DEM and GIS analysis of geomorphic indices for evaluating tectonic activity of Phetchabun province

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ABSTRACT

Phetchabun province, central Thailand is vulnerable to various geohazards, with the potential for significant harm to people and property. Phetchabun province has many lineaments that is a source of tectonic activities. In this study, terrain analysis techniques are used in order to determine geomorphic indices related to tectonic activity. we evaluate active tectonics using 30 meters resolution Digital Elevation Model (DEM) data, and a total of 38 drainage basins were extracted using ArcGIS software. we derived drainage network and geomorphic indices: stream-length gradient (SL), mountain front sinuosity (S_{mf}), hypsometric integral (HI), hypsometric curve (HC), basin shape index (B_s). According to the result, the SL index is calculated in percentage on stream which selected 90 to 100 percentage to represent anomalous values. The S_{mf} index computed for 207 lineaments. Most of lineaments has been supported the low active tectonics of the area. The HI values changes between 0.06 to 1.00. High value of HI indicates less impact from tectonic activity which has been found in the western and southern of the study area, The HC has 3 classes; results show most drainage basins in concave curves. The high value of B_s found in most drainage basins that are related to high tectonic activity. Additionally, the geomorphic indices are significantly affected by lithology especially sedimentary rocks that most found in the study area and structure geology.

Keywords: Terrain analysis, Geomorphic indices, Tectonic activities, Phetchabun province

1. Introduction

Geomorphic indices are able of indicating landform response to tectonics and have been widely used to investigate tectonic geomorphology (Brookfield, 1998; Chen, Sung, and Cheng, 2003; El Hamdouni et al., 2008; Kobor and Roering, 2004). And some indices are particularly useful for identifying relative tectonic activities. Moreover, in recent years Digital Elevation Model (DEM) and GIS software have been extensively used to determine the geomorphic indices of tectonically active in the large-scale characteristic of landscape (Bishop et al., 2002; Bishop, Shroder, and Colby, 2003; Korup, 2005; Pérez-Peña et al., 2009; Sarp et al., 2011; Troiani and Della Seta, 2008; Walcott and Summerfield, 2008) the main objective of this study is to define the spatial distribution of significant geomorphic indices to the relative tectonic activity located on the Phetchabun province by using GIS techniques.

Geomorphic indices have been developed as basic tools to identify areas experiencing tectonic activities (Bull W. B. and McFadden L.D., 1997, Keller E.A. and Pinter N., 1996). Some of the geomorphic indices used for tectonic activities studies are: stream-length gradient (SL), mountain front sinuosity (S_{mf}), hypsometric integral (HI), hypsometric curve (HC), basin shape index (B_s). Recently, the SL has been described tectonic activity of a stream network in in Yenicaga basin, Turkey and

Hindu Kush located in northern Pakistan and Afghanistan (Mahmood and Gloaguen, 2012; Sarp et al., 2011), the S_{mf}, which applied to evaluated tectonic activates along mountain front (Soria-Jáuregui, Jiménez-Cantizano, and Antón, 2018). The HI, HC and B_s are calculated to detect tectonic activities in drainage basins (Giaconia et al., 2012; Mahmood and Gloaguen, 2012).

2. Study Area

The study area is the entire of the Pa Sak River basin which is located in the central part of Phetchabun province, Thailand. The GPS coordinates between 16°30' to 17°20' N and 100°60' to 100°80' E with a surface area of approximately 12,600 square kilometers (Figure 2), 70 kilometers north of Bangkok. It borders with Loei to the north, Lopburi to the south, Chaiyaphum and Khon Kaen to the east and Phitsanulok, Phichit and Nakhon Sawan to the west.

There is complex mountainous area in the north serves as the catchment basin of the Pa Sak River. It passes through the central Phetchabun as the backbone of the province, flowing north to south along a steep cliff. It has been banked by terraces and a series of hills and is surrounded by mountain ranges running along both the western and eastern sectors. The area mainly composed of hills, strongly incised plateau and piedmont, varying in altitude as from 30 to about 1,760 meters above sea level (Figure 2). The highest area is Phu Thap Boek Mountain. The lowest part of terrain is floodplain where most important hazards has occurred.

3. Geological setting and structural geology

3.1 Geological setting

The classification of rocks in Phetchabun is based on lithology, depositional environment and fossils that were found in the Late Paleozoic rocks. In this report, the geological map of Thailand on 1:250,000 scale (Chonglakmani and sattayarak, 1979) is used for relative age of rocks identification. The following are the study area's stratigraphy in order from oldest to youngest.

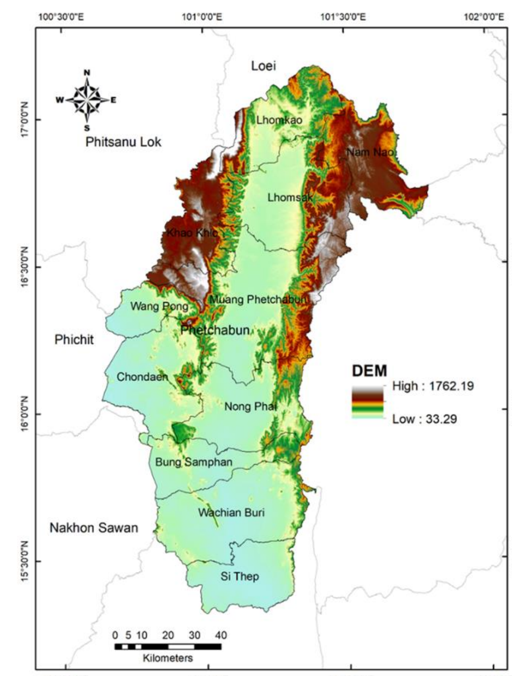

Figure 1. Phetchabun province showing spatial distribution of topography analyzed by Digital Elevation Model (DEM) data.

The Dok Du Formation represents the Carboniferous strata in Loei-Phetchabun Ranges region which consists of shale, sandstone, siltstone and dark grey limestone. Most parts of limestone melted during the intrusion of igneous rocks and turned into marble. These outcrops are widespread in western mountain area extending from Wang Pong district to Chon Daen district. The Huai Som Formation has been designed for Carboniferous-Late Permian rocks. It is younger than Dok Du Formation consisting of tuffaceous sandstone, tuffaceous siltstone, tuffaceous mudstone, conglomerate and chert with intercalations of lenticular limestone. The Early Permian-Middle Permian rocks in Phetchabun belong to Pha Nok Khao Formation. The main lithologies in ascending order are nodular or layered chert, shale and dark-gray massive too thick-bedded limestone. Hua Na Kham Formation presents the Middle Permian-Late Permian consisting chiefly of clastic sediments, shale, siltstone and sandstone unit with limestone lenses or beds. Andesite, tuff and agglomerate also can be found in this formation. The non-marine Triassic rocks belong to Huai Hin Lat Formation of Khorat Group. Reddish-brown basal conglomerates, sub-graywacke, calcarenite and siltstone are the main lithologies of these rocks. Epidote and diopside are also present in calcarenite. Quartzite, metamorphosed by sandstone, can be found in the area that the magma intruded. There are the Triassic igneous rocks indicating magma intrusive. The Nam Phong and Phu Kradung Formations consist of red-brown micaceous sandstones, siltstones, mudstones and conglomerates. It unconformably overlies the Late Triassic Huai Hin Lat and older strata. It can be interpreted as having been deposited by meandering and braided rivers in semi-arid to arid conditions. The Phra Wihan Formation in Khorat Group represents the Late Jurassic. It is composed almost entirely of thick bedded to massive white sandstones which identify that they have been deposited by a stacked series of braided rivers. The Quaternary sediments are classified by geomorphology, lithology, depositional environments and fossils. The lowland area and watershed are composed mainly of Quaternary sediments. They are rich in mineral resources and construction materials. It is interpreted that has been deposited 1.6 million years ago to today. The classification of Quaternary sediments can be divided into 2 types. The first one is terrace gravel which is reserved in the west and the east of Phetchabun basin. Some terraces contain laterite which height approximate 130-190 meters. The terrace gravel forming is related to the Pa Sak River. The second one is alluvial deposits the main sediments of alluvial deposits are clay sand and silty sand overlying gravels and bed rocks. The major source of sediments is caused by the process of gully erosion which running water through the Pa Sak River cuts new unstable channels into erodible soil and weathered rock. The Phra Wihan Formation in Khorat Group represents the Late Jurassic. It is composed almost entirely of thick bedded to massive white sandstones which identify that they have been deposited by a stacked series of braided rivers.

The igneous rock can be divided into 2 main types according to where the molten rock solidifies. The first one is intrusive or plutonic rocks crystallizing from magma which is trapped deep inside the earth's surface. They have a coarse-grained texture (i.e., larger than 1 mm). The well-known intrusive rock is granite, commonly used in building, which associated with many economic minerals such as tin, wolfram, fluoride and barite. The second type is extrusive or volcanic rocks which is produced when magma cools above or very near the earth's surface. The texture is a fine grain that is too small to be seen by unaided eyes. It related to the metallic ore minerals such as gold, copper and other metals. The sediments that were formed by the weathering of igneous rock is nutrient rich. Thus, they are often the most fertile agricultural areas. Rhyolites are the majority rock that accumulated in the study area. Their phenocrysts are clinopyroxene, hornblende and plagioclase. The other rocks that can be found are andesite, basaltic andesite, agglomerate and tuff or welded tuff which commonly found as dikes, sills, lava flow and pyroclastic deposits.

3.2 Structural geology

In this study, the Late Paleozoic strata has not been found a cleavage. Also, there is a low dip angle fault. These features indicate that the study area is situated outside the intense folding zones which is caused by plate tectonics. Therefore, the investigation zone shows uncomplicated structural geology especially in comparison to the Phetchabun Folds and Thrust Belts, examined by Helmke et al. (1985), which is located on the opposite side in Phetchabun basin. The following are the summary of the interest area's structural geology.

An unconformity is defined as a contact between two strata which the lower unit is much older than the upper unit because of an extended period of buried erosion. There are several causes of unconformity such as by tectonic plate uplifts or by eustatic sea-level fall. An unconformity preserves time missing (hiatus) from the geological record. Thus, the other clues are used to discover the part of the geologic history of the area. In this study, the unconformities are defined by the tectonic event as follows: the angular unconformity can be observed as the boundary between the late Paleozoic and Triassic, the unconformity between the late Triassic has been found as a disconformity and nonconformity overlying on igneous rocks and the unconformity that separates the Tertiary sequence from the Permo-Triassic units because movement of tectonic plate to form Phetchabun basin in the early Tertiary.

The late Paleozoic fold features open and broad. The axial surfaces have developed paralleling with the current rock layers orientation which is north-south axis with the lower plunge. It formed as a large syncline. The fold axes can be observed in the Triassic sedimentary rocks in Wang Pong district distributing southward to Chon Daen district. The western and eastern outer layers of fold limb is found as the Carboniferous rocks and Permian rocks. There is the north-south direction fault strikethrough the Carboniferous rocks causing subsidence and formed as a basement of Phetchabun basin.

From the aerial photographs and field work showing the fractures and faults occurring in Phetchabun as follows: NNE-SSW and NNW-SSE faults with the length is longer than 5 to 15 kilometers have been interpreted to be formed in Pleistocene, NE-SW and NW-SE faults seem to be strike slip or oblique slip fault which the displacement of rocks and E-W faults with low displacement.

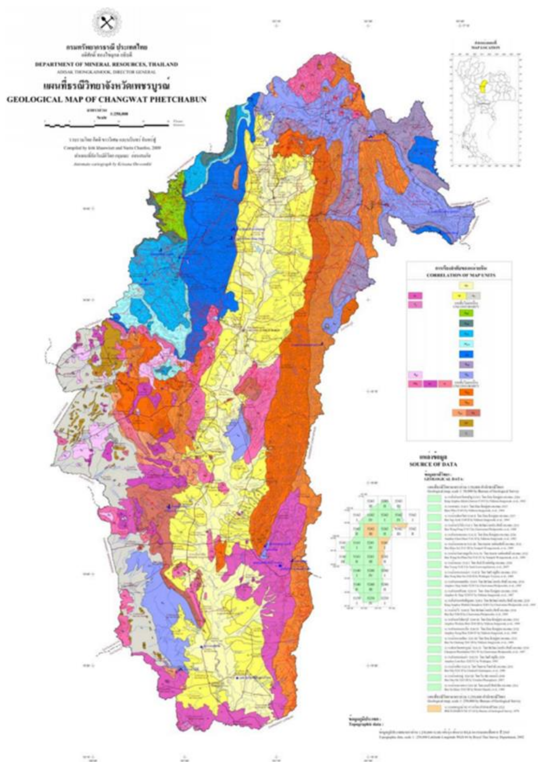

Figure 2. Geological map of Phetchabun province (Department of Mineral Resource, 2009).

4. Methodology

Geomorphic indices are evaluation index to study tectonic activity using digital elevation model (DEM). This study concludes 5 indices that are stream-length gradient index (SL), mountain front sinuosity index (S_{mf}), hypsometric integral (HI), hypsometric curve and basin shape index (B_s).

4.1 Stream-length gradient index (SL)

In general, the stream has reached equilibrium. Stream-length gradient index (SL) is an indicator to measure changes in river profile (Figure 3). It is sensitive to the river slope. SL changing influences by tectonic activity, erosion resistance, climate and topographic features (Hack, 1973). In other words, a river gradient change produced by tectonic movement increases the value of SL. The SL calculation use the following equation:

$$SL = (\Delta H / \Delta L) * L \qquad (1)$$

where ΔH is the change of elevation (m), ΔL is the length of reach (m) and L is the horizontal length (m) from the midpoint of the reach to river head.

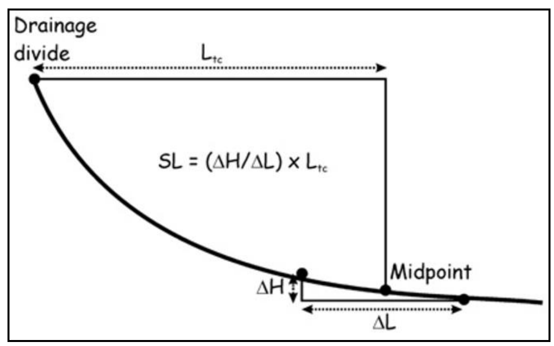

Figure 3. Mechanism of calculation of SL following steam (Hack, 1973).

4.2 Mountain front sinuosity index (S_{mf})

Mountain front sinuosity index has been used to evaluate relative tectonic activities along mountain front (Figure 4) (Silva et al., 2003). An active tectonic uplift which predominates erosional processes shows straight fronts with low values of S_{mf}, while inactive or less active fronts reveals high values of S_{mf}. The S_{mf} is defined as:

$$S_{mf} = L_{mf} / L_s \qquad (2)$$

where Lmf is the straight-line distance along a contour line and Ls is the true distance along the same contour line.

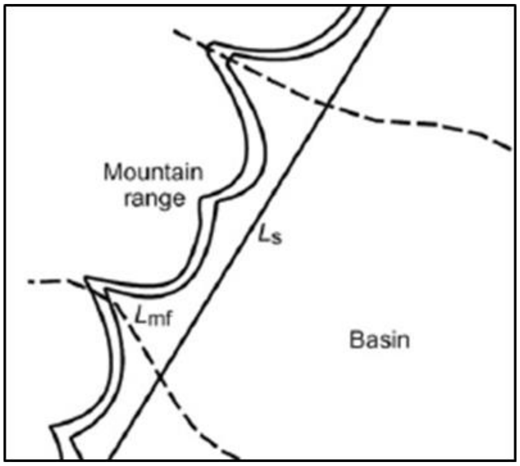

Figure 4. Mechanism of calculation of Smf following mountain rage (Mahmood et al., 2011).

4.3 Hypsometric integral (HI)

The HI is an index that explains the distribution of elevation of area of a landscape, particularly a drainage basin (Strahler, 1952). The index is defined as the area below the hypsometric curve and expresses the volume of the basin that has not been eroded (Dehbozorgi et al., 2010). The equation that calculates the HI index (Mayer, 1990; Keller and Pinter, 2002) is:

$$\mathrm{HI} = \frac{\mathrm{Elev_{mean}} - \mathrm{Elev_{min}}}{\mathrm{Elev_{max}} - \mathrm{Elev_{min}}} \quad (3)$$

where $Elev_{max}$ is maximum elevation of drainage basin, $Elev_{mean}$ is mean elevation of drainage basin and $Elev_{min}$ is minimum elevation of drainage basin.

4.4 Hypsometric curve (HC)

A hypsometric curve is plotted to measure the distribution of landmass volume in a basin. The curve is determined from selecting area elevation (a), the total area of basin (A), selecting elevation (h) and the highest elevation of basin (H) on every point in basin. Then, plotted the proportion of basin area (a/A) and proportion of total basin elevation (h/H) (Figure 10) into hypsometric diagram (Strahler, 1952). There are 3 classes which are class 1 with concave hypsometric curve, class 2 with concave-convex hypsometric curve and class 3 with convex hypsometric curve.

4.5 Basin shape index (B_s)

the basin in tectonically active areas has elongation shape and parallel to slope. The elongation shape (Figure 5a) can be transformed into circular shapes (Figure 5b) as the tectonic activity has been slowing down with time and has continued evolution (Bull and MCFadden, 1997). The transformation is caused by the energy of stream that has been directed primarily to downcutting. The horizontal projection may be explained by B_s (Ramírez-Herrera, 1998). The B_s is expressed as:

$$B_s = B_l/B_w \quad (4)$$

where Bl is the length of the basin measured from headwater to outlet and Bw the width of basin measure at widest point.

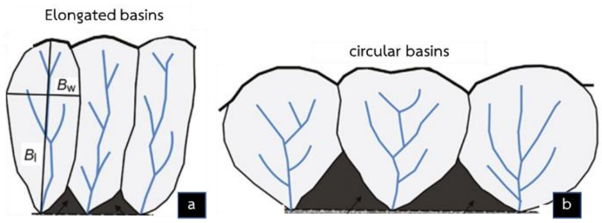

Figure 5. Calculation method of Bs and shape of drainage basin that related to Bs index: (a) elongated basin, and (b) circular basin (Mahmood and Gloaguen, 2012).

5. Result

5.1 Stream-length gradient index (SL)

The SL analysis allows us to identify anomalous points along streams that are related to tectonic activity. Phetchabun province can be divided into 6 orders, which contain an enormous number of points to the point that it is impossible to calculate (Figure 6). Hence, this study plots the histogram for choosing the suitable interval to create a map. Finally, this study selects a range of SL values to be in the 90-100 normalized percentage due to the aberrant interval observed from SL histogram in that particular range. The high value points in the 90-100 range represent high tectonic activity causing by fault, lineament and local uplifting. The high value of SL appearing on the map following stream order can be divided to six orders. There are a total 6,120 points of SL value in the 90-100 percentage range.

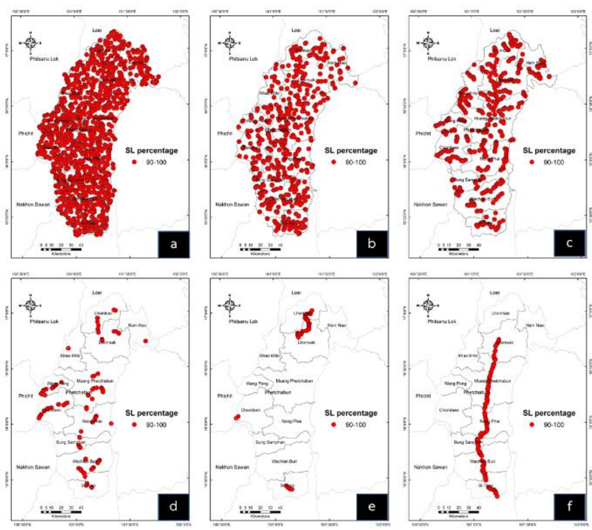

Figure 6. Map of Phetchabun province showing distribution map of SL following stream order 1-6: (a)order 1, (b) order 2, (c) order 3, (d) order 4 (e) order 5, and (f) order 6 (red points indicate anomaly of SL)

5.2 Mountain front sinuosity index (S_{mf})

In Phetchabun province, there are total lineaments are 207 lines (Figure 7). The result of the S_{mf} values range from 1.02 to 6.92 (Figure 33). According to the investigation of Keller and Pinter, 1996, if S_{mf} is close to 1, then mountains fronts show straight lines corresponding to lineament. Referring to this mention, the result has been demonstrated that the central and northeast Phetchabun indicate high recent tectonic. Since it expresses high S_{mf} value. Mostly of this zone situated in mountain area. In contrast, the S_{mf} value for eastern and southern Phetchabun, mostly located in the plain area, indicate low tectonic activity due to its low S_{mf} value. Therefore, it means that there are higher tectonic and more erosion in the central and northeast area than eastern and southern of study area.

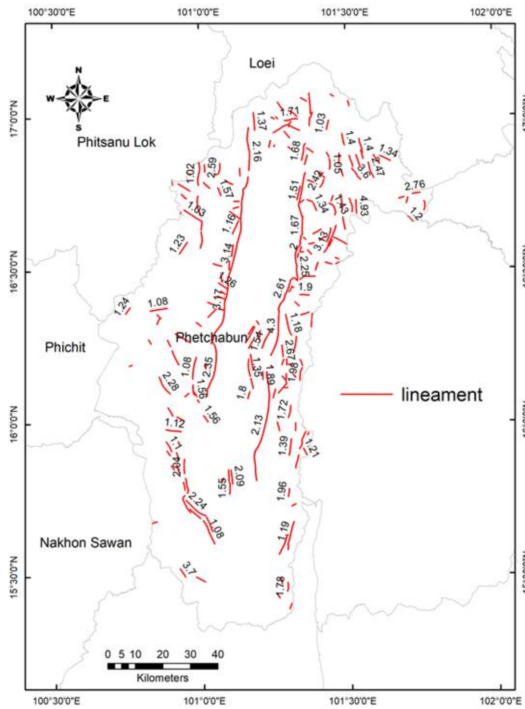

Figure 7. Map of Phetchabun province showing S_{mf} distribution.

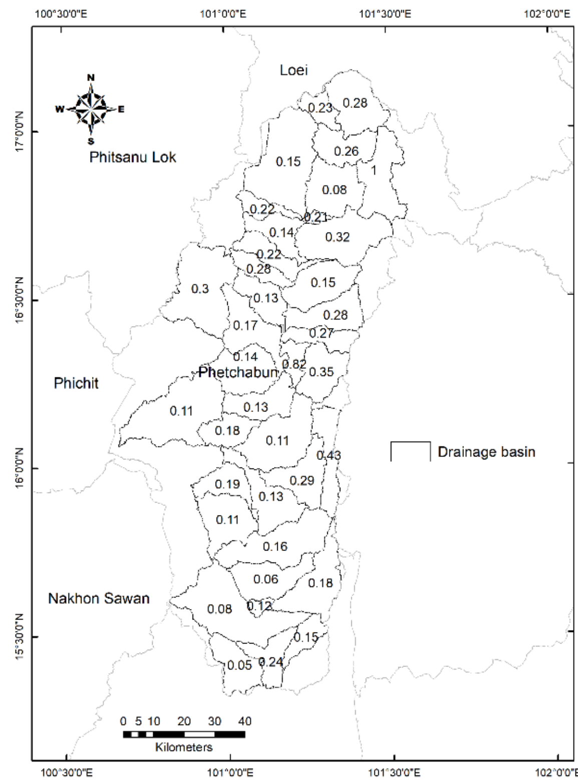

Figure 8. Map of drainage basins in Phetchabun province showing HI distribution.

5.3 Hypsometric integral (HI)

The HI values in Phetchabun province range from 0.05 to 1.00 (Figure 8). Most basins have quite low HI value in which the lowest value is 0.05 in the Southern area. Meaning that, drainage basins in Phetchabun province have been more eroded and less impacted by active tectonics especially in western and Southern areas than eastern areas which have high value from 0.48-1.00. Therefore, the HI value can be interpreted that Western and Southern area have low tectonic activity and are older when compared to Eastern of study area.

5.4 Hypsometric curve (HC)

The hypsometric curve is related to the HI that the area below the hypsometric curve defines tectonic activity and age of the drainage basin as HI value. The curve can be divided into 3 classes: i) concave hypsometric curve, ii) concave-convex hypsometric curve and iii) convex hypsometric curve. In the study area of 38 drainage basins, there are 31 basins identified as Concave HC, 6 basins identified as Concave-convex HC, and 1 basin identified as convex HC. (Figure 9)

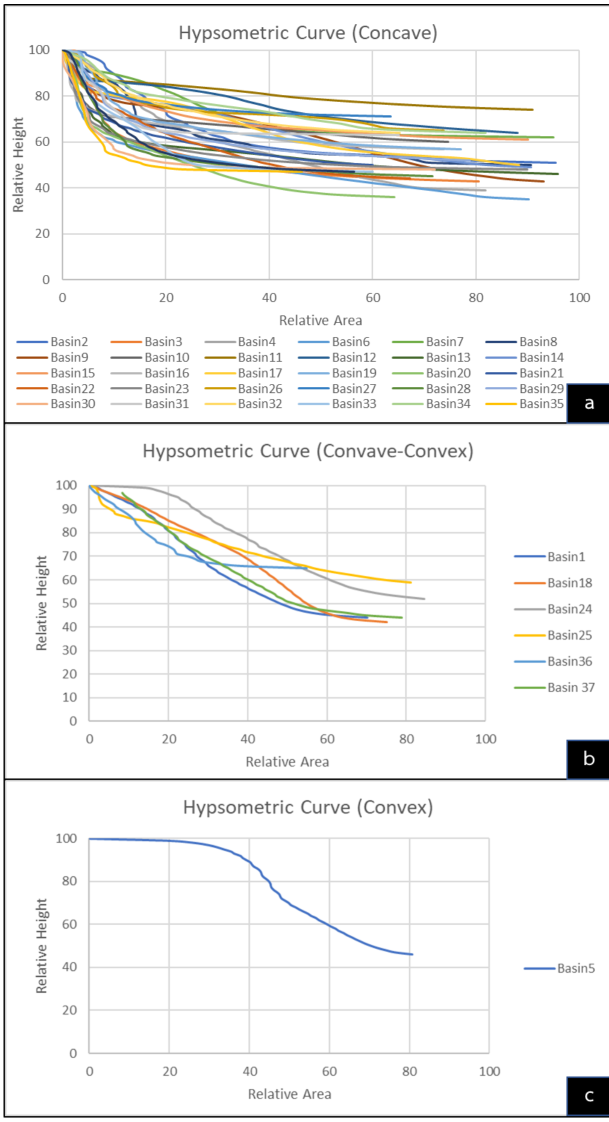

Figure 9. Graph of drainage basin in Phetchabun province showing classification of hypsometric curve: (a) concave, (b) concave-convex, and (c) convex.

5.5 Basin shape index (B_s)

Results of the B_s in Phetchabun province have the value range from 0.31 to 5.80 (Figure 10). High B_s value is shown in Central Phetchabun, ranging from 1.37 to 3.06. Other parts show low B_s value around 1 and the lowest value is 0.31. From this result, this study can conclude that most drainage basins in Phetchabun province indicates comparatively high tectonic activity or low activity of erosion process.

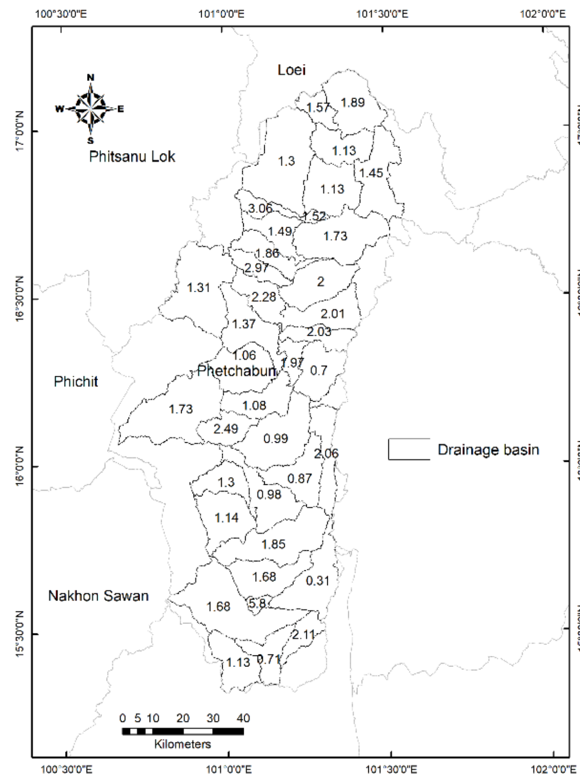

Figure 10. Map of drainage basin in Phetchabun showing distribution of B_s

6. Discussion

6.1 Comparatively geomorphic indices

From the result, SL map can be classified into three types: type 1 (Cheng et al., 2016), type 2 (Mahmood and Gloaguen, 2012) and type 3 (Sarp et al., 2011). However, in this study decide to classify the stream order 5 and order 6 as they provide the obviously anomalous values of SL which can indicate the tectonic activity of the main stream in

Phetchabun province. According to the 3 types of classification of the stream order 5 and 6, SL in Phetchabun province has been supported low tectonic activities along stream.

The S_{mf} values can be classified into three types: type 1 (Mahmood and Gloaguen, 2012), types 2 (Partabian, Nourbakhsh, and Ameri, 2016) and type 3 (Ntokos, Lykoudi, and Rondoyanni, 2016). Two types of classification (type 1-2) in S_{mf} along the mountain front show less or inactive mountain front and low erosional processes. However, type 3 indicates an active or less mountain front. Then, the type 3 provide difference classification which is medium active mountain front and medium erosion process. So, mountain front in the study area indicate low to medium tectonic activities and low to medium erosion process.

According to the result of HI ma, it can be divided into three types: type 1 (Mahmood and Gloaguen, 2012), types 2 (Cheng et al., 2016) and type 3 (Nikoonejad et al., 2015). From three types classification with HI. Most drainage basins in Phetchabun province indicate area that are less impacted by active tectonic, old age drainage basin and low erosional processes.

HC in the result, it has three classes: class 1 concave HC, class 2 concave-convex HC and class 3 convex. HC Phetchabun province show 31 drainage basins in class 1 that indicate old age and less or inactive tectonic activities, 6 drainage basins in class 2 which represent mature age and still develop to landscape and class 3 has 1 drainage basin which show the youngest drainage basin and active tectonics (Figure 65). Therefore, drainage basins in Phetchabun province in HC present that most drainage basins are old age and less or inactive

Table 1 classification of each geomorphic index. (class 1 means low tectonic activities and class 5 means high tectonic activities)

Classification types	Class Geomorphic index				
	SL	S_{mf}	HI	HC	B_s
Sarp et al., 2011	1	-	-	-	-
Mahmood and Gloaguen, 2012	1	3	1	-	3
Nikoonejad et al., 2015	-		1	-	
Cheng et al.,2016	1		1	-	5
Partabian, Nourbakhsh, and Ameri, 2016	-	2	-	-	1
Ntokos, Lykoudi, and Rondoyanni, 2016	-	2	-	-	-
Tectonic activities	Low	Low to Medium	Low	Low	Low to High

tectonics.

Lastly, the result from B_s map, it can be classified into three types: type 1 (Mahmood and Gloaguen, 2012), types 2 (Cheng et al., 2016) and type 3 (Partabian et al., 2016). From two types classification (type 1-2) with B_s. Most drainage basins in Phetchabun province indicate elongated shape drainage basins that are highly active tectonic. Then the type 3 shows difference classification which has been supported circular shape drainage basins and low tectonic activities therefore drainage basins calculated by B_s show low to high tectonic activities. All types classification of each geomorphic index that indicated tectonic activities is shown in Table 1.

6.2 Geomorphic indices and geological setting Hack (1973) and Harkins, Anastasio, and Pazzaglia (2005) suggested that lithological differences influence SL. According to this study, it has 8 periods following the geological time scale. There are Quaternary, Tertiary, Cretaceous to Jurassic, Jurassic, Triassic, Permian, Permo-Triassic and Carboniferous. Most SL points are shown in Quaternary (5,013 points). The Carboniferous (C) mainly contains sedimentary rocks that are conglomerates, sandstones, slaty shales, grey shales and gray cherts. In the Triassic (TR_{np}), there are Triassic reddish-brown sandstones with calcrete layers at top of cycle and interbedded with reddish brown calcareous siltstones and calcareous mudstones. The Triassic (TR_{hl}) consists of brownish-red siltstones, sandstones, conglomeratic sandstones and basal conglomerates. Granites and granodiorites are found in the Triassic (TR_{gr}). In addition, there are fossiliferous limestones, cherts, pillow basalts and serpentinites (Ps), tuffs, rhyolitic tuffs and andesite tuffs in the Permo-Triassic (pTR_v). There are siltstones interbedded sandstones and intercalated conglomerates in the Cretaceous (K_{kk}). Moreover, there are white and pink sandstones, conglomerates and pebble sandstones, gray siltstones and claystone in the Cretaceous to Jurassic (JK_{pw}). The Jurassic (J_{pk}) consists of reddish-brown siltstones and claystone. The Tertiary period found semi-consolidated claystone; red siltstones, ignites and mudstones in the Tertiary (T) and dark gray to black basalts in the Tertiary (bs). The Quaternary period can be separated into two units that are alluvial deposit in the Quaternary (Q_a) and terrace deposit in the Quaternary (Qt). According rock units in the study area, most SL points in the study area are found on Qt (2,620 points), Q_a (1,513 points), Ps (1,125 points), pTR_v (839 points), TR_{hl} (815 points), bs (659 points), JK_{pw} (514 points), J_{pk} (258 points), TR_{np} (213 points), K_{kk} (87 points), TR_{gr} (76 points), C (35 points) and T (1 points). Thus, the rock unit that shows the most SL point is Qt that is gravel sand and clay (Figure 69a).

As reported by Pedrera et al. (2009), the SL is sensitive to active folds where the hard rocks are outside. However, it is insensitive in the sedimentary rocks because of erosional processes on easily erodible sediment. Sedimentary-metamorphic rocks and igneous rocks cover most area in this study. Therefore, most SL points are found on the sedimentary-metamorphic rocks (7,315 points) and igneous rocks (1,574 points) respectively (Figure 69b).

The S_{mf} value obtained from the mountain front. The HI value, HC and B_s gained from drainage basin in this study. They seem to be related to the occurrence of tectonic activities and represent erosional processes. The S_{mf} value and HC showed the low tectonic activities because sediment erosion is important for the length of mountain front, relative area and relative altitude to calculation of S_{mf} and HC respectively. In general, the erosional process simply occurred on the sedimentary rocks more than metamorphic or igneous rocks both performed by water and by wind. The erosional processes and low tectonic activities in the result has supported the high Smf values and concave HC from mountain front and HC from drainage basin. In addition, sedimentary rocks as mentioned above have covered most areas of Phetchabun. However, the B_s show high tectonic activities and elongated drainage basin shape. It will be affected by lineament as mentioned and folds a large syncline with north-south axis in the Triassic sedimentary rocks.

7. Conclusion

The geomorphic indices are effective tools for evaluating the influence of tectonic activities. These models can be used as surveying instruments to detect the geomorphic anomalies related to tectonic activity. The method is valuable to Phetchabun province which is available for active tectonics based on absolute dating. We evaluated the relative active tectonics using DEM 30 resolution. They acquired the drainage network and five geomorphic indices which are SL, S_{mf}, HI, HC, and B_s.

The values of SL percentage have been found to be anomalies along the stream that was related to the influence of tectonic activity. The values of S_{mf} proposed that the majority of the mountain fronts are tectonically low to medium active. The values of HI and HC for drainage basin determine high tectonic activity and young stage. Moreover, most drainage basins show the high value of B_s that indicate elongated shape drainage basin that represents tectonically active.

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