Determination of the hydrological properties of a small-scale catchment area in Northern Greece from ASTER and SRTM DEMs and accuracy assessment with a local DTM

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Introduction

The combined use of Geographic Information Systems and recent high-resolution Digital Elevation Models (DEMs) from Remote Sensing imagery offers a unique opportunity to study the hydrological and hydrographic properties of basins.

Moreover, they provide a powerful tool to monitor catchment dynamics and derive the hydrological features of specific regions of various spatial scales.

Until recently, the availability of global DEMs was restricted to low-resolution and accuracy models, e.g., ETOPO5, ETOPO2 and GTOPO30, compared to local Digital Terrain Models (DTMs) derived from photogrammetric methods and offered usually in the form of topographic maps of various scales.

The advent of the SRTM and ASTER missions, offer some new tools and opportunities in order to use their data within a GIS to study the hydrological properties of basins and consequently validate their performance in terms of the results derived from a local DEM.

The present work focuses on the use of the recent SRTM v2 90 m and ASTER v2 30 m DEMs along with the national 500 m DEM generated by the Hellenic Military Geographic Service (denoted as HMGS DEM in the sequel), within a GIS in order

Data manangement and processing

In order to work on the satellite data and to produce appropriate datasets, ArcGIS v9.3 was used. For the hydrological analysis and to estimate potential flow, data such as: i) slope, ii) aspect, iii) contours, iv) basin areas, and v) flow lines were produced from SRTM and ASTER data.

Also, contours and flowlines (rivers) from the HMGS maps were digitized to produce DEM and raster sets for the comparison with the satellite image data.

The HYDROLOGY tool of Spatial Analyst (ArcGIS) was employed three times, one for each different dataset (HMGS, SRTM, ASTER).

The Hydrology Spatial Analyst Tool provides the algorithms for the creation of sequential raster files and the calculation and visualization of hydrological parameters.

The raster files produced from the SRTM and ASTER data are the following:

BASIN: creates drainage basins and sinks within the area of analysis by identifying ridge lines between basins. This results in a raster of drainage basins and sinks with specific pour points.

FILL: corrects the surface raster to remove small imperfections in the data and sinks.

FLOW ACCUMULATION: Creates a raster file showing direction of flow out of each cell for the study area.

FLOW DIRECTION: determines the direction in which water would flow out of each cell

FLOW LENGTH: Calculates distance or weighted distance along a flow path.

The data from the aforementioned raster files were used as input to calculation fields for the determination of maximum flow for each basin. The algorithm created for this purpose demands the following inputs from the processed raster files: Max Basin Elevation, Min Basin Elevation, Mean Basin Elevation, Flow Length, Basin Area.

The empirical equation of Turazza-Giandotti was used for this study, which is the most appropriate according to the Greek Legislation for evaluating *tc* (concentration time) in hrs., as follows:

$$t_c = \frac{4 \cdot \sqrt{F} + 1{,}5 \cdot L}{0{,}8 \cdot \sqrt{Z}}$$

where, F is the basin area in km^2, L is the flow length in km and Z is the Mean Basin Elevation-Min Basin Elevation in m. tc is needed for the calculation of maximum flow in the lowest outflow point of a basin.

The Max Flow is then calculated based on the following equation:

$$Q=A*i*C$$

where, Q is the Max Flow m^3/sec, A is Basin area m^2, I is the rainfall intensity in mm/hr and c is the curve number, showing runoff potential.

The rainfall intensity equation used for the study area, according to the Democritus University of Thrace (DUTH) is $i=(22.48*T^{0,1601})/t_c^{\,0.61455}$, where T took the value of 50 (years) of maximum rainfall reoccurrence. Curve number was determined as c=0.5 as a mean value for all basins.

Nr. of basins/subbasins and estimation of total max flow

DEM	BASINS	MAX FLOW (Q) in m^3/sec
SRTM	8 main basins +7 subbasins	845.35
ASTER	5 main basins +8 subbasins	887.63
HMGS	6 main basins +8 subbasins	974.72

Objectives

The main objective of this work is to evaluate the performance of the satellite-based DEMs to derive the hydrographic and hydrological characteristics of a small-scale catchment area in Northern Greece, a part of river Kosynthos. The main aim was to determine the most appropriate dataset, that provides reliable results for further use in hydrolocial and hydraulic analysis. The primary data needed in such studies, should provide spatial and elevation data for the calculations and analysis of characteristics of hydrological basins. From the processing of this data, results such as basin characteristics and hydrographic network characteristics are derived. These characteristics comprise the input to an evaluation model for the determination of flow and potential flooding. The final objective was to calculate and visualize the floodplain results of a total river length of 12.5 km which is the last part of river Kosynthos from the city of Xanthi to the borders of the Prefecture of Xathni, approximately 2.5Km away from its outflow in the Vistonida Lake.

The ASTER 1", SRTM3" DEMs and topographic maps by the Hellenic Military Geographic Service (HMGS) of 1:50,000 and 1:5,000 of scale are utilized to determine the topographic characteristics of the area under study bounded between 41.0° ≤ ϕ ≤ 41.5° and 24.6° ≤ λ ≤ 25.2°.

These refer to parameters like aspect, slope, hillshade, etc. and to the evaluation of the DEM differences themselves. For the validation, the local HMGS DEM derived by digitization of topographic maps has been used as ground truth.

Following that, the hydrographic characteristics of the area are modeled from all available data sources, referring to stream network geometry and classification, as well as to basin delineation.

Finally, the hydrological characteristics are presented, referring to flow accumulation, curve number, flooding areas, etc..

Stream classification is based on the Strahler system, while all processing has been done utilizing the Hydrology, Spatial Analyst and 3d Analyst tools within ArcGIS v9.3, and HEC-RAS v. 4.1.

Statistics of the available HMGS (local), ASTER and SRTM DEMs and their comparison

	max	min	mean	rms	std
DEMs					
HMGS	1715.000	1.000	535.975	±633.048	±336.868
ASTER 1″	1819.000	4.000	536.679	±633.562	±336.715
SRTM 3″	1814.000	0.000	542.193	±638.759	±337.698
DEM Differences					
HMGS-ASTER	210.992	-222.164	1.047	±47.913	±47.902
HMGS-SRTM	249.000	-286.000	-9.454	±53.621	±52.781
ASTER-SRTM	164.875	-136.063	-6.060	±22.522	±21.691

Flood estimation

The max flow Qmax derived from the different datasets shows significant variations that would lead to different flooding areas. The HMGS results were chosen to be the input in RiverCAD Professional (Autodesk). In order to analyse and model the hydraulics of water flow through natural rivers and other channels. RiverCAD supports river modeling with a built-in CAD engine using HEC-2 and HEC-RAS software (U.S. Army Corps of Engineers).

The Geometric data imported in RiverCAD were derived from field surveying carried out to a total length of 12.5 km with a surveying zone of 1.1 km width from the river reach.

The Floodplain Map Analysis gives the option for generating GIS coverages of flooding areas. The coverage was then reintroduced to ArcGIS visualizing the flooding area. The maximum flow from HMGS was finally used to determine the flooding areas as it provided the overall maximum value compared to ASTER and SRTM.

Conclusions

Global DEMs provide a representation of local topographic features with reasonable agreement compared to the local HMGS model. The differences of the order of ~47-52 m are considered satisfactory given the accuracy of the local DEM itself (estimated at the order of ~10 m).

Such global based DEM data can be used for hydrological studies, given proper control with local models.

The derived hydrological characteristics from ASTER and SRTM need to be corrected so that no discontinuities and blunders in the derived features exist.

Even though the satellite data agree well with the ones from HMGS, in flood-related studies one should predominantly work with the overall maximum flow, so as to be on the safe side, w.r.t., flood risk management and flood prevention.

DEMs and Validaiton

From the available global and local DEMs, their topographic characteristics have been derived.

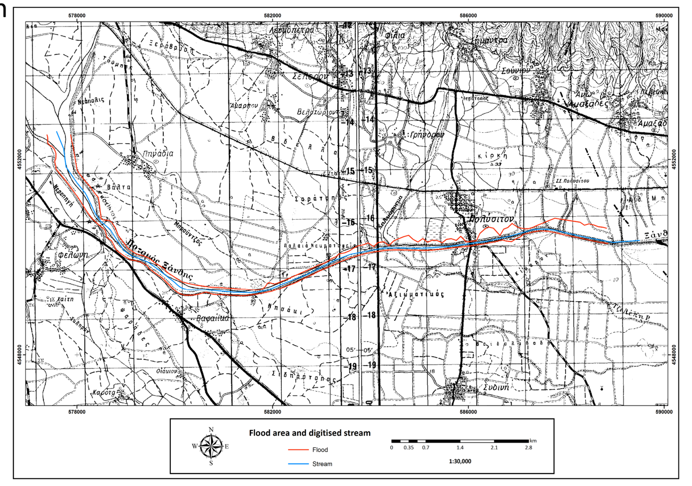
Comparing ASTER 1" with the local model, an agreement at the ±48 m was found, while the mean value was very small reaching only ~1m. This is shows that the ASTER DEM can be considered as bias-free, at least compared to the local DEM.

On the other hand, the SRTM3" differences with the local DEM was at the ±53 m, with a larger mean of ~10m. The two global DEMs show a difference of ±22 m with a mean of ~6 m.

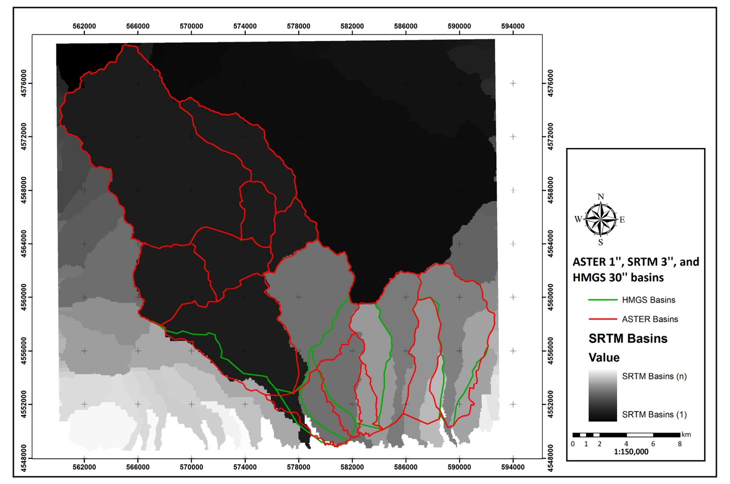
From the histogram of the differences between the DEMs, it can be seen that the one between ASTER and HMGS show a normal distribution with small side-lobes, while the ones between SRTM and HMGS have larger side-lobes with smaller concentration within a 1σ and 2σ region.

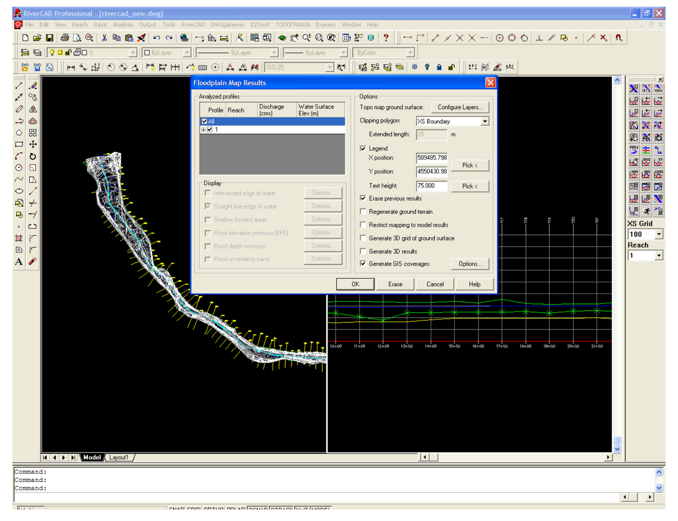
As expected, the largest differences are found in areas with high altitude and steep slope, where the resolution of the local DEM is not capable to represent the fine detail given by the ASTER and SRTM DEMs. It is interesting also to note that SRTM has a tendency to provide smaller heights.

Flood area and digitized stream



Basin delineation from the available DEMs



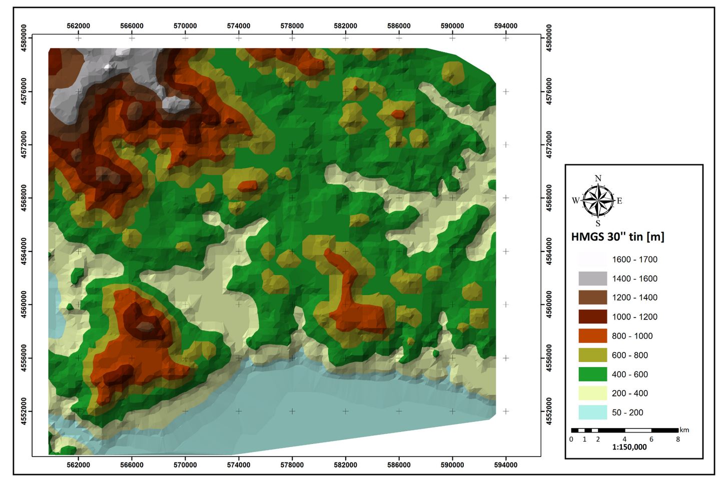


Floodplain analysis and modeling in RiverCAD

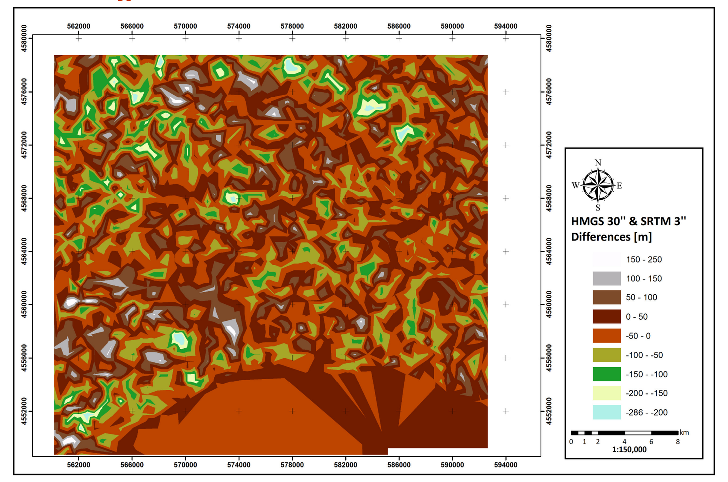
From the hydraulic analysis it was finally derived that severe flooding occurs in approximately 5 km downstream.

In some areas the flooding width exceeds 150 m from the river banks.

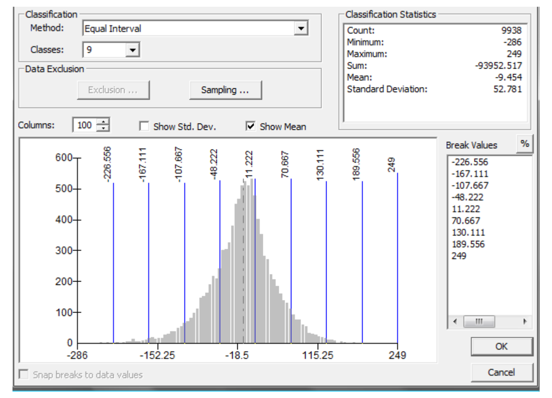
Local HMGS DEM



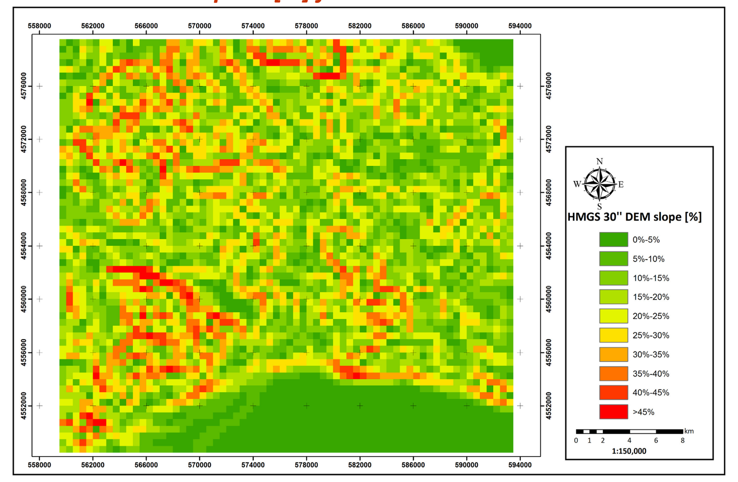
Differences between the HMGS and SRTM DEM



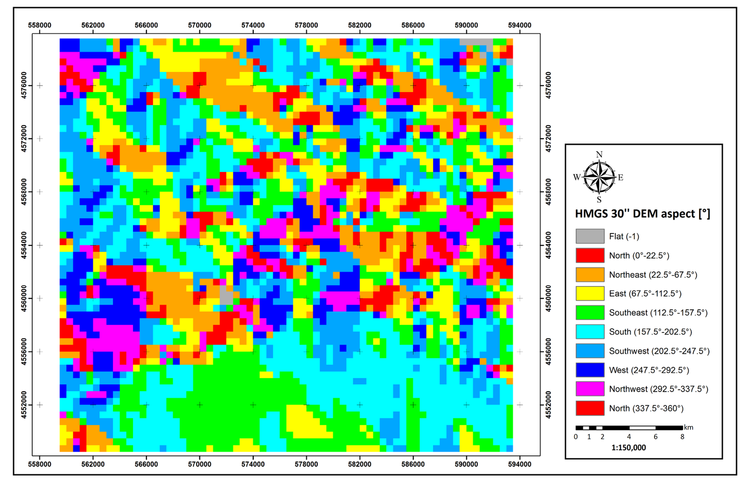
Distribution of the differences between the HMGS and SRTM DEM



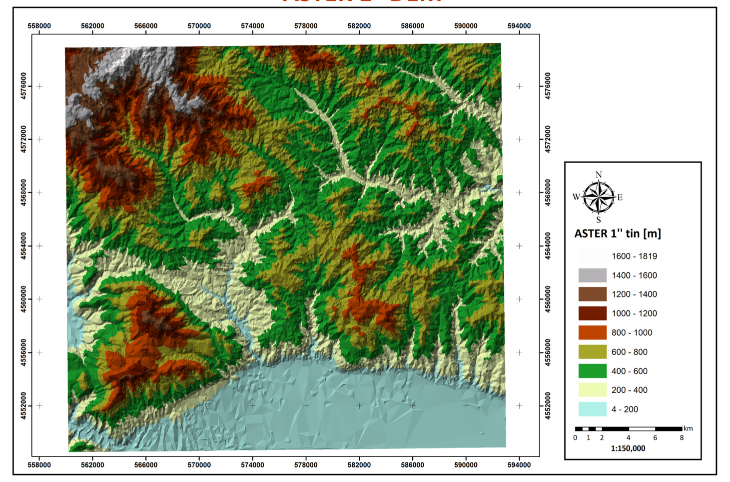
Slope in [%] from the HMGS DEM



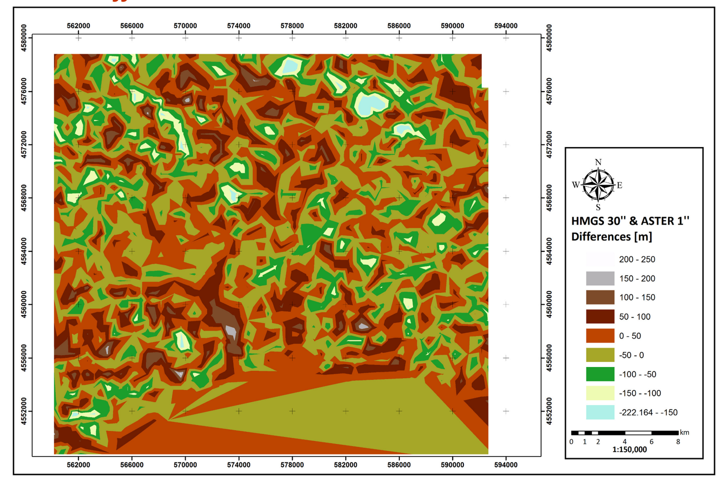
Aspect in [°] from the HMGS DEM



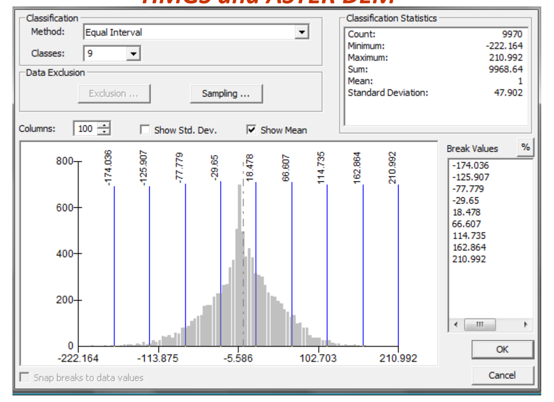
ASTER 1″ DEM



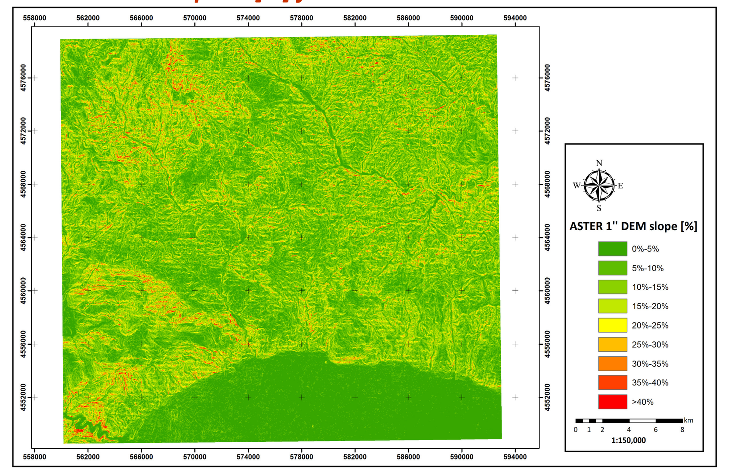
Differences between the HMGS and ASTER DEM



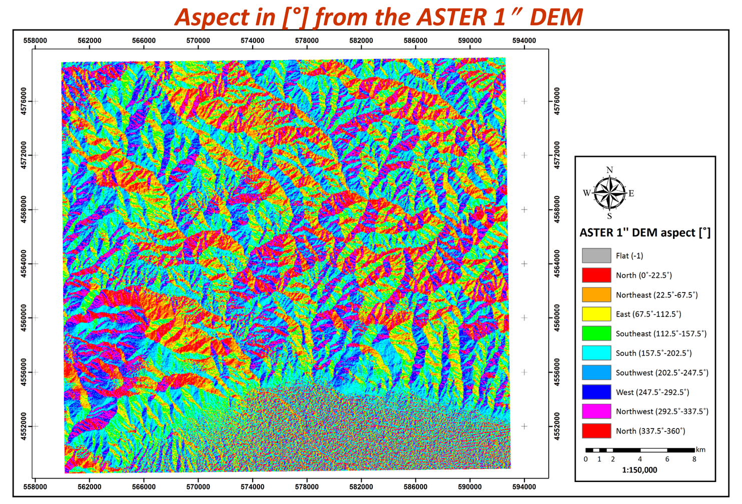
Distribution of the differences between the HMGS and ASTER DEM



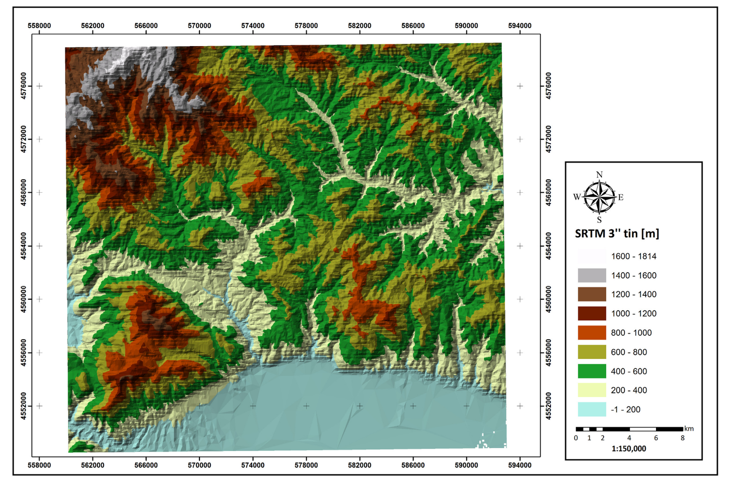
Slope in [%] from the ASTER 1″ DEM



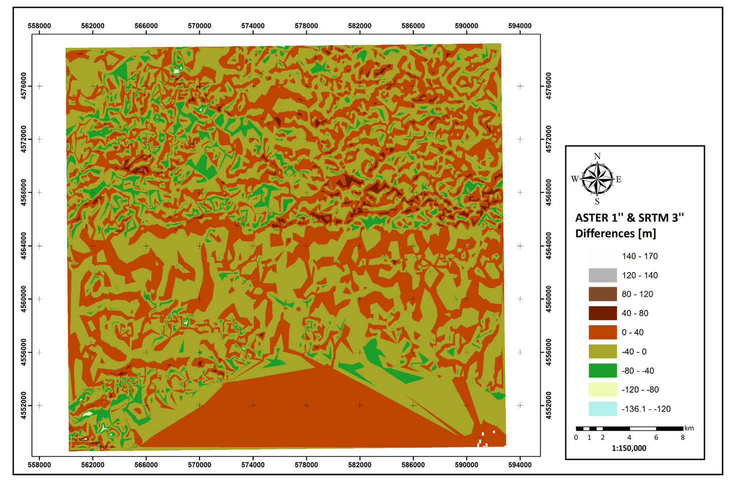
Aspect in [°] from the ASTER 1″ DEM



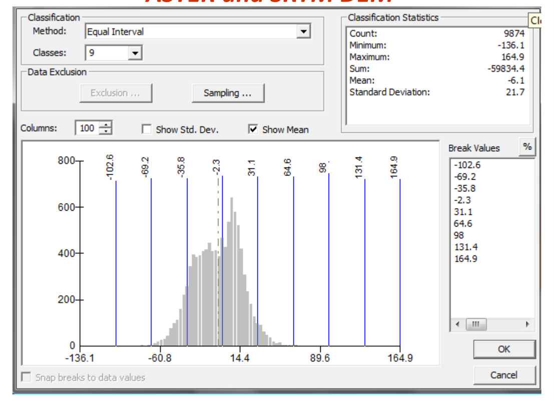
SRTM 3″ DEM



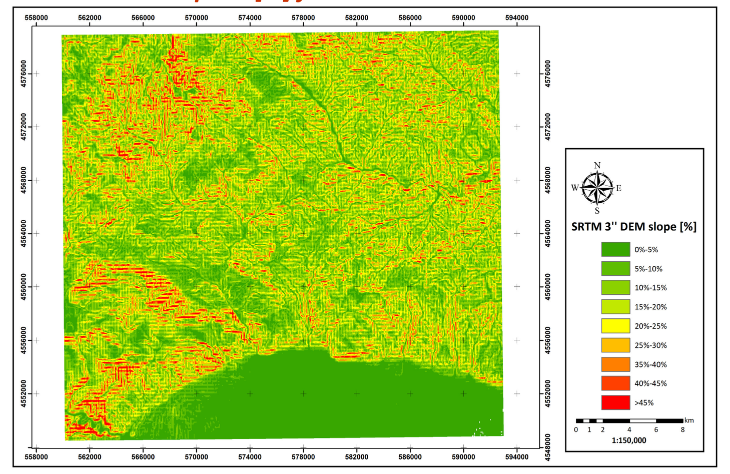
Differences between the ASTER and SRTM DEM



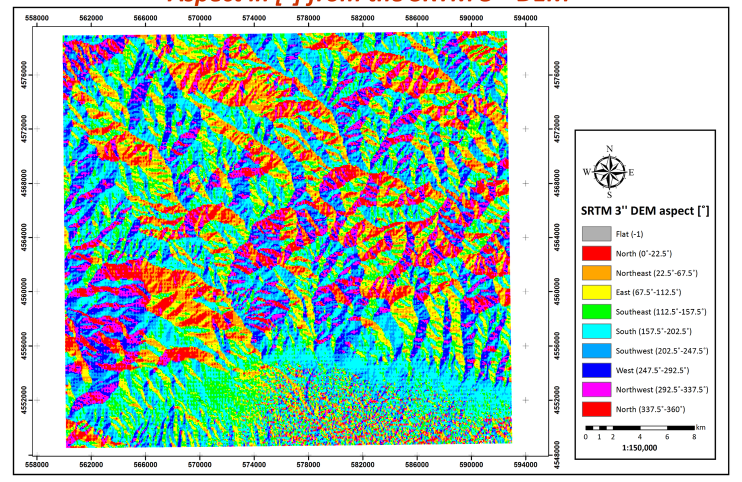
Distribution of the differences between the ASTER and SRTM DEM



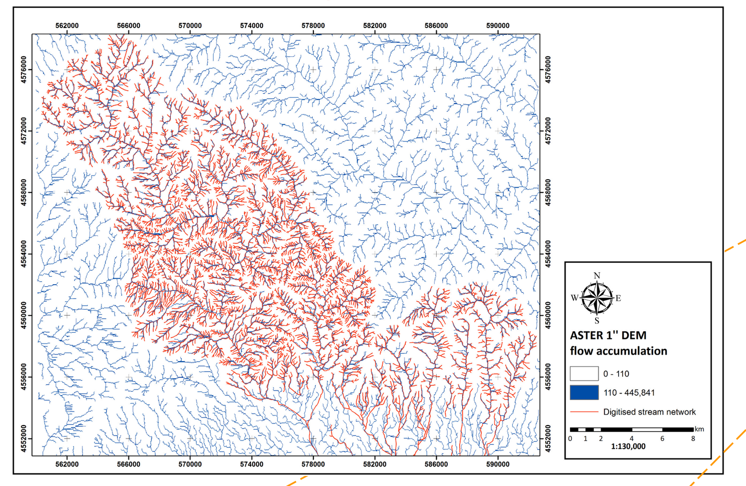
Slope in [%] from the SRTM 3″ DEM



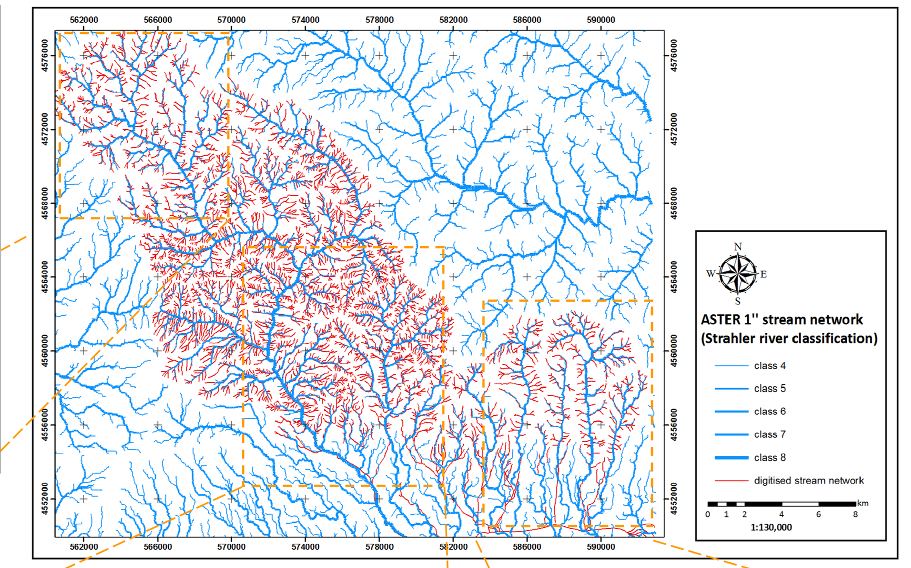
Aspect in [°] from the SRTM 3″ DEM



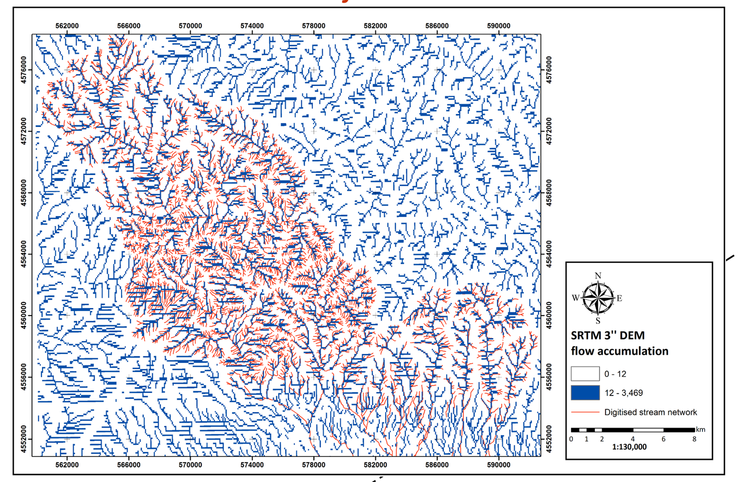
Flow accumulation from the ASTER 1″ DEM



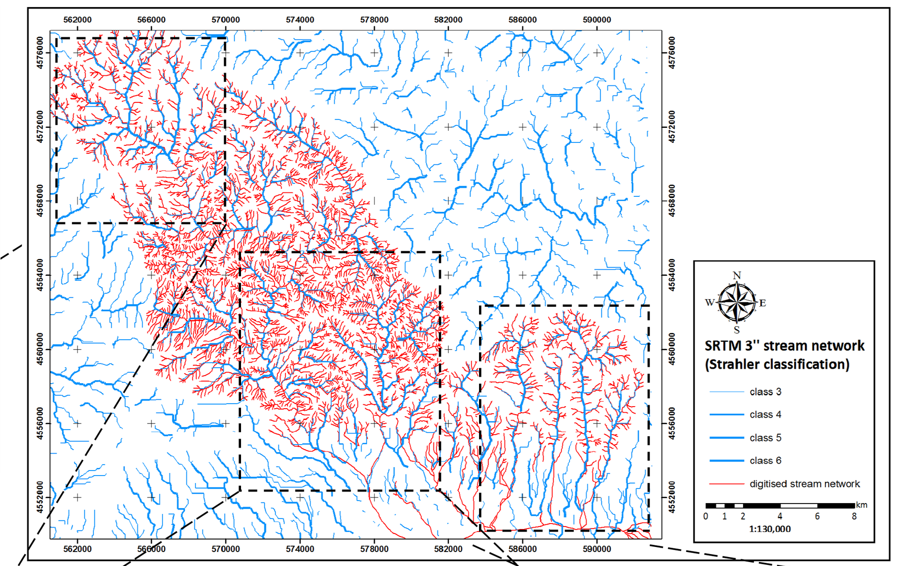
ASTER 1″ DEM stream classification and correlation with the local DEM

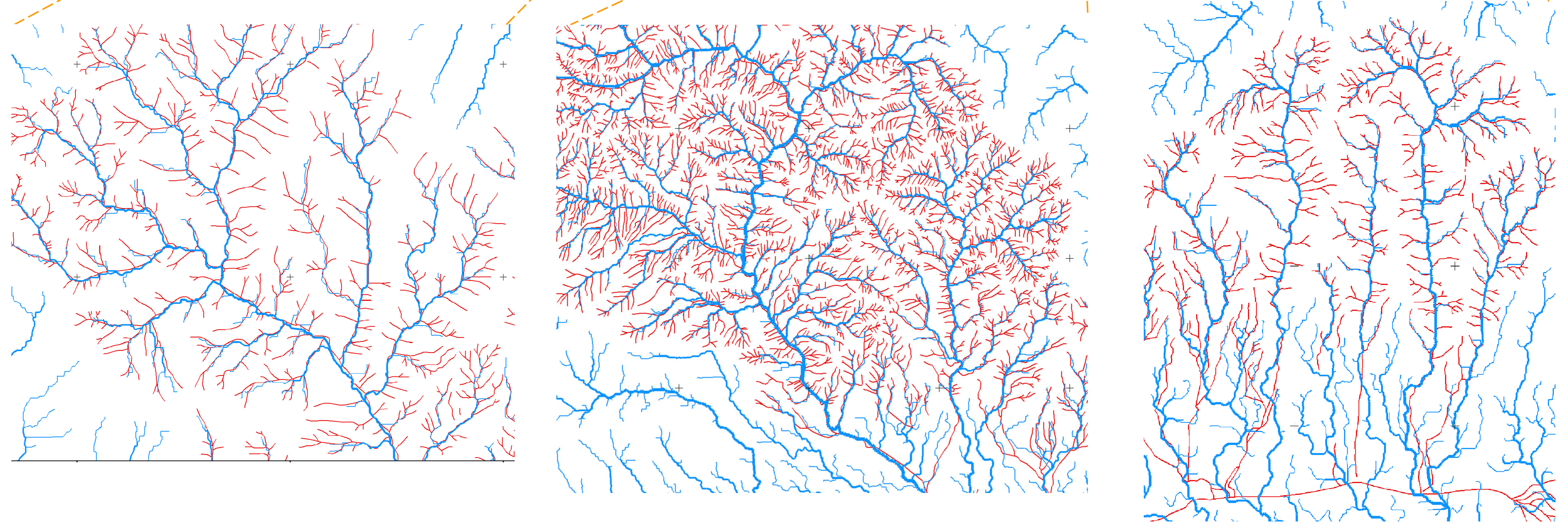


Flow accumulation from the SRTM 3″ DEM

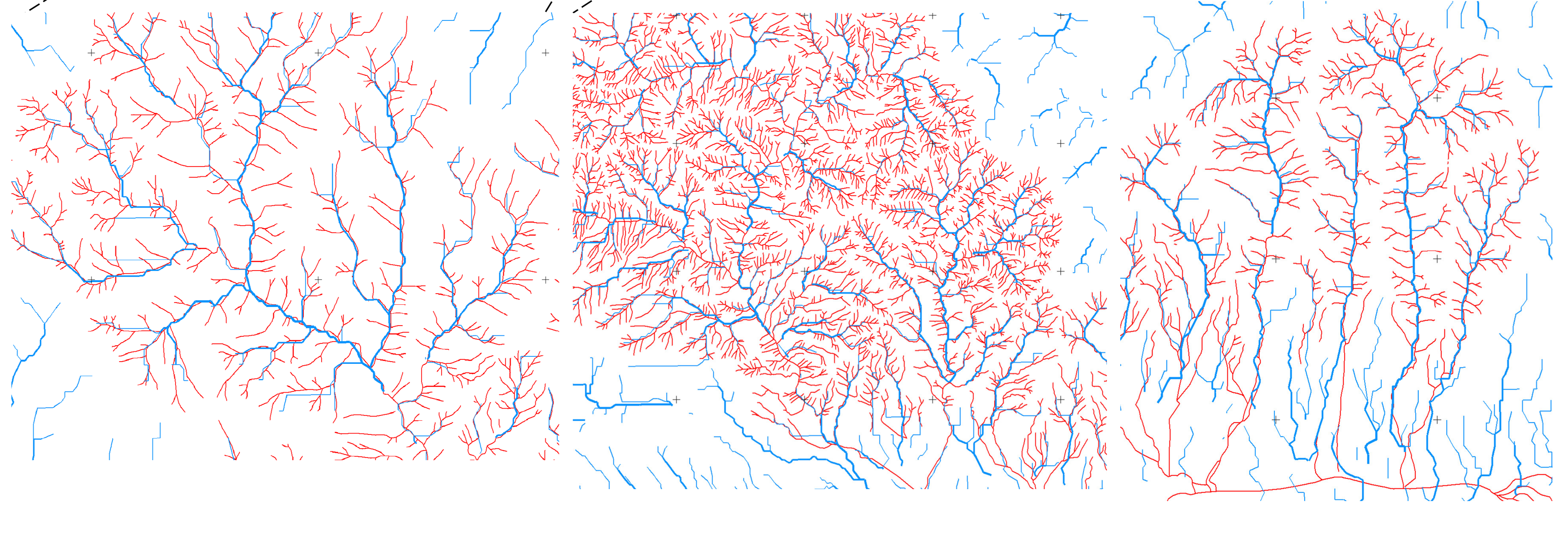


SRTM 3″ DEM stream classification and correlation with the local DEM





ASTER 1″ DEM stream classification and correlation with the local DEM for three inner areas within the wider area under study



SRTM 3 DEM stream classification and correlation with the local DEM for three inner areas within the wider area under study

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