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Optimum Locations Suitability: Analysis for Tsunami Warning Centres

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Abstract: More than 35,000 lives were lost due to the Tsunami disaster, occurred in 2004. That time, early warning towers had not been established to warn people before this kind of a disaster. After the disaster, 77 early warning towers were established in the coastal area of the country. Geographic Information System (GIS) can be identified as a tool which has the capability of providing most recent and accurate information which is necessary for making most suitable decisions for a problem. As well as a mapping system which has been developed for storing, analysing, modifying and displaying spatial data of any place existing in the entire world. GIS has become a very useful tool which can be used in the vulnerability and hazard assessments. A research based on GIS Analysis has been done to find out the optimum locations to the Tsunami early warning towers located in between coastal line of Matara and Dickwella. It has been identified the most vulnerable areas for a future Tsunami disaster and has done an analysis to check the coverage of the existing Tsunami towers. Finally, a comparison between the optimum locations and the existing locations has been done and has identified the areas which have no protection from a future Tsunami disaster in the research area.

Keywords: Optimum location, Tsunami Early Warning Tower, Vulnerable areas

Introduction:

"Tsunami" was a new word for Sri Lankans till 26th of December 2004. About eighteen (18) countries around the Indian Ocean like India, Indonesia, Malaysia, Bangladesh, Thailand and Sri Lanka have been affected with this disaster. This happened because of the Sumatra-Andaman Islands earthquake occurred in Sumatra island. The magnitude of the earthquake has been recorded as 9.1 on the Richter scale. In 2004, almost two-thirds of the Sri Lankan coast were affected by this disaster highlighting the country's vulnerability to low-frequency but high impact events. Coastal districts of Jaffna, Mullativu, Trincomalee, Batticaloa, Ampara, Hambantota, Matara and Galle were highly affected by tsunami disaster. Though it happened 16 years ago, still people are suffering from that disaster because it destroyed everything that belonged to people within few minutes.

A. Problem Statement

Tsunami disaster was the worst natural disaster faced by Sri Lankans. The need of early warning towers had been raised up because of this disaster. After the tsunami disaster in 2004, 77 early warning towers were established all over the country more than 14 years ago. Within this 14 years of period Sri Lanka had not experienced a Tsunami disaster. So, it is very important to check the effectiveness of this Tsunami towers and whether they are adequate or not to the community. In Matara district, 7 Tsunami early warning towers have been established to cover the coastal area. (Matara, Dickwella, Mirissa, Polhena, Naotunna, Weligama and Devinuwara). After the establishment of these early

warning towers, there were many geographical, social changes as well as many other factors have been changed. So, there is a doubt whether these early warning towers have the ability to cover the coastal area or not. Therefore, it is essential to find out whether the current locations of the existing tsunami early warning towers are suitable for locate in existing places when considering about the present conditions.

B. Aim

The main aim of this research is to find the suitability of the existing locations of the Tsunami towers locating in coastal area of Sri Lanka and the ability of the towers to provide the maximum coverage for vulnerable areas in future Tsunami disaster.

C. Objectives

1. To find out whether the strength and coverage of the existing towers are adequated.
2. To identify the factors which affect for a location of a Tsunami early warning tower.
3. To Identify the best Locations for early warning towers according to present context.
4. To conduct a comparison between existing location and proposed location.

Literature Review

There are 77 early warning towers now located in the coastal line of Sri Lanka. According to author's findings, the pre-recorded message with the siren and live voice message cover more than one kilometer from the base of the tower. The message delivers to the public in any disaster situation as an alert, warning, evacuation and withdrawal. Furthermore, it has been mentioned that coverage of these towers depends on the climatic condition and the weather (Jayarathne, 2016). But according to the data gathered from the community, the coverage of these towers depends on the time of the day too. As well as some areas of the coastal line, only hear the siren, and cannot hear the voice message. Here also, it has been taken 1 km as the coverage area of the Tsunami towers.

According to the findings of Wijerathna S., Weligama bay was affected by the Tsunami disaster in 2004 and this caused nearly 400 deaths locally in addition to the destruction of valuable properties. Main objective of this research was to examine how the waves of the Tsunami disaster affected the coastal environment of Weligama Bay area. When finding out the optimum location determination of the Tsunami early warning towers also, damage analysis from the 2004 Tsunami and mapping of the hazardous areas are very important. For this research, author has used ArcGIS software as the main data analysing software. (Wijeratne, 2015)

A researcher has found out the ability to study the problems regard with the locations by using the science of modern GIS software. This was done by providing the input as raw data to display the model results. The most common data formats which were used in GIS can be identified as raster based Digital Elevation Model and the Triangular Irregular Model which are based on the raster models. Researcher further expressed that these two types of data formats are doing a great job at representing a continuous surface and important in solving surface modelling problems. Both of these models give the results which can be easily illustrate in a graphical method in a map on computer screen. (Church, 2002)

A researcher has used LiDAR (Light Detection and Ranging) data sets to create a DEM raster in the research area. Bing

maps were used to identify the data of town features tend to identify the road networks. The buffer zones have made to categorize the zones of multiple towers. Accordingly, the new locations of the towers have been identified by considering slope analysis and the height of each tower. After determination of the locations of the towers, a view shed analysis has been done by the researcher. (BENHAM, 2012)

Wijethunga J.J. has considered about east, south and the west coasts of Sri Lanka as the study area. The Tsunami heights were basically identified by the visually based on the witnesses of the community, watermarks and according to the damages on the structures. Here hand-held Global Positioning System (GPS) was used to obtain the corresponding location in the ground. According to the researcher, the deepest wave height penetrates at Hambantota in the south coast, nearly to a weave with a height of 10m. Researcher has further found that the Tsunami waves had been conveyed to the inland through the water bodies such as lagoons and lakes which are opening to the sea. The composition in the beaches such as sand dunes and steep beaches were identified by the researcher in the southern coastal area. (Wijetunge, 2015)

Methodology

A. Study Area

The research area for this research is coastal line of Matara district from Matara to Dickwella, of southern province in Sri Lanka. This area covers 44km^2. This area was selected inside to the country as nearly 2kms from the coastal line. This 2km distance was selected because the maximum inundation distance towards the inland of the tsunami wave was near to 2kms in some areas of the Matara district. (Wijetunge, 2015)

B. Data Collection

The data that needed for this research was collected from,

- Field visits in the research area
- Disaster Management Center, Sri Lanka
- Survey Department, Sri Lanka
- Census and Statistical department, Sri Lanka
- Interviews held with community in the research area

C. Identification of the current Locations of the Tsunami Towers in between Matara and Dickwella

In this research, CTDroid mobile application was used to locate the points. CTDroid app facilitate visualizing coordinates in WGS84 (World Geodetic System) Kandawala and it allows projected forms and saving waypoints. It works with the aid of GPS receivers in the smartphone which use to run this application. The application allows to examine stored locations, deleting the locations and exporting them in different file formats such as comma separated value (CSV) format, Key hole mark-up language (KML) format and Global Position exchange (GPX) format. This Software was freely available in the google play store for the android devices. (Alahakoon AADC, 2014)

D. Importing Data to ARC GIS 10.3 Software

Arc GIS software was used as the main Software for the Data Analysis in this research. This software can be used to preparae the location maps with the aid of digital data layers. (Piyadasa, 2012)

The geographical locations of the Tsunami towers were exported in to CSV format through the CTDroid software. The coordinate system which used to store these coordinates in CTDroid application was “WGS84 Coordinate system”. The

coordinate system of digital data layers of the research area which was collected from the survey department was stored in the format of "GSC Kandawala" coordinate system.

E. Check the Coverage of the existing Tsunami towers

From the field survey, which was done with the community in the research area, 50 locations were selected out of 200 of sample sizes to confirm that the coverage of this existing Tsunami towers is spreading around 1km or not. The locations of the interviewed points were positioned with the aid of CTDroid software. These points were classified according to community which can hear the early warning siren and community which cannot hear the early warning siren.

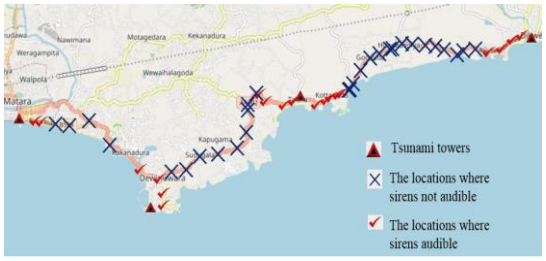

Figure 1. Locations of 4 Tsunami towers and locations of the interviewed points
Source: Survey Department, Sri Lanka

Following figure shows the locations which the Tsunami early warning siren is audible and locations which the siren is not audible.

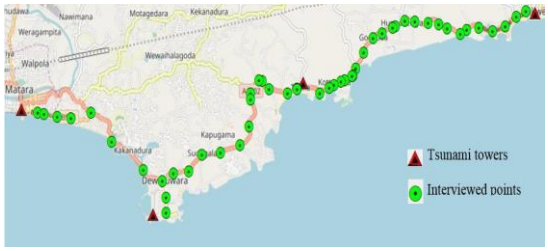

Figure 2. Locations where sirens are Audible and not.
Source: Survey Department, Sri Lanka

F. Determination of Optimum Locations for The Tsunami Warning Tower

Mainly 2 factors can be identified for the determination of the best location for the Tsunami early warning towers.

- What are the areas should cover with the Tsunami towers?
- What are the factors to be concern for the protection of the Tsunami towers?

G. The Elevation and Geographical condition of the areas.

When comparing Matara District with Galle and Hambantota districts in the Southern province, the areas which affected with the Tsunami disaster in December 2004 was comparatively less (Wijetunge, 2015). A Triangulated Irregular Networks (TIN) were developed using Arc GIS 10.3 software to represent the surface morphology in the research area.

Figure 3. The Triangular Irregular Networks (TIN) model which developed for the Research area
Source: Survey Department, Sri Lanka

The light blue color indicates the elevations in between 0-5 meters. The light blue color areas which near to the sea are the most vulnerable areas for a future Tsunami disaster. This area must be covered with Tsunami early warning towers.

H. The areas locate near to the water resources which connect with the sea

According to the research area, there were 5 water resources (Nilwala river and 4 lagoon areas) which connect to the sea that can be identified by the digital data layers of hydrological features.

Figure 4. Areas which have a risk of Tsunami due to water resources which connected with the sea
Source: Survey Department, Sri Lanka

I. The Areas which don't cover with any authorities to warn the people in such incidents like Tsunami

In this research area, 2 police stations have been identified as Gandara and Dickwella. According to the data collected from Disaster management center, they have the capability to send a Tsunami early warning message between 30– 60 minutes for the people around 1 to 2 km area from the police stations before a Tsunami. The police stations have the strength to distribute such kind of a warning message within the coastal area through loud speakers and mega phones. By using 1km buffer area in Arc GIS, the areas which do not cover with police stations have identified as follows.

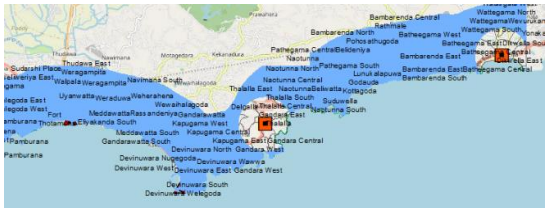

Figure 5. Areas which do not cover with the police stations
Source: Survey Department, Sri Lanka

J. Reasonable distance from the coastal line

The height of the Tsunami wave in December 2004 was differed 3m to 6m in the research area. (Wijetunge, 2015) So the Tsunami towers can be damaged by Tsunami waves. The main important thing is Tsunami is not a single wave. The most vulnerable area for a Tsunami disaster was 100m away from the coastal line. So, it was designed to locate the Tsunami towers 100m away from the coastal line, but not more than 500m away from the coastal line. According to the above conditions, the appropriate area was found using Arc GIS 10.3 software as shown in the figure below.

Results and Discussion

A. Strength and the coverage of the existing towers

Figure 6. Area in between 100m and 500m away from the coastal line
Source: Survey Department, Sri Lanka

According to the GPS coordinates which were obtained by the CT Droid software, current locations of the Tsunami towers were identified, and those locations were represented graphically in the Arc GIS software as shown in the figure below. According to the data collected from the Disaster management center, all these four towers were in working condition.

Figure 7. Locations of 4 Tsunami towers in between Matara and Dickwella
Source: Survey Department, Sri Lanka

3 buffer zones were developed to determine what is the actual coverage area of Tsunami towers in the research area. The 3 buffer zones were selected as 500m, 1000m and 1500m. According to the results, the coverage of the Tsunami towers was taken as 1000m away from the base of the Tsunami towers. Disaster Management Center of Sri Lanka also considered the coverage of the Tsunami early warning towers as 1000m from its base. The areas inside this 1000m buffer zone, can be identified as the areas which are safe from such kind of disasters.

Among the 43 Grama Niladari divisions which affected from the Tsunami disaster, the most important thing was to identify the areas which do not cover with the

current Tsunami towers. The coverage area of the existing Tsunami towers in any time of the day (depend on climatic and weather changes) was represented by 1km buffer area from the base of the tower

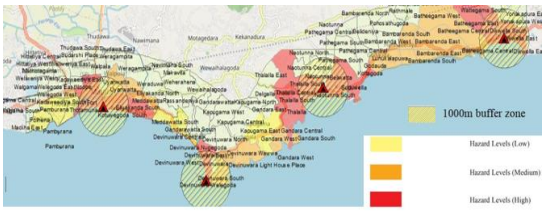

Figure 8. The Coverage area of existing tsunami towers with 1000m buffer area
Source: Survey Department, Sri Lanka

Out of the 43 Grama Niladhari divisions in the research area, 16 Grama Niladhari Divisions were not covered with the current Tsunami towers. So, cannot satisfy with the current coverage of the Tsunami towers in between Matara and Dickwella area.

B. The factors which affect for the location of Tsunami early warning towers

The following factors were identified as the factors which affect for the location of Tsunami early warning towers.

1. Should be located by considering the elevation and geographical condition of the areas.
2. Should cover the land areas which the water resources connect with the sea
3. Should cover the areas which are not covered by the police or any other similar authorities to warn the community in the research area.
4. Should be located after considering distance from the sea. (to minimize the effect of a Tsunami wave on the tower)
5. Should locate in a place with low risk of floods.
6. Should locate near main road network system.
7. Should locate in the most densely populated areas.
8. Should locate near to the evacuation paths.

Above 8 factors were identified by the information gathered from Disaster Management Center and the literature review.

In this research, it was taken only the first five factors according to the Disaster Management Center. Consideration of first five factors is most important to identify the location of the tsunami tower. Here it was considered about the areas which should be covered from the Tsunami early warning towers and the factors which affect for the protection of the Tsunami early warning towers.

According to the information collected from the Disaster Management Center the coastal area in between Matara and Dickwella had not a high risk of floods. So, in this research, it was not considered about the fifth factor when finding the optimum location of Tsunami early warning towers.

C. Identification of the best location for early warning towers according to the present context

The most dangerous areas according to the geographical features of the research area are shown as below.

Figure 9. The Most vulnerable areas according to the Geographical features and the data collected from the respective authorities of the area.
Source: Survey Department, Sri Lanka

The areas around the water features which were connected to the sea also determined as dangerous areas for a future Tsunami disaster. So, the most vulnerable areas with the water resources were shown as following figure.

Figure 10. The Most vulnerable areas in between Matara and Dickwella by considering all the factors.
Source: Survey Department, Sri Lanka

There are 2 police stations located in this research area as Gandara and Dickwella. So, the areas which are not covered by these police stations were identified as in the following figure.

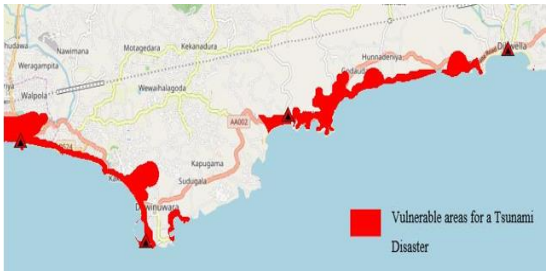

Figure 11. The Most vulnerable areas in between Matara and Dickwella which not covered by police stations
Source: Survey Department, Sri Lanka

To find the optimum locations for the Tsunami early warning towers, the protection and the security of the Tsunami towers also considered. The places where the Tsunami towers can accommodate with the protection and the areas should cover with the early warning towers are shown in the following figure.

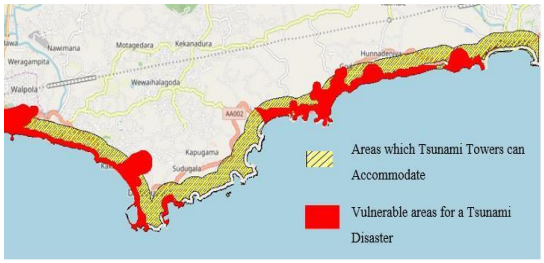

Figure 12. Identification of the areas which Tsunami Towers can accommodate
Source: Survey Department, Sri Lanka

So, to identify the optimum locations for the Tsunami early warning towers in between Matara and Dickwella, the current locations of the Tsunami towers were neglected. The optimum locations for the Tsunami early warning Towers were identified by Buffer tool of the Arc GIS software. A distance of 1000m from the base of the Tsunami towers was used as the coverage of Tsunami towers. The optimum locations of the Tsunami towers were represented graphically as shown in the figure 4.8. According to that, at least 7 early warning towers should be located in the Area between Matara and Dickwella. But there are only 4 towers still located in this area.

Figure 13. Optimum Locations of the Tsunami Early warning Tower
Source: Survey Department, Sri Lanka

D. Comparison of optimum locations and the current locations of the tsunami Early Warning Towers in between Matara and Dickwella.

The graphical representation of the coverage of the proposed early warning towers and the coverage of current Tsunami towers are shown in figure below

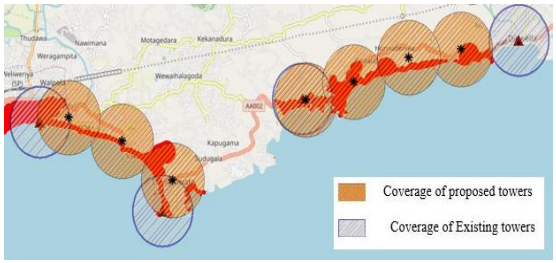

Figure 14. The coverage of the proposed Early warning towers and the coverage of existing Tsunami towers
Source: Survey Department, Sri Lanka

Here the coverage of Tsunami towers in Matara and Naotunna matches with the coverage of the proposed Tsunami towers. But there was a huge difference of the coverages of Devinuwara Tsunami tower and the Dickwella Tsunami tower.

Dickwella Tsunami tower is located inside the police station of Dickwella. Actually, there is no requirement to locate this tower inside a police station. Police has the capability to warn the areas around the police stations rather than a Tsunami Early warning tower. So, if this tower was located in between Batheegama central and the Batheegama east, it will be much better than the current location. Devinuwara tsunami early warning tower is located at the Puranawella area of devinuwara.

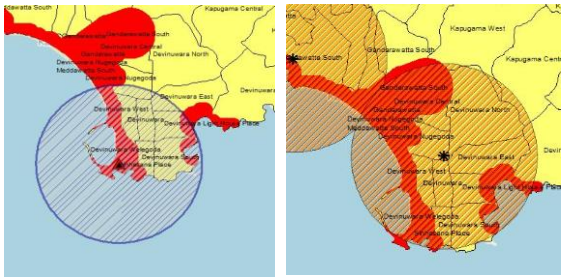

Figure 15. The coverage of the Devinuwara Early warning tower in existing location and proposed location respectively
Source: Survey Department, Sri Lanka

E. The areas do not cover by Tsunami Early Warning Towers or police stations in between Matara and Dickwella.

To identify the areas which are not covered by both early warning towers and Police stations were identified graphically as follows.

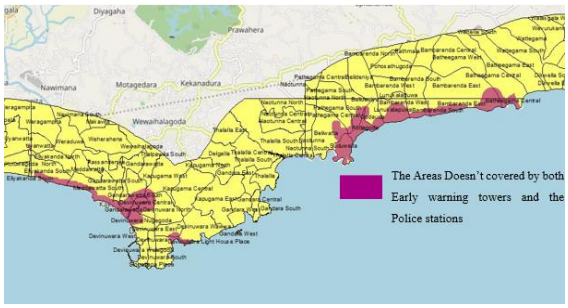

Figure 16. Areas do not cover by both early warning towers and the police stations
Source: Survey Department, Sri Lanka

So, from the figure it can be easily identified there are many areas in between Matara and Dickwella which do not cover with any tsunami tower or police station. These areas were listed according to the DS divisions as follows.

Table 1 The GN divisions Doesn't covered by both Early warning towers and the Police stations

Matara DS division	**Devinuwara DS division**	**Dickwella DS division**
Eliyakanda South	Devinuwara central	Suduwella
Meddawaththa South	Devinuwara Nugegoda	Beliwaththa
	Devinuwara Light house place	Kottagoda
	Devinuwara East	Godauda
		Lunukalapuwa
		Bambarenda East
		Batheegama Central

Source: Author

Conclusion

Field surveys were conducted in the research area to identify the locations and the current conditions of the Tsunami towers. 4 Tsunami towers were identified in the areas of Matara, Devinuwara,

Naotunna and Dickwella. The coverage of the Tsunami towers was mainly determined by the interviews carried with the community of the research area. The further details regarding Tsunami towers and details about the Tsunami affected areas were collected from the Disaster management center and Census and Statistical department Sri Lanka. Arc GIS 10.3 Trial version was used to store data in digital format and further data analysis purposes. The coverage of the Tsunami towers has been depended on the weather and the climatic conditions of the area. From the data collected by interviewing people and data collected from the respective authorities, the coverage of the Tsunami towers was found around 1km from the tower base. From the maps developed with this 1km buffer zone from the base of the Tsunami tower and the data collected from the Census and Statistics department (the most damaged areas from Tsunami disaster 2004), it can conclude that the coverage of the existing 4 Tsunami towers are not enough.

When locating a Tsunami tower, it should consider whether the Tsunami towers could cover the most vulnerable areas as well as the protection of the Tsunami tower. The most vulnerable areas for the Tsunami disaster were identified by considering the geographical features of the research area and the data collected from the Disaster Management Center. Steep beaches in the coastal line of the Matara District was identified as natural protector for a Tsunami disaster. The factors such as the geographical features in the area, the water resources which connect to the sea, the areas which do not have any coverage from police or any other respective authorities and the protection of the Tsunami early warning tower were identified as the factors which affect for the location of the Tsunami early warning tower.

With the analysis of data from the Arc GIS 10.3 software it was found that minimum 7 early warning towers must be located in between the coastal area of Matara and Dickwella area.

According to the current locations of the existing towers of Dickwella and Devinuwara, it cannot be satisfied with the coverage of these 2 Tsunami towers. It was found that these 2 locations to be shifted to Batheegama and Devinuwara East area respectively. If the Devinuwara tower is shifted about 1km to the Devinuwara North from the existing location, it could cover the land areas of 4 more GN divisions which can be affected from a future Tsunami disaster. The existing Dickwella Tsunami tower is in the premises of Dickwella Police. In an emergency, the existing coverage areas of the Dickwella Tsunami tower can be covered by the police too. Same as the Devinuwara early warning tower, if the existing Dickwella tower is shifted to Batheegama area it could cover vulnerable areas of 2 more GN divisions which do not have any protection from Police stations as well as existing Tsunami warning towers.

According to the present situation the vulnerable areas of 13 GN divisions were identified as areas which are not covered with either the Tsunami towers or police stations in this research area. If Devinuwara and Dickwella towers could shift to new locations as mentioned above, the most dangerous areas of these 13 GN divisions could be minimized up to 7 GN divisions.

So following recommendations can apply to increase the number of areas which cover with Tsunami early warnings.

- Implementation of new Tsunami early warning towers for the areas which do not have any protection.
- Inform the community using mobile warning system.

- Practice the community with Tsunami evacuation drills.
- Appoint personnels such as Grama Niladhari in this most risky areas to keep update by early warning messages with respective authorities

In this research, the research area was minimized to the area between Matara and Dickwella in southern coast. So, in future it is very important to identify areas which are not covered with any of the warning system in the other coastal areas in Sri Lanka.

Further, in this research it was found some people in these coastal areas still do not aware about the Tsunami early warning towers. So, it needs to find the methods that can be carried out to make these community to aware about the Tsunami early warning systems.

Acknowledgement

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Abbreviations and specific symbols

LiDAR - Light Detection and Ranging
DEM - Digtal Elevation Model
GIS – *Geographic Information System*
GPS - Global Positioning System
WGS84 - World Geodetic System
CSV - comma separated value
KML - Key hole mark-up language
GPX - Global Position exchange
TIN - Triangulated Irregular Networks
GN Divisions – Grama Niladhari Divisions

Author Biography

KH Wanniarachchi, received his BSc. (Hons.) in Civil Engineering from General Sir John Kotelawala Defence University, Sri Lanka. He is currently working as a Civil Engineering Officer (Lieutenant) at Sri Lanka Navy. His research interests include Geographical Information Systems and Surveying Science.