2018

Solar Irradiance Measuring sites in Bangladesh

Conducting a National Photo Voltaic Resource Assessment Study/ Research and Training in Bangladesh for SrepGen Projects of UNDP Bangladesh.

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Content

Acronyms:

GoB	Government of Bangladesh
RE	Renewable Energy
SREDA	Sustainable and Renewable Energy Development Authority
PV	Photo Voltaic
GHI	Global Horizontal Irradiance
GHG	Green House Gas
RBIS	River Basin Information System
CSV	Comma Separate Value
SEVIRI	Spinning Enhanced Visible and Infrared Imager
ITT	Institute for Technology and Resources Management in the Tropics and Subtropics
ITTrms	ITT-resources management studies e.V.
UNDP	United Nations Development Programme
GEF	Global Environment Facility
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
PVGIS	Photovoltaic Geographical Information System
SARAH	Surface Solar Radiation Data Set - Heliosat
MVIRI	Meteosat Visible Infra-Red Imager
SEVIRI	Spinning Enhanced Visible and InfraRed Imager
METEOSAT	Meteorological Satellite
CH	Calinski-Harabasz Index
WSS	Within-Cluster Sum of Squares Index
RMSE	Root Mean Square Error
GHI	Global Radiation on a Horizontal Surface
DHI	Diffuse Radiation on a Horizontal Surface

1. Introduction

1.1 Background

Power Division, Ministry of Power Energy and Mineral Resources, Government of Bangladesh (GoB) is implementing GEF-Funded Project "Development of Sustainable Renewable Energy Power generation (SREPGen)". The objective of the Project is to reduce the annual growth rate of Green House Gas (GHG) emissions from the fossil fuel-based power generation by exploiting Bangladesh's renewable energy resources for electricity generation. In this project UNDP is working with GoB as an implementing partners to foster energy access for poor people. The basic approach of the Project will be to promote renewable energy in Bangladesh through the recently established Sustainable and Renewable Energy Development Authority (SREDA).

Through this project ITTrms will install 10 Nos. solar irradiance monitoring station across Bangladesh. However, before installing the monitoring stations, a pre-feasibility assessment is required to identify the potential locations of the monitoring sites. Methods applied on efficient planning of ground-based monitoring networks of surface solar irradiance could provide valuable scientific results and be useful for accurate monitoring and efficient planning of solar energy applications. The need of efficient planning of a ground-based network for accurate monitoring of an observed variable has been addressed in recent years.

Bangladesh is located in the South Asian subtropics and tropics, almost completely surrounded by India, neighbouring also only to Myanmar in the West and the Bay of Bengal in the South. It ranges from 20°42'11.2" to 26°37'57.3" North and 88°00'32.2" to 92°40'44.1" East. Due to its location, the solar angle ranges from 40 to 90 degrees. As shown in figure 1, the average solar irradiance in Bangladesh ranges from 215 W/m² in the north-west to 235 W/m² in the south-west per day. Nevertheless, the country is strongly affected by the southwest-monsoon from May to October, resulting in different climatic conditions and cloudiness in the regions. Due to the climatic conditions and different degrees of cloud cover during the year, it makes sense to implement photovoltaic measuring sites. This allows the solar irradiance to be measured on site and available satellite products can be validated and improved.

1.2 Objectives

This study has two main objectives: 1) to quantify the number of stations that would be needed in order to provide a climatology of surface solar irradiance for the photovoltaic assessment in Bangladesh. Due to different geographical features a great number of stations is required to capture the high temporal and spatial variability of solar surface irradiance. 2) to identify the potential locations for installing the solar irradiance station.

This study takes the advantage of the new release of solar irradiance and cloud albedo derived from geostationary Meteosat imagery (2005 - 2015) within the EUMETSAT Satellite Application Facility on Climate Monitoring; a clustering method is then applied in order to reveal the number of needed ground-based stations and their spatial representativeness for sufficient monitoring of surface solar irradiance in Bangladesh.

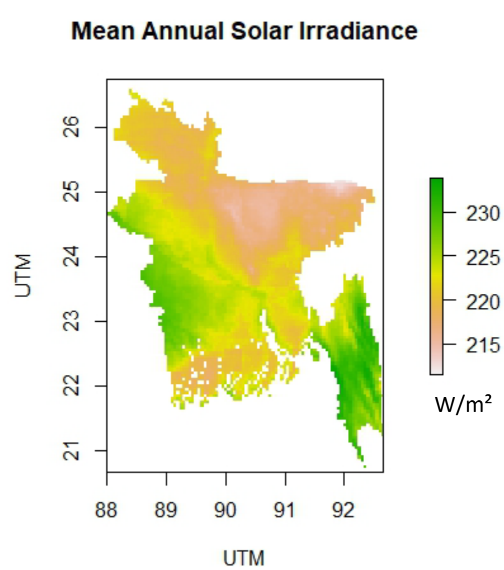

Figure 1 Mean Annual Solar Irradiance for Bangladesh | Data: PVGIS © European Communities, 2001-2017

2. Data

The Surface Solar Radiation Database - SARAH, provided by the Photovoltaic Geographical Information System (PVGIS) of the Joint Research Centre of the European Commission, was used to determine the photovoltaic measurement sites. The PVGIS provides free and publicly accessible solar radiation data for Europe and Africa, as well as large parts of America and Asia and can be accessed via this link (http://re.jrc.ec.europa.eu/pvgis.html).

The PVGIS-SARAH data provides global irradiance data for a horizontal surface, for an optimal inclined surface and for a two-axis sun-tracking surface, both monthly and annual averaged. For the analysis, the monthly solar irradiance data on an optimally inclined surface was used, as the measuring stations are also optimally aligned.

The data is derived by the visible channels of the MVIRI and SEVIRI instruments on board the METEOSAT geostationary satellites using the MAGIGSOL method, which combines the Heliosat method for cloud albedo with the SPECMAGIC clear-sky model. In this regard, it considers the effective cloud albedo n:

$$n = \frac{p - p_{srf}}{p_{max} - p_{srf}}$$

Here, p is the observed reflectance for each pixel and time, p_{srf} is the clear-sky reflection and p_{max} is an estimation about the highest reflectance observed by the satellite.

Furthermore, the clear-sky surface irradiance, considering diffuse and direct fraction, is calculated using both spatial and temporal information as well as atmospheric information about aerosols, water vapour and ozone.

Combined, the average solar surface radiation, e.g. surface irradiance is calculated, taking into account both day and night time. The data set is calculated over the period 2005 to 2015, with a grid cell size of 0.05° measured in W/m². The accuracy for the monthly data, determined against surface reference measurements, is 5.5 W/m².

3. Methodology

In order to find suitable locations for solar irradiance measurement sites in Bangladesh, regions with similar irradiance patterns during the year have to be evaluated. Patterns within these regions are more similar to each other than compared to patterns of neighbouring regions. In this regard, a measurement site within a region can give in-situ data representable for its region. Combined, the measurement sites can then give in-situ solar irradiance data representable for whole Bangladesh.

Cluster analysis is used to group data sets according to similar patterns of various criteria. The twelve raster images were stacked and a vector for each pixel was calculated, representing the irradiance pattern over time (Figure 2).

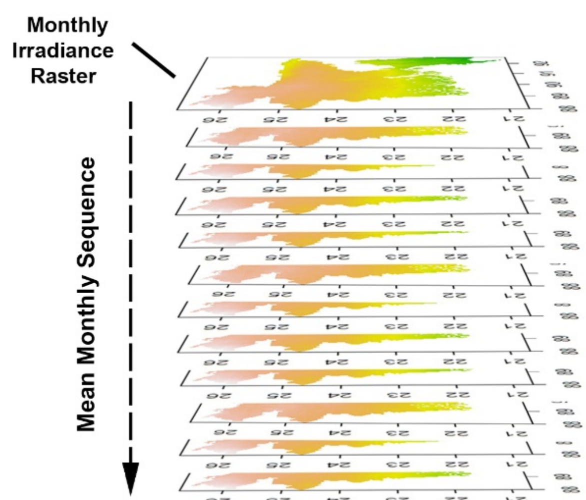

Figure 2 Creating Irradiance Pattern Vector per Pixel

The raster images were analysed with the k-means algorithm. It is one of the most widely used clustering algorithm within various disciplines due to its very simple and robust application. Its main purpose is to organize data into a priori known number *k* of clusters. Having a set of *n* data objects $X = \{x_1, x_2 \ldots, x_n\}$ the algorithm computes *k* cluster centres $C = \{c_1,$

$c_2,..,c_k\}$, iteratively minimizing the within-cluster sum of square distance between the cluster-centroid c_j and the other data objects x_j of that cluster, using the formula:

$$J = \sum_{i=1}^{k} \sum_{j=1}^{n} || x_j - c_j ||$$

With || . || as the L^2 distance´s norm chosen as the distance measure.

1. Randomly select k clusters and calculate each cluster-centroid.
2. Calculate the Euclidian distance d_{jk} between every data object x_j and every cluster-centroid c_i:

   $$d_{jk} = || x_j - c_i | \quad |^2$$

   with $1 \leq j \leq n$ and $1 \leq i \leq k$
3. Re-assign every data object x_j to its nearest centroid c_k.
4. Re-calculate each cluster-centroid for each cluster, due to the new assignation.
5. Calculate the objective function *J.* If the function converges, the algorithm delivers the final position of the cluster-centres. Otherwise the steps 2 to 5 are repeated.

As shown in figure 3, the SARAH data can be grouped into various numbers of clusters.

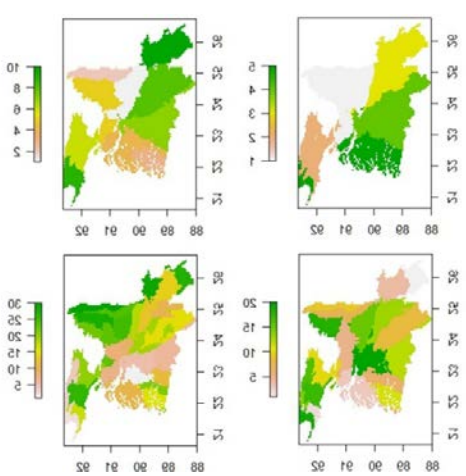

Figure 3 Grouping into 5, 10, 20 and 30 clusters | Data: PVGIS © European Communities, 2001-2017

In order to find the most suitable number of clusters, the compactness within a cluster has to maximized whereas the separation between each cluster has to be maximized as well (Figure 4). For example, with an increasing number of clusters, the similarity within a cluster is increasing but also the similarity between each cluster is increasing. It is therefore necessary to find the number of clusters that best meet both criteria

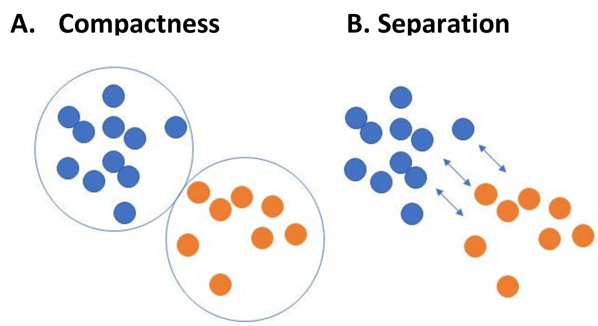

Figure 4 Compactness and Separation of Clusters

To determine the correct number of clusters, two cluster validation methods were used in this analysis, the Calinski–Harabasz (CH) index as well as the Within-Cluster Sum of Squares (WSS) index. Both were each calculated for a cluster number of two to one hundred.

The Calinski-Harabasz index is the quotient between separation and compactness. It is formed as:

$$CH = \frac{trace_{BCSM}}{trace_{WCSM}} \times \frac{n-k}{k-1}$$

with $trace_{BCSM}$ as the sum of squares of the distances between each cluster-centroid c_k and the global centroid mean vector x̂ of all data-object x_i and $trace_{WCSM}$ as the sum of squares of the distances between the data objects x_j and their related cluster-centroids c_j. Large values of CH therefore indicate well separated clustered data-objects, where the cluster-centroids are in distance to each other with a compact intra-cluster distance. In figure 5 you can find the CH indices plotted against the number of clusters.

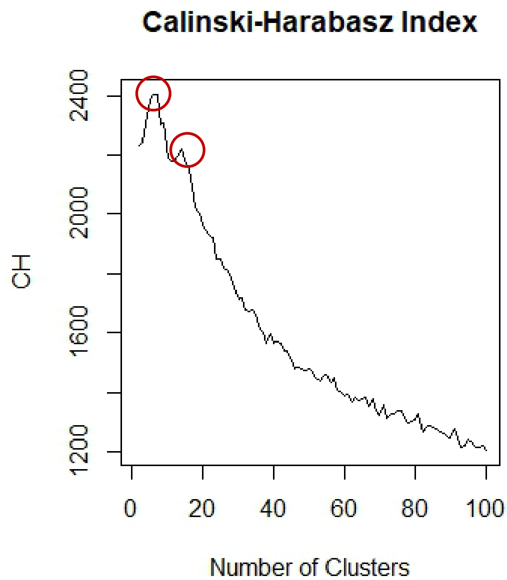

Figure 5 Calinski-Harabasz Index for k Clusters

Within-Cluster Sum of Squares (WSS) index is calculating the sum of the deviation squares of observed data-objects x_j and their cluster-centroid c_j.:

$$WSS = \sum_{k=1}^{K} \sum_{i \in S_k} \sum_{j=1}^{p} (x_{ij} - \overline{x_{kj}})^2$$

with S_k as the set of observations in the *kth* cluster and $\overline{x_{kj}}$ as the *jth* variable of the cluster centre for the *kth* cluster.The smaller the value of the index, the more similar the values are within the clusters. Because the similarity within the clusters automatically increases with the number of clusters, the WSS can be described through a strictly monotonously decreasing exponential function. The optimal number of clusters is located here at the so-called "elbow point", the point at the strongest curvature of the function.

Using the "L-method", this point can be determined. For this purpose, two linear regressions are optimized so that the root mean square error (RMSE) of both regressions is lowest (figure 6).

The minimal total RMSE of all linear regression gives the exact number of clusters, where the WSS reaches its optimum value (figure 7)

All the analysis in this study was done by R software.

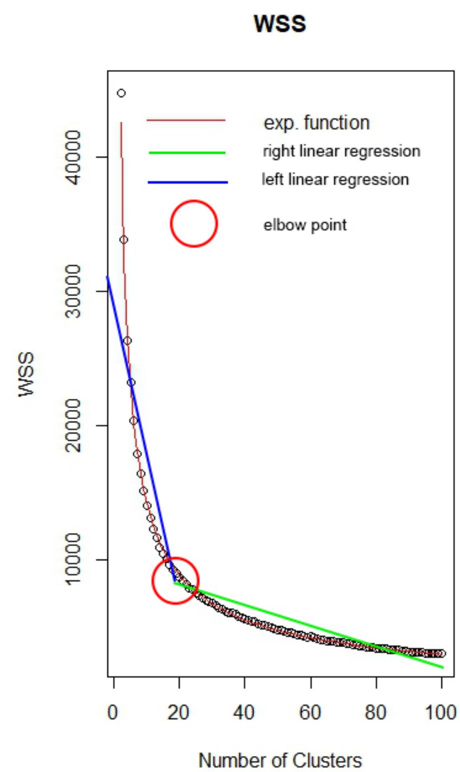

Figure 6 Schematic Representation of L-Method

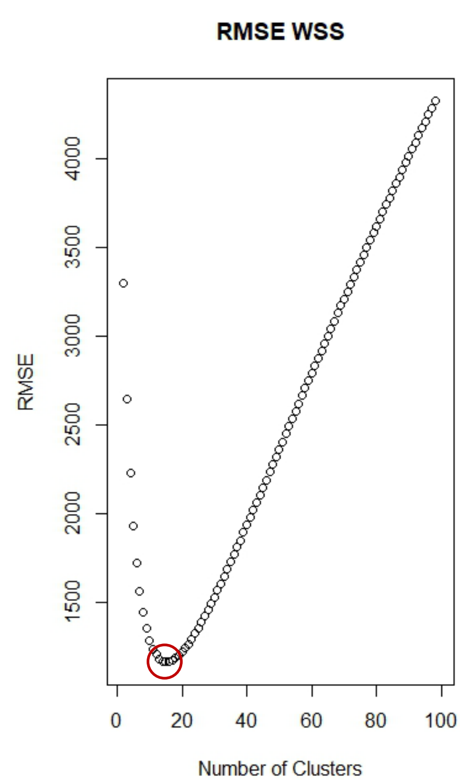

Figure 7 RMSE for WSS

4. Results

As shown in figure 5, six clusters obtain the highest value of the Calsinski-Harabasz (CH) index. Still, we can find another dominant peak of the index at fourteen clusters. Since the selection of clusters concerns real measuring stations, the value 14 is preferable to 6. Even if the separation of the clusters is less high, more measuring sites can better represent the solar irradiance in Bangladesh. Looking at the Within-Cluster Sum of Squares index, the optimal number of clusters is as well 14 (figure 7). The locations of the measuring sites are calculated by the geometric centroids of each cluster. In order to find a suitable location for implementing the sites, a radius of 25 km was set around the centroids. Within this boundary, the location of the site does not significantly affect the representability of the in-situ data. The optimal clustering scheme of 14 spatial numbered clusters by k-means is shown in Fig. 8.

5. Installation and Site specification

Al though 14 different locations have been selected to install the ground - based radiation stations, initially it has been decided to install 10 nos. radiation station on first phase. These 10 nos. station will be installed at 7 different locations. The station category has been grouped in two different types. Type-1: will be used to monitor global radiation on a horizontal surface (GHI) and Type-2: will be used to monitor both the GHI and diffuse radiation on a horizontal surface (DHI). For type 1, 4 locations will be selected, where 4 GHI will be used; while for the type 2 stations, 3 GHI and 3DHI sensors will be installed.

For site selection, it is important to consider the following criteria

1. It is ideal to install the sensor at high location, i.e., top of the building which is not affected by any kind of shadow from neighbouring building or any structure
2. Within 10 meter radius there will not be any tree or obstacles
3. The site should be accessible on regular basis.
4. Each one week, the pyranometer need to be cleaned. While installing the cleaning accessories will be provided.
5. The site should be located at a place which is free from regular dust (e.g., avoid location where is industrial plant, coal-based power plant, brick field)
6. The site should be under the coverage of mobile phone network with GPRS/3G network.

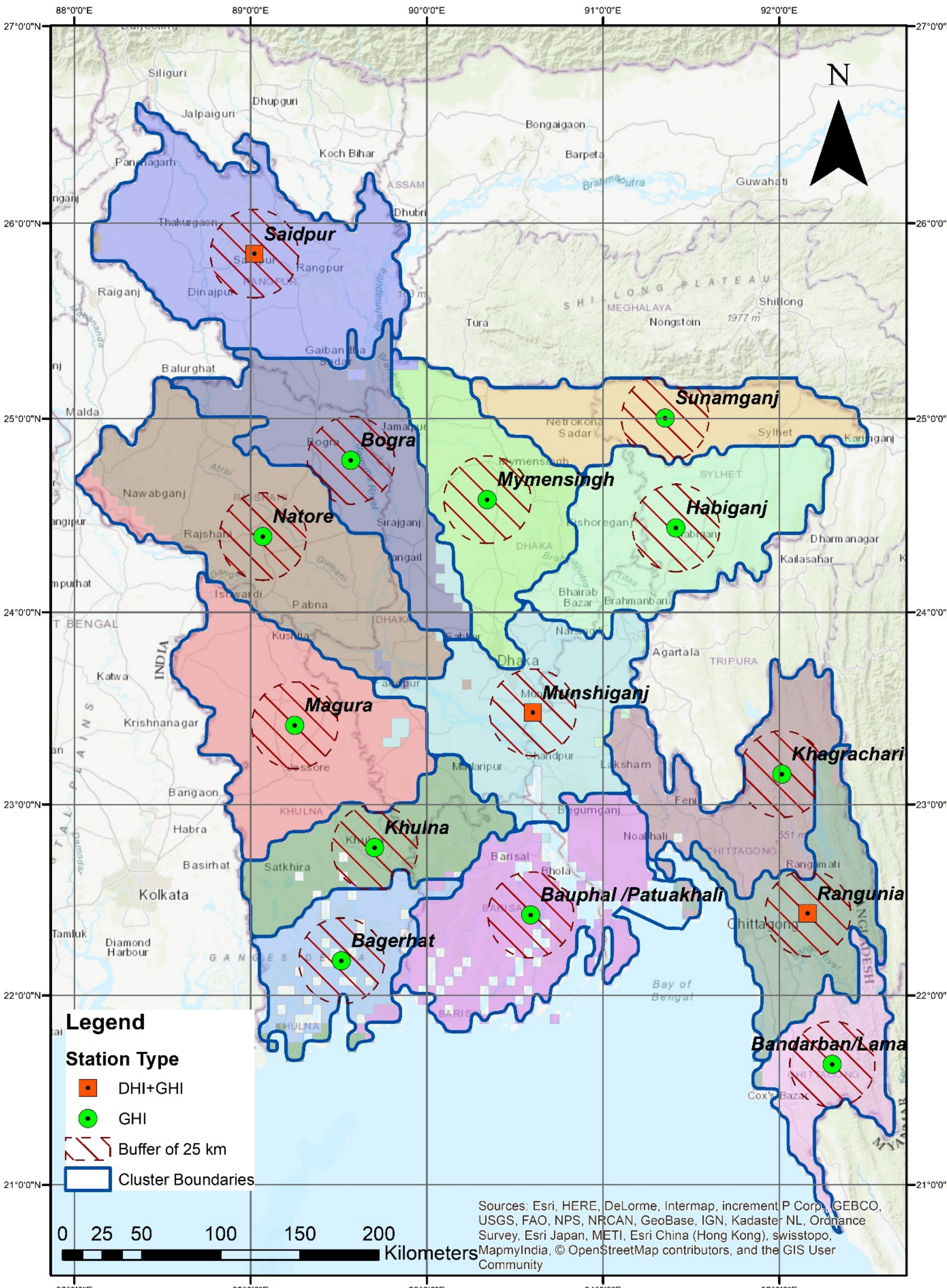

Figure 8 An optimal spatial partition of the area over Bangladesh into 14 clusters as derived from the CH index as well as application of the L-method to the WSS Index.