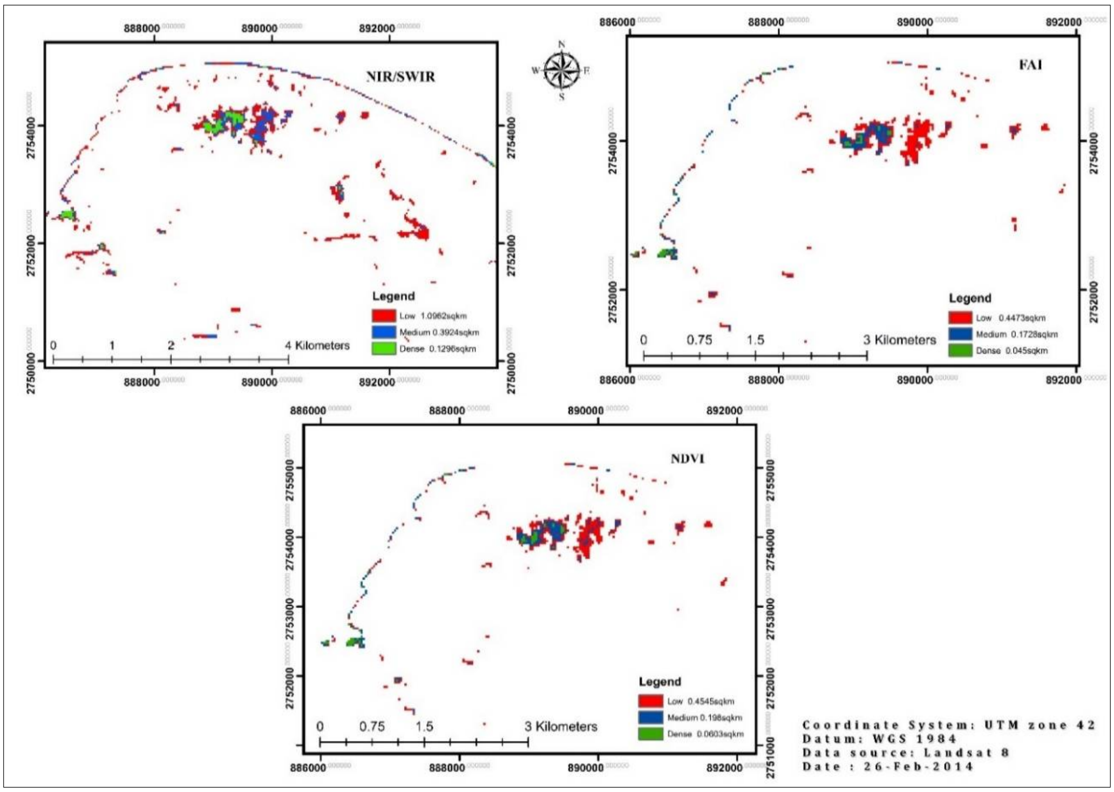

Figure 7: Area Estimation of Seaweed

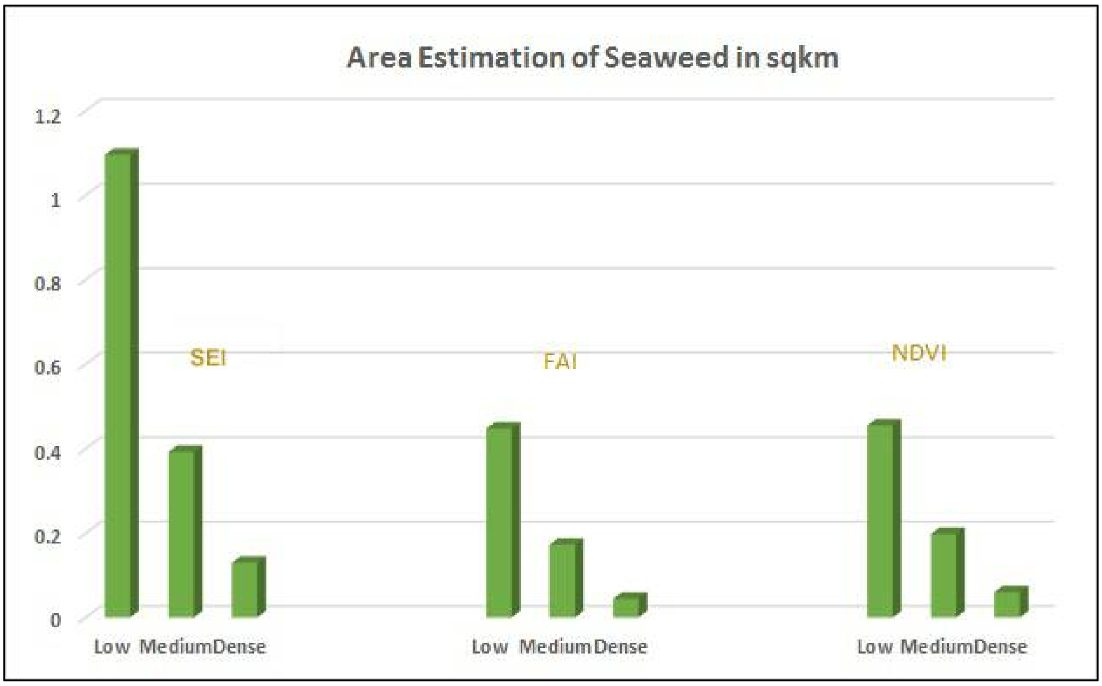

Figure 8: Graph of Area Estimation of Seaweed

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For validation of the SEI index, the same technique was applied on the California coast, the USA with confirmed seaweed locations (Figure 9). Landsat 8 data, dated December 14, 2013, of the site, were acquired for this purpose. The spectral signature of mangrove, seaweed, and water class were taken as shown in (Figure 10).

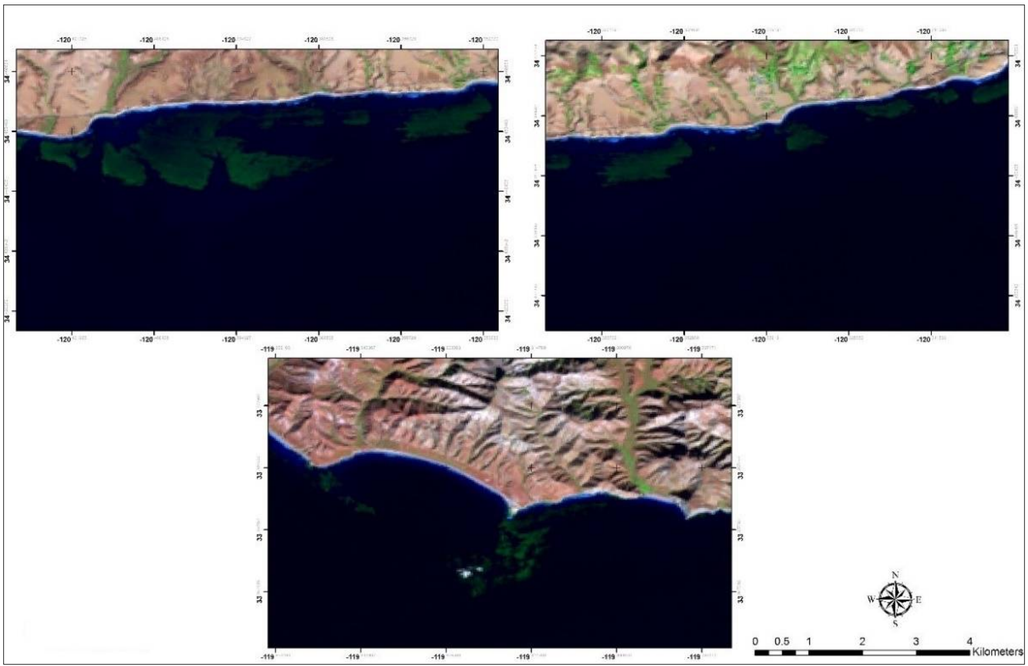

Figure 9: Seaweed Patches along the California Coast, USA

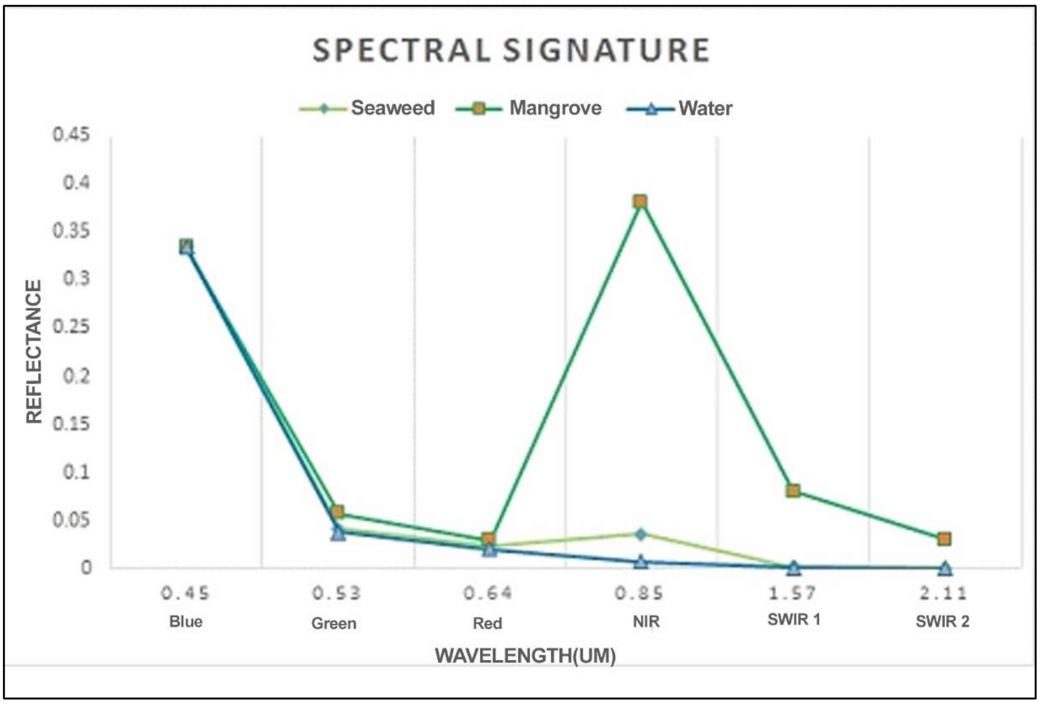

Figure 9: Spectral Signatures of Seaweed, Mangrove Vegetation, and Water

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The spectral signatures of seaweed along Karachi and California coasts were found to be quite similar and show same reflectance peak at band 5 (NIR) and band 6 (SWIR). SEI was applied at California coast image that enhanced seaweed patches along Santa Barbara areas, Central California. This evidence supported the applicability of the newly proposed SEI (Figure 10).

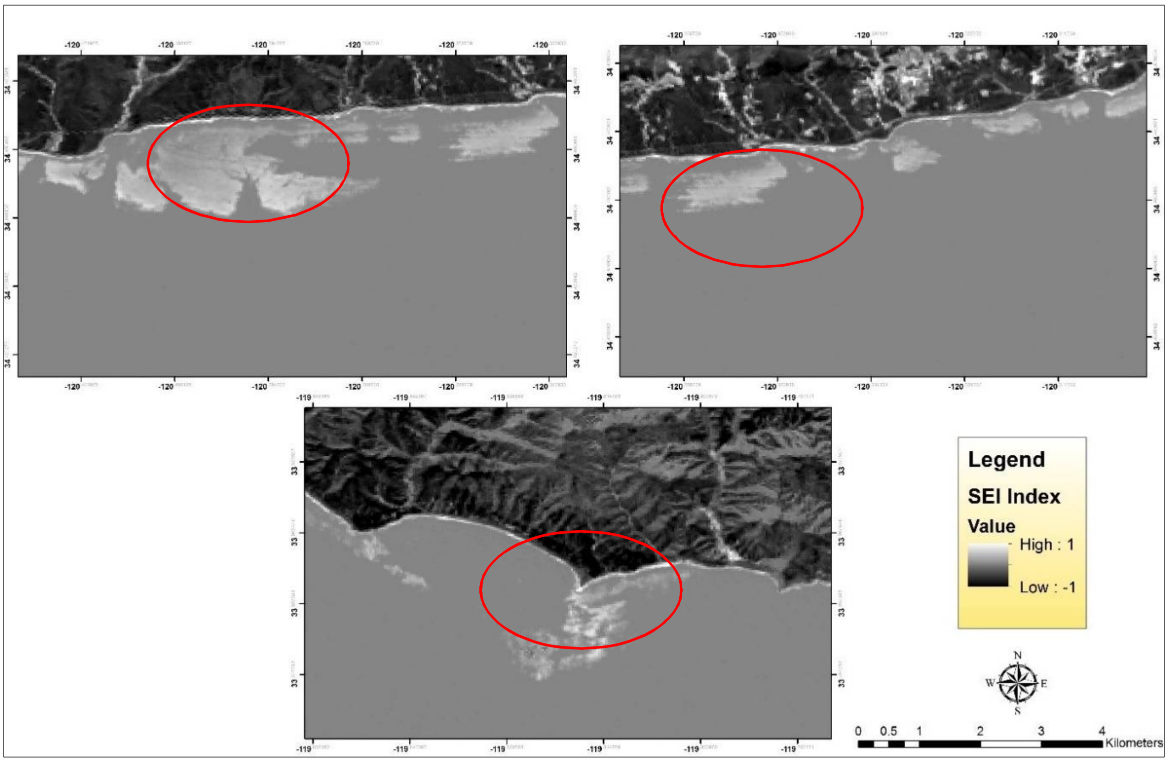

Figure 10: Circles Showing Enhanced Seaweed Patches along the California Coast, USA

4. Conclusions

In this study, three indices were applied; FAI, NDVI, and newly developed Seaweed Enhancing Index (SEI). Analyzing satellite mapped data and environmental factors that influence seaweed growth, the following trends are observed;

- The Short Wave Infrared (SWIR) band of Landsat 8 is quite good for Phytoplankton, green tide, and floating algae mapping studies.
- SEI, based on NIR and SWIR, bands enhanced seaweed, especially submerged patches along Karachi coast more effectively than NDVI and FAI.
- FAI and NDVI could enhance only the surface patches of seaweed, but SEI also mapped the submerged seaweed pixels. Therefore, SEI can be considered a better index for seaweed mapping as compared to other indices.
- SEI was applied on the California coast that gave a satisfactory result which supports our proposed index.

Seaweed assessments are not only important for fisherman community but also for policymakers, food and cosmetics industries who are the primary stakeholders for ensuring food and other economic security issues of the country. These studies, if prepared attentively, can be beneficial to support Pakistan coastal resources. In this study, it has become possible to identify seaweed location using remote sensing techniques. This methodology will help in future seaweed resources studies, which will be beneficial in introducing seaweed market in the country.

Author Contributions: 1.2; perceived the idea and developed the concept. 1.2.3; collected field data and executed the computations. All authors discussed the outcomes and contributed to the final manuscript.

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