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THE RELATIONSHIP BETWEEN MONTHLY RAINFALL AND ELEVATION IN THE CISANGKUY WATERSHED BANDUNG REGENCY

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Abstract- Many watershed areas have no equipments of rain gauges so that difficulty to comprehend hydroclimatological processs is emerging at the area particularly at area with high elevation. For the purpose, it needs to estimate the relationship between rainfall and elevation. The research on the relationship between rainfall and elevation in Cisangkuy Watershed Bandung Regency has been conducted to be used in estimation of rainfall at certain elevation for the agenda of water resources management. Spatial monthly rainfall from WorldClim for 50 years and Digital Elevation Model (DEM) from CGIAR-CSI have been studied and analyzed in Cisangkuy watershed to understand the relationship between rainfall and elevation. Study was based on the derivation of rainfall profile to elevation from 650 m mean sea level (msl) which is downstream Cisangkuy river till 1530 m msl which is upstream at the Cileunca lake by using GIS (CD line). Regression analysis showed strong linear relationships between monthly rainfall and elevation which coefficient of correlation is 89%. The increase of monthly rainfall with elevation is averaged 11.62 mm/ 100 m increase of elevation on CD line profile, except in August shows the increase stopping at 1156 m then decrease slowly at the rate 9.5 mm/100 m. Wet season which is represented by December, January and February show the increase with the elevation is 17.7 mm while dry season which is represented by June, July, August show the increase with the elevation is 5.9 mm/100 m elevation increased. Using the regression analysis of the relationships between monthly rainfall and elevation, one get the simple model but effective to approximate the rainfall in certain elevation at watershed.

Keywords - Rainfall, Elevation, Watershed, DEM, Regression Analysis

I. INTRODUCTION

Many watershed areas have no equipments of rain gauges so that difficulty to comprehend hydroclimatological processs is emerging at the area particularly at zona with high elevation like mountain and plateau. Mountain has strong influence to atmosphere that is able to change air current and has response of solar radiation which is different from atmosphere around it. Thereby around mountain area hence rainfall increases in some places and decreases in part of other place. For example a very real recognized is existence of rain shadow area that is area with very low rainfall at topography area under lee ward or maximum rainfall at mountain side where wind move on the top [1]. Interaction between topographies and atmosphere can yield rainfall patterns. Spatial scale from this patterns can vary from mountain measure to come up with valley and hillslope. Differences of spatial in this rainfall can influence geomorphology directly with changing erosion processs speed or undirectly through its influence to mountain ecosystems [2]. The research of rainfall pattern impact at mountain geomorphology study is being taking place till now. Thereby, knowledge of atmosphere processs yielding rainfall patterns in mountaineous watershed play an important role in hydrology and management of water resources. Rainfall shows behavior of spatial and temporal which complex. Behavior of spatial which is complex often related to topography. By determining interaction scale of observed rainfall with topography then one can make analysis the spatio-temporal of rainfall, so it can be estimated natural processs involving in forming of rainfall. In particular, knowledge of the scale of the dependence of precipitation on topography can be used to optimize interpolation methods that incorporate topographic dependence for estimating the spatial distribution of quantities related to precipitation [3]. The interpolation method plays important role in wide scope of applying in related to assessment of climate impact at agriculture, ecology, hydrology and tourism. Interpolatory methods also play a key theoretical role when it comes to assessing the performance of climate models, because physically based precipitation models present forecasts in the form of gridded surfaces that are typically made at grid resolutions from tens to hundreds of kilometers, the methods for interpolating precipitation that is observed at discrete locations have an important part to play in the calibration and validation of such models [3]. Reference [4] applies Precipitation-Elevation Regressions on Independent Slopes Model (PRISM) to model monthly and annual rainfall above various sub-region in United State. PRISM applies concept orograhic elevation for interpolation of rainfall value of weather station.

Geographically Indonesia located in tropical region experiencing two seasons that is rain season and dry season. Rain season normally takes place in months December, January and February while dry season takes place in months

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June, July and August. Other months is transition months from rain season to dry season or on the contrary. Rainfall pattern in Indonesia region can be grouped into three forms of pattern according to time series analysis, that is monsoonal, equatorial and local pattern [5], [6], [7]. Besides temporal patterns, also spatial pattern is important to be studied in Indonesia region with reference to large topography disparity varying from sea level until ice cap in Jaya Wijaya mountain in Papua Island.

Mountains closes over 25% surface of earth and dwelt by 26% from global population and yields 32% overland flow [8]. Mountain and plateau occupies 21% continent surface, 20% population and 19% from overland flow [9]. Orographic rain type is considered to be the ground water supplier, lake, dam and river because taking place in headwaters [10]. One way that is directly topography influences weather is its strength to control local rainfall distribution where Cisangkuy is mountaineous watershed. Cisangkuy river is important role in supplying amount of raw water required to consume some resident of Bandung regency and Bandung city each of 500 l/dt and 1800 l/dt [11]. Quantity of water supply is hardly influenced by condition of rainfall happened in headwaters which is main augmentation in a watershed. Torrential rain above mountaineous terrain often yields flash flood in downstream area and becomes challenge in its predictibity.

Therefore, research about relationship between rainfall and elevation is very importance done in undestanding hydroclimatology in mountaineous watershed area and management of water resources. The purpose of this paper is to estimate the monthly rainfall at certain elevation and formulate the simple model. Writing structure in this paper consist introduction commenting result of former research about the importance of understanding interaction phenomenon between mountains with atmosphere which is playing an important role as freshwater supplier for downstream area. Then is followed with chapter about data and method applied that consist location of research, data which processed and method applied. Research result is written in result and discussion chapter which is elaborating about relationship between rainfall and elevation formulated in simple linear equation, slope, correlation and seasonality pattern then is terminated with important points written in conclusion chapter.

II. MATERIAL AND METHOD

Location of research is Cisangkuy watershed which is located between -06^{o}59'24" to -07^{o}13'51" Latitude and 107^{o} 28'55" to 107^{o} 39'84" Longitude, 200 km south east from Jakarta and 50 km south from Bandung. Topography of Cisangkuy watershed varies from height of 2327 m msl in Malabar Mountain, until 661 m in its junction with mains river, that is Citarum river as shown in Fig. 1. Annual hydrology and rainfall distribution at Cisangkuy watershed varies out of 3500 mm/year until 2000 mm/year. Dry season happened at Cisangkuy watershed takes place in June until August with September, October, November as transition months from dry to rain and rain season at period December, until Februari with March, April, May as transition months from rain to dry. The upstream Cisangkuy watershed is catchment which in the form of northwards open basin. Damage of ecology in headwaters hardly affecting at downstream area with annoyed debit and water supply for downstream area.

Spatial average of monthly rainfall data from WorldClim [12] during 50 years with 1 km grid can be donwloaded from http://www.worldclim.org/ which is can be downloaded from http://www.cgiar-csi.org/. WorldClim is aggregate layer data of global climate in the form of grid with spatial resolution around 1 km built by some researchers in University of California, Berkeley [12]. *CGIAR-CSI* is a global partnership of research organizations dedicated to reduce poverty and hunger, improve human health and nutrition, and enhance ecosystem resilience through agricultural research. Consortium for Spatial Information (CGIAR-CSI) is spatial science community that facilitates CGIAR's international agricultural development research using spatial analysis, GIS, and remote sensing [13].

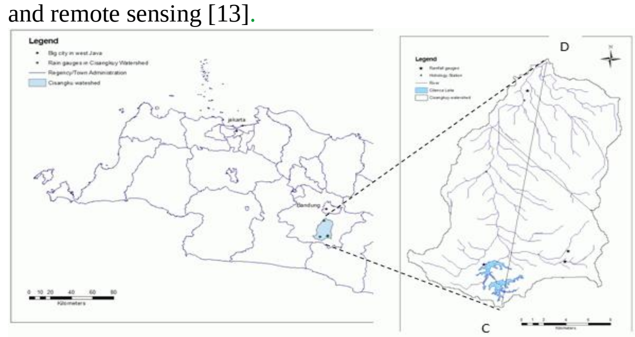


Fig. 1 Cisangkuy watershed which is located in Bandung Regency and shown the CD line, West Java Province Indonesia

Rainfall data and DEM were processed by using GIS (Geographic Information System). GIS is computer based information system applied to process and store geographical data or geographical information [13]. GIS has an ability to connect various data at one particular certain point in the Earth, merges them, analyses and finally results the maps of them. Processed data in GIS should be spatial data, that is a geographical oriented data and having location at certain coordinate systems as its the reference base. The application of GIS can answer some questions like; location, condition, trend, pattern, profile, the relation and modelling of its spatial. A flow diagram of methodology to process the rainfall data and DEM and the relation of both can be shown

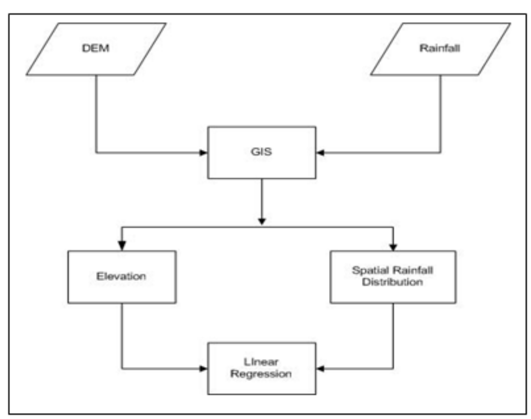


Fig. 2 Flow diagrams of processing the spatial rainfall data and DEM with GIS to get each their profiles.

III. Result and Discussion

Digital Elevation Model (DEM) is raster data model which is able to be processed by GIS. The result of processing DEM for the Cisangkuy watershed and mountaineous situation as shown in Fig. 3

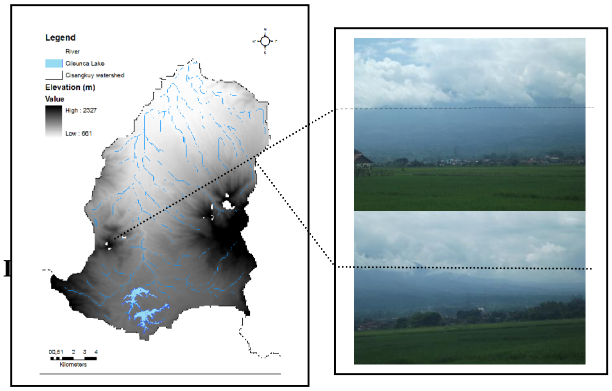


Fig. 3 Digital Elevation Model (DEM) and photograhs show a condensation level line along the mountain slope of Cisangkuy watershed, Bandung Regency.

DEM consist altitude information of ground surface which will be applied to derive a height class map and slope of mountain. DEM used in this paper is result from remote sensing mission with active satellite censor around year of 2000 by the name of SRTM (Shuttle Radar Topography Mission) [13]. This international mission yields DEM product with resolution 90 m. Height and slope of mountain represent the physical characteristics of the region. The height is measured by precise instrument above mean sea level with unit of metre. For river stream and watershed size of a region, DEM data is masked with delineation of high topography of watershed by using GIS and finally result is obtained location of study, like shown at Fig. 3. By using spatial analysis in GIS hence is obtained a height profile expected like at CD line (see Fig. 1). Orographic scale effect observed is a real important thing in analysis at this paper based on by usage of elevation data of DEM which is having 90x90 m grid. There is unconformity implicitly in scale when using the relation between elevation and rainfall of points of weather station at grid cells of DEM. Elevation in center of grid cell DEM doesn't depict elevation at the point but depicting mean elevation or elevation is refined depicting entirety grid cell. Thereby elevation of grid cell DEM seldom be acurate with elevation of weather station if only station resided in precise at center of grid cell. In general, resolution DEM which is smoother grid cell, more precise of elevation hence grid cell would be compatible at point of the weather station. Reference [3], they have done a research to check about a minimum spatial resolution of rainfall dependence influence to topography seems to be explained in Australian continent resided in the range of 5-10 km. By using spatial analysis tool applied GIS at the profile of CD line (see Fig. 1), hence one obtained the rainfall data having 13 grids while DEM data has 136 grids. Approximation of the relation of rainfall grid value to DEM grid value is 1 rainfall grid corresponding with 10 DEM grids, so that 90 x 10 m grid size in DEM data comes near 1 km which is grid size in rainfall data. Thereby 13 x 10 grids rainfall data will come near 136 grids at DEM data. Rainfall data and elevation is ploted together to get equation of its linear regression, so that is obtained the Fig. 4 to Fig. 7.

Linear regression of rainfall and elevation data is calculated to be every month for average of monthly rainfall during 50 years period 1950-2000 of Worldclim data [12] so that is obtained slope, Pearson coefficient of correlation (r) for each month. Correlation coefficient for the relationship between monthly rainfall and elevation (r) varies between 67% until 97% with average of 89%. Slope of linear regression also varies in the range of 1.9 mm to 21.8 mm every 100 m increase in height with average of 11.62 mm, except to August happened decrease gradually from height of 1156 m with slope of minus 9.5 mm.

Seasonality pattern shows some differences relationship between rainfall and elevation. If monthly rainfall is divided into four groups based on season, consist the rain season represented by December, January and February (DJF) and dry season is represented by June, July and August (JJA) and March, April, May (MAM) and September, October, November (SON) represents transition months from rain season to dry or on the contrary. Analysis of seasonal pattern indicates that to rain season represented by December, January, and Februari (DJF), as shown in Fig. 4 having an average slope of 17.7 mm every increase of 100 m elevation with correlation coefficient equal to 95%. The biggest slope value is observed of 21.8 mm in January and lower value of 12.7 mm in December every increase of 100 m elevation. This phenomenon is comprehended by strong of westerly monsoon wind which persistent and more humid in the months.

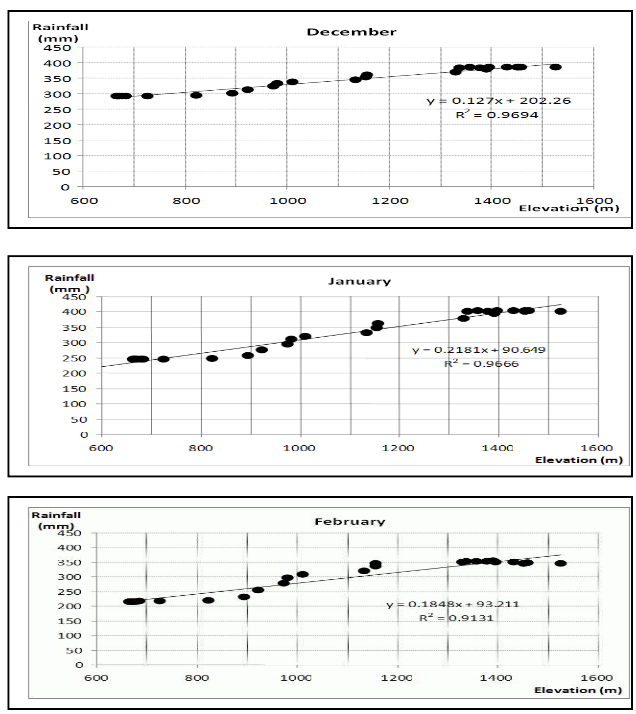


Fig.4 Increase of rainfall to elevation at rainy season represented by December, January, and Februari (DJF) in Cisangkuy watershed.

If humid air is forced to go up at mountain slope side of its wind direction hence the air will expand and to be chillier which will cause droplet condenses when saturated air. These droplets will form cloud and grows yields raindrops that is generally fall in the form of rain at topography of mountain slope side of the prevailing wind direction. After reaching culminated at the top of mountain hence air current to decline at side down draft (lee side) to be contraction and increase of its temperature causing droplets evaporate and minimizes raindrop to be rainfall. The relationship between rainfall and topography is the dominance in mountain range areas where there is consistent wind direction and provides humid air.

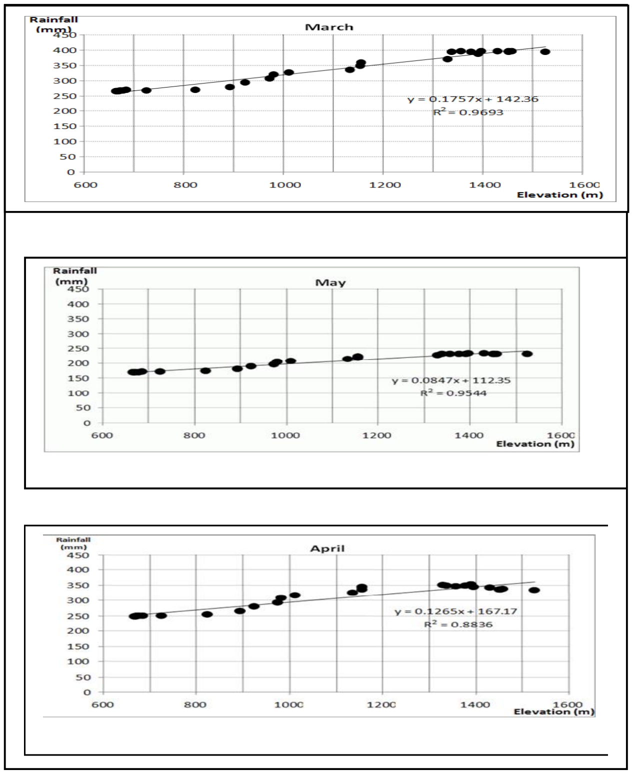
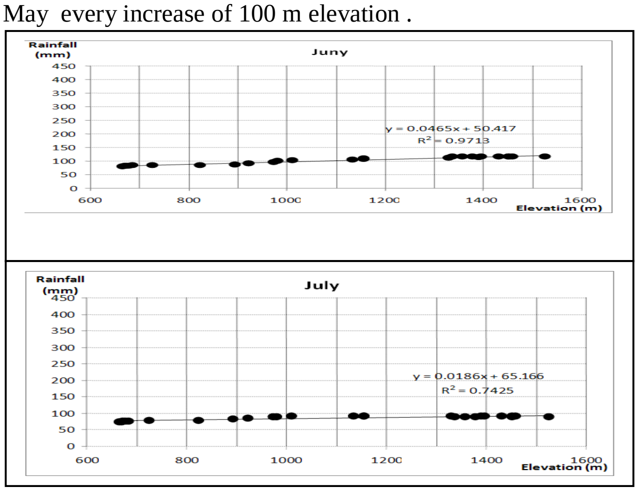


Fig. 5 Increase of rainfall to elevation at transition season from wet to dry represented by March, April, and May (MAM) in Cisangkuy watershed.

In transitional month from wet to dry represented by March, April, and May (MAM) slope shows the average value of 12.9 mm every increase of 100 m elevation with correlation coefficient 93% (Fig. 5). The biggest value is observed of 17.6 mm happened in March and lower value of 8.5 mm in May every increase of 100 m elevation .



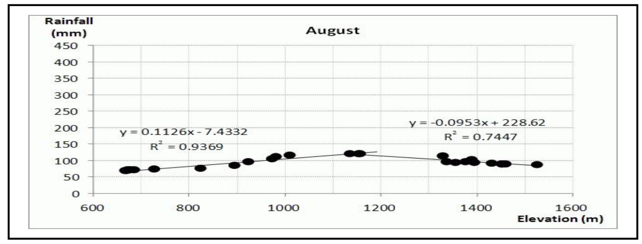


Fig. 6 Increase of rainfall to elevation at dry season represented by June, July, August (JJA) in Cisangkuy watershed.

In the dry season represented by June, July, August (JJA) slope has the average value of 5.9 mm to every increase of 100 m elevation with correlation coefficient 88% as shown in Fig. 6. The biggest value show the average of 11.2 mm happened in August and lower value of 1.9 mm observed in July to every increase of 100 m elevation. But in August increase of rainfall to elevation only take place until height of 1156 m and then happened decrease gradually with slope minus 9.5 mm. The above value is able to consider the interaction of topography and atmosphere in dry season can give the significant contribution to rainfall at mountain terrain as main augmentation of watershed. Rainfall in dry season is source of necessary water to lake, river and ground water.

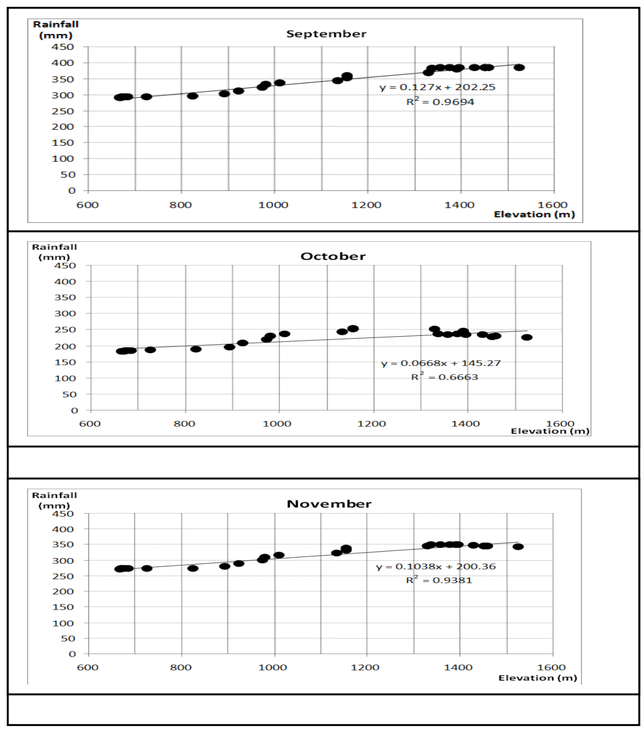


Fig. 7 Increase of rainfall to elevation at transitional season from dry to wet represented by September, October, November (SON) in Cisangkuy watershed.

In transitional season from dry to wet represented by September, October, November (SON) is observed the slope value of 9.9 mm average to every increase of 100 m elevation with correlation coefficient 86% (Fig. 7). The biggest value of 12.7 mm is observed in September and lower value of 6.7 mm in October for every increase of 100 m elevation. Linear regression equation of each month, slope and correlation coefficient can be summarized in Table 1.

TABLE I ESTIMATION OF LINEAR REGRESSION ALONG WITH SLOPE AND PEARSON CORRELATION COEFFICIENT WITH 600 < X<1600

Month	Slope (Rainfall (mm)/100 m)	Estimation of Linear Regression (x=Elevation, y=Rainfall)	correlation coefficient (r)
1	21.8	y = 0.2181x + 90.649	97%
2	18.5	y = 0.1848x + 93.211	91%
3	17.6	y = 0.1757x + 142.36	97%
4	12.7	y = 0.1265x + 167.17	88%
5	8.5	y = 0.0847x + 112.35	95%
6	4.7	y = 0.0465x + 50.417	97%
7	1.9	y = 0.0186x + 65.166	74%
8	11.2	y = 0.1126x – 7.4332	94%
	-9.5	y = -0.0953x + 228.62	75%
9	12.7	y = 0.127x + 202.25	97%
10	6.7	y = 0.0668x + 145.27	67%
11	10.4	y = 0.1038x + 200.36	94%
12	12.7	y = 0.127x + 202.26	97%

The results is very consistent with the research which have been done by the researchers in subtropics region as in Himalaya, Alpen, Peru and Rocky Mountain. Especially in tropical region [14] obtained the result of their research that is almost looks like got by authors that show the strong correlation coefficient between rainfalls and elevation with value of 85%-98%. Slope pattern of rainfall linear regression equations related to change of elevation is hardly influenced by season, as shown in Fig. 8.

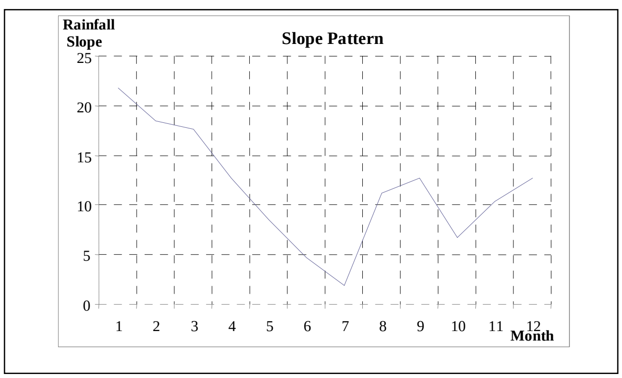


Fig. 8. Slope pattern of rainfall increase to change of elevation is hardly influenced season.

The results of measurement and climate model also indicates that rainfall increase to mountain back relative to valley. This phenomenon describes the persistence of climate. Geomorphic effects of rainfall pattern have hardly minim source of reference but modelling of landscape evolution indicates that the rainfall pattern have a potency to influence hypsometri, slope, top elevation and canal concavity [2].

At spatial scale in some kilometre hence rainfall pattern remain to be hardly limited in mountains range. New technology like precipitation radar satellite presents ability to document the patterns. Geomorphic impact which is possible from this patterns still is unknown. Rainfall is driving force in controlling to erosion processes and to strongly control at distribution of ecosystem. These rainfall patterns are important possiblly in comprehending mountain geomorphology. With knowing of rainfall regression equation to elevation especially in the study area which is site-spesific hence hydroclimatology processses which is important in research of watershed will be able to be comprehended step by step.

IV. CONCLUSIONS

Estimation of relationship between rainfall and elevation need to be done in watershed areas that has no equipments of rain gauges to comprehend hydroclimatological processs es which is emerging at the region. Linear regression analysis between monthly rainfall which is downloaded from WorldClim [12] with elevation of DEM data in Cisangkuy watershed Bandung Regency during period 1950-2000 has been studied and analysed. Linear regression analysis shows strong relationship between monthly rainfall and elevation with average of correlation coefficient equal to 89%. Increase of rainfall with elevation has a mean slope value of 11.62 mm every increase of 100 m elevation. Rain season represented by months of DJF have the increase of 17.7 mm and dry season represented months of JJA have the increase of 5.9 mm every increase of 100 m elevation, except to August the increase of rainfall is happened until height of 1156 m then decrease with speed of 9.5 mm every 100 m decrease of elevation. In transitional season from wet to dry represented by March, April, and May (MAM) have a mean slope value of 12.9 mm every increase of 100 m elevation with correlation coefficient 93%. The biggest value is calculated in the mount of 17.6 mm happened in March and lower of 8.5 mm in May for every increase of 100 m elevation. In transitional season form dry to wet represented by September, October, November (SON) have a mean slope value of 9.9 mm every increase of 100 m elevation with correlation coefficient 86%. The biggest value which is happened in September in the mount of 12.7 mm and lower of 6.7 mm in October for every increase of 100 m elevation. Slope pattern of rainfall incease to elevation change is hardly influenced by season. The pattern looks like seasonal rainfall pattern especially in Indonesia region southern of equatorial line.

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