

RESEARCH ARTICLE

A comparative study of elevation data from different sources for mapping the coastal inlets and their catchment boundaries

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Abstract: Mapping coastal inlets and their catchment areas is essential for management of the coastal zone. The coastal inlets are important channels of exchange of nutrients, water and sediment between the land and sea. They are also important elements of the coastal hydrological system and play a vital role in controlling the water flow into the sea during floods. Blocking of the coastal inlets is one of the main causes of flooding in the lower reaches of the major rivers in Sri Lanka.

Delineation of the boundaries of inlet catchments is essential for modelling the inlet processes and this is normally done using elevation data. The traditional sources of elevation data are the topographic maps. In Sri Lanka, detailed topographic maps (1:10,000) are available only for a limited area, and the rest of the country is covered by 1:50,000 and 1:63,360 maps. The low resolution maps are not sufficiently detailed in areas of low relief, such as the coastal lowlands. As a result, the catchment boundaries based on these data sources are not accurate enough for inlet studies. Two alternative sources of elevation data that can be used for this type of studies are the shuttle radar topography mission (SRTM) global data set and light detection and ranging (LiDAR) data (5 m) available for a limited area of the coastal belt. This study compares the traditional map data for the Galle district with the SRTM digital elevation models (DEM) at 30 m and 90 m resolutions and LiDAR DEMs. At first, the DEMs derived from all data sources were compared using the cross-sectional profiles. Secondly, a comparison was made using the spot heights obtained from 1:10,000 maps with the corresponding heights from the SRTM 30 m DEM. The 1:10,000 scale agricultural based mapping project (ABMP) (10 k ABMP) was used as the reference data set and all other data products were compared with that.

The analysis of the data revealed that the LiDAR data set has the best match with the 10 k ABMP dataset. The SRTM

30 m DEM showed a high level of correlation with 10k ABMP maps at the high elevations, but the match at the low elevations was less as indicated by the low R^2 values. However, the SRTM data is marginally better than the 50 k ABMP in the coastal area. This suggests that SRTM 30 m data set is the best data set available for the delineation of inlet boundaries in the coastal areas.

Keywords: Coastal inlets, elevation data, LiDAR, mapping, SRTM.

INTRODUCTION

Although Sri Lanka's coastline has hundreds of inlets, there is a general lack of information about their occurrence, hydrodynamics and ecology. This may partly be due to the fact that they have not been recognized as important elements of the coastal landscape or their economic value is perceived to be insignificant. The existing maps depict only the major inlets; their catchment areas have not been delineated. This is despite the fact that these inlets are extremely important pathways of fresh water and brackish water exchange and therefore essential for coastal hydrologic modelling.

In Sri Lanka, most coastal inlets are associated with rivers directly or through an estuary. Although the major rivers and streams have been mapped using different scales, there is only one river basin map covering the whole country. This map was first published in 1959 using a scale of 1:250,000 by the Survey Department of Sri Lanka (1959) and has not been revised since then.

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The river basin map divides the island into 103 'main basins' and a large number of inter-basin areas with or without stream courses. Some of the major rivers have estuaries, while others have no clearly marked estuaries. The river mouths of all these rivers are associated with one or many inlets. In addition, there are lagoonal inlets, which cut through barrier islands. There are streams flowing into some lagoons, while others are devoid of any significant stream flow. Those without streams receive freshwater from storm water runoff. The small inter-basin catchments respond more rapidly to high intensity rainfall than the larger river basins.

"There is no simple, restrictive definition of inlets; based on the geological literature and on regional terminology, almost any opening in the coast, ranging from a few meters to several kilometres wide, can be called an inlet" (U.S. Army Corps of Engineers, 1995). These inlets may have cut through diverse material, ranging from barrier islands, shoals, clay, rock, etc. Through coastal inlets, "water, sediments, nutrients, planktonic organisms, and pollutants are exchanged between the open sea and the protected embayments behind the barriers" (U.S. Army Corps of Engineers, 1995). The above broad definition of inlets was adopted in this study. In the case of coastal water bodies such as lagoons and estuaries, the inlets are narrow channels. The large inlet channels are often used as navigational

channels in some parts of the world. In Sri Lanka most inlets are too small to be used as navigational channels other than for small boats.

The delineation of catchment boundaries, both small and large in low relief areas require detailed topographic maps. The most detailed maps available in Sri Lanka are the 1:10,000 series but they do not cover the entire island. In the absence of such data, it is important to determine the usability of the available medium resolution elevation data from maps and space/air borne sensors. The required map resolution for high relief and low relief areas has to be determined at the outset. Use of high resolution maps may be too expensive or too cumbersome in an island-wide application, even when maps are available. It is therefore necessary to determine the optimum map resolutions for different terrain types. In high relief areas larger contour intervals are acceptable, but in flat areas smaller contour intervals are required to identify the divide on a map to a sufficient level of accuracy. Spot heights are also an invaluable source of elevation data. The contour interval and the number of spot heights available are closely related to the map scale. In coastal areas, accuracy of the catchment boundaries is therefore linked to the availability of large scale topographic maps. This study had access to 1:10,000 scale maps of the Galle district only.

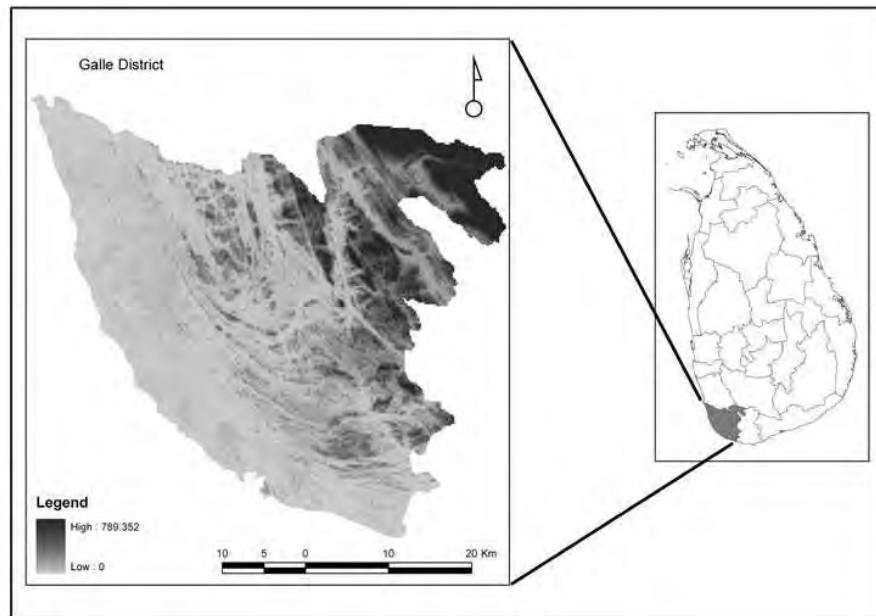


Figure 1: Study Area

This study compares the elevation data obtained from the medium and high resolution data sources. The former includes 1:50,000 agricultural based mapping project (ABMP) maps and shuttle radar topography mission (SRTM) data, while the latter includes 1:10,000 ABMP maps and light detection and ranging (LiDAR) data. This was done to determine the best medium resolution data source for delineating catchment boundaries in the coastal terrain of Sri Lanka. The Galle district with all four data types were used in this study and its results are expected to be valid for the rest of the coastal areas (Figure 1). High resolution satellite imageries were used to identify the coastal inlets, which are not shown on topographic maps.

DATA SOURCES AND METHODOLOGY

Sri Lanka is covered completely by two sets of semi-detailed topographic maps, using the scales of 1:63,360 (one-inch) and 1:50,000. The latter was produced by ABMP and the former is the older of the two map series, which was based on ground surveys done in the early part of the 20th century (1900-1935). The contour interval of the first series is 30 m (100 feet) and there are some spot heights as additional elevation information. The second map series is an improvement on the first and has 20 m or 30 m (100 feet) contour intervals and also some spot-heights. There are no other medium to large scale maps that cover the entire land area of Sri Lanka. The 1:10,000 (ABMP) series that is currently being produced covers only a part of the country. These maps have detailed topographic information and are particularly suitable for delineating the catchment boundaries in flat areas, such as the coastal plain. The contour interval is 5 m and there is a denser set of spot-heights than the other two map series. However, the limited coverage of these

maps compels one to seek other sources of topographic information for deriving detailed terrain information for the entire country.

Fortunately, there are alternative non-traditional sources of terrain information from several sources. They are SRTM digital elevation model (DEM) for the whole of Sri Lanka and LiDAR DEMs covering a limited area of the coastal zone. SRTM DEMs are available in two spatial resolutions, 90 m and 30 m. These two are from the global elevation datasets, which are freely available to users. The vertical and horizontal accuracy of the SRTM data is expected to be about 20 m and 16 m (Smith & Sandwell, 2003). A field test conducted by Gorokhovich and Voustianiouk (2006) found that the vertical accuracy of SRTM 30 m data can vary from region to region. They found an error of 4.07 m in Thailand and 7.58 m in the USA. However, SRTM data set has more detailed information on the elevation of the coastal plain than the 1:50,000 scale maps.

The LiDAR data set is even more detailed with a pixel size of 5 m. This is the most informative data set available, but it covers only a narrow belt along the coastline from Puttalam on the northwest coast to Batticaloa of the east coast. It has a vertical accuracy of about 0.5 m.

The river basin map (Survey Department, 1959), which divides Sri Lanka into 103 main river basins and inter-basin areas lumps together smaller catchments. However, this map was used as the outline map to be improved using more detailed information from 1:50,000 and 1:10,000 maps and the DEMs, particularly in the coastal areas. The present study discusses the suitability of available data for the improvement of the river basin map.

Table 1: Data sources

Data layer	Source	Resolution	Covered area
SRTM	http://glcf.umiaccs.umd.edu	90 m	Island
Landsat Mosaic	IWMI	15 m	Island
High resolution images - Ikonos	Asia Pacific Disaster Centre	1 m / 4 m	Galle District
High resolution images - Quick Bird	Asia Pacific Disaster Centre	60 cm/2.5 m	Galle to Colombo & Thirukkivil to Samanthurai and Pottuvil to Ampara
LiDAR	CCD		Coastal belt- Puttalam to Arugam Bay (Ampara District)

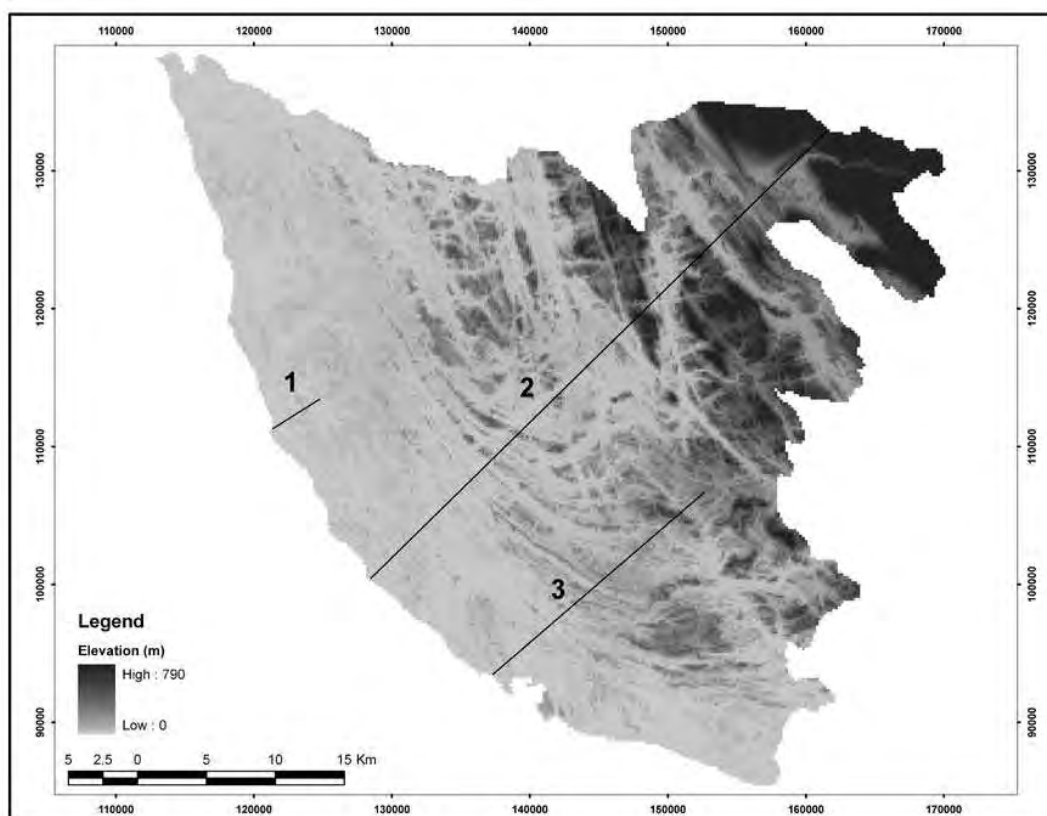


Figure 2: Locations of cross-sectional profiles for comparison of data sources

All topographic data used in this study (Table 1) are in Sri Lanka National Grid coordinate system with the central meridian and reference latitude centred on Pidurutalagala and false origin at 200,000 and 200,000.

This study compares results obtained from 1:50,000 map and SRTM DEM with more detailed topographic information obtained from 1:10,000 maps and LiDAR DEMs. The Galle district was selected for this study due to the availability of data from all the above sources in order to determine the adequacy of 1:50,000 maps and SRTM DEM for the delineation of catchment boundaries.

The comparison was based on elevation information derived from 3 profiles across the terrain and also using locations where spot heights are available from 1:10,000 maps. The profiles were obtained from the profiling tool in ArcGIS 3D Analyst and resampling the heights from the profile graphs for predefined distance intervals. The data obtained from different sources were plotted and R^2 was calculated for all pairs. The goodness-of-fit of the regression curve was estimated by R^2 statistic, which

is the percentage variance of the dependant variable explained by the independent variable. The profiles are also drawn using line graphs to show the differences among the different data sources.

The first step was to convert all available elevation data types to a common format. The elevation information from ABMP maps (1:50,000 and 1:10,000) were used to create two triangulated irregular networks (TINs), which were converted to DEMs using ArcGIS 3D analyst. For this comparison, three cross-sections extending from the coastline to the interior were selected and profiles were created for each DEM separately (Figure 2). The profile data were compared in order to determine the detailed topography shown by them in the flat coastal areas. The location of the three profiles is shown in Figure 2.

RESULTS

Profile 1 covers only the lowest elevations up to about 30 m near the coast (Figure 2), whereas profiles 2 and 3 cover more variable terrains. As can be seen from Figure 3, the

elevation of the land surface in the coastal area increases linearly from the coastline towards the interior on the 1:50,000 (ABMP 50k) DEM. Even though 1:10,000 maps (ABMP 10k) have spot heights below 5 m contour, the curve is almost flat in the coastal area. By contrast the curve obtained from LiDAR shows much greater variation. It can be said that the most irregular surface was obtained from LiDAR data, whereas 1:10,000 and 1:50,000 ranked second and third respectively in terms of topographic detail among the data compared.

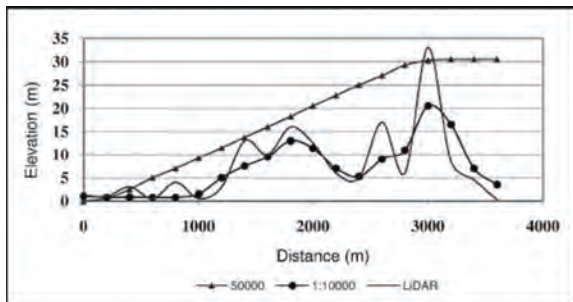
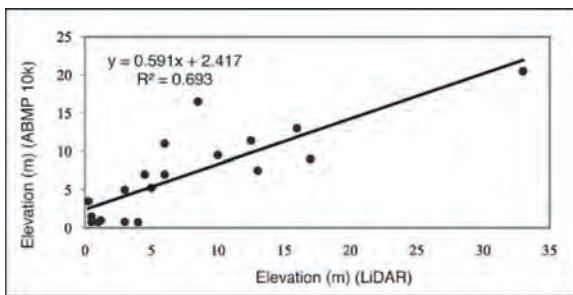
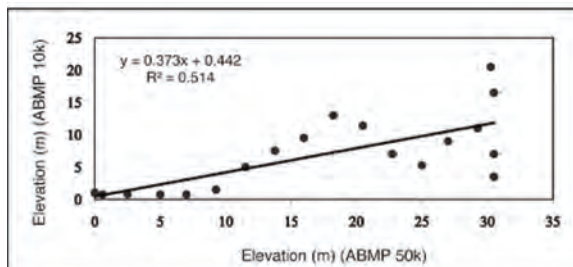


Figure 3: Variation of elevation along the profile 1



(a) Profile 1 - Elevation data from the LiDAR and 1:10,000 DEMs



(b) Profile 1 - Elevation data from the two maps (1: 10,000 and 1: 50,000)

Figure 4: Relationship between different data sources

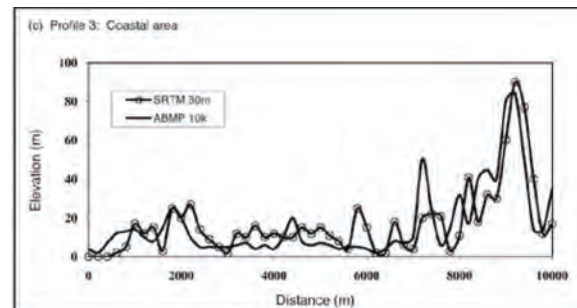
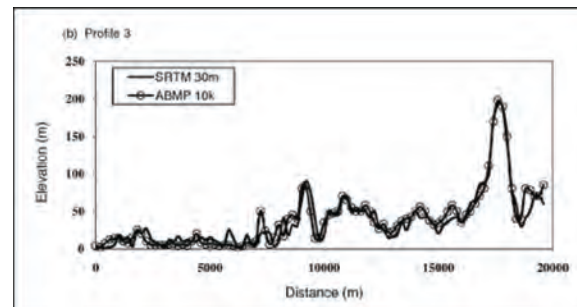
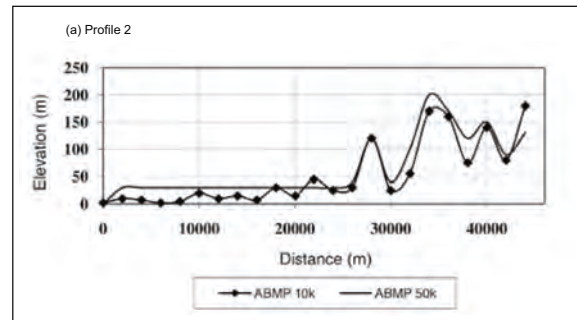


Figure 5: Elevation values from 1: 10,000 and 1: 50,000 DEMs (Profiles 2 and 3)

The elevation data from LiDAR, ABMP 10 k and 50 k DEMs were plotted and R^2 was calculated (Figure 4). Two scatter plots were produced using elevation values from LiDAR and the two ABMP DEMs. As can be seen from Figure 4a, elevation values from 10 k and LiDAR have a R^2 value of 0.69 compared to the lower value of 0.51 (Figure 4b) obtained for the two ABMP maps.

The ABMP 50 k map has failed to capture the relief accurately compared to the 10 k map in the coastal area (Figure 4b). Lower correlation suggests that the contour interval of the 50k map is not adequate for flat areas.

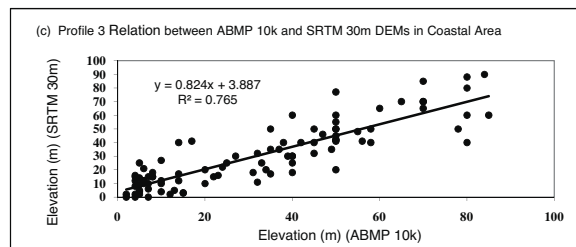
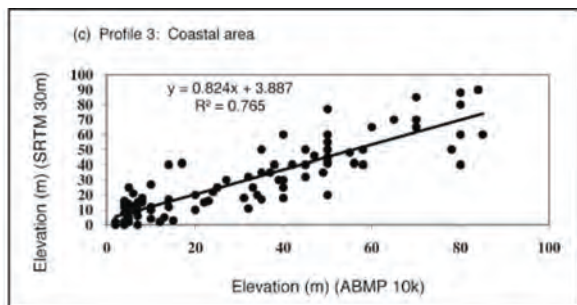
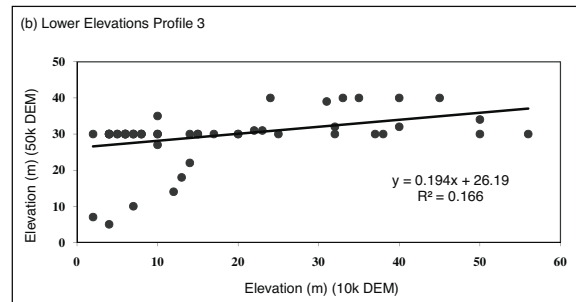
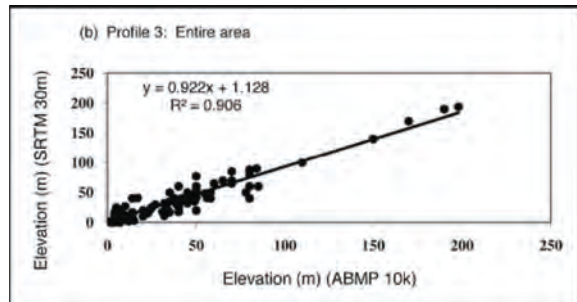
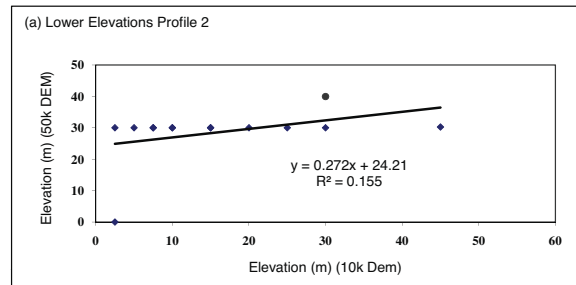
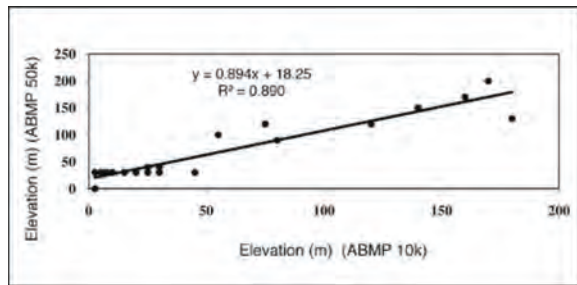


Figure 6: Relationship between ABMP 10 k and 50 k and SRTM 30 m DEMs for elevations from 0 to 200 m

Figure 7: Relationship between 1: 50,000 and 1: 10,000 DEMs at low elevations (0 to 40 m)

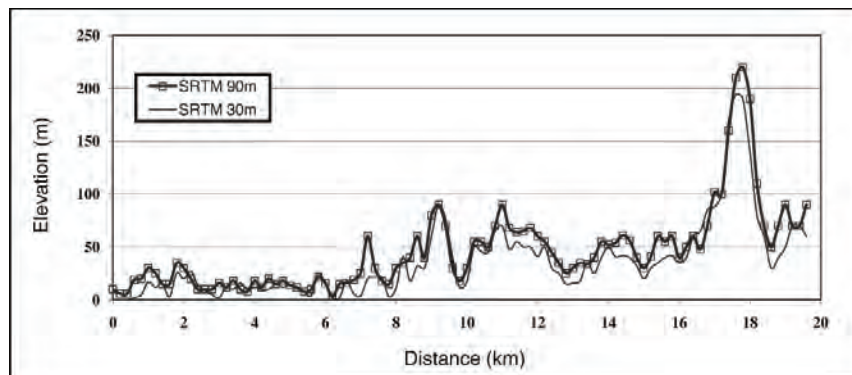


Figure 8: Elevation values from SRTM 90 and SRTM 30m DEMs

Figure 5 illustrates the variation of elevation in profiles 2 and 3 covering much greater distances from the coast. Profile 2 extends over a distance of about 44 km and covers a range of topographies, where elevation varies from the sea level to about 200 m.

At elevations above 30 m, the two ABMP maps show a vertical difference in elevation of about 25–50 m but the peaks of the curves tend to be at the same position.

A comparison between the Figures 5a and 5b shows that there is a better match between the SRTM and ABMP 10 k DEMs. A stronger match exists between the DEMs at high elevations than at low elevations (Figures 5a, b and c). This is well illustrated by the scatter plots and R^2 values (Figure 6). When the entire profile is used, high R^2 values of 0.89 and 0.91 were obtained between the two ABMP maps and between the SRTM 30 m and ABMP 10k DEMs, respectively. The latter R^2 value is slightly higher than the former. But when the data were confined to the coastal area up to about 100 m elevation, R^2 value between the SRTM and the ABMP DEMs dropped abruptly to 0.77. Lack of elevation data below the 20 m contour is the reason for the flat curve in the

profile derived from the ABMP 50 k DEM. In contrast, both SRTM 30 m DEM and ABMP 10 k DEM show fairly high degree of variation of elevation values in the coastal area.

The R^2 values obtained for the ABMP maps based on the lower parts of the Profiles 2 and 3 are 0.16 and 0.17, respectively (Figure 7). In contrast, the SRTM data shows a statistically significant relationship with ABMP 10 k map for the same area.

These results suggest that ABMP 50k maps are not suitable for the delineation of catchment boundaries near the shoreline where the terrain has a very low relief. It also shows that they are sufficiently accurate at elevations above 30 – 40 m.

The SRTM DEMs with 30 m and 90 m pixel size were compared in order to determine the effect of the pixel resolution on the accuracy (Figure 9). The match between two SRTM DEMs is very high when the entire profile is taken ($R^2 = 0.91$). However, the R^2 value drops to 0.4 at lower elevations. The SRTM DEM with 30 m resolution is therefore a better source of elevation data than the 90 m DEM.

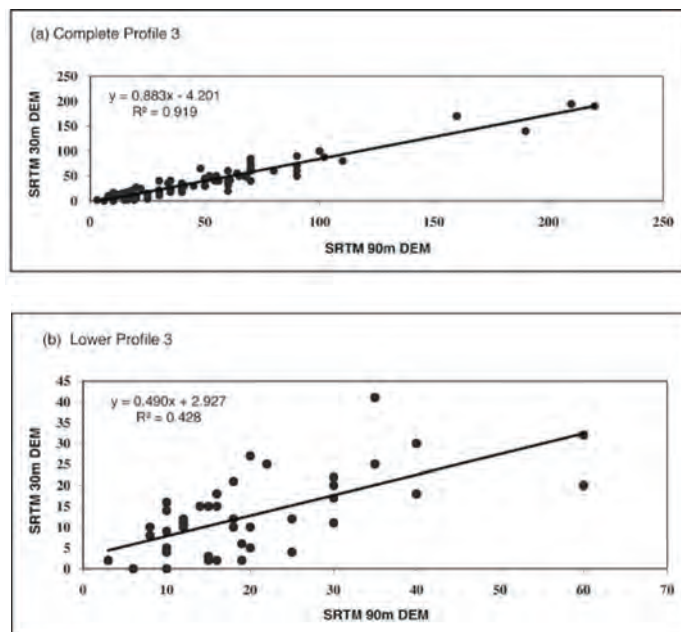


Figure 9: Correlation between SRTM 90 m and SRTM 30 m DEMS

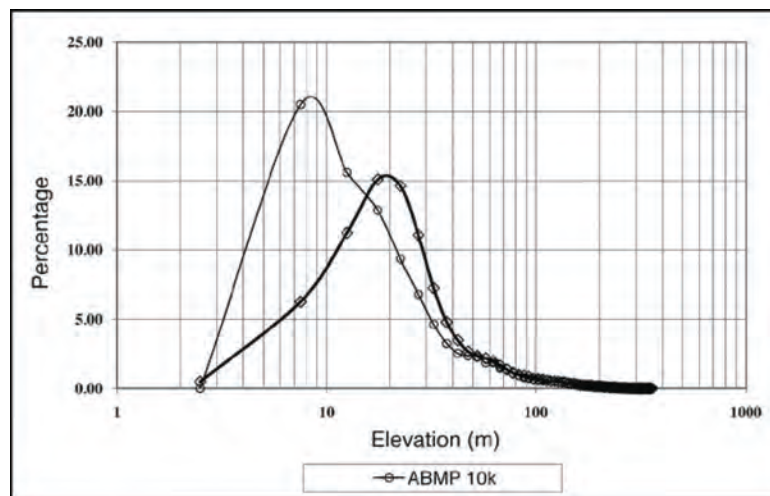


Figure 10: Frequency distributions of elevation obtained from 1: 10,000 map and SRTM DEM.

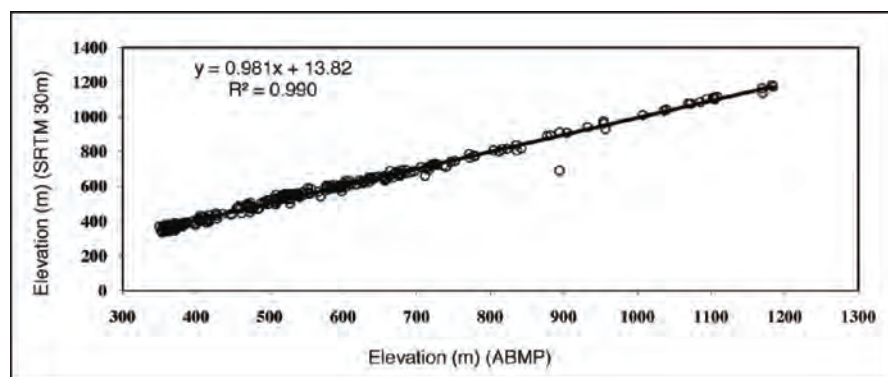


Figure 11: Relationship between ABMP 10 k and SRTM 30 m data above 350 m terrain

The comparison of spot heights from the ABMP 10 k maps of the Galle district and the SRTM 30 m confirms the results reported using the profiles. Figure 10 shows that the two curves peak at two different elevation levels (5–10 m class for ABMP data and 15–20 m class for SRTM data). It also shows that the peak of the SRTM curve is much lower than that of the ABMP curve. This suggests that the greatest mismatch in the elevation values is at the lower levels.

Log-normal graph was used to plot the data because of the long tail of high values in the curve.

Because the coastal area was identified as the problem area in the results discussed above, the two data sources, ABMP 10 k and SRTM 30 m were compared with the LiDAR data for the Galle district. The effect of the terrain height on the accuracy of the SRTM data was assessed separately for the elevations above and below 350 m contour. Figure 11 shows that at high elevations there is a strong correlation between the ABMP 10 k and SRTM data. The high R^2 value (0.99) indicates that the two data sources have a good match.

In the coastal area covered by the LiDAR DEM,

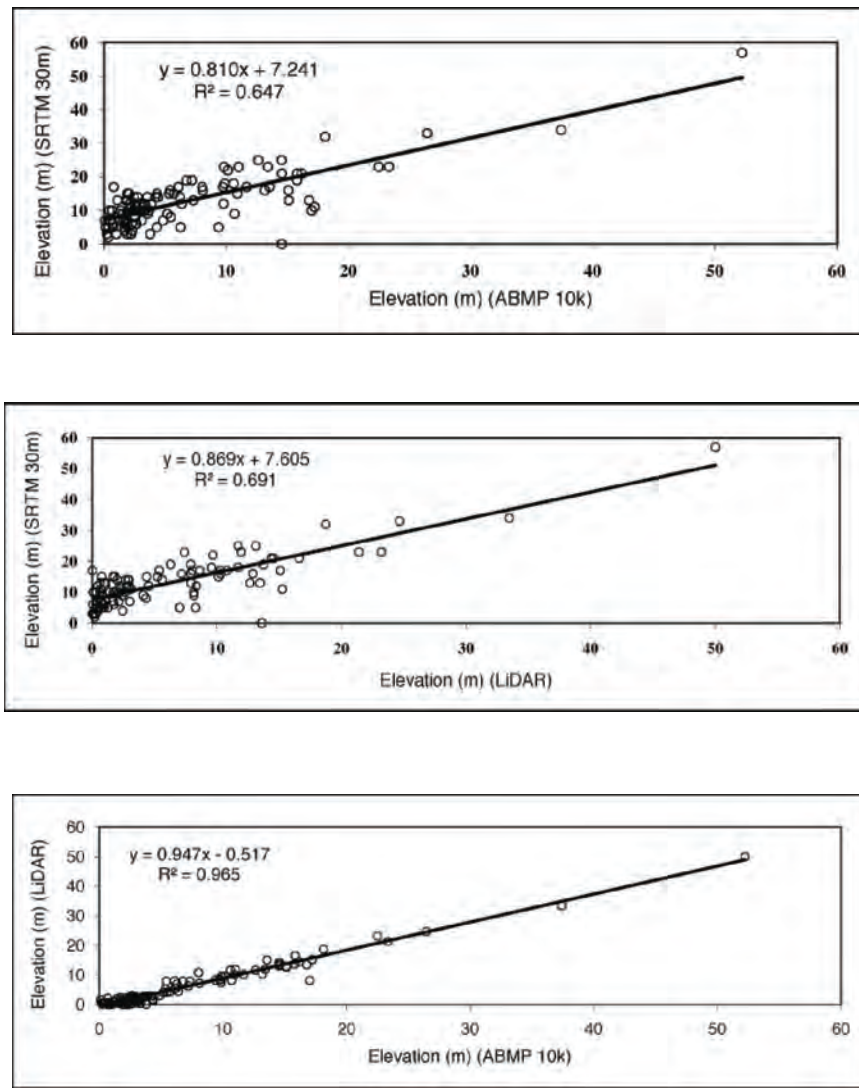


Figure 12: Comparison of elevation data for the coastal area

the elevation ranges from 0 – 60 m. A sample of 110 spot heights from ABMP 10 k maps was used in this comparison. Scatter plots were produced using SRTM 30 m, LiDAR, ABMP 50 k DEMs and spot heights from 10k maps (Figure 12). Of the pairs of data compared, the highest match was found between the LiDAR and the spot heights (ABMP 10 k) and the lowest between the two ABMP maps (10 k and 50 k). There is a slightly higher R^2 value (0.69) between SRTM 30 m and LiDAR data (Figure 12).

Figure 13 covers an area around the city of Galle. The elevation of the area varies from the sea level to about 78 m. The high elevation areas such as the Rumassala Hill on the southwestern side of the bay and the other hills in the southwestern area can be identified in all three DEMs. Similarly the hilly area to the northeast of bay can also be identified in the three DEMs. The closest match is between LiDAR and ABMP 10 k DEMs but the SRTM DEM displays a high level of match.

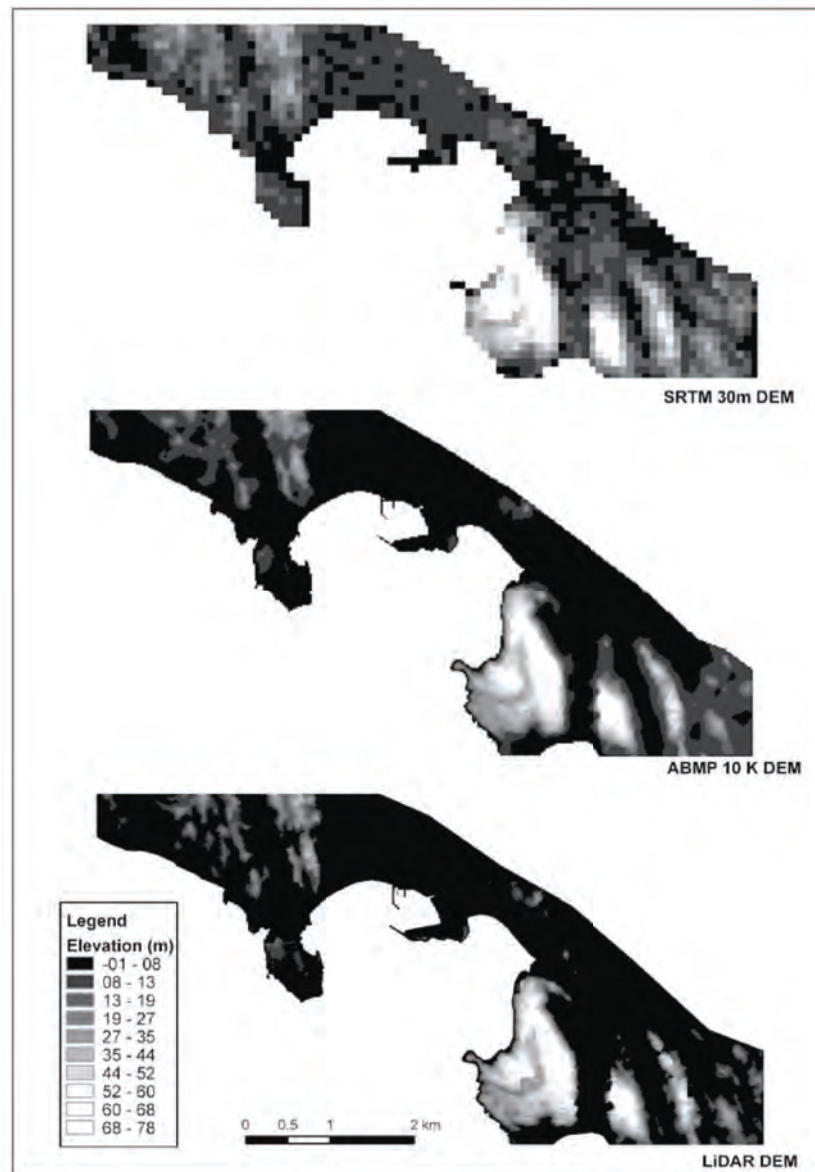


Figure 13: Elevation distributions in SRTM 30 m, ABMP 10 k and LiDAR DEMs

DISCUSSION AND CONCLUSION

The results of this study highlights the problems in the use of available maps for the delineation of catchment boundaries and the potential of new data sources in remedying this problem to a certain extent. The 1:50,000 maps were proven to be insufficient as an elevation data source for the delineation of catchment boundaries in the

flat areas due to the absence or sparseness of elevation data. Most coastal areas of Sri Lanka are flat terrain making it impossible to identify the catchment boundaries from ABMP 50 k maps. The most detailed source of elevation information among the available maps is the 1:10,000 ABMP series, but it does not cover the entire island at the present time. LiDAR data can be used as an alternative data source, which has the highest match with the 1:10,000 ABMP maps but its coverage is limited

to a 2 km wide belt along the coastline from Puttalam to Arugam Bay (Ampara district). This data source therefore is not adequate to use for the entire island. The SRTM 90 m dataset, which has been derived from the original 30 m compilation does not have sufficient accuracy in the coastal area. Even though the vertical error of the SRTM 30 m data is somewhat high as seen in this study as well as in the other studies described earlier, the profiles show that the high and low elevations in the terrain are captured by the SRTM 30 m DEM to the same level of accuracy as the ABMP 10 k DEM. Of all the datasets with island-wide coverage, SRTM 30 m dataset appears to hold promise for catchment delineation.

The SRTM DEM was selected as the most accurate elevation dataset for delineating the coastal inlet catchment boundaries to an acceptable level of accuracy for the entire island. The districts for which 1:10,000 series maps were not available, SRTM data was a viable source. It was also compatible with 1:50,000 maps in areas with high relief. This allows the use of SRTM data to map the catchment boundaries throughout the country.

Even though the vertical error of the data can be high at places, the position of the catchment boundaries can be mapped from the SRTM data for which only the relative height of the terrain is required. The results of inlet mapping study will be communicated in a subsequent paper.

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