Locating H-Based Potential Alternatives for Micro-Hydropower Development using Medium-Scale DEM Data and GIS

Paengwangthong, W.[1] and Sarapirome, S.[2]
School of Remote Sensing, Institute of Science, Suranaree University of Technology, Mueang District, Nakhon Ratchasima, 30000, Thailand, E-mail: wipop_p@hotmail.com[1], sunyas@sut.ac.th[2]

Abstract
The knickpoint or anomaly steepness of a stream segment is the most important characteristic to be the potential H-based location either for micro-hydropower plant or weir site and gateway for irrigation canal. This study aims at locating anomaly-steepness segments of major streams using abrupt-slope change technique and normalized stream steepness indexing through medium-scale (1:50,000) DEM data of the Nam Khek watershed. The first technique compares slope of every pair of consecutive segments. The indexing applies the slope-area relationship expressed in terms of steepness (k_s) and concavity indexes (θ) of each segment. Segments were identified as anomaly when their changes and indexes were higher than the thresholds. Through slope change and indexing analyses, 30 and 39 anomaly segments, H-based potential alternatives, were respectively identified out of total 177 segments. These anomaly segments were compared to proposed sites investigated by National Energy Administration (NEA, 1988) and well-known waterfalls in the area. A number of anomaly segments screened from the proposed methods help saving great budget and time consume for further field investigation.

1. Introduction

With the energy shortage crisis, there has been an enormous increase in the global demand for energy in recent years as a result of industrial development and population growth (IAEA, 2013 and WNA, 2013). Micro-hydropower is one of renewable and clean energy sources that can serve a part of the demand and reduce importing of fossil fuel which depends on the world energy market price. Also, it can lead the way toward energy self-sufficiency and contribute to reducing gaseous pollutants emission into the atmosphere (DEDE, 2013 and UCS, 2013). Therefore, any high potential sites available for micro-hydropower development, particularly in remote area, should be determined and evaluated as potential alternatives for feasibility study and field survey prior further designing stage.

Disadvantage and advantage of available techniques used in locating H-based potential sites is an essential issue. The H-based potential alternatives can be determined by various methods varying from an expert's manual site selection using conditions e.g. forest restricted area, trivial number of electric power productivity, non-perennial stream (NEA, 1988, Kupakrapinyo, 2003 and Rojanamon et al., 2009) to universal searching using each pair of contour interval along a stream (Sarapirome et al., 2010). The former method is not directly corresponding to that potential and sometimes can end up with no potential site while the later method can result in a huge number of alternatives.

Conventionally, experts operate siting a number of potential locations for micro-hydropower development using their experience on available topographic maps and information (NEA, 1988). The results can be uncertain, more subjective, and can cause conflicts among them, particularly on fact and interest (Malczewski, 1999). Apart from the conventional method, identification and selection of the H-based potential alternatives for development in large mountainous area using merely field investigation, providing the most acceptable results, has to deal with difficulty on accessibility, operation, and tremendously high cost and time consumption (Rawat et al., 2013). With reliable techniques, indirect investigation and determination using a medium-scale DEM data and GIS facility has become an effective tool for selecting potential development sites in a large mountainous area prior confirming by field investigation. This can reduce a big number of locations to visit and certainly can significantly save cost and time (Kupakrapinyo, 2003, Rojanamon et al., 2009 and Sarapirome et al., 2010).

At first, it has to be realized that medium-scale DEM data with acceptable quality are preferred for this activity and proper in operating on large mountainous area. This study proposes the most accurate DEM data by evaluating from available ones with the same scale.

With DEM data and GIS facility, a number of methods can be operated to achieve anomaly stream segments having potential for hydrological development. These cover slope and abrupt-slope-change analyses of stream segments including normalized stream steepness indexing using slope-area relationship (Howard and Kerby, 1983, Duvall et al., 2004 and Wobus et al., 2006). With GIS facility, slope of each stream segment can be easily determined. In general, as the basic understanding, it is believed that higher-slope segments indicate higher potential locations for development (Heitz and Khosrowpanah, 2012). In fact, knickpoints being within and connecting stream segments are the target locations sought for. Because they are actually high potential locations for development. This concept supports abrupt-slope-change analysis and normalized stream steepness indexing to be more effective methods when certain anomaly segments can be selected from the parameters that are above the reasonable thresholds. Therefore, the main objective of the study is to identify H-based potential locations on medium-scale DEM data using 2 proposed procedures. Abrupt-slope-change analysis can identify a knickpoint between two anomaly segments while normalized stream steepness indexing is theoretically appropriate to detect a knickpoint within an anomaly segment.

2. Study Area

The Nam Khek Watershed of Thailand located upstream of N.24 gauge station was chosen as the study area (Figure 1). It is situated between the northeastern part of Phitsanulok province and the western part of Phetchabun province with latitudes between 16° 22′ 32″ to 17° 2′ 46″ N and longitudes between 100° 28′ 38″ to 101° 5′ 7″ E. The watershed area coverage is 1,861 square kilometers (km^2). The topography of the area is mainly characterized by high mountain range in the east. Its elevation is between 41 m to 1,805 m above mean sea level. Stream network in the watershed shows mainly trellis pattern due to their geology characterized by the sequences of fine-coarse grained clastic rocks of the Khorat Group of which bedding exhibits gentle dipping. Nam Khek River is a tributary of Nan River and considered having potential for micro-hydropower development, particularly run-of-river type. As reported by NEA (1988), there were 7 proposed sites having potential for run-of-river type of mini hydropower plant development. In essence, the area is experiencing rather unstable electrified state because of its very long transmission-line through remote and rural area.

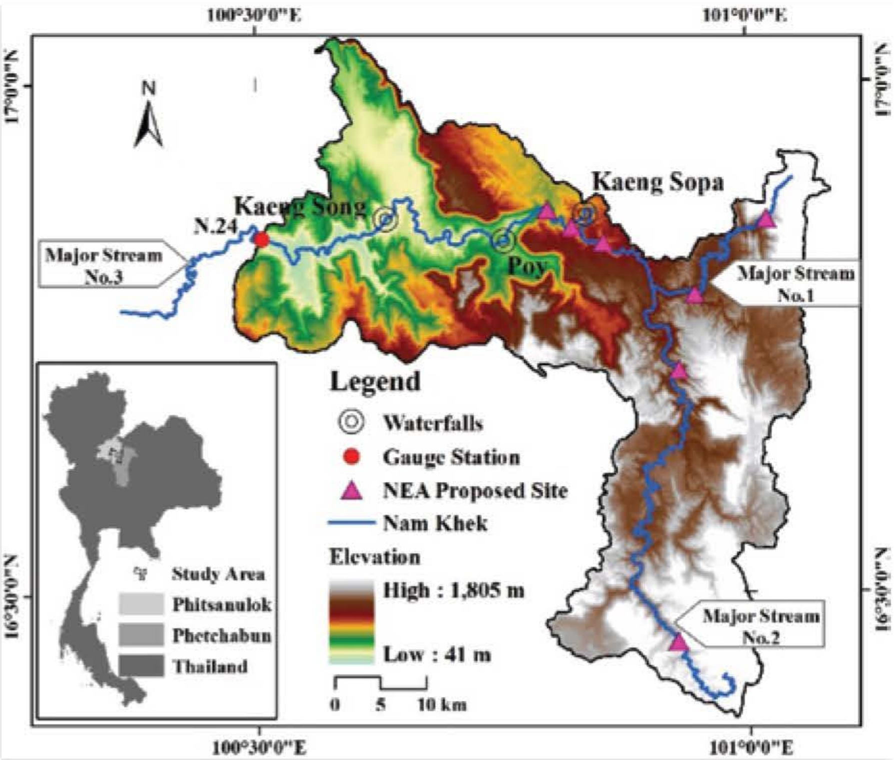


Figure 1: Topography of the study area including waterfalls and 7 proposed sites for run-of-river mini hydropower plant investigated by NEA (1988)

The cables can be easily broken by both natural and human-made causes. One promising solution for this local problem is rural electrification development corresponding to physical potential of the area.

There are 3 major streams available in the area, which are targets for locating stream segments having potential for micro-hydropower development. Their lengths are 31, 81, and 77 kilometers for stream no.1, 2, and 3, respectively. Stream no.1 is located in high elevation area like stream no.2 but its profile shows comparatively highest slope. Stream no.3 is located in lower elevation area. Its profile appears to be high slope at the upper middle part and becomes rather flat at the lower part.

3. Medium-Scale DEM Data

Medium-scale DEM data available in Thailand comes from several sources, i.e. Shuttle Radar Topography Mission (SRTM-DEM), ASTER Global Digital Elevation Map (GDEM), Royal Thai Survey Department (RTSD-DTED2), and Self-generated DEM (SG-DEM), which are different in acquiring methods, spatial resolution, spatial position, and elevation accuracy. RTSD-DTED2 data was acquired at one-arcsecond (approximately 30 m) intervals in latitude and longitude using SAR interferometry based on radar images from NASA's shuttle (Slater et al., 2006). SG-DEM data was interpolated from RTSD contour data (1:50,000 topographic map) using Topo to Raster tool of ArcGIS™. Additionally, from different sources, DEM data can be normally generated from sets of remotely sensed data with different sets of control points and geometric correction methods. Therefore, their accuracy can affect the parameters which in turn will affect the applications. From the studies of Amans et al., (2013), Du et al., (2012), Fabila and Paringit (2012) and Rawat et al., (2014), they assessed the elevation accuracy of SRTM-DEM and GDEM using RMSE (Root Mean Square Error). It reveals that SRTM-DEM provides better accuracy.

From the study of Paengwangthong and Sarapirome (2012), available DEM data in Thailand were prepared in the scale of 30 m cell size to fit to the preliminary feasibility study of Nam Khek watershed. Accuracy of the parameters, i.e. stream horizontal positions and elevations in the area extracted from available DEM data were assessed based on referent MOAC-DEM (Ministry of Agriculture and Cooperatives) data, acquired by systematically digital photogrammetry of large-scale aerial photographs. Matching percentage for stream positions and RMSE of stream elevations were estimated and compared. The result reveals that, among available DEM data, RTSD-DTED2 data was proved to be most acceptable for this purpose in the study area. These DEM data provide 0.61 and 5.14 for matching ratio of stream position and RMSE of stream elevation.

4. Methodology

The research methods comprises (1) preparing stream segments from medium-scale DEM data, (2) detecting anomaly segments using abrupt-slope-change analysis, (3) detecting anomaly segments using slope-area relationship analysis, and (4) result comparison. The main steps of the study are illustrated in Figure 2.

4.1 Preparing Stream Segments from Medium-Scale DEM data

To prepare data for further analyses, 3 main streams of the area were extracted from the selected medium-scale DEM data, RTSD-DTED2, after a series of analyses i.e. fill sinks, flow direction, and flow accumulation was operated in Hydrology, a tool in Spatial Analyst of ArcGIS™. Considering the debris flow effect, grid cells along extracted major streams with upstream drainage area less than critical threshold (A_{cr}) of 1 km^2 were suggested to be removed (Whipple and Tucker, 1999 and Wobus et al., 2006). To avoid possible sinks and peaks along longitudinal profiles of main streams, the elevations along streams were smoothed by moving average of 30 pixels (approximately 1,000 m) because this length implies structural length of water pipe used in plant construction. It was assumed to be approximately 1,000 m in horizontal similar to those of the well-known Mae Kam Pong, Mae Ton Luang, and Bo Kaeo micro-hydropower projects (NEA, 1984). Subsequently, 3 sets of ordered pairs between the upstream drainage areas calculated from flow accumulation layer and elevations of stream pixels from 3 major streams were converted into Microsoft Excel tables. Segmentation of each major stream was operated to achieve consecutive 30 pixels for each stream segment.

4.2 Detecting Anomaly Segments using Abrupt-Slope-Change Analysis

The abrupt-slope-change analysis is considered as segment-based analysis that can identify a knickpoint between a pair of connecting segments. The method includes calculating slope of stream segments, estimating slope change of each pair of connecting segments and identifying segments with abrupt-slope change using threshold. Slope of each segment was calculated using the difference of smoothed elevation and distance between most upstream and downstream cells of each segment. Then, the change of slope of each segment when compared with its upstream connecting segment was calculated.

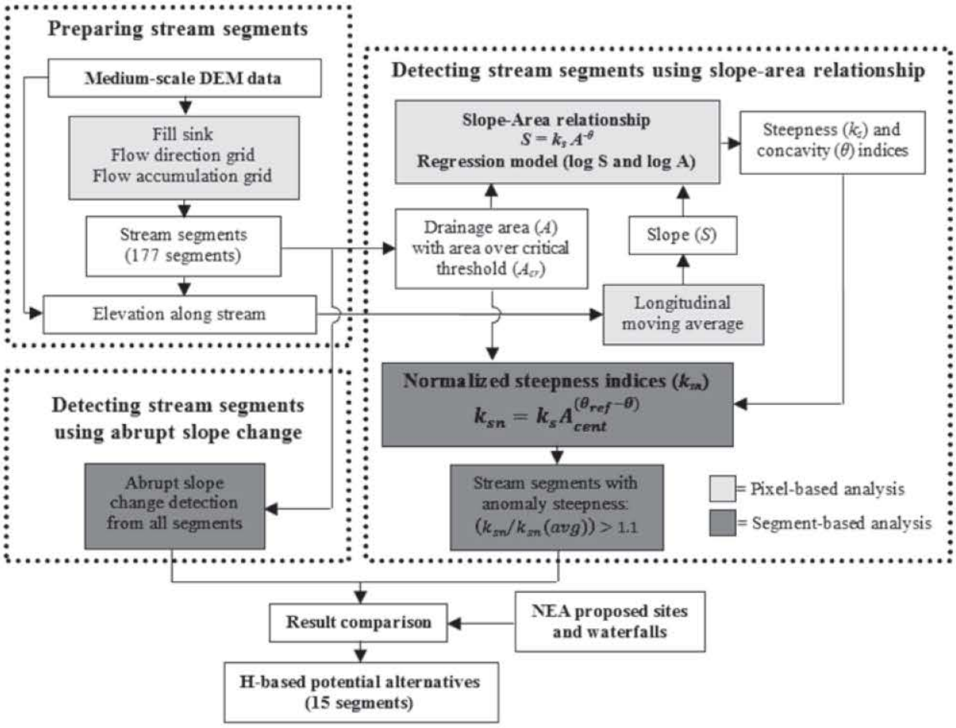


Figure 2: Framework diagram of the study

Finally, anomaly segments were identified based on a threshold of slope change that refers to the potential of natural characteristic of the study area. Big waterfalls available in the area, namely Kaeng Sopa, Poy, and Kaeng Song were considered as natural potential. The least slope change of segment containing waterfalls was used as the threshold. Any segments having slope change exceeding the threshold were identified as anomaly segments. It means that the knickpoint found will locate at the downstream end cell of the upstream segment or the starting cell of the downstream segment in the pair that slope change was estimated.

4.3 Detecting Anomaly Segments using Slope-Area Relationship Analysis

According to Bishop et al., (2005), Wobus et al., (2006) and Wang et al., (2014), it is noted that slope-area relationship can be used to detect anomaly steepness stream segment more accurately. The method can be used for investigating spatial variation of bedrock uplift in stream channels and detecting geological boundaries among different rocks types (Shahzad et al., 2007). This method has been proved to be appropriate for identifying knickpoints or points with abrupt change of the stream gradient (Whipple et al., 2007 and Gonga-Saholiariliva et al., 2011). For this study, the method is considered as pixel-based analysis that can identify a knickpoint within an anomaly segment. The method includes estimating normalized steepness index of stream segments and identifying their anomaly using a threshold.

The normalized stream steepness index applies the slope-area relationship based on an assumption of longitudinal bedrock channel profile (Howard and Kerby, 1983, Duvall et al., 2004 and Wobus et al., 2006). The relationship in a variety of natural setting typically reveals in power regression form as:

$$S = k_s A^{-\theta}$$

Equation 1

Where S is the local channel slope, A is the upstream drainage area, and k_s and θ are parameters which describe the relative steepness and concavity of the channel, respectively. In practice, after segmentation of streams extracted from medium-scale DEM data, both parameters of each segment can be estimated using the regression analysis of slope and area upstream from every grid cell of a segment, as suggested in the equation 1. An example of separating longitudinal channel profile into consecutive segments with power regression lines is displayed in Figure 3 (Wobus et al., 2006). Among available regression lines, it is obvious that a line with abrupt change or having a knickpoint in it shows the different orientation whereas others have been spatially uniform. Therefore, when there is an abrupt change in any segment, k_s and θ are obviously deviated to show a degree of anomaly steepness. However, before using them to identify anomaly segments, these indexes will be normalized with the reference concavity (θ_{ref}) through the following equations (Wobus et al., 2006, Foster, 2010 and Gonga-Saholiariliva et al., 2011):

$$k_{sn} = k_s A_{cent}^{\theta_{ref}-\theta}$$

Equation 2

and

$$A_{cent} = 10^{(\log A_{max} + \log A_{min})/2}$$

Equation 3

Where k_{sn} is a normalized steepness index of a segment, k_s and θ are determined by regression analysis, A_{min} and A_{max} bound the segment of the profile analyzed, and A_{cent} is the area at midpoint value of the segment analyzed.

4.3.1 Estimating normalized steepness index of stream segments

To find anomaly segments, the steepness and concavity indexes of each stream segment were calculated using equation 1 with input slope and area upstream from every cell of a segment. These indexes were later used as input for normalized stream steepness indexing. The ordered pairs with slope value equal to zero were firstly removed from that calculation. The normalized stream steepness index (k_{sn}) of each segment was calculated through equation 2 and 3 using concavity reference and drainage area at midpoint of each segment. Herewith, a reference concavity (θ_{ref}) of 0.45 was chosen corresponding to the suggestion of previous studies (Whipple et al., 2007, Hu et al., 2010 and Foster, 2010).

This is because it is inherent of the slope-area relationship based on longitudinal bedrock channel profile (Duvall et al., 2004) and could also provide the k_{sn} able to compare with data from other areas (Wobus et al., 2006).

4.3.2 Identifying anomaly normalized steepness stream segments

The anomaly steepness segments were identified using $k_{sn}/k_{sn}(avg)$>1.1 as a filter. The reason is that the effect of wide range of smoothing windows or segment length to normalized steepness index will typically fall within 10% (Wobus et al., 2006). This is based on the plot of varying segment lengths and $k_{sn}/k_{sn}(avg)$.

4.4 Result Comparison

Practically, the resulting anomaly stream segments having potential for development from those 2 methods could be hardly validated by field investigation due to difficult accessibility including great time and cost consumption. However, their locations from different methods could be compared to each other and to locations of proposed sites from the study of NEA (1988) as well as well-known waterfalls in the area. Their agreement and inconsistency can be observed in terms of their identical numbers and identical percentages. Identical number is the number that segment locations resulting from different methods and the proposed sites from the study of NEA (1988) as well as well-known waterfalls in the area are overlapped. Identical percentage is the percentage of a ratio between the number of overlapped segment locations and the sum of anomaly segments in case results from two methods are compared, or a ratio between the number of overlapped locations and the sum of anomaly segments and sites (NEA proposed sites or waterfalls).

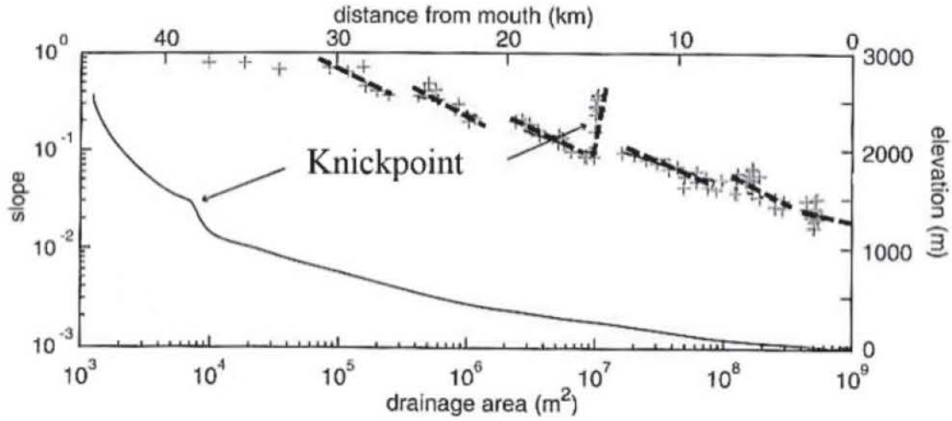


Figure 3: Example of separating longitudinal channel profile (solid line) into consecutive segments with power regression lines (dash line) (Wobus et al., 2006)

5. Results and Discussion

5.1 Stream Segments

Three major streams in the study area were divided to be totally 177 segments as listed in Table 1. The number of segments are put in order from downstream to upstream. There are 29, 75, and 73 segments belong to stream no. 1, 2, and 3, respectively. They were input data for abrupt-slope-change and slope-area relationship analyses to locate anomaly segments.

5.2 Anomaly Segments Resulting from Abrupt-Slope-Change Analysis

The threshold applied herein was 0.0038 adopted from the slope change of Kaeng Song waterfalls. From the entire 177 segments, there were 30 anomaly segments having slope change exceeding the threshold as shown in Table 1 and distributing in the stream profile as shown in Figure 4. There are 5, 17, and 8 anomaly segments distributed in stream no. 1, 2, and 3, from total 29, 75, and 73 segments of each major stream, respectively. From Figure 4, it is crucial to note that although slope of stream no.1 looks very high compared to others, 17.24% of segments having knickpoints were found by the use of this method while they were found 22.67% in stream no.2 which looks in general having less profile slope. This is because the method used concentrates to detect only knickpoints between connecting segments in observed pairs. It indicates that in stream no.1 there are many consecutive segments containing high slope but less change while in stream no.2 there are more slope change in high slope segments. In stream no.3, only 10.96% of segments having knickpoints were found. The stream no.3 shows least number of segments having knickpoints because almost half of its segments are located in less slope or rather flat downstream area. By using this method, 16.95% of segments having knickpoints were totally found in all major streams.

Table 1: k_{sn} values and related parameters of stream segments

Stream ID	Segment No.	Length (m)	k_{sn}	$\frac{k_{sn}}{k_{sn}(avg)}$	Slope from RTSD-DTED2	A	B	C	D
1	1	1019	0.026	0.37	0.00065	-	-	-	-
1	2	994	0	0	0.01827	-	-	-	-
1	3	1019	0.188	2.69	0.01527	√	-	-	-
1	4	994	0.432	6.17	0.03577	√	√	-	-
1	5	1056	0.206	2.95	0.02411	√	√	√	-
1	6	1081	0.091	1.30	0.00823	√	-	-	-
1	7	1044	0	0	0.00853	-	√	-	-
1	8	982	0.025	0.36	0.00166	-	-	-	-
1	9	1044	0.021	0.30	0.00118	-	-	-	-
1	10	1032	0.019	0.27	0.00001	-	-	-	-
1	11	1007	0.018	0.26	0.00189	-	-	-	-
1	12	982	0.014	0.19	0.00001	-	-	-	-
1	13	1106	0.050	0.72	0.00624	-	-	-	-
1	14	982	0.091	1.30	0.01188	√	√	-	-
1	15	1019	0.027	0.38	0.00265	-	-	-	-
1	16	1044	0.018	0.26	0.00294	-	-	-	-
1	17	1044	0.013	0.18	0.00125	-	-	-	-
1	18	1106	0	0	0.00072	-	-	-	-
1	19	1081	0.023	0.33	0.00333	-	-	-	-
1	20	1019	0	0	0.00546	-	-	-	-
1	21	1044	0.078	1.12	0.01066	√	-	-	-
1	22	994	0.086	1.22	0.01512	√	-	-	-
1	23	1019	0.098	1.41	0.01586	√	-	-	-
1	24	1044	0.122	1.74	0.02194	√	-	-	-
1	25	1056	0.315	4.50	0.05150	√	-	√	-
1	26	1032	0.346	4.94	0.06880	√	-	-	-
1	27	994	0.348	4.97	0.08083	√	√	-	-
1	28	1069	0.171	2.44	0.04528	√	-	-	-
1	29	1032	0.340	4.86	0.09252	√	-	-	-
2	1	920	0	0	0.00384	-	√	-	-
2	2	1032	0.037	0.53	0.00001	-	-	-	-
2	3	982	0	0	0.00217	-	-	-	-
2	4	1069	0.038	0.54	0.00094	-	-	-	-
2	5	994	0.161	2.30	0.00942	√	√	-	-
2	6	932	0	0	0.00268	-	-	-	-
2	7	920	0	0	0.00065	-	-	-	-
2	8	932	0.048	0.68	0.00001	-	-	-	-
2	9	1044	0.044	0.63	0.00001	-	-	-	-
2	10	1081	0	0	0.01255	-	-	-	-
2	11	1019	0.851	12.15	0.04900	√	√	-	-
2	12	1094	0	0	0.01707	-	√	-	-
2	13	1081	0.039	0.56	0.00197	-	-	√	-
2	14	920	0.038	0.54	0.00275	-	-	-	-
2	15	982	0	0	0.00180	-	-	-	-
2	16	957	0.052	0.75	0.00331	-	-	-	-
2	17	1044	0	0	0.00958	-	√	-	-
2	18	1032	0	0	0.00194	-	-	-	-
2	19	1032	0.031	0.44	0.00171	-	-	-	-
2	20	1044	0.030	0.43	0.00001	-	-	-	-
2	21	1056	0.040	0.57	0.00208	-	-	-	-
2	22	1119	0.125	1.79	0.00805	√	√	-	-
2	23	1007	0.028	0.40	0.00116	-	-	-	-
2	24	945	0.059	0.84	0.00001	-	-	-	-
2	25	1044	0	0	0.00134	-	-	-	-
2	26	1007	0.066	0.94	0.00358	-	-	-	-
2	27	969	0.242	3.45	0.02077	√	-	-	-
2	28	982	0.181	2.59	0.02023	√	√	-	-
2	29	1106	0	0	0.00609	-	√	-	-
2	30	969	0.033	0.46	0.00001	-	-	-	-
2	31	1032	0.027	0.39	0.00019	-	-	-	-
2	32	1056	0	0	0.00076	-	-	-	-
2	33	1032	0.024	0.34	0.00129	-	-	-	-
2	34	1032	0.020	0.29	0.00001	-	-	-	-
2	35	932	0.037	0.53	0.00001	-	-	-	-
2	36	1094	0	0	0.00001	-	-	-	-
2	37	1081	0.050	0.71	0.00001	-	-	-	-
2	38	1032	0	0	0.00423	-	√	-	-
2	39	1106	0.022	0.32	0.00001	-	-	-	-
2	40	1081	0.023	0.33	0.00176	-	-	-	-
2	41	1156	0.012	0.17	0.00046	-	-	-	-
2	42	1044	0.015	0.21	0.00109	-	-	-	-
2	43	1007	0.015	0.21	0.00106	-	-	-	-
2	44	1069	0.019	0.27	0.00175	-	-	-	-
2	45	982	0	0	0.00001	-	-	-	-
2	46	932	0	0	0.00147	-	-	-	-
2	47	1069	0.017	0.24	0.00094	-	-	-	-
2	48	1119	0.016	0.23	0.00033	-	-	-	-
2	49	1032	0.016	0.23	0.00052	-	-	-	-
2	50	932	0.017	0.24	0.00089	-	-	-	-
2	51	1007	0.114	1.63	0.01212	√	√	-	-
2	52	1081	0.022	0.31	0.00185	-	-	-	-
2	53	1007	0.018	0.26	0.00142	-	-	-	-
2	54	1081	0.086	1.22	0.01221	√	√	-	-
2	55	1081	0.016	0.23	0.00462	-	-	-	-
2	56	1106	0.027	0.39	0.00247	-	-	-	-
2	57	1044	0.023	0.33	0.00310	-	-	-	-
2	58	994	0.044	0.63	0.00684	-	√	-	-
2	59	1069	0.011	0.16	0.00181	-	-	-	-
2	60	1032	0.030	0.42	0.00443	-	-	-	-
2	61	1044	0.042	0.60	0.01201	-	-	-	-
2	62	1007	0.129	1.84	0.02152	√	-	√	-
2	63	1094	0.155	2.22	0.02143	√	√	-	-
2	64	1044	0.979	13.98	0.01389	√	-	-	-
2	65	1007	0.097	1.38	0.01881	√	√	-	-
2	66	1131	0.020	0.29	0.00516	-	-	-	-
2	67	1056	0.027	0.38	0.00786	-	-	-	-
2	68	1069	0.076	1.09	0.01999	-	√	-	-
2	69	1056	0.037	0.52	0.00779	-	-	-	-
2	70	1094	0.070	1.00	0.01692	-	√	-	-
2	71	1106	0.013	0.18	0.00151	-	-	-	-
2	72	969	0.091	1.30	0.01736	√	-	-	-
2	73	1019	0.034	0.49	0.01603	-	-	-	-

Stream ID	Segment No.	Length (m)	k_{sn}	$\frac{k_{sn}}{k_{sn}(avg)}$	Slope from RTSD-DTED2	A	B	C	D
2	74	1069	0.039	0.56	0.01375	-	√	-	-
2	75	994	0.013	0.18	0.00379	-	-	-	-
3	1	994	0	0	0.00070	-	-	-	-
3	2	969	0.148	2.12	0.00481	√	-	-	-
3	3	1032	0.165	2.36	0.00556	√	√	-	-
3	4	1069	0	0	0.00103	-	-	-	-
3	5	1081	0.083	1.19	0.00228	√	-	-	-
3	6	1019	0	0	0.00357	-	-	-	-
3	7	982	0	0	0.00129	-	-	-	-
3	8	932	0.031	0.44	0.00075	-	-	-	-
3	9	1081	0	0	0.00022	-	-	-	-
3	10	1069	0	0	0.00001	-	-	-	-
3	11	932	0.064	0.91	0.00050	-	-	-	-
3	12	1019	0	0	0.00075	-	-	-	-
3	13	1081	0	0	0.00133	-	-	-	-
3	14	1044	0	0	0.00252	-	-	-	-
3	15	1032	0	0	0.00323	-	-	-	-
3	16	1032	0	0	0.00449	-	-	-	-
3	17	1081	0	0	0.00287	-	-	-	-
3	18	945	0	0	0.00244	-	-	-	-
3	19	1106	0	0	0.00470	-	-	-	-
3	20	1056	0	0	0.00697	-	√	-	√
3	21	1019	0	0	0.00317	-	-	-	-
3	22	994	0	0	0.01036	-	√	-	-
3	23	957	0.160	2.28	0.00585	√	-	-	-
3	24	969	0	0	0.00894	-	√	-	-
3	25	1069	0.091	1.30	0.00396	√	-	-	-
3	26	994	0	0	0.00325	-	-	-	-
3	27	1081	0	0	0.00114	-	-	-	-
3	28	1069	0	0	0.00246	-	-	-	-
3	29	1032	0	0	0.00145	-	-	-	-
3	30	1007	0	0	0.00149	-	-	-	-
3	31	1019	0.099	1.42	0.00530	√	√	-	-
3	32	1056	0	0	0.00114	-	-	-	-
3	33	1032	0	0	0.00042	-	-	-	-
3	34	957	0	0	0.00010	-	-	-	-
3	35	969	0	0	0.00072	-	-	-	-
3	36	969	0	0	0.00117	-	-	-	-
3	37	945	0.029	0.41	0.00001	-	-	-	-
3	38	1019	0	0	0.00134	-	-	-	-
3	39	1019	0.096	1.37	0.00376	√	-	-	-
3	40	920	0	0	0.00721	-	-	-	-
3	41	1069	0.226	3.23	0.00908	√	-	-	-
3	42	969	0	0	0.00646	-	-	-	-
3	43	1069	0	0	0.01276	-	√	-	√
3	44	982	0.060	0.85	0.00289	-	-	-	-
3	45	1044	0.034	0.48	0.00057	-	-	-	-
3	46	1119	0.028	0.40	0.00001	-	-	-	-
3	47	945	0	0	0.00001	-	-	-	-
3	48	1069	0.059	0.85	0.00193	-	-	-	-
3	49	1156	0	0	0.01194	-	-	-	-
3	50	994	0	0	0.02206	-	-	-	-
3	51	957	0.448	6.40	0.01982	√	-	√	-
3	52	969	0.456	6.51	0.01967	√	-	-	-
3	53	1081	0.358	5.12	0.01591	√	-	-	-
3	54	1056	0	0	0.01483	-	-	-	-
3	55	932	0	0	0.01702	-	-	√	-
3	56	1069	0.626	8.94	0.02826	√	-	-	-
3	57	969	0.979	13.98	0.04559	√	√	-	√
3	58	1019	0	0	0.00893	-	√	-	-
3	59	1044	0.035	0.51	0.00096	-	-	-	-
3	60	994	0	0	0.00184	-	-	-	-
3	61	1069	0	0	0.00134	-	-	-	-
3	62	1056	0	0	0.00114	-	-	-	-
3	63	969	0.065	0.92	0.00001	-	-	-	-
3	64	932	0.057	0.81	0.00001	-	-	-	-
3	65	1081	0	0	0.00466	-	-	-	-
3	66	1069	0.037	0.53	0.00106	-	-	√	-
3	67	1143	0	0	0.00230	-	-	-	-
3	68	1019	0	0	0.01446	-	-	-	-
3	69	1119	0	0	0.01240	-	-	-	-
3	70	1081	0	0	0.01141	-	-	-	-
3	71	982	0	0	0.00774	-	-	-	-
3	72	1032	0.077	1.10	0.00414	-	-	-	-
3	73	982	0	0	0.00071	-	-	-	-

Note: A = Anomaly segment using slope-area relationship analysis, B = Anomaly segment using abrupt-slope-change analysis, C = NEA proposed sites, and D = Existing waterfalls

5.3 Anomaly Segments Resulting from Slope-Area Relationship Analysis

By applying slope-area relationship, k_s, θ and A_{cent} of each stream segment were calculated. k_{sn} of each stream segment was subsequently calculated and shown in Table 1. Followed by anomaly normalized steepness segment identification based on their average of 0.070, there are 39 anomaly segments found from the total 177 as their spatial distribution shown in Figure 4. There are 14, 12, and 13 segments or 48.28, 16.00, and 17.81% of segments in which knickpoints were found from stream no. 1, 2, and 3, respectively. By using this method, 22.03% of segments having knickpoints were totally found in all major streams. It is observable that stream no.1 contains comparatively higher percentage of anomaly segments. This can be explained that in many high slope segments of stream no.1 contains knickpoints. They can be found because this method concentrates on detecting knickpoint in a segment using slope-area relationship in the pixel-based level as discussed above.

5.4 Result Comparison

Location comparisons of anomaly segments resulted from different methods to proposed sites from the study of NEA (1988) as well as well-known waterfalls in the area were operated for each stream and in total. The results are shown in Table 2. Comparing results from 2 methods, there are totally 15 and 21.74% (or 15x100/(30+39)) of identical number and percentage. The highest agreement of comparison falls in to the stream no. 2 of which its identical percentage is 27.59%.

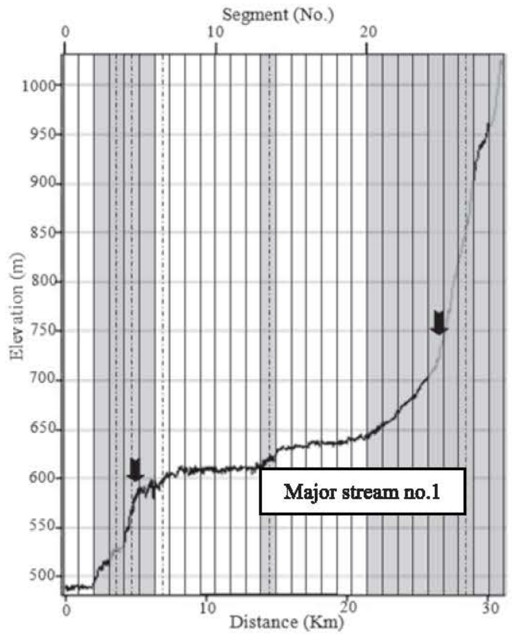
Comparing results from 2 methods to NEA proposed sites, slope-area relationship analysis shows better result with 8.7 (or 4x100/(39+7)) of total identical percentage. Stream no.1 shows the highest identical percentage of 12.50 (or 2x100/(14+2)). It is observable that no identical number were found in stream no. 2 and 3 when using abrupt-slope-change analysis while some were found when using slope-area relationship analysis. This should be because of unfitting segmentation and its length including thresholds. NEA proposed sites were also selected based on additional Q-based characteristic while this study concentrates only H-based characteristic.

Comparing results from 2 methods to well-known waterfalls which are available only in stream no.3, abrupt-slope-change analysis provides better result with identical percentage up to 27.27 while the result from slope-area relationship analysis shows only 6.25%. This is because of the limitation of the indexing ability when dealing with rather flat and oversize drainage area in the most downstream part. Data on well-known waterfalls of stream no.1 and 2 are not available. This is more likely depend upon difficulty on accessibility of the area.

Table 2: Result comparison between 2 methods and proposed sites from the study of NEA (1988) as well as well-known waterfalls

Stream ID.	PNEA	EWF	Abrupt-slope-change analysis (ASC)					Slope-area relationship analysis (SAR)					Identical ASC and SAR	
			A	INEA	INEA %	IWF	IWF %	A	INEA	INEA %	IWF	IWF%	No.	%
1	2	*	5	1	14.29	*	*	14	2	12.50	*	*	4	21.05
2	2	*	17	0	0	*	*	12	1	7.14	*	*	8	27.59
3	3	3	8	0	0	3	27.27	13	1	6.25	1	6.25	3	14.29
Total	7	3	30	1	2.70	3	9.09	39	4	8.70	1	2.38	15	21.74

Note: A = No. of anomaly segments, PNEA = NEA proposed sites, EWF = Existing waterfalls, INEA = No. of segments identical to NEA proposed sites, IWF = No. of segments identical to Waterfalls, and * = No data on existing waterfalls



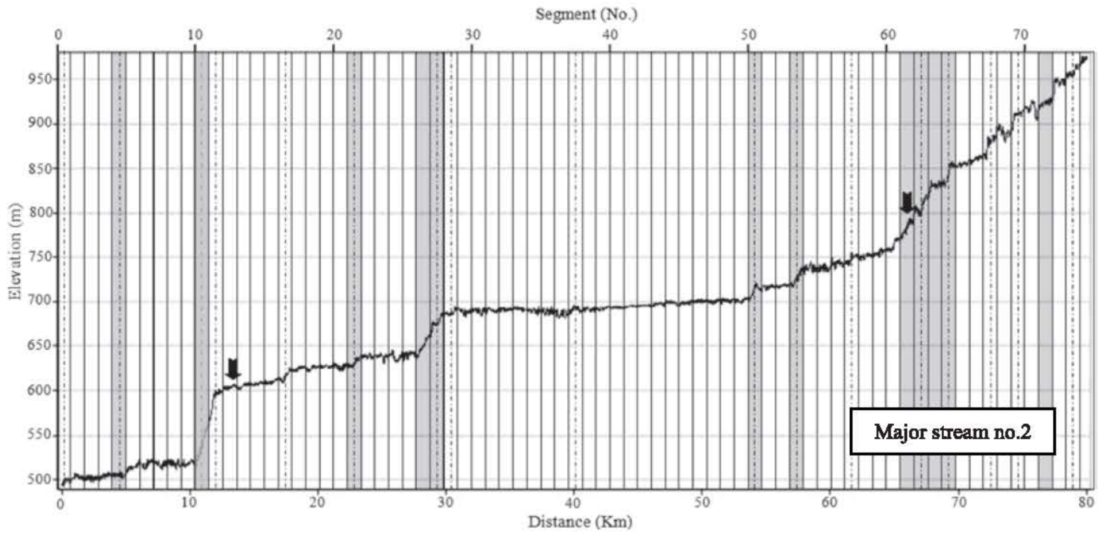


Figure 4: Longitudinal profile of major streams including existing waterfalls and proposed sites by NEA (1988)
(Continued Next Page)

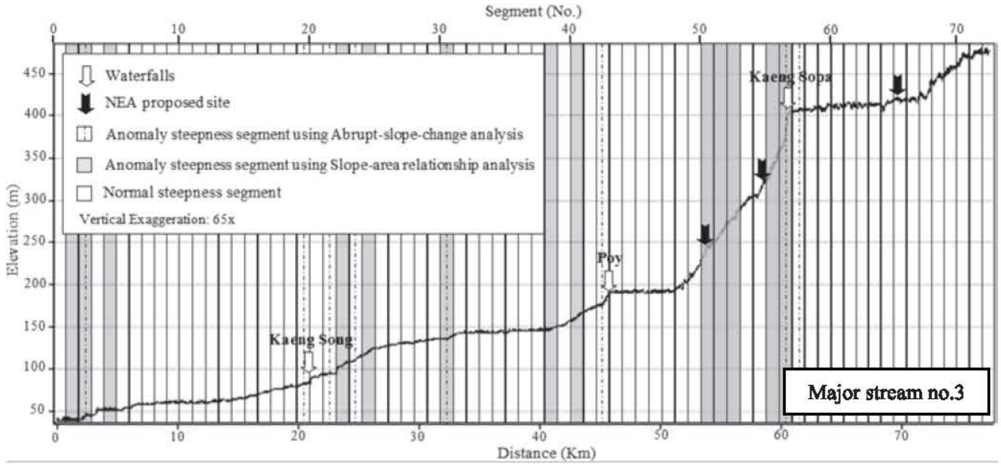


Figure 4: Longitudinal profile of major streams including existing waterfalls and proposed sites by NEA (1988)

6. Conclusions

Compared to conventional methods for locating the H-based alternatives, using normalized steepness indexing together with abrupt-slope-change analysis operating on medium-scale DEM data can provide more advantage in terms of stability of result, thorough stream profiles consideration, time and cost saving. From the results of the study, it can be concluded that those 2 proposed methods and medium-scale DEM data can be effectively applied to locating H-based potential alternatives in stream segments. Identical segments from both methods could be considered as confirmed anomaly stream segments. Additional Q-based identification and field investigation of anomaly stream segments are strongly recommended to specify their potential development.

Acknowledgements

The authors would like to express appreciation to the anonymous reviewers for their valuable comments and contributions to the manuscript. The Royal Thai Survey Department (RTSD) is also acknowledged for providing the DEM data for the research.

References

Amans, O. C., Beiping, W. and Ziggah, T. T., 2013, Assessing Vertical Accuracy of SRTM ver 4.1 and Aster GDEM ver 2 using Differential GPS Measurements-Case Study in Ondo State Nigeria. *International Journal of Scientific and Engineering Research*, 4(12): 523-531.

Bishop, P., Hoey, T. B., Jansen, J. D. and Artza, I. L., 2005, Knickpoint Recession Rate and Catchment Area: the case of Uplifted Rivers in Eastern Scotland, *Earth Surface Processes and Landforms*, 30: 767-778.

Department of Alternative Energy Development and Efficiency (DEDE), 2013, Alternative Energy: Micro Hydro Power. Bangkok, Thailand: DEDE. Available from: www.dede.go.th. Accessed date: Dec 2, 2013.

Duvall, A., Kirby, E. and Burbank, D., 2004, Tectonic and Lithologic Controls on Bedrock Channel Profiles and Processes in Coastal California, *Journal of Geophysical Research*, 109(F3): 1-18.

Du, X., Guo, H., Fan, X., Zhu, J., Yan, Z. and Zhan, Q., 2012, Vertical Accuracy Assessment of SRTM and Aster GDEM over Coastal Regions of CHINA: A Comparative Analysis. *Proceedings of the 33rd Asian Conference on Remote Sensing*; November 26-30, 2012; Pattaya, Thailand, 1236-1243.

Fabila, J. L. D. and Paringit, E. C., 2012, Calibration and Accuracy Assessment of Aster GDEM for the Major River Basins in Philippines. *Proceedings of the 33rd Asian Conference on Remote Sensing*; November 26-30, 2012; Pattaya, Thailand, 1865. Abstract no. H5-6.

Foster, M., 2010, Knickpoints in Tributaries of the South Fork Eel River, Northern California, (MSc. Thesis). Humboldt State University. California, USA, 87.

Gonga-Saholiariliva, N., Gunnell, Y., Harbor, D. and Mering, C., 2011, An Automated Method for Producing Synoptic Regional Maps of River Gradient Variation: Procedure, Accuracy Tests, and Comparison with other Knickpoint Mapping Methods, *Geomorphology*, 134(2011), 394-407.

Heitz, L. F. and Khosrowpanah, S., 2012, Prediction of Flow Duration Curves for use in Hydropower Analysis at Ungaged Sites in Kosrae, FSM. Water and Environmental Research Institute (WERI), University of Guam, Mangilao, Guam, Report No.137. 28. Available from: http://www.weriguam.org. Accessed date: Nov 20, 2014.

Howard, A. D. and Kerby, G., 1983, Channel changes in Badlands, *Geological Society of America Bulletin*, 94, 739-752.

Hu, X., Pan, B., Kirby, E., Li, Q., Geng, H. and Chen, J., 2010, Spatial Differences in Rock Uplift Rates Inferred from Channel Steepness Indices along the Northern Flank of the Qilian Mountain, Northeast Tibetan Plateau, *Chinese Science Bulletin*, 55(27-28), 3205-3214.

International Atomic Energy Agency (IAEA), 2013, Tackling the Global Energy Crisis. Vienna, Austria: IAEA. Available from: www.iaea.org. Accessed date: Dec 2, 2013.

Kupakrapinyo, C., 2003, Preliminary Feasibility Study on Run-of-River type Hydropower Project in Thailand: Case Study in Maehongson Province, (MSc. Thesis). King Mongkut's University of Technology Thonburi. Bangkok, Thailand, 133.

Malczewski, J., 1999, *GIS and Multicriteria Decision Analysis*, (Newyork: John Wiley & Sons, Inc).

National Energy Administration (NEA), 1984, Development of Mae Kam Pong, Mae Ton Luang, Huai Pui, and Bo Kaeo Micro-Hydropower Projects, Ministry of Science Technology and Energy, Bangkok. 202. Available from: http://lib.dede.go.th:8000/.

National Energy Administration (NEA), 1988, Master Plan of Mini Hydropower Development. Ministry of Science Technology and Energy, Final report. Bangkok. 787. Available from: http://lib.dede.go.th:8000/.

Paengwangthong, W. and Sarapirome, S., 2012, DEM Data Assessment for Hydrologic Applications: A Case Study in Nam Khek Watershed, Thailand. *Proceedings of the 33rd Asian Conference on Remote Sensing*; November 26-30, 2012; Pattaya, Thailand, 336-342.

Rawat, K. S., Krishna, G., Mishra, A., Singh, J. and Mishra, S. V., 2014, Effect of DEM Data Resolution on Low Relief Region Sub-Watershed Boundaries Delineating using of SWAT Model and DEM Derived from CARTOSAT-1(IRS-P5), SRTM and ASTER, *Journal of Applied and Natural Science*, 6(1), 144-151.

Rawat, K. S., Mishra, A. K. and Tripathi, V. K., 2013, Hydro-Morphometrical Analyses of Sub-Himalyan Region in Relation to small Hydro-Electric Power, *Arabian Journal of Geosciences*, 6(1), 2889-2899.

Rojanamon, P., Chaisomphob, T. and Bureekul, T., 2009, Application of Geographical Information System to Site Selection of Small Run-of-River Hydropower Project by Considering Engineering/Economic/Environmental Criteria and Social Impact, *Renewable and Sustainable Energy Reviews*, 13(9), 2336-2348.

Sarapirome, S., Teaumroong, N., Kulworawanichpong, T., Ongsomwang, S. and Paengwangthong, W., 2010, Locating Potential Alternatives for Micro-Hydropower Plants along Streams within Low-Relief River Basin using GIS. *Proceeding of the 31th Asian Conference on Remote Sensing*; November 1-5, 2010; Hanoi, Vietnam, 184-189.

Shahzad, F., Mahmood, S. A. and Gloaguen, R., 2007, Stream Profile and Neotectonic Analysis in Hazara Kashmir Syntaxis using Shuttle Radar Digital Elevation Data. *Proceeding of the 2007 International Conference on Emerging Technologies*; November 12-13, 2007; Islamabad, Pakistan, 84-88.

Slater, J. A., Garvey, G., Johnston, C., Haase, J., Heady, B., Kroenung, G. and Little, J., 2006, The SRTM Data "Finishing" Process and Products. *Photogrammetric Engineering and Remote Sensing*, 72(3): 237-247.

Union of Concerned Scientists (UCS), 2013, Benefits of Renewable Energy Use. Massachusetts, USA: UCS. Available from: www.ucsusa.org. Accessed date: Dec 2, 2013.

Wang, T., Yang, X., Xiong, L. and Ye, J., 2014, Assessment of Fluvial Knickpoint Identification Based on Aster GDEM and SRTM DEM-A Case Study in Lushan Mountain. *Proceedings of the 2014 International Conference on Water Resource and Environmental Protection*; June 7-8. 2014; Hong Kong, China, 232-237.

Whipple, K. X. and Tucker, G. E., 1999, Dynamics of the Stream-Power River Incision Model: Implications for Height Limits of Mountain Ranges, Landscape Response Timescales, and Research Needs, *Journal of Geophysical Research*, 104(B8): 17661-17674.

Whipple, K., Wobus, C., Crosby, B., Kirby, E. and Sheehan, D., 2007, New Tools for Quantitative Geomorphology: Extraction and Interpretation of Stream Profiles from Digital Topographic Data, *Geological Society of America Annual Meeting*, Short Course Guide.

World Nuclear Association (WNA), 2013, World Energy Needs and Nuclear Power. London, United Kingdom.: WNA. Available from: www.world-nuclear.org. Accessed date: Dec 2, 2013.

Wobus, C., Whipple, K. X., Kirby, E., Snyder, N., Johnson, J., Spyropolou, K., Crosby, B. and Sheehan, D., 2006 Tectonics from topography: Procedures, promise, and pitfalls, *Geological Society of America*, Special Paper 398: 55-74.