

A Measure of Intense in West and Central Java Through Manifestation of River Basin Morphometry Development on Quaternary Volcanic Deposits

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ABSTRACT

Indications exhibiting active tectonic movements in Java occur in many places, characterized by unstable regions, such as active faults, earthquakes, volcanic eruptions, *etc.* The results of researches conducted at several areas in West and Central Java on tectonic morphometry developments of river basins both in Quaternary deposits and Tertiary sediments exhibit a degree of active tectonic intensity. Such the researches are very important regarding to the spatial development design that is related to a region of active tectonism that should be well understood by planners for decision making mainly through comprehensive approach, in which the phenomena involved explaining the characteristics of the region as part of an active plate margin. Statistic approach as the chosen methodology had been utilized to gain meaningful conclusions through the verification of hypotheses, which are based on valid and reliable tested data obtained from the fields and satellite imagery. Results of regression-correlation tests between azimuths of river segment and lineaments in both chronostratigraphic systems mentioned earlier are significant with several large values of correlation coefficients r of no less than 0.9. On the other hand, results of t -tests are not a significant difference of means of bifurcation ratio (R_b) and drainage density (D_d) from many to river basins. The results of all tests have verified the effect of active tectonic control on the morphometry development process regarding to river segments and density of drainage patterns development in Tertiary and Quaternary deposits.

Keywords: tectonic morphometry, degree of tectonic intensity, neotectonic activity, river basin, bifurcation ratio, drainage density

SARI

Aneka indikasi pergerakan tektonik aktif di Pulau Jawa terdapat di beberapa tempat yang ditandai oleh wilayah tidak stabil, di antaranya oleh pergerakan sesar aktif, gempa bumi, letusan gunung api, dsb. Hasil riset di beberapa daerah di Jawa Barat dan Tengah tentang perkembangan morfometri tektonik daerah aliran sungai pada endapan Kuartar dan pada batuan sedimen Tertier, memberikan tingkatan intensitas tektonik aktif. Penelitian demikian sangat penting sehubungan dengan perencanaan tata ruang yang terkait dengan wilayah berkondisi pergerakan tektonik aktif, yang seyogianya difahami dengan baik oleh para perencana untuk pengambilan keputusan, khususnya melalui pendekatan komprehensif dengan keterlibatan fenomena yang menjelaskan karakteristik wilayah yang bersangkutan. Pendekatan statistik digunakan sebagai metodologi untuk mendapatkan kesimpulan yang kuat melalui pembuktian beberapa hipotesis berdasarkan data absah dan handal yang diperoleh dari lapangan dan citra satelit. Hasil uji regresi-korelasi antara azimuth segmen sungai dengan kelurusan pada dua sistem kronostratigrafi tersebut di atas (endapan Kuartar dan batuan Tersier) adalah signifikan dengan nilai-nilai koefisien korelasi r yang tidak kurang dari 0,9. Dalam hal lain, hasil uji beda rata-rata (t -test) baik untuk nisbah percabangan sungai (R_b) maupun untuk kerapatan pengaliran (D_d) daerah-daerah aliran sungai tidak berbeda secara signifikan. Hasil-hasil uji tersebut telah memverifikasi dampak kendali tektonik aktif terhadap proses pengembangan morfometri terkait segmen-segmen sungai dan kerapatan pola pengaliran pada batuan Tersier dan endapan Kuartar.

Kata kunci: morfometri tektonik, tingkatan intensitas tektonik, aktifitas neotektonik, daerah aliran sungai, nisbah percabangan sungai, kerapatan pengaliran

INTRODUCTION

As has been mentioned earlier in the abstract of this paper, indications exhibiting active tectonic movements in Java occur in many places. This region is part of one of the most active plate margins around the globe. These phenomena, also known as neotectonic movements, are manifested by unstable regions, in which active faults, land subsidences, earthquakes, volcanic eruptions, rock mass movements, *etc.*, occur. Recent flexural deformations are good indicators to the surface movement characterizing recent tectonic activity or neotectonism (Nakata *et al.*, 1996). Active tectonic movement in West Java plays an important role in affecting the development of river basin morphology on Quaternary volcanic deposits (Hirnawan *et al.*, 1998; Hirnawan and Muslim, 2006).

Tectonic movement is also known as tectonism. Tectonism or diastrophism is a general term for all movement of the crust caused by all tectonic processes, including the formation of trenches and ocean basins, volcanic belts, continents, plateaus, and mountain ranges. Tectonism is more suitable for the more specific term (Bates and Jackson, 1984; McNeil, 1999).

This paper is written based on results of four researches on neotectonic activity conducted by the author himself and his team, and his previous postgraduate students.

The objective of the researches is to get the measures of tectonic intensity based on manifestations of measurable and verifiable morphometry developments as the responses to the tectonism itself. The method utilized in these researches was the verification of data of deformation pattern and river basin morphometry, instead of the usual approach of descriptive and qualitative characterization of the phenomena. Basin morphometry, in terms of geomorphology development, was determined by active tectonic movements in the region between eastern West Java (Hirnawan, 1997; Hirnawan and Muslim, 2006; Sophian, 2009), western Central Java (Hirnawan *et al.*, 2007), and Yogyakarta (Budiadi, 2008) as shown in Figure 1. At least, in the region, four variables encompassing lineament, river segment, drainage density, and bifurcation ratio of drainage basins developing in areas of distribution of both Quaternary volcanic deposits and the unconformably underlying Tertiary marine sediments were measured, analyzed, and tested for the verification of the hypotheses.

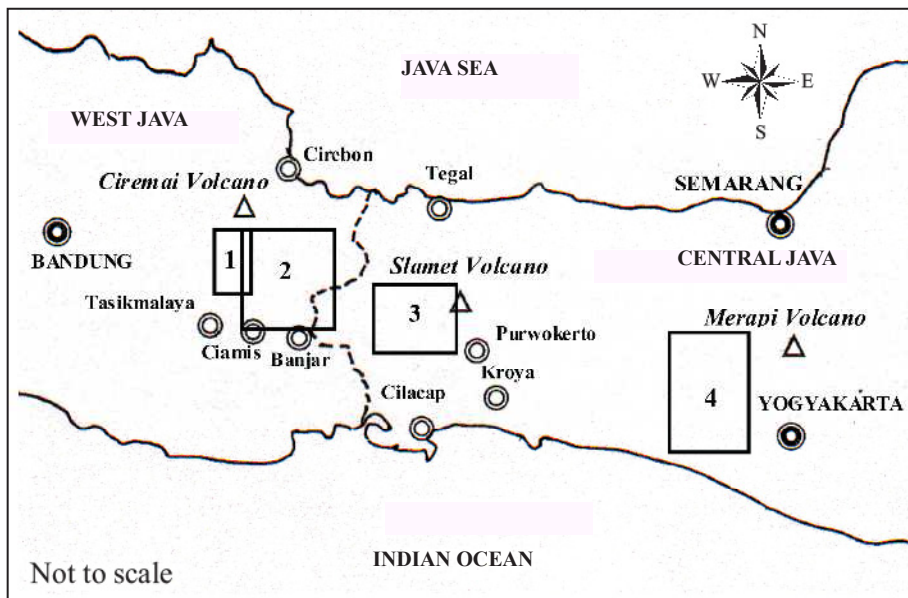


Figure 1. Locations of researched areas between Ciremai Volcano (West Java) and Merapi Volcano (Central Java). 1) Panawangan Area (Hirnawan, 1997); 2) Rancah Area (Sophian, 2009); and 3) Bumiayu Area (Hirnawan *et al.*, 2007), 4) Kulon Progo mountainous region (Budiadi, 2008).

Geomorphology of a region should be of destructional or constructional origin. Destructional origin generates erosional and residual features, whereas constructional origin generates depositional feature (Linsley *et al.*, 1975). Valleys were developed by an erosional process, along which streams flow following geological weaknesses, such as joints or faults (or lineaments), bedding planes, unconformities, zones of weak rocks, *etc.*, in the region. In other words, this erosional feature is governed by the pattern of erodible geological weaknesses and the climate, by which the characteristics of river basins are generated (Stewart and Hancock, 1994; Keller and Pinter, 1999).

Deformation pattern of the geological weaknesses, for example lineament distribution pattern, originated from tectonism should govern the development of network of streams in a region forming a river basin. The river basin development on deformed Quaternary volcanic deposits, as a result of erosional process following the deformation pattern due to recent tectonism, enable us to measure both the pattern and the degree of tectonic intensity as indicators of the tectonism using a morphometry comparison approach with that on Tertiary rock formation. This technique was applied in the researches mentioned earlier.

While the erosional features are being developed the residual features are also generated forming a mountainous region, in which the network of valleys in this region are continuously eroded. This is the way that the process of destructional origin works. On the other hand, a constructional origin generates a constructional feature, for example a delta, which is constructed by the process of sedimentation in low lands.

The involvement of active tectonism in the destructional origin is preserved in the region exhibited by development of tectonic geomorphology of river basins as erosional features, in which mountainous ranges as residual features are generated. Tectonic geomorphology, as has been well known by geologists, involves the processes of tectonism, erosion, and deposition in a region (Burbank and Anderson, 2001). Understanding of this statement according to these authors is tectonic geomorphology that developed after the deformation pattern in the region was generated due to previous tectonism. Therefore, geomorphologic units that had been generated through

denudation process should portray the pattern of geometry of the existing geological structures due to the previous tectonic activity before Quaternary Period in the region, whereas none of deformation occurs in the Quaternary deposits.

In case of active tectonism involved in the development process of a tectonic geomorphology of a region, which is studied in the region between Ciremai and Slamet volcanoes, and southeast of Merapi volcano mentioned in the foregoing part, the Quaternary deposits is being deformed determining the river basin morphometry.

Morphometry is the measurement and mathematical analysis of the configuration of the earth surface and of the shape and dimensions of its landforms (Clarke, 1966, in McNeil, 1999). This morphometry developing on the Quaternary deposits enables us to measure the tectonic intensity in the region. Geological structures, such as folds, faults, and joints appear to control the drainage networks or drainage patterns. Morphometry concerns the measurement of drainage network or the form characteristics of rivers, lakes, *etc.* and their basins as a river system. Drainage basins are the entire area drained by the river system, which contains the rivers and all of its tributaries (Splitz and Schumm, 1997).

Scientific problems as the reason to conduct the researches of the active tectonic region with the occurrences of the indications mentioned above are as follows : 1) how far has the recent tectonic activity been controlling or determining river segments development pattern of drainage network; 2) how far has the tectonic activity generated deformation configuration in terms of lineament pattern and density that facilitated the river basin morphometry developments on both Quaternary and Tertiary rock deposits.

These two problems need to be answered specifically using quantitative approach of methodology in terms of statistical approach. The answer will be a degree of activity and intensity of the tectonic movements in the region manifested by the measure of river basin tectonic morphometry.

To answer the scientific problems as the objective of these researches mentioned earlier hypotheses should be formulated through deduction way of thinking. On the other hand, through induction way of thinking, this objective can be achieved by testing the hypotheses with the support of data of the

variables mentioned above obtained from satellite imagery interpretation and the measurements done during field works executed in river basins in the respective Panawangan and Rancah areas (Researched Areas 1 and 2) in eastern West Java, Bumiayu area (Researched Area 3) in Central Java, and Kulon Progo mountainous region (Researched Area 4) in Yogyakarta Province (Figure 1).

In this kind of hypothetico-deductivism research, as well as in other researches of this type, both deduction and induction ways of thinking should meet the same point, which means that a hypothesis is testable or verified to generate a proper or reliable conclusion about the phenomenon of the neotectonic activity determining the river basin morphometry development on both Quaternary volcanic deposits and the unconformably underlying rock formations. This tectonic geomorphology phenomenon, in which many morphometry variables involved gives scientific reasons to conduct the verification of the hypotheses to achieve the measured, tested and powerful conclusions instead of qualitative interpretations.

The formulated hypotheses that should be verified using statistics are presented below :

1. Active tectonic movement has been determining river segment development patterns or drainage network, in which correlation between river segment azimuth and lineament azimuth significantly confirms this process.
2. An intensely active tectonic movement generated similar deformation pattern and density developing on Quaternary volcanic deposits with that on Tertiary sedimentary rocks respectively, by which both bifurcation ratio and drainage density of river basins (the entire area drained by a river and its tributaries. Cf : drainage basin; McNeil, 1999) being formed on these rock formations are not significant difference.

METHODOLOGY

As has already been well known, statistical analyses were used by many authors for geomorphological approach before 1960s (Doornkamp, 1986). The present author has already used these analyses for verifying the effects of either reverse or strike slip fault on joint configuration patterns and

bedding plane mean orientation values developing in the rock blocks separated by these faults in Regency of Kuningan, West Java, in year 1987 (Hirawan, 1987). Geomorphological approach of drainage basin developments in eastern West Java mentioned earlier had successfully been conducted using statistics to verify the similar deformation pattern and density of joints both on Quaternary and that on Tertiary rock deposits as the measurable effect of neotectonic intensity on tectonic morphometry (Hirawan, 1997), instead of ordinary approach of descriptive characterizations in generally studying geomorphology, known as grounded research (Haig, 1995).

This methodological approach is then widely used in postgraduate program of geosciences in his university as a guidance of post-positivism paradigm for students to conduct their hypothetico - deductivism researches of phenomena, such as erosion, volcanic products of Merapi Volcano, distribution of fossil - bearing beds, sedimentary facies, *etc.*, and tectonic phenomena, in which he is involved as one of the supervisors.

The result of the research by his previous student of doctor program in Kulon Progo mountainous region, for example, suggested that tectonic activity since Eocene period has generated a similar morphometry of drainage basins developments on five rock formations of Tertiary marine sediments with that on Quaternary rock deposits (Budiadi, 2008). In this region the occurrences of three tectonic deformation patterns were successfully verified as had been originated from Sumatra, Java, and Meratus tectonic patterns. This reliable conclusion of ten other results of successful verification of hypotheses in this research, had not only been the support of previous interpretations in terms of hypotheses proposed by many authors, which had not been tested before, but had also generated the measurable degree of tectonic intensity in determining the morphometry developments on three chronostratigraphic systems of Eocene, and Oligo-Miocene sedimentary rocks, and Quaternary volcanic deposits in the mountainous region.

This scientific invention obtained through a research of this type had confirmed the applicable plate tectonic theory for the explanation of the origin of Kulon Progo mountainous region, instead of previous and unexplainable Van Bemmelen's theory

of gliding tectonics. Steps of works carried out in the implementation of the methodology used in this hypothetico-deductivism research are as follows.

Before taking the samples for testing the Hypothesis 1 stated earlier, it is important to identify the suitable studied populations, on which the phenomenon of active tectonic movement is able to be measured using the variables involved as being represented by the data. The populations are both deformed Tertiary sedimentary rock formations and unconformably overlying Quaternary volcanic deposits (both formations are deformed). The involved variables measuring the phenomenon are lineament and river segment azimuths, which should be tested to exhibit the sufficient coefficient of correlation between them. This correlation measures the effect of lineaments on origin of river segment azimuths resulting in the drainage network particularly on Quaternary volcanic deposits due to neotectonic activity, and also on Tertiary rock formations. The measures of this phenomenon of tectonism through the verification of the Hypothesis 1 for Researched Areas 1, 2, 3, and 4, are the significant correlation coefficient r between river segment and lineament azimuths in terms of the measures of how close the relationship between these variables are constructing the linear curves. These high correlation coefficients between the two variables measure the very high degree of dependency of river segment heading development on the lineament azimuths in the researched areas, which means that deformation pattern due to recent tectonic activity has been governing the river basin development mainly on Quaternary volcanic deposits.

For testing the Hypothesis 2 stated in the foregoing part, two morphometry variables developing on those abovementioned Tertiary and Quaternary rock formations are involved. These variables are drainage density D_d and bifurcation ratio R_b . The measure should be the result of the hypothesis verification using the data samples of these variables. The hypothesis is exactly the measure of the comparison of morphometry development originated from tectonism on both Tertiary and Quaternary rock formations. In other words, in conducting the verification of this hypothesis, the tectonic morphometry developing on Quaternary volcanic deposits is compared with that on Tertiary rock formations. As the results of the verifications, no significant dif-

ferences between two means of either D_d or R_b , and also both D_d and R_b representing their populations (Tertiary and Quaternary rock formations). Those suggest that the tectonism exists. The test measured the indifferent means of D_d and/or R_b of the river basins morphometry developing on these respective formations due to tectonism.

Sampling Technique

For every researched area test of Hypothesis 1 needs data of lineaments and river segment azimuths, while test of Hypothesis 2 needs data of drainage density D_d and bifurcation ratio R_b of river basin. A probabilistic approach gives a clear understanding that a sample is known as a group of n individual data representing a population. Hypothesis 1 needs to be tested using one-grouped sample of lineaments and river segment azimuths taken from either a Tertiary or a Quaternary rock formation as the respective tested populations to verify if these two variables closely correlate or relate to each other. Hypothesis 2, on the other hand, needs to be tested using two-grouped sample for verifying the difference between two means of the samples. Both one- and two-grouped samples are statistic nomenclature, which are presented below.

1. To obtain data of drainage network of a river basin as a phenomenon of tectonic morphometry, both river segment and lineament azimuths were employed as involved variables representing the phenomenon. Either aerialphoto or satellite imagery interpretation was utilized to identify lineaments originated from tectonic activity distributed in the river basin, which were then plotted on the topographic base map, as shown on Figure 4 and 6. These lineaments, along which river or stream segments have been developing and flowing to follow the lineament directions, were selected as the members of the studied population. So, this population is a group of pairs of the involved variables. Every lineament without being paired by a river segment is not a member of the population or is not a representation of the subject of study, which shall not be taken as a sample member.
2. In preparing the sample representing the studied population mentioned above, every single pair of these data variables was then randomly taken and gathered as a sample representing the studied

phenomenon. This kind of sampling technique is known as one-grouped sampling taken from one population, of which every single member of the sample presents two variables. These one-grouped samples taken from respective Studied Areas 1, 2, 3, and 4 represent their populations on both Tertiary and Quaternary rock deposits.

3. Every river basin as a subject of study of tectonic morphometry phenomenon, of which its drainage network shows indications of being affected by deformation pattern represented by lineaments due to tectonic activity, such as rectangular, trellis patterns, *etc.*, was selected from area of distribution of Tertiary sedimentary rock formations and also from deformed Quaternary volcanic deposits.
4. Besides the abovementioned variables, the other variables explained below are also studied. The study is conducted to measure river density (originated from fracture density) of the river basin developing on deformed rock formations of both Tertiary marine sediments and Quaternary volcanic deposits. To achieve the objective of the study, comparison of samples taken from these respective chronostratigraphic systems were carried out using statistical test of difference between two means of variables indicating the phenomenon of the effect of tectonic activity on the river density. The employed variables are D_d and R_b (explained in section of Testing Hypothesis 2). Sampling technique carried out for taking such the samples is two-grouped sampling. The result of samplings is presented in Appendices 1 up to 4. In other words, two-grouped samples are taken each from two respective populations and then grouped together for test of difference between two means. The populations in this case are drainage basins on both Quaternary and Tertiary rock formations, of which the studied variables from every population are D_d and R_b representing phenomenon of their tectonic morphometry developments due to recent tectonism.

Statistical Analyses

Data analyses were carried out to verify the hypotheses. For testing the Hypothesis 1 regression-correlation tests were conducted, while for verifying the Hypothesis 2 tests of difference between two means were carried out. These tests applied both

monovariate (t-test) and multivariate (T2-Hotelling) approaches. The results of the tests suggest the intensity of tectonism in the studied areas governing the morphometry development of drainage networks.

Based on the formulated hypotheses the data of all variables involved in the studied phenomena were collected from Landsat satellite imageries or aerial photo interpretations and from the field measurements. The data should be properly measured to achieve their validity and reliability that need to be tested using suitable statistical tests, before being used for the analyses and the verifications of the hypotheses in order to gain the powerful conclusion of the research.

River basins consisting of subriver basins distributed on both Tertiary rocks and Quaternary deposits in the researched areas were the studied populations, in which the respective variables of river segment, lineament, bifurcation ratio (R_b), and drainage density (D_d) were randomly taken as sample members for the verification of the hypotheses. In this case, both one-grouped samples and two-grouped samples were taken as sampling techniques of the researches. Lineaments were identified and plotted on a map using Landsat satellite imagery interpretation, which were then randomly taken as samples to be validated as mentioned above. This step of research is very important to avoid either α or β error, which means to avoid error from either rejecting acceptable hypothesis or accepting rejectable hypothesis because of invalid and unreliable data. Table 1, for example, presents the result of tests of validation of lineament samples versus other joint samples taken from the Halang and Kumbang Formations and also from Quaternary volcanic deposits in the field.

As the results of testing this validity and reliability in Table 1, the difference of means between lineament samples obtained from the Landsat or aerial photos and other means of joint samples of the rock formations were not significant at level $\alpha = 0.05$ or at level of significance 95 %, which suggested that the samples of lineament were able to be used for the next verification purposes in the research. The samples were well accepted as valid and reliable samples. Again, the result of tests in Table 1 also exhibited that means of joint samples obtained from the Halang and Kumbang Formations of flysch sediments and breccia respectively, that represent Tertiary marine sediments, were not

Table 1. a) Result of Tests of Difference between Two Means of Joint Samples from the Field and Lineament Samples from Satellite Imagery Interpretation on Tertiary Sediments and Quaternary Volcanic Deposits (Qbx); b) Result of the Same Test for Joint Samples from Exposures of the Halang (Tmph) and Kumbang Formations (TmPk) of Tertiary Rocks Formations (Hirnawan *et al.*, 2007).

a) Joint samples from field vs. lineament samples from satellite imagery interpretation							
Variable tested of	Mean values		n1/n2	t _{calc.}	t _(0.975)	Decision	Conclusion
	Field	Satellite Imagery					
Tmph Joints vs. Tertiary Lineaments	92.625	89.250	88/32	0.323	1.980	accept Ho	no difference
TmPk Joints vs. Tertiary Lineaments	89.571	89.250	77/32	0.029	1.983	accept Ho	no difference
Qbx joints vs. Quaternary lineaments	92.436	93.000	39/26	0.045	1.998	accept Ho	no difference
b) Joint samples from Halang Formation (Tmph) vs. Kumbang Formation (TmPk)							
TmPk joints vs. Tmph joints	89.571	92.625	77/88	0.379	1.975	accept Ho	no difference

significantly different. This suggests that they represented the same deformation pattern in the same chronostratigraphic system in the researched area.

ANALYSES AND RESULTS

Outline of Geology

In region between eastern West Java and Central Java (Figure 1) rock exposures had already been mapped by many geologists, which gave a general conclusion that two chronostratigraphic systems occur. These systems being separated by an unconformity consist of Tertiary marine sediments and Quaternary deposits. The Tertiary sediments consist of sedimentary rock formations, known as the Pemali, Rambatan, Halang, Kumbang, Tapak Formations, *etc.* of Early Miocene to Early Pliocene age. These formations had been being folded, jointed, and faulted by tectonic activity during Neogene orogeny. The deformed formations were involved in the process of magmatism, from which intrusive rocks formed at many places, followed by volcanism generating Quaternary volcanic deposits distributed in large areas.

The recent tectonic movement is active manifested by indicators, such as volcanic eruptions,

active faults followed by landslides, land subsidences, and earthquakes that frequently happen, in which Quaternary deposits involved. Figure 2, for example, as one of the researched areas giving the geological data for this paper, and Figure 3 presents the geology of Kulon Progo mountainous region, Province of Yogyakarta.

In West-Central Java region, the drainage networks of river basins developing on Tertiary rock formations exhibit trellis and rectangular patterns in most cases, and on Quaternary volcanic deposits they show a combination pattern of subdendritic and rectangular, for example in Figures 2 and 4. These drainage networks are indicators of active tectonism in the region, by which the development of stream or river segments, mainly on the Quaternary deposits, were governed by the deformation pattern in terms of lineaments distribution configuration.

These indicators of active tectonism had been the scientific reason to the author and his team to conduct the researches to verify the degree of tectonic intensity.

The results of data analyses and verifications of hypotheses from four researched areas are discussed below, which reveal the active tectonic movement or



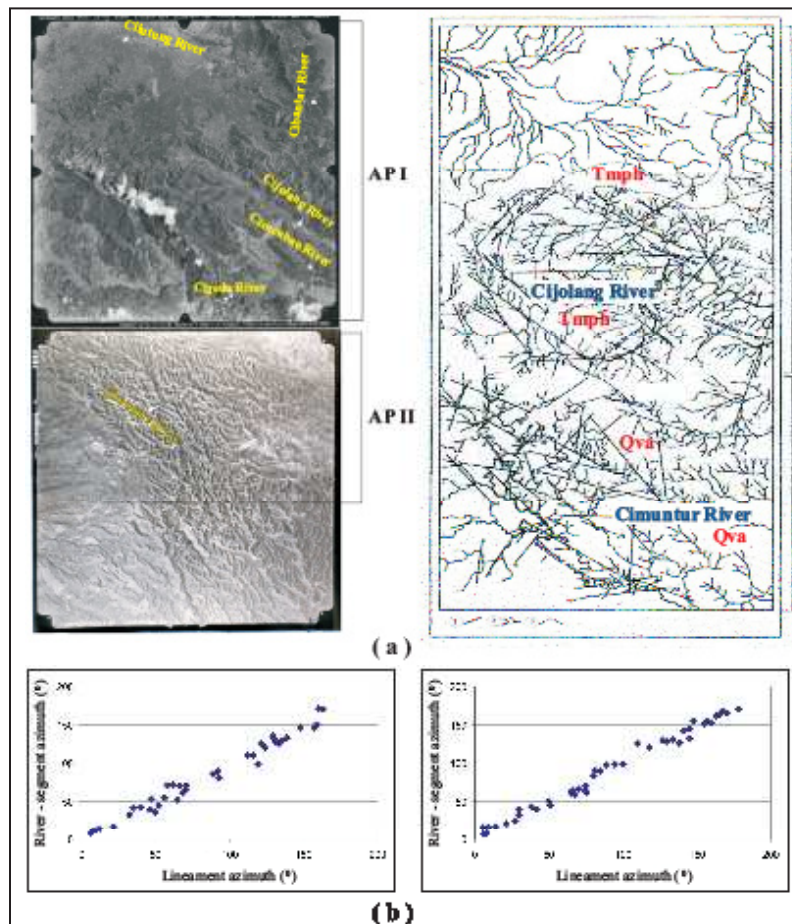


Figure 4. (a) Aerial photos of the Cijolang River Basin on Tertiary Halang Formation (Tmphi) and Cimuntur on Quaternary volcanic deposits (Qva) and the drainage pattern with lineaments (b) linear relationships with $r > 0.9$ between river segment and the lineament in the Cijolang (left) and Cimuntur Rivers (right), suggesting an active tectonism that determined the river morphometry development in Panawangan area, Research Area 1 (Hirnawan, 1997)

neotectonism and its degree of the intensity deforming the Quaternary volcanic deposits and governing morphometry development.

Active Tectonism Determining River Segment Development (Testing Hypothesis 1)

Quaternary volcanic deposits have been being deformed by the neotectonic activity. In Researched Area 3 for example, the deposits (Qbx) were folded and jointed forming gently folds, which were observed in the surface (Figure 5). This active tectonism determining river segment development was measured by large correlation coefficients between lineament and river segment azimuths on the deformed Quaternary deposits in Researched Area 3

(Figures 6), as the results of testing Hypothesis 1.

The result of regression-correlation analyses (Hypothesis 1) verifies how close are the relation between patterns of these variables are for the tributaries of the Cimuntur and Pemali Rivers on the Quaternary volcanic deposits, as well as the Cijolang and Pemali Rivers on Tertiary rocks in Researched Areas 1 and 3 (Figures 4 and 6).

Figure 4.a on the right side, shows the plotted lineaments both on the Cijolang and Cimuntur River Basins on respective Tertiary and Quaternary rock formations. The lineaments are the results of photo interpretation of the photographs on the left side. The samples of numerical data pairs of lineament and river segment azimuths are presented as diagrams on



Figure 5. An exposure of folded Quaternary volcanic deposits exhibiting a neotectonic activity in Bumiayu Area, Central Java, in Researched Area 3. This rock unit is folded and jointed. Measurements of joints were conducted at this outcrop location for validating the lineament sample taken through satellite imagery interpretation (see Table 1; field sample Qbx).

Figure 4.b which exhibit the significant coefficient of correlation (very close relationship) between the variables involved. This suggests morphometry developments on both rock formations (separated by an unconformity) are determined by deformation pattern (lineaments) due to recent tectonic activity.

From the Researched Area 3, the linier regression formula constructed from the analysis is $Y = -1.227 + 0.988 X$ with coefficient of correlation r is as large as 0.999 (Figure 6.a, Table 2), which suggests that river segment development on Quaternary deposits is governed by a deformation pattern of the rock unit due to a recent active tectonic movement.

Figure 6 being supported by Table 2 shows a similar phenomenon occurring in the Pemali River Basin in Bumiayu area to that in the above-mentioned river basins in Figure 4. The constructed linier formula is $Y = 0,178 + 1.000 X$ with the large coefficient of correlation r is 0.998 (Figure 6b, also Table 2). The diagrams in Figure 6 show that the straight

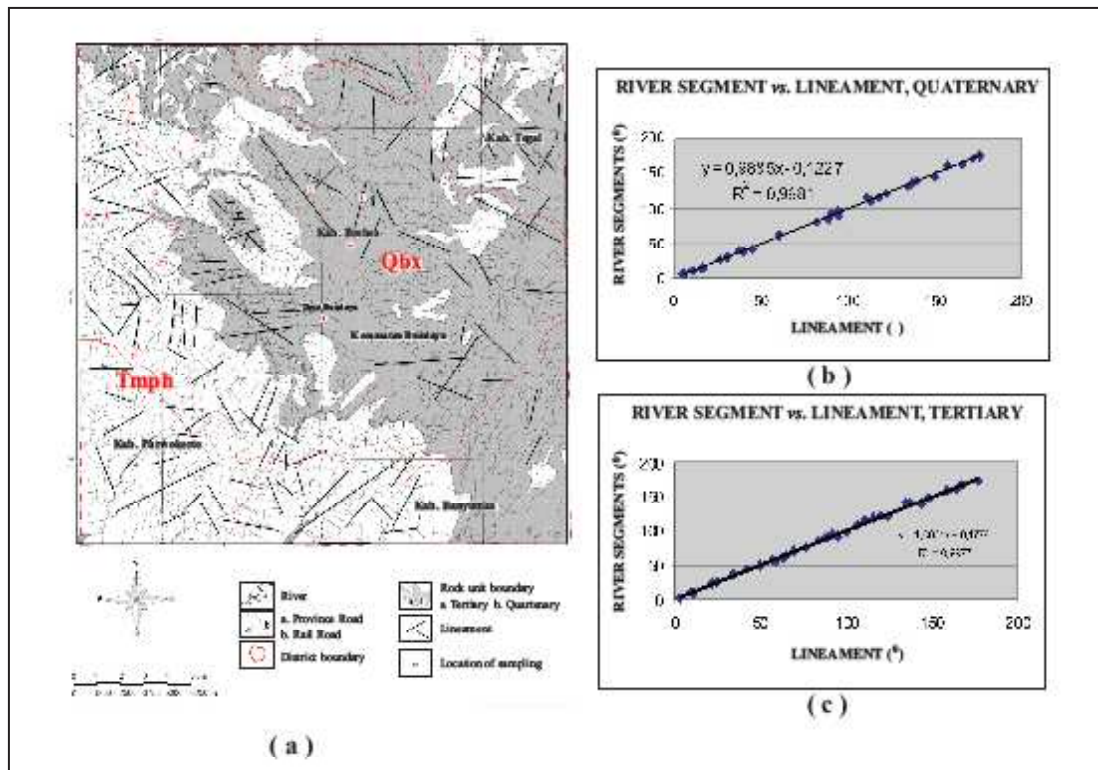


Figure 6. a) Plotted lineaments obtained from satellite imagery interpretation on the Quaternary volcanic deposits (Qbx) and Halang Formation of Tertiary marine sediments (Tmph) in Researched Area 3; b) Diagram exhibiting large coefficient of correlation between river segment and lineament azimuths of the Pemali River Basin on Qbx; c) ditto of the same river basin on Tmph (Hirawan *et al.*, 2007).

Table 2. Result of Regression-Correlation Analyses between River Segment and Lineament Azimuths both in Quaternary Volcanic Deposits and Tertiary Marine Sediments in the Pemali River Basin, Bumiayu Area, Researched Area 3 (Hirnawan, 2009)

Ages of Rocks	n	r	R ²	T _{calculated}	t _(0.01)	Decision	Conclusion
Quaternary	26	0,999	0,998	115,3921	2,7969	reject H ₀	close relation
Tertiary	32	0,998	0,997	109,8253	2,7500	reject H ₀	close relation

lines indicate the constants of proportion of nearly 1. The lines clearly explain that every single plotted point on X and Y-axes respectively of the diagrams represents almost the same value of every lineament and the river-segment azimuth. This phenomena are also displayed in Figure 4 representing similar mean values of the variables taken from both Cijolang and Cimuntur river basins, which are clearly illustrated as rose diagrams in Figure 7 (see nearly the same mean values; see App. 1, Table 1 and 2).

Figure 8 also exhibits a close correlation between the two variables mentioned above, representing Quaternary volcanic deposits in Researched Area 2, while Table 3 as the result of regression-correlation analyses shows the same phenomena occurring in three formations, which unconformably underlie

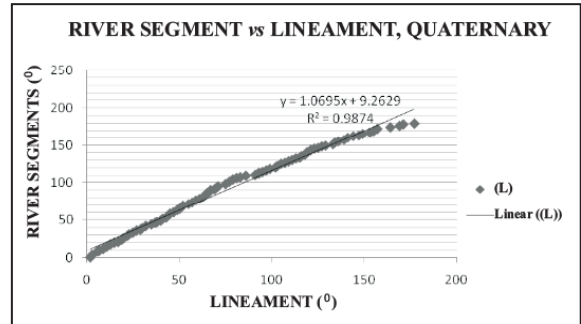


Figure 8. Scattered diagram exhibiting a significant relationship between river segment and lineament in the Quaternary volcanic deposits in Rancah area, Researched Area 2 (Sophian, 2009).

the Quaternary deposits (Sophian, 2009). These phenomena suggest the active and intense tectonism in the researched area.

Table 3 showing the result of verification of Hypotheses 1 in Researched Area 2 exhibits the similar phenomenon of morphometry development of river basins in this area with that in Researched Areas 1 and 3. In this table three morphometry of river basin developments are proven to be determined by the lineament pattern on three formations, but on Figure 7 only the regression formula for drainage basins on Quaternary volcanic deposits is presented for exhibiting the involvement of the recent tectonism.

In Kulon Progo mountainous region the phenomena of a strong relation between lineaments and river segment azimuths of river basins are presented in Figure 9, in which four populations of pair of samples of these two variables taken from four formations of Eocene to Quaternary exhibit the large correlation coefficient of the variables. The result of the tests proves the active tectonic control on the Quaternary volcanic deposits, on which the morphometry development was governed by the deformation pattern.

Figure 9 shows the same phenomenon as well

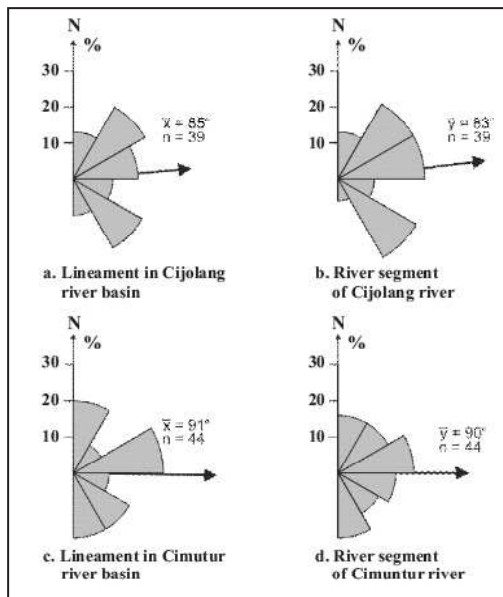


Figure 7. Rose diagrams of lineament azimuths and stream-segment azimuths in Panawangan area, Researched Area 1, exhibiting the similar means in both river basins. Arrows in rose diagrams show vector means; n = number of sample member of measurements (Hirnawan, 2007).

Table 3. Result of Regression-Correlation Analyses between River Segment and Lineament Azimuths in the respective Halang, Kumbang, and Tapak Formations of Tertiary Epoch in Rancah Area, Researched Area 2 (Sophian, 2009)

Epoch	Formation	n	r	R ²	Reg. formulae	Decision	Conclusion
Tertiary	Halang	86	0.999	0.999	$y = 1.0169x - 3.3913$	reject H_0	close relation
	Kumbang	61	0.9997	0.9996	$y = 0.9948x + 0.2799$	reject H_0	close relation
	Tapak	44	0.998	0.9976	$y = 0.9804x + 2.4598$	reject H_0	close relation

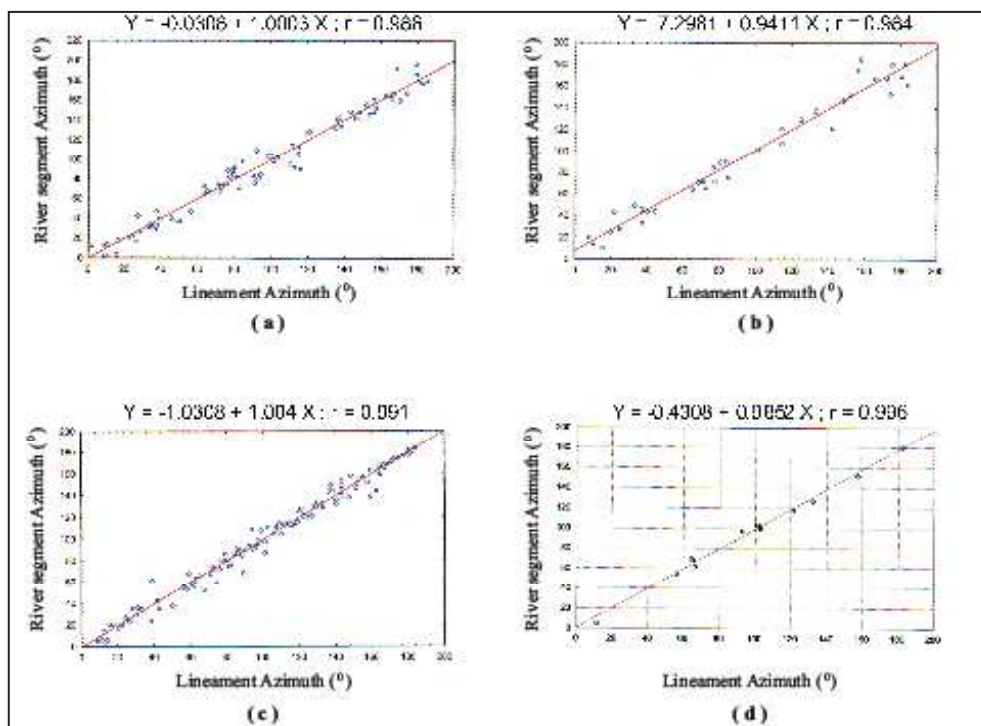


Figure 9. Linier relationships of large correlation coefficient between river segment and the lineament on formations as follows : (a) Quaternary volcanic deposits; (b) Sentolo and Jongrangan Formations (Late Miocene to Late Pliocene); (c) Kali-gesing and Dukuh Formations (Oligo - Miocene); (d) Nanggulan Formation (Eocene). Each formation is separated from the others by an unconformity (Budiadi, 2008).

as those occurring in Researched Areas 1, 2, and 3 presented above.

A Measure of intense Degree of Tectonism (Testing Hypothesis 2)

The measurements of degree of tectonic intensity, in terms of verification of Hypothesis 2 from four researched areas in Figure 1, were carried out by testing the difference between two means of the following variables representing the morphometry of river basin development on respective Tertiary

marine sediments and Quaternary volcanic deposits. The variables of drainage basins involved for this test are drainage density (D_d) and bifurcation ratio (R_b).

Drainage density (D_d) is the average length of streams per unit area (total stream length L divided by total basin area A): $D = L/A$ (Horton, 1945 in Jun Xu, 2007). Drainage density is one of the mostly used basin morphometric parameters because it is a good indicator of the relationship between climate, geology, soil, and vegetation. Drainage density varies largely, mostly from 0.5 to 30, but it can

be as high as 100. This variable mainly represents fracture density of river basin bed rock due to the tectonic activity.

Bifurcation ratio (R_b) is the ratio between the total number of streams of one order (N_u) to that of the next higher order (N_{u+1}) in a drainage basin. $R_b = N_u / N_{u+1}$ (Horton, 1945 in Jun Xu, 2007; Senadeera *et al.*, 2007). The bifurcation ratio changes from one order to the next, but tends to be constant, mostly within the range from 3 to 5.

These data of drainage density (D_d) and bifurcation ratio (R_b) are taken from Research Areas 1, 2, 3, and 4.

The results of testing the hypothesis using data from all researched areas give conclusions that degree of tectonic intensity in several places were very intense, by which mean difference between drainage density (D_d) of Cimuntur River Basin manifesting lineament density on Quaternary volcanic deposits of Ciremai Volcano in Panawangan area in Researched Area 1, for example, and that of the Cijolang River Basin on unconformably underlying the Halang Formation is not significant (Table 4).

Bifurcation ratio (R_b) means of the Cijolang and Cimuntur River Basins respectively and also their abovementioned drainage density (D_d) means of these river basins are not significantly different. The insignificant difference of mean of D_d suggests that intense degree of the active tectonic movement had deformed the Quaternary volcanic deposits as well as the Tertiary rocks even being separated by an unconformity. No significant difference of mean of R_b gave a conclusion that river basin morphometries on both Quaternary volcanic deposits and Tertiary rock formation have been developing into the similar numbers of river junctions of the same stream orders

(one order and the next higher order) governed by lineament pattern of the respective river bed rocks due to the intense tectonism.

Other different phenomenon occurs, exhibiting a less intense tectonic activity in the western slope region of Slamet Volcano in Bumiayu area, in Researched Area 4, which is indicated by a significant difference between two means of drainage density (D_d) on Tertiary and Quaternary rocks in Table 5. Such the phenomenon also occurs in Rancuh studied area (Sophian, 2009).

The insignificant difference between means of bifurcation ratio R_b of the river basins on the respective rocks manifests a fracture pattern that facilitates a similar river basin morphometry development in two systems (Tertiary and Quaternary rocks) due to the tectonic activity. On the contrary, the significant difference of means of those river basin drainage densities (D_d) was presented earlier, of which the variable mean on Tertiary rocks is larger, suggests that the fracture density in Quaternary deposits is lower than that in Tertiary rocks, or degree of active tectonic intensity deforming the deposits is less, compared with that in area around Ciremai Volcano mentioned in the foregoing part.

Table 6 confirms the conclusion of the active tectonism in Kulon Progo mountainous region, which had been drawn using correlation-regression tests in Figure 8. In this table, the result of tests also exhibits the intense degree of the tectonic activity, by which the Quaternary deposits of System III had been deformed intensively as well as the unconformably underlying Sentolo and Jonggrangan Formations of System II of Late Pliocene epoch (Budiadi, 2008).

This author had also conducted the same t-tests of difference between means of both R_b and D_d repre-

Table 4. Multivariate Test of Difference between Morphometric Variable Means of the Cijolang River Basin developing in the Tertiary Halang Formation and the Variable Means of the Cimuntur River Basin in Quaternary Volcanic Deposits of the Ciremai Volcano in Researched Area 1 (Hirnawan, 1997)

No	Variables	Cijolang River Basin Mean value	Cimuntur River Basin Mean value	$T^2_{.10}$	$T^2_{calc.}$	Decision, Conclusion
1	Bifurcation ratio, R_b	3.9228	3.8350	4.458	2.6392 ^{ns}	accept H_0 , no difference
2	Drainage density, D_d	4.2319	3.8732			

Table 5. a) Result of T²-Hoteling Test of Difference between Vector Means of R_b and D_d in Quaternary Deposits and Tertiary Sediments in the Pemali Rver Basin in Bumiayu Area, Research Area 3; b) Results of t-test of R_b and D_d (Hirawan *et al.*, 2007)

a) Result of T ² -Hoteling test								
Population	T ² -Hoteling		T ² _(0.05,2,39)	Decision, Conclusion				
Quaternary deposits vs. Tertiary sediments	13,8675		6,642	reject Ho, significant difference				
b) Results of t-tests								
Variable tested	Mean values		n1/n2	F _{calculated}	F _{0,5}	t _{calculated}	T _{0.975}	Decision, Conclusion
	Quaternary	Tertiary						
Bifurcation ratio (R _b)	3.584	3.997	16/25	2,585	2.110	-1.592	-2.132 up to 2,064	accept Ho, no difference
Drainage density (D _d)	2.429	3.251	16/25	3,163	2.110	-3.893	-2.132 up to 2,064	reject Ho, significant difference

Table 6. Results of t-test of R_b and D_d in Kulon Progo Mountainous Region, Researched Area 4 (Budiadi, 2008)

Variable tested	Mean values		n1/n2	t _{calculated}	T _{0.975}	Decision, Conclusion
	Quaternary (System III)	Tertiary (System IIA)				
Bifurcation ratio (R _b)	3.41	3.7542	12/41	1.0356	2.0076	accept Ho, no difference
Drainage density (D _d)	2.801	2.790	12/41	0.041	2.0076	accept Ho, no difference

senting the Nanggulan (Eocene) and Kaligesing and Dukuh Formations (Oligo - Miocene) of System I. The results suggested an intense degree of tectonic activity, by which the mean differences of both drainage density and bifurcation ratio on the Quaternary deposits with those on the unconformably underlying two systems, including the oldest Nanggulan formation, are not significant. These results of tests had suggested the continuous tectonic activity in Kulon Progo since post - Eocene.

The degree of this intensive tectonic activity had generated three tectonic patterns or orientations, in terms of direction means of lineament and/or major fault development in Kulon Progo mountainous region, of which Sumatra, Java, and Meratus tectonic patterns are known to occur in this region. This verified conclusion invented by the author had supported the role of plate tectonic movements, rather than previous undation theory by Van Bemmelen in 1949, in the genesis of this region.

DISCUSSION

The active tectonism in several places in West and Central Java, which had been verified through the manifestation of river basin morphometry development exhibits intense degree of deformation. The Quaternary volcanic deposits distributed and unconformably overlying the Tertiary rocks in this region had been weakly deformed forming folds, joints, and faults, which facilitated and governed both the pattern and density of river basin morphometry development. This tectonic morphometry or also known as a morphotectonic phenomenon is very important to be studied. The result should be a base for a land stability mapping prior to any area development plan particularly in this country of active tectonism.

The degree of tectonic intensity particularly with respect to stability of region is an important information needed for decision making in an area development planning, which should be well under-

stood and considered as an important determinant in a comprehensive approach of characterization of a region. This aspect has not been seriously considered so far in this intellectual tasks or assignments.

Zonation of degree of tectonic intensity should be able to be mapped using verified indicators discussed in the foregoing part, by which zones of low to high tectonic intensities can be delineated. This zonation map can be very helpful in supporting the tasks.

CONCLUSION AND RECOMMENDATION

1. The results of these researches conducted in the region between eastern West Java and Central Java have proven and strongly supported the conclusion that the recent tectonism is active. This neotectonic activity manifested by frequent shallow earthquakes, active faults, and landslides, *etc.*, enables the present author to measure its stage of intensity through the similarity of tectonic morphometry development of river basins on Quaternary to that on Tertiary rock deposits. This phenomenon is as the continuation of the former post Tertiary tectonic period generating deformation pattern in Quaternary volcanic deposits, which is similar to that for the Tertiary marine sedimentary rock formations. In other words, as the result of deformed Quaternary deposits by the intense recent tectonic movements, the drainage network and the morphometry of river basins developing in this deposits are similar to that in Tertiary rock formations. Therefore, this phenomenon is as a measure of the recent tectonic activity or neotectonism in terms of degree of tectonic intensity.
2. Manifestations of drainage basin morphometry development being determined or controlled by deformation pattern in Quaternary volcanic deposits, which are similar to that in Tertiary marine sedimentary rock formations in several places in the region due to neotectonism are as follows :
 - Correlation coefficients r of no less than 0,9 between river segments and lineaments on Quaternary volcanic deposits are very significant,
 - Differences between means of bifurcation ratio of river basins on Quaternary volcanic deposits and those on Tertiary rock formations are not significant, and
 - Differences between means of drainage density of river basins on Quaternary volcanic deposits and those on Tertiary rock formations are not significant, except in Rancah and Bumiayu areas, where the differences are significant.
3. The manifestations of the active tectonic movements mentioned above suggest the following conclusions:
 - River segment development on Quaternary volcanic deposits are merely governed or determined by lineament or deformation pattern due to active tectonic movements.
 - Drainage network on Quaternary volcanic deposits is similar to that on Tertiary rock formations due to active tectonic movements.
 - Fracture density as the basic factor determining the drainage density of river basins on Quaternary deposits is similar to that on Tertiary rock formations due to neotectonism. This phenomenon measuring the intense degree of tectonic activity is verified, except in Rancah and Bumiayu areas, where the active tectonic effect is less intense.
4. The response of river basin morphometry to active tectonism, developing on Quaternary volcanic deposits compared to that on Tertiary sedimentary rock formations exhibits the measure of the degree of tectonic intensity. This study is important for the characterization of region under the control of active tectonism regarding an area development planning, by which zonation of degree of tectonic intensity should be mapped. The result of such the mapping can be very helpful in decision making, mainly through a comprehensive approach for the area development planning.

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REFERENCES

- Bates, L.B. and Jackson, J.A., 1984. *Dictionary of geological terms*. The American Geological Institute, Anchor Book Doubleday, New York, 571 pp.
- Budiadi, 2008. *Role of tectonism in the development of Kulon Progo mountainous region*, Yogyakarta, PhD Thesis, Padjadjaran University, unpublished.
- Burbank, D.W. and Anderson, R.S., 2001. *Tectonic geomorphology*, Massachusetts, Blackwell Science.
- Djuri, M., Samodra, H., Amin, T.C., and Gafoer, S, 1996. *Geological Map of Purwokerto and Tegal Sheet, Java, scale 1:100.000*. Geological Research and Development Centre, Bandung.
- Doornkamp, J.E., 1986. Geomorphological approach to the study of neotectonics. *Journal of Geological Society. London*, (143), p.335-342.
- Haig, Brian, D., 1995. Grounded Theory as Scientific Method, Philosophy of Education. *University of Canterbury*. Retrieved August 8, 2006, from <http://www.ed.uiuc.edu/EPS/PESYearbook/95/docs/haig.html>
- Hirnawan, F., 1987. The effect of reverse fault on patterns of strike and dip of bedding planes and joints in Halang Formation, Bantarujeg, Regency of Kuningan, West Java. *Riset, Geologi dan Pertambangan*, Puslit Geoteknologi, p. 31-40.
- Hirnawan, F., 1997. Morphometry characteristics of drainage system in the region of active tectonic effects – Case Study of Cijolang and Cimuntur Drainage System) : Analisis Sistem. *BPPT (Technology Evaluation and Application Board)*, Kedeputan Bidang Analisis Sistem, IV (9), p. 67-77.
- Hirnawan, F., Sudarsono, U., and Soehaimi, A., 1998. Tracing landslide hazards zonation of slope stability dynamic system and the stabilization by optimizing the integrated role of vegetation and slope-geometry, State Ministry Office of Research and Technology, National Research Council, Multy Years Research Report of 1995-1998 Riset Unggulan Terpadu Program (Integrated Research Program), Field of Environment Protection - Technology, 141 pp.
- Hirnawan, F. and Muslim, D., 2006. Drainage morphometry characterizing active tectonism in West Java. *Proceedings of 2006 Map Asia International Conference Agustus-September 2006, Bangkok, Thailand*, 18 pp.
- Hirnawan, F., Agus Nur, A., and Sophian, I., 2007. Response of Quaternary morphometry to active tectonism as area constraint for spatial and infrastructure development program, Bumiayu, Central Java, *Research Institute*, Padjadjaran University.
- Jun Xu, 2007. Watershed Hydrology. <http://hydrology.lsu.edu/10/23/2007>.
- Kastowo and Suwarna, N., 1996. *Geological Map of Majenang Sheet, Java, scale 1:100.000*, Geological Research and Development Centre, Bandung.
- Keller, E.A., and Pinter, N., 1999. *Active tectonism*. New York, Prentice Hall Inc., 337 pp.
- Linsley, R.K., Kohler, M.A., and Paulhus, J.L.H., 1975. *Applied Hydrology*. MacGraw Hill Pub. Co. Ltd., New Delhi.
- McNeil, L., 1999. *Illustrated Dictionary of Earth Science*. The American Geological Institute, Tasa Graphic Arts, Inc.
- Nakata, T., Odaka, J., Goto, H., Asahi, K., Chida, N., Suzuki, Y., Watanabe, K., and Nakamura, T., 1996. A trench study on the surface fault rupture in Awaji Island associated with the 1995 Hyokogen - nambu earthquake. *Journal Active Fault Research*, (14), p. 23-27.
- Senadeera, K.P.G.W., Piyasiri, S., and Nandalal, K.D.W., 2007. The evaluation of Morphometric Characteristics of Kotmale Reservoir catchment using GIS as a tool, Sri Lanka, Department of Civil Engineering, University of Peradeniya, Peradeniya, Sri Lanka. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 34 (XXX).
- Sophian, R.I., 2009. *Contribution of neotectonic activity to drainage basin morphometry development in Tertiary rock formations and Quaternary volcanic deposits in Rancah area, Regency of Ciamis, Province of West Java*. Master Thesis, Padjadjaran University, unpublished.
- Splitz, W.J. and Schumm, S.A., 1997. Tectonic geomorphology of Mississippi Valley between Osceola, Arkansas and Friars Point, Mississippi. *Engineering Geology*, 46, p 259-280.
- Stewart, I.S. and Hancock, P.L., 1994. *Neotectonics*, PL Hancock Ed., Continental Deformation, Pergamon Press, p. 370-404.