COMPARISON AND ASSESSMENT OF SRTM AND ASTER GDEM AGAINST NATIONAL TOPOGRAPHIC MAPS AS DEM SOURCES FOR LEYTE GEOTHERMAL PRODUCTION FIELD, PHILIPPINES

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ABSTRACT: Energy Development Corporation (EDC) has been using 1:50,000 topographic maps produced by the National Mapping and Resource Information Agency (NAMRIA) as geothermal resource exploration and management base maps since the 1950's. EDC, however, begun to explore other conceivable sources of digital elevation models (DEM) owing to lack of updates in the NAMRIA maps and the release of publicly available remotely-sensed global elevation information. The aim of this research is to evaluate the suitability of SRTM and ASTER DEMs as possible alternative sources of elevation information, relative to currently used topographic base maps, at EDC's geothermal field in Leyte. The study area is located in the moderately mountainous western part of Visayas, Philippines. The assessment of SRTM and ASTER DEMs was done through visualization and statistical analysis in a GIS platform. Transect lines, passing through locations with different profiles and land cover types, were statistically analyzed (i.e. through min, max, mean, and RMSE) in order to characterize the global DEMs against the national DEM. Results show that SRTM and ASTER DEMs have similar RMSE values of 4-6 m when compared against NAMRIA topographic maps. However, maximum elevation differences of around 40-100 m were seen especially at locations with relatively high elevations. Based from the results presented in this research, an updated and appropriate supplement for currently used national topographic maps in Leyte suitable for geothermal exploration and management purposes is recommended.

1. INTRODUCTION

Digital Elevation Models (DEM) are mathematical or statistical representations of terrains that are usually expressed in X, Y, Z coordinates (Li, Zhu, & Gold, 2005; El-Sheimy, et. al., 2005). Other alternative names used are Digital Height Models (DHM), Digital Ground Models (DGM), Digital Terrain Models (DTM), Digital Terrain Elevation Data, and Digital Surface Models (DSM). DEMs, which were initially introduced during the 1950's, are now seeing widespread use because they can yield accurate representations of relief and can be easily processed using computers (Cirés, et. al., 1997).

For example DEMs have been used in mapping geologic structures and rock unit boundaries (ibid.), three-dimensional modeling of geothermal reservoirs (Hlavácová, 2009), landslide and geohazard prediction and modeling in Geographic Information Systems (GIS) (Gorsevski, et. al., 2006), environmental and hydrologic watershed studies (McDougall, Liu, Basnet, & Apan, 2008), and pipeline route selection in geothermal fields through GIS for engineering construction purposes (Kjaernested, et. al., 2011). In fact, nowadays, satellite-derived or remotely-sensed DEMs are also widely used in various scientific and engineering applications. Some studies include topographic modeling of volcanoes using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data (Kervyn, et. al., 2006), hazard analysis using geophysical flow models and Shuttle Radar Topography Mission (SRTM) data, and the use of SRTM DEM for short-wavelength gravity reduction for geoid modeling purposes (Manandhar & Forsberg, 2008).

With such vast applications in mind, this paper aims to characterize and analyze existing and available DEMs at the Leyte Geothermal Production Field (LGPF). This research is also a response to the perceived underutilization of existing DEM data at the disposal of EDC. The company, throughout the course of the past years, has already accumulated vast satellite imagery and remotely sensed data that just sit inside digital storages. This study is also one of the ways of addressing the common and growing concern among map users in the company that existing base maps no longer represent actual locations on ground.

Analysis in this research will be done through visualization and statistics. The DEMs that will be used are from traditional sources (i.e. national mapping authorities) and remotely-sensed data. It is envisioned that this research will spearhead DEM-based applications that will be beneficial to Energy Development Corporation's (EDC) geothermal resource exploration and management activities.

2. STUDY AREA

The chosen study area for this research is the development block of LGPF, found at the moderately mountainous part of Leyte Island, Western Visayas, Philippines (Fig. 1).

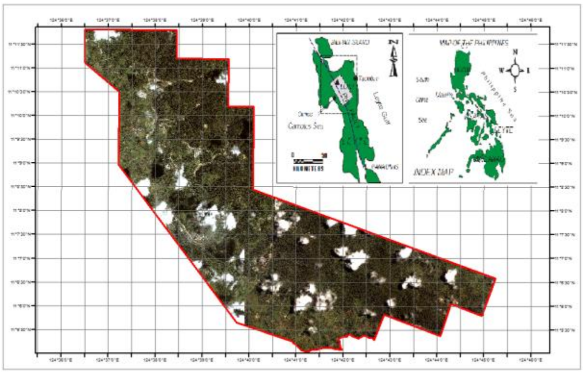

Figure 1. Location of the Leyte Geothermal Production Field.

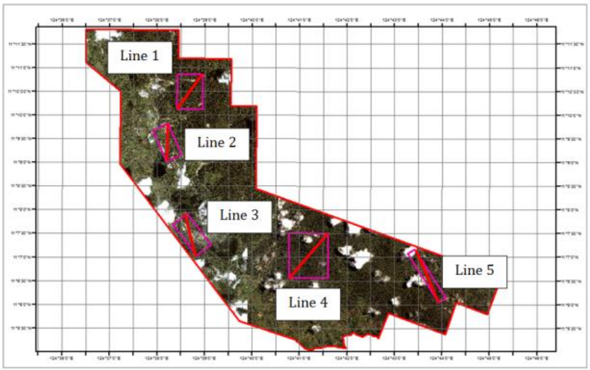

Figure 2. LGPF development block showing locations of transect lines.

LGPF spans Ormoc City and the Kananga Municipality in West Leyte, covering an area of almost 108,000 hectares. LGPF is the world's largest wet-steamfield geothermal facility with over 700 MW of total plant capacity.

The red boundary (Fig. 2) indicates the extent of the development block of LGPF which covers approximately 780 hectares of land. It is located along the northwest trending of the Philippine Fault and encompasses six important geographic sectors, namely, Mahiao, Sambaloran, Malitbog, Mamban, Mahanagdong and Bao valley. Two independent hydrothermal systems also exist within the block, namely, the Tongonan geothermal field and the Mahanagdong geothermal field (Apuada, et. al., 2005).

3. DATA SOURCES

Three sources of DEMs were used in this research. The first ones are the national topographic maps produced by NAMRIA. NAMRIA topographic maps were generally published during the 1950's and are sold as 1:50000 maps with 20 m – 100 m contour intervals. NAMRIA maps are usually projected at the Luzon 1911 datum (National Mapping and Resource Information Agency, 2011). For this research, digitized versions of NAMRIA maps covering the area of interest were used.

SRTM-3 90m x 90m DEMs covering the area of interest were also analyzed in this research. The US space shuttle Endeavor carried the SRTM payload into space on Febuary 11, 2000 (www2.jpl.nasa.gov/srtm). During its eleven-day mission, SRTM used radar interferometry in order to obtain topographic data of 80% of the Earth. The SRTM-3 data (i.e. srtm_61_10 tile) used in this study were downloaded from CGIAR-Consortium for Spatial Information website (http://srtm.csi.cgiar.org/).

The third source of DEM for this research is the ASTER DEM (http://asterweb.jpl.nasa.gov/). The ASTER payload, which is a joint project of US and Japan, is onboard the satellite Terra orbiting the Earth at around 705 km. It is using an imaging system that uses a Nadir and Aft viewing camera, enabling the sensor to generate stereoscopic images suitable for DEM generation (Reuter, et. al., 2009). The ASTER DEMs used in this study (i.e. ASTGTM_N11E124 and ASTGTM_N11E124 tiles) were downloaded at the Global Visualization Viewer (GloVis) website (http://asterweb.jpl.nasa.gov/glovis.asp) of US' Jet Propulsion Laboratory (JPL).

4. METHODOLOGY AND RESULTS

All of the DEMs used in this research were visualized and analyzed in a Geographic Information Systems (GIS) platform. This is deemed advantageous since all the other ancillary data (i.e. boundaries, 1m-spatial resolution satellite image, etc.) used in this research were already stored in a GIS environment.

The SRTM and ASTER DEMs were first truncated so that only the portion covering the LGPF development block will be included in the analysis. Grid files were created for each DEM and subsequently, contour lines were extracted from the raster grids. For the NAMRIA DEM, the reverse was done since what were available at first were contour lines. Major contours were given at 100 meter-intervals while minor contour lines were at 20-m intervals. From these contour elevations, a raster grid file from the NAMRIA topographic maps was generated.

The generated grid images and contour lines were then visually analyzed by comparing the general behavior of the contour lines and by overlaying the grid images onto the available Very-High Resolution (VHR) image of LGPF. No noticeable deviations between the generated raster grids and the VHR image base map were noticed during visual inspection. However, despite the fact that all were eventually re-sampled to equal grid cell sizes, the contour lines generated for each of the grid files did not overlay completely. This is attributed to the differences in resolution of the DEM sources (i.e. approx. 90 m-grid cells for SRTM, approx. 30 m-grid cells for ASTER, and 20-m contour intervals from NAMRIA topographic maps).

As expected, the NAMRIA DEM gave the most detail in terms of displayed elevation values (i.e. there are lots of vertices in the contour lines, closer contour intervals, etc.). ASTER and SRTM generated DEM were less detailed and looked smoother in appearance. However, noticeable spurious contours (i.e. sudden peaks and troughs) were noticed in the ASTER contour map and DEM, especially at the western side of the study area. Figs. 3-5 below show the derived DEM/contours for each of the data sources. Ranges of elevation values for the DEM grids are in meters.

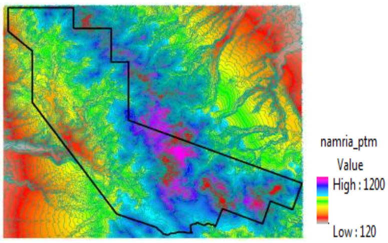

Fig. 3. NAMRIA DEM and contour.

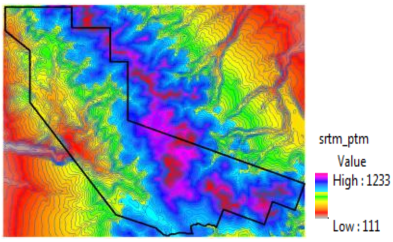

Fig. 4. SRTM DEM and contour.

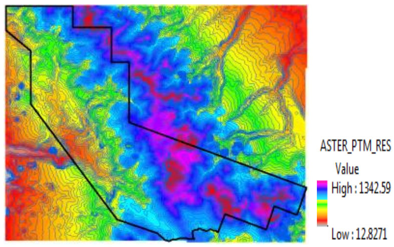

Fig. 5. ASTER DEM and contour.

Statistical comparison of the satellite-derived DEMs against the NAMRIA-derived DEM was done by comparing the mean, maximum, minimum, standard deviation, and root-mean-square values of elevations derived from transect lines. Transect/profile lines were made to pass-through five locations (Fig. 2) that more or less characterize the overall manner of the topography within the development block of LGPF.

In this research, SRTM and ASTER elevation were represented as “Z” and NAMRIA-derived elevations were represented as “Z*”. The statistical values were then derived as

$$\min = \min(|Z^* - Z|) \quad (1)$$
$$\max = \max(|Z^* - Z|) \quad (2)$$
$$\text{mean} = (|Z^* - Z|)/n \quad (3)$$
$$\text{rmse} = \text{sqrt}((|Z^* - Z|)/n) \quad (4)$$
$$\text{stdev} = \text{sqrt}((\Sigma(Z^* - ((|Z^* - Z|)/n))/(n-1)) \quad (5)$$

where n is the total number of points where elevations are extracted (Sertel, 2010). Profile graphs and statistical results are shown below.

Fig. 6. Profile of Transect Line 1.

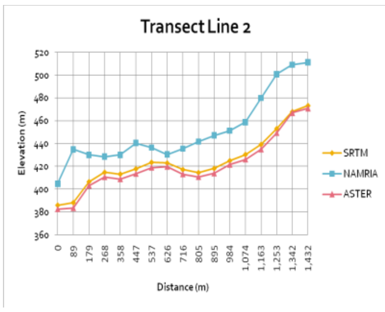

Fig. 7. Profile of Transect Line 1.

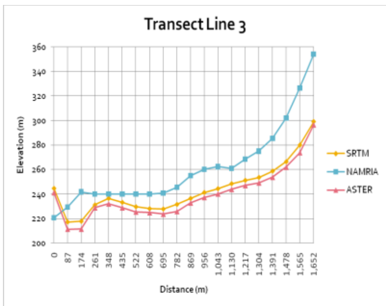

Fig. 8. Profile of Transect Line 1.

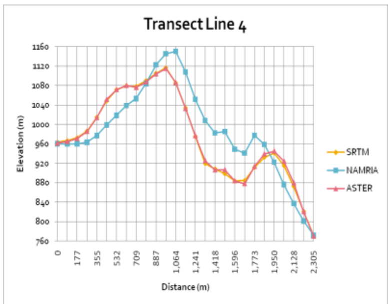

Fig. 9. Profile of Transect Line 1.

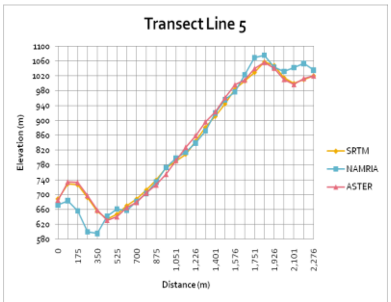

Fig. 10. Profile of Transect Line 1.

Table 1. Derived statistical values of transect lines. All values in meters.

	Transect Line 1		Transect Line 2		Transect Line 3		Transect Line 4		Transect Line 5	
	NAMRIA vs SRTM	NAMRIA vs ASTER	NAMRIA vs SRTM	NAMRIA vs ASTER	NAMRIA vs SRTM	NAMRIA vs ASTER	NAMRIA vs SRTM	NAMRIA vs ASTER	NAMRIA vs SRTM	NAMRIA vs ASTER
min	0.62	1.37	7.54	10.79	3.51	8.01	0.31	1.39	0.88	1.27
max	40.83	40.64	47.72	51.67	55.06	57.64	88.43	82.77	92.91	98.02
mean	16.77	14.57	27.05	30.81	19.94	23.97	40.57	40.61	21.98	24.10
stdev	12.83	11.55	12.14	11.98	13.00	13.07	26.86	26.63	23.17	24.01
rmse	4.10	3.82	5.20	5.55	4.46	4.90	6.37	6.37	4.69	4.91

As can be seen on the profile graphs (Figs. 7-11), all three DEMs generally follow the same form or shape. This is seen to be as a good indication of how the DEMs represent the actual shape of the terrain at LGPF. However notice that there is no clear trend on whether the derived values for the NAMRIA DEM are always greater or lesser than the derived elevation values from ASTER and SRTM DEMs. It can also be seen that the SRTM and ASTER DEMs have greater correspondence to each other.

Transect Line 1, which traverses a hilly part of the Upper Mahiao sector, precisely shows how the terrain changes in elevation (Fig. 6) as the transect line goes from the northeastern to southwestern direction (Fig. 2). As can be seen on Table 1, the NAMRIA vs. ASTER and NAMRIA vs. SRTM columns have similar min, max, stdev, and rmse values.

Transect Line 2 (Fig. 7), which goes from the Tongonan Power Plant towards the direction of the Administration Complex (Fig. 2), shows a consistent positive difference between the NAMRIA DEM against the SRTM and ASTER DEMs even though their profile more or less follow the same shape. The ASTER DEM shows greater min and max values against the NAMRIA DEM when compared to the SRTM DEM min and max values. However both NAMRIA vs. SRTM and NAMRIA vs. ASTER have similar stdev and rmse values.

Transect Line 3 (Fig. 8) follows a river found at the eastern side of the development block (Fig. 2). As expected, Transect Line 3 gives the lowest elevation values of all transect lines since the line goes through the lower part of the development block (i.e. Bao Valley). There is a noticeable systematic error, i.e. shift, between the NAMRIA DEM and the satellite-derived DEMs especially at the front part of the profiles. Again the ASTER DEM gives greater difference values to the NAMRIA DEM when compared against the SRTM DEM, as shown on Table 1.

Transect Line 4 (Fig. 9) gives the highest set of elevation data since the transect line goes along the mountainous part of the development block near Mamban and Malitbog areas (Fig. 2). The systematic error between the NAMRIA DEM and remotely-sensed DEMs is more pronounced in this transect line. The maximum differences between NAMRIA vs. SRTM and NAMRIA vs. ASTER elevation values for this transect line are as high as 88.43 m and 82.77 m, respectively.

Transect Line 5 (Fig. 10) shows a good correspondence amongst the NAMRIA DEM and the satellite-derived DEMs between the 740 m to 1020 m elevation values. However systematic errors are still seen at the front and tail-ends of the profile lines. This transect line is located at steep part of the eastern side of the Mahanagdong area. This profile also gives the largest differences of elevations amongst the NAMRIA and SRTM/ASTER DEMs (92.91 m and 98.02 m, respectively).

5. CONCLUSIONS AND RECOMMENDATIONS

As can be seen in the results of this research (Figs. 3-5 and 6-10; Table 1), there are glaring elevation differences between the NAMRIA-derived DEM and the satellite-derived elevation models. These differences are attributed to the temporal difference of the creation of the maps (i.e. NAMRIA topographic maps were created during the 50's and was only digitized in the 2000's while ASTER and NAMRIA DEMs are more recent models), occurrence of natural phenomena within the LGPF development block (i.e. landslides) which result changes on the terrain surface, systematic errors (i.e. shift component) probably due to differences in reference datum (i.e. Luzon 1911/Luzon PTM and WGS 84/EGM 96), and the effect of vegetation and land cover on the models; among others. Also, based from the generated profile lines, we can see that there is close correspondence between the SRTM DEM and ASTER DEM. However, the relative accuracy (i.e. positive or negative shift of elevation values) of the NAMRIA DEM versus the satellite-derived models cannot be completely ascertained since there was no clear pattern seen on the profile lines.

The differences that were qualitatively and quantitatively shown and described in this research should be taken into consideration by EDC especially that DEMs have always been used (i.e. in its GIS- based maps) by the company in its geothermal resource exploration and management activities. Table 2 shows the impact of the use of DEMs at EDC's activities.

Table 2: Uses and implications of DEMs to EDC geothermal resource exploration and management activities.

Group	Current Use of DEMs	Future use and implications
Geochemistry	Used as planimetric base maps for reservoir tracing activities. No apparent use in tracer analysis and modeling.	Can serve as a bounding surface for three-dimensional chemical tracing of geothermal reservoirs. Will affect the interpolation and modeling of tracer behavior inserted into the reservoir system.
Geophysics	Used as planimetric base maps for their geophysical exploration survey activities. Discrepancies between maps and actual ground features have been reported.	Can be used in completely reducing gravity readings onto the terrain. Will affect the geophysical characterization of the geothermal field.
Geology	Used as base maps for geological surveys and well design and monitoring activities. Problems with the coordinates of well heads, structural maps, and thermal manifestations have been pinpointed.	Can be used in automating regional structural mapping. Can be used in orthorectification of available imagery. Can be used in geohazard monitoring and setting of well-head elevation during design. Will affect the well design module in terms of visualization of the field.
Reservoir Engineering	Only sporadically used in geothermal reservoir modeling	Will affect their modeling activities
Engineering and Construction/ Civil works	Used in regional characterization of terrain. Offsets between actual surveys and NAMRIA-derived contours have been reported.	Can be used in pipeline and other structural designs. Can be used as base map in geotechnical activities and mitigating landslides.
Environmental Management	Used in watershed delineation and base mapping. Regional DEMs are being used for regional planning but they need more detailed sources of information.	Will result in better watershed models suitable for localized environmental monitoring. Can be used in water/hydrological flow modeling.

Based from the results presented in this research, it is recommended that only SRTM DEMs and NAMRIA DEMs be further evaluated for use by EDC in its activities. This is because NAMRIA maps, though probably "outdated" already, give more topographic detail than both satellite-derived DEMs. The SRTM DEM, on the other hand, gave more reasonable overall behavior over the ASTER DEM. SRTM used Synthetic Aperture Radar technology that is generally unaffected by weather or cloud cover. ASTER DEMs show lots of spikes and troughs which are probably effects of cloud cover and other noise sources (i.e. weather conditions) (Nikolakopoulos and Chrysoulakis, 2006). These spikes and troughs give inconsistent and questionable DEMs which will affect the results of EDC's geothermal resource exploration and management activities.

It is also recommended that further evaluation and study be conducted at LGPF and other production fields so that EDC will be able to better characterize the differences between the DEMs more. This will result in better utilization of available elevation models and may even result in a final DEM to be used in all EDC activities. Further evaluation may include comparison against higher resolution DEMs from orthophotos (i.e. from Quickbird/Ikonos imagery or aerial photos), conducting geodetic spirit leveling, and observing GNSS-based elevation profiles at the production fields.

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8. REFERENCES

Apuada, N. A., Olivar, R. E., & Salonga, N. D., 2005. Repeat Microgravity and Leveling Surveys at Leyte Geothermal Production Field, Leyte, Philippines. 30th Workshop on Geothermal Reservoir Engineering. California: Stanford University.

Cirés, J., Marturià, J., De Paz, A., Casanovas, J., & Lleopart, A., 1997. Digital Elevation Models: A Useful Tool for Geological Mapping. Some examples from Catalonia. Cartography and Geographic Information Systems, pp. 297-304.

El-Sheimy, N., Valeo, C., & Habib, A., 2005. Digital Terrain Modeling: Acquisition, Manipulation, and Applications. Norwood, MA, Artec House, pp. 1-18.

Gorsevski, P. V., Gessler, P. E., Foltz, R. B., & Elliot, W. J., 2006. Spatial Prediction of Landslide Hazard Using Logistic Regression and ROC Analysis. Transactions in GIS, 10(3), pp. 395-415.

Hlavácová, L., 2009. 3D Modeling of Geothermal Reservoirs. Akureyri: The School for Renewable Energy Science.

Kervyn, M., Goossens, R., Jacobs, P., & Ernst, G., 2006. ASTER DEMs for Volcano Topographic Mapping: Accuracy and Limitations. Int. Assoc. for Mathematical Geology XIth International Congress. Liège: Université de Liège - Belgium.

Kjaernested, S., Jonsson, M., & Palsson, H., 2011. A Methodology for Optimal Geothermal Pipeline Route Selection with Regards to Visual Effects using Distance Transform Algorithms. 36th Workshop on Geothermal Reservoir Engineering. California: Stanford University.

Li, Z., Zhu, Q., & Gold, C., 2005. Digital Terrain Modelling. CRC Press, Florida, pp. 1-12.

Manandhar, N., & Forsberg, R., 2008. Concepts towards cm-geoid for Nepal. Nepalese Journal on Geoinformatics, pp. 1-7.

McDougall, K., Liu, X., Basnet, B., & Apan, A., 2008. Digital Elevation Model Accuracy Requirements for Catchment Management. Queensland Spatial Conference. Gold Coast, Queensland.

National Mapping and Resource Information Agency. (n.d.). Topographic Maps. Retrieved June 13, 2011, from NAMRIA: http://www.namria.gov.ph/

Nikolakopoulos, Konstantinos G. and Nektarios Chrysoulakis, 2006. Updating the 1:50000 Topographic Maps using ASTER and SRTM DEM: The Case of Athens, Greece. Proceedings on Remote Sensing for Environmental Monitoring, GIS Appilcations, and Geology VI, Vol. 6366.

Reuter, H. I., Nelson, A., Strobl, P., Mehl, W., & Jarvis, A., 2009. A First Assessment of ASTER GDEM Tiles for Absolute Accuracy, Relative Accuracy, and Terrain Parameters. International Geoscience and Remote Sensing Symposium, IEEE, pp. 240-243.

Sertel, E., 2010. Accuracy Assessment of ASTER Global Digital Elevation Model Over Turkey. ASPRS/CaGIS 2010 Fall Specialty Conference. Orlando, Florida: ISPRS Technical Commission IV & AutoCarto.