International Journal of GEOMATE, Jan., 2020, Vol.18, Issue 65, pp. 34 - 40
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2020.65.2657
Geotechnique, Construction Materials and Environment

RELATIONSHIP BETWEEN RAIN CLOUDS DIRECTION, TOPOGRAPHY AND AMOUNT OF PRECIPITATION IN BETWEEN THE OSAKA PLAIN AND THE SOUTH IKOMA MOUNTAINS, MIDDLE OF JAPAN

Hiroki Nishiwaki[1] and Hiroyuki Ii[2]

[1]1Graduate School of Systems Engineering, Wakayama University, Japan
[2] Faculty of Systems Engineering, Wakayama University, Japan

*Corresponding Author, Received: 28 Nov. 2018, Revised: 6 Dec. 2019, Accepted: 31 Dec. 2019

ABSTRACT: The area between from the Osaka Plain to the Ikoma Mountains faces sea at only west direction and is surrounded by mountains at the other directions. Then, rain clouds can directly encounter the Ikoma Mountains only from west direction before crossing any mountains. On the other hand, rain clouds cannot encounter the Ikoma Mountains from the other directions before crossing surrounding mountains. Only when rain clouds migrated from west direction, amounts of precipitation in the Ikoma Mountains were observed to be 41 % higher than in the Osaka Plain. The altitude difference between both areas is about 400 m. When rain clouds migrated from the other directions, both amounts of precipitation for the Ikoma Mountains and the Osaka plain were almost the same. Therefore, altitude effect of amounts of precipitation for foot of mountain and top of mountain was observed only when rain clouds directly encountered the mountain before crossing the other mountains.

Keywords: Altitude effect for precipitation, Topography, Rain clouds direction, Ikoma Mountains

1. INTRODUCTION

The estimation for amount of precipitation in mountainous area was necessary for preventing water-related disasters or securing water resources more efficiently [1]. To estimate of amount of precipitation, it was important to clarify precipitation characteristics for various topography. Many papers for amount of precipitation depending on topography of mountain have been studied [2]-[5]. Generally, annual amount of precipitation in mountain area was higher than that in flat area and amount of precipitation in windward of mountain increased with altitude (altitude effect). It has reported altitude effect was variable for each precipitation event [6]-[8]. When rain clouds encountered a mountain after crossing inland, amount of precipitation did not increase with altitude in mountainous area [8].

The mechanism of high precipitation in mountainous area was explained by occurrence of orographic clouds and occurrence of orographic clouds was characterized by relationship between wind direction and topography of mountain [9]-[12]. When wet air or cloud originated from sea encountered a mountain directly, air or cloud go up along a slope on the mountain and orographic clouds occurred. Since orographic clouds enriched raindrops from rain clouds originated from sea (Seeder-feeder effect) [13], relative amount of precipitation in mountain area became high. After orographic clouds increased amount of precipitation around a mountain, wet air became dry. Dry air was hard to occur orographic clouds. Thus, relationship between wind direction and topography were important for increase of amount of precipitation in mountainous area and then altitude effect was thought to depend on the relationship.

In mountainous area facing sea on only one direction and surrounding by mountains on the other directions, when only wet air or rain clouds encountered a mountain from sea directly, orographic clouds was thought to occur. By contrast, when wet air or rain clouds migrated from the other direction, since they encountered the mountain after crossing surrounding mountain, amount of precipitation was not thought to increase.

The Osaka Plain and the Ikoma Mountains on central Japan was determined to be study area depending on topography. The west of Osaka Plain faces to Osaka Bay and the Osaka Plain are bounded by the Hokusetsu Mountains and the Rokko Mountains on the north side, the Ikoma Mountains on the east side and the Kongo-Izumikatsuragi Mountains on the south side. Since the Asia monsoon blows from west, wet air or rain clouds go to the Ikoma Mountains from the Osaka Bay through the Osaka Plain in many precipitation event. Therefore, the purpose of this study was to clarify characteristic of precipitation between from the Osaka Plain to the Ikoma.

2. METHODE

2.1 Topography and Climate around Osaka Plain and Ikoma Mountains

Fig.1 shows location of study area. The location of this study was between from the Osaka Plain to the south Ikoma Mountains in middle of Japan. There are the Ikoma Mountains about 18 km to the east from Osaka Bay. The altitude of the Osaka Plain are about 10 m. The altitude of ride of the Hokusetsu Mountains, the Rokko Mountains, the Ikoma Mountains and the Kongo-Izumikatsuragi Mountains are 300 to 800 m, 300 to 900m, 300 to 600 m and 400 to 800m, respectively. The Kii Mountains are composed of many mountains with over 1500 m height on south side of Kongo-Izumikatsuragi Mountains. Since the Asia monsoon crossed the Shikoku Mountains or the Chugoku Mountains before the monsoon arrived at the Osaka Plain, annual amount of precipitation were 1,000 to 1,600 mm and lower than annual precipitation in Japan as 1,750 to 1,850 mm.

2.2 Sampling and Analysis

Fig.2 shows location of sampling point and Fig.3 shows cross-section for A-A' Line in Fig.2. There were 6 rain gauged points, Plain, East Plain, Foot, Hillside, Ridge, and East Hillside on east side of the Ikoma Mountains. Rain sampling was performed 54 times by every precipitation from May in 2014 to December in 2015. 500 ml bottle made of polyethylene with wide mouth, 43.6 mm in diameter was used for sampling. It was put on the ground at each sampling points.

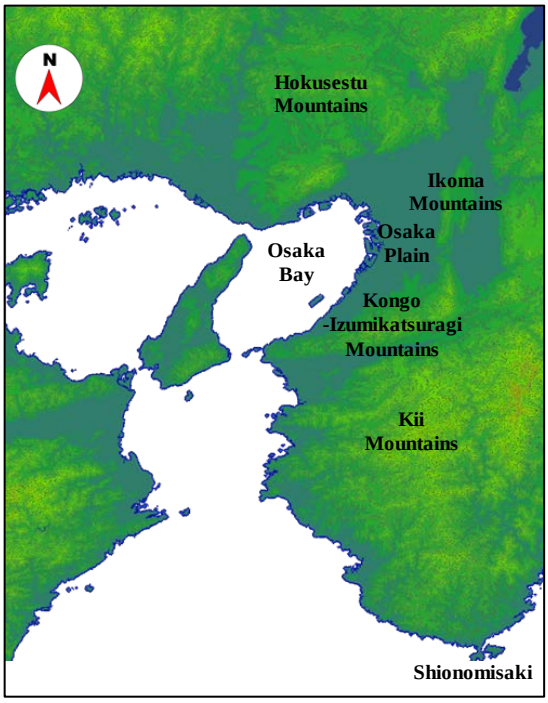

Fig.1 location of sampling points

Amount of precipitation was measured by the following equation.

$$P=((W/\rho))/(((C/2)^2\times\pi))$$

P: Amount of precipitation (mm), W: Weight (g), ρ: Density of water (10^{-3} g/mm³), C: Caliber of Sampler (43.6 mm).

To estimate weather condition in the sampling points and surround area, the data measured by JMA (Japan Meteorological Agency) were used [14]. Wind direction data measured at 925 and 900 hPa points at 9:00 AM in rainy day in the Shionomisaki observatory were used. Since wind directions observed at 925 and 900 hPa atmospheric pressure were not affected by the building, their

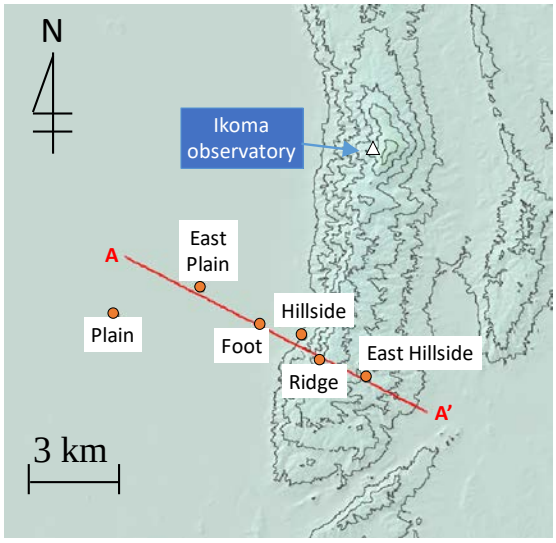

Fig.2 Location of sampling point. Contour lines were drawn every 100m altitude. Circles are sampling points and Triangles were observatory of Japanese Meteorological Agency

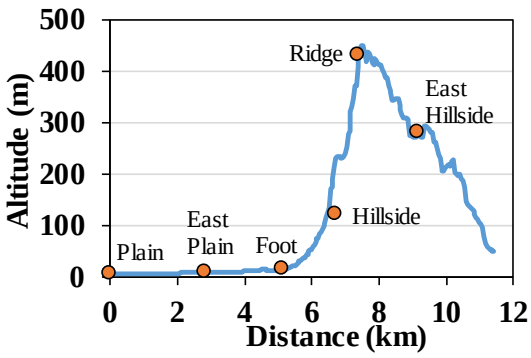

Fig.3 Cross-section for A-A' Line in Fig.2

altitudes were 430 to 900 m and 670 to 1130 m and then measured wind direction altitude agreement

with altitude of the Ikoma Mountains.

The aerological observatory in the Shionomisaki is located about 120 km south of the observatory Yao City. Measured wind direction was classified into 8 directions.

Cloud migration direction was estimated by rainfall radar chart every one hour made by JWA (Japan Weather Association) [15] and was also classified into 8 directions.

3. RESULT AND DISCUSSION

3.1 Relationship between annual amount of precipitation and direction with aerological wind

Fig.4 shows relationship between altitude and annual amounts of precipitation observed by JMA in the Osaka Plain and the Ikoma Mountains from 2011 to 2015. From 2011 to 2013, annual amounts of precipitation in the top of Ikoma Mountains 300 to 360 mm higher than those in the Osaka Plain. In 2014, difference of annual amount of precipitation between the Ikoma Mountains and the Osaka Plain were small as about 100 mm. In 2015, annual amounts of precipitation in the top of Ikoma Mountains was about 400 m higher than that in the Osaka Plain. In the four years except 2014 from 2011 to 2015, annual amounts of precipitation in the top of Ikoma Mountains was higher than that in the Osaka Plain.

Fig.5 shows annual rate of each direction with aerological wind observed at 925 and 900 hPa atmospheric pressure from 2011 to 2015. Altitude at 925 and 900 hPa atmospheric pressure were 430 to 900 m and 670 to 1130 m. From 2011 to 2013, the west wind rate was the largest in all wind directions as from 20 to 30 % each year. In 2014, the annual rates of west wind at 925 hPa atmospheric pressure were 15 % and they were 6 % lower than those of south wind which were the highest percentage. In 2015, the west wind at 925 hPa were the largest in all of wind direction as 21 %. In the four years except 2014 from 2011 to 2015, the west wind was the largest in all of wind directions and the annual rate of west wind at 925 hPa in 2014 were lower than those in the four years except 2014 from 2011 to 2015. The results of wind at 900 hPa atmospheric pressure were similar with that at 925 hPa atmospheric pressure.

From the result, when rate of aerological wind from west was high, relative annual amount of precipitation in the Ikoma Mountains were high. When rate of aerological wind from southwest was high, relative annual amount of precipitation in the Ikoma Mountains were not high.

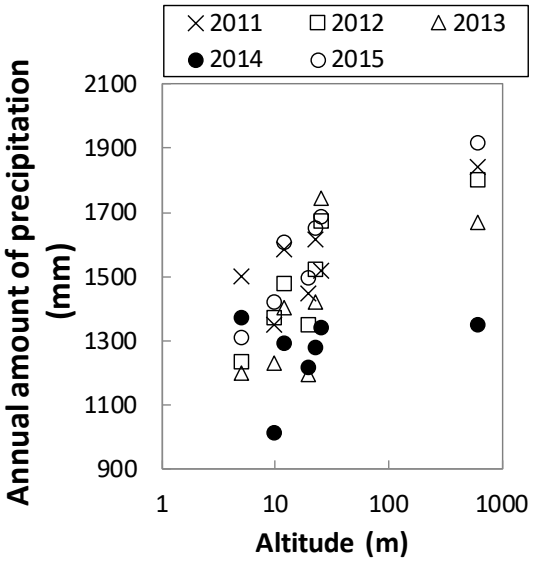

Fig.4 Relationship between altitude and annual amounts of precipitation observed by JMA in the Osaka Plain and the Ikoma Mountains from 2011 to 2015.

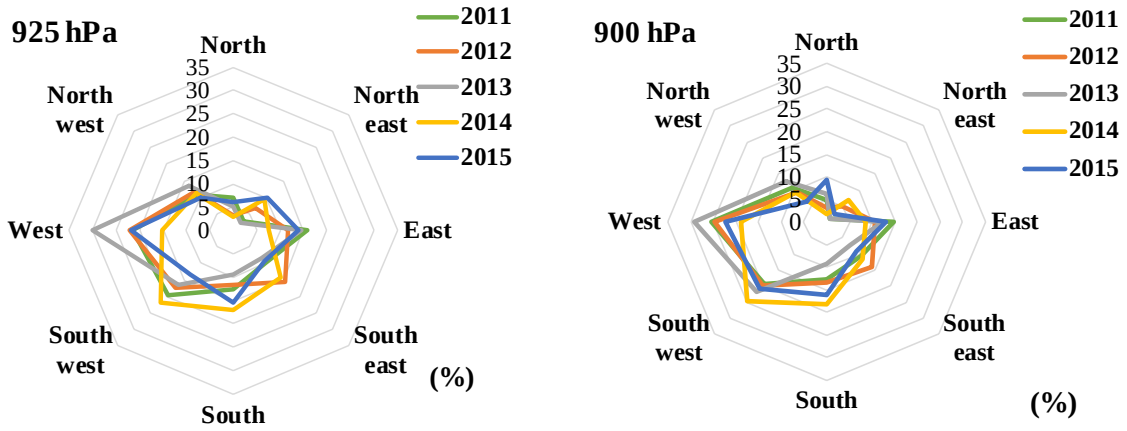

Fig.5 Annual rate of each direction with aerological wind observed at 925 and 900 hPa atmospheric pressure from 2011 to 2015.

3.2 Cloud migration direction depending on topography

When rate of aerological wind from west was high, relative annual amount of precipitation in the Ikoma Mountains were high. Aerological wind was observed only twice a day at 9:00 AM and 9:00 PM. On the other hand, rainfall radar charts made every one hour was on view to public and cloud migration on rainfall radar chart was thought to estimate aerological wind direction in rain time. Thus, cloud migration directions were investigated each event.

Rain clouds migrated from west direction on rainfall radar chart encountered the Ikoma Mountains from the Osaka Bay directly. Rain clouds migrated from directions except west on rainfall radar chart encountered the Ikoma Mountains after crossing the Hokusetsu Mountains, the Rokko Mountains or the Kongo-Izumikatsuragi Mountains. When rain cloud encountered the Ikoma Mountains, it thought that rain clouds migrated from west direction held a lot of vapor and rain clouds migrated from directions except west lost some vapor.

3.3 Relationship relative amount of precipitation in the Ikoma Mountains and cloud migration direction

In this study, due to compare topography change, relative precipitation was defined as difference between amount of precipitation for each sampling point and amount of precipitation at the plain area. Altitudes of three sampling points, Plain, East Plain, and Foot are 6, 6, and 10 m and their sampling points were in the plain area. The sampling point East Plain was represented point in the plain area because of sampling number. Altitudes of three sampling points, Hillside, Ridge, and East Hillside are 120, 430 and 280 m and their sampling points were in the mountainous area. The value of relative precipitation was able to indicate altitude effect for each event as the plain area was low altitude and other sampling points were mountainous areas. Relative precipitation for each events were calculated from amount of precipitation in each sampling point subtracted by amount of precipitation in the sampling point East plain as the plain area.

Fig.6 shows relative precipitation from the Osaka Plain to the Ikoma Mountains under the condition of west direction cloud. When rain clouds migrated from west direction and encountered the Ikoma Mountains from the Osaka Bay directly, in most precipitation events, relative precipitation for three sampling points in plain area, Plain, East Plain and Foot varied -5 to 7 mm and their median were about 0 mm. In most precipitation events, relative precipitation for three sampling points in mountainous area Hillside, Ridge and East Hillside were over 0 mm and their median values were about 5 mm respectively. When clouds crossed the Ikoma Mountains from west, amounts of precipitation in the Ikoma Mountains were higher than that in the Osaka Plain.

Fig.7 shows relative precipitation from the Osaka Plain to the Ikoma Mountains under the condition of rain clouds crossing the surrounding mountains. When rain clouds migrated from

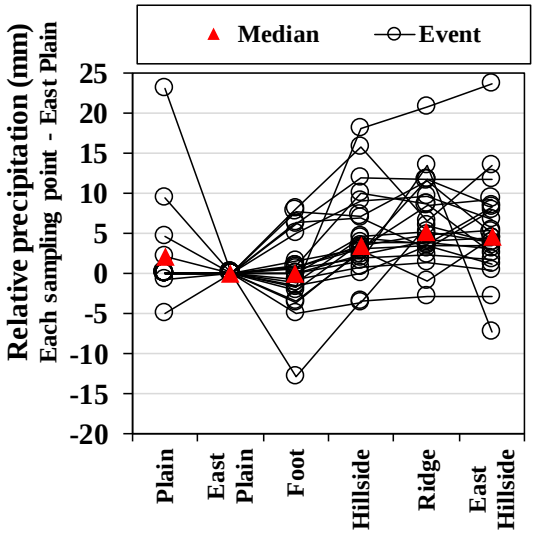

Fig.6 Relative precipitation from the Osaka Plain to the Ikoma Mountains under the condition of west direction cloud. The same event connected by a line.

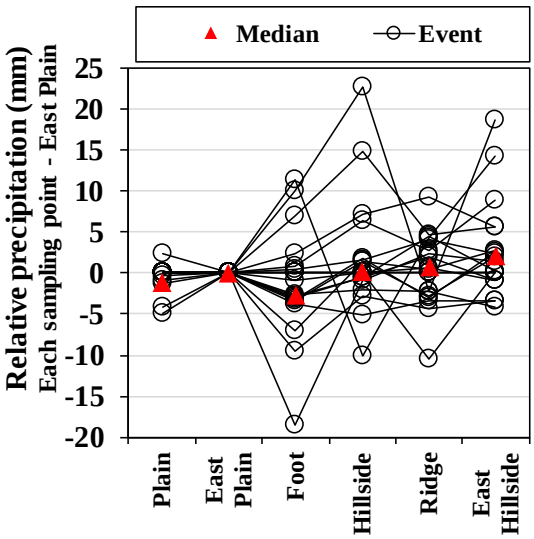

Fig.7 Relative precipitation from the Osaka Plain to the Ikoma Mountains under the condition of rain clouds crossing the surrounding mountains. The same event connected by a line.

directions except west encountered the Ikoma Mountains after crossing the other mountains, in most precipitation events, relative precipitation for all sampling points were -10 to 10 mm and their median were about 0 mm. When clouds crossed the Ikoma Mountains from the direction except west, difference of amount of precipitation between the Osaka Plain and Ikoma Mountains were small.

Therefore, it was found that when rain clouds originated from the Osaka Bay migrated from west and encountered the Ikoma Mountains directly, amounts of precipitation in the Ikoma Mountains were higher than that in the Osaka Plain because rain clouds holds a lot of vapor. On the other hand, rain clouds from directions except west crossed the Hokusetsu Mountains, the Rokko Mountains or the Kongo-Izumikatsuragi Mountains before they encountered the Ikoma Mountains. As the result, when rain clouds crossed the Ikoma Mountains, rain clouds were dry and amounts of precipitation in the Ikoma Mountains were not higher than those in the Osaka Plain.

3.4 The estimating altitude effect in mountainous area

Fig.8 shows relationship between relative precipitations for the sampling points Hillside or Ridge and amount of precipitation in the sampling point East Plain under the condition of west direction cloud. Relative precipitation in the straightly increased with amount of precipitation in the East Plain. Relative precipitation in the Hillside did not straightly increased with amount of precipitation in the East Plain. Regression analysis was performed from amount of precipitation in the East Plain and relative precipitation in the Ridge when rain cloud encountered directly except two events June 26th and March 18th in 2015.

From the regression analysis, difference of amount of precipitation between Ridge and East Plain (relative precipitation) per amount of precipitation in the East Plain were 0.41 and coefficient of determination was 0.9. Difference of amount of precipitation between Hillside and East Plain per amount of precipitation in the East Plain were 0.27 and coefficient of determination was 0.2.

Fig.9 shows relationship relative precipitation in the Ridge or Hillside and amount of precipitation in sampling point East Plain under the condition of rain clouds crossing the surrounding mountains. In events that clouds encountered the Ikoma Mountains after the clouds passed through other mountain, when amount of precipitation were high, relative precipitation in the ridge of the Ikoma Mountains did not tend to be high.

It was found that amount of precipitation at 430 m altitude in the Ikoma Mountains was 1.41 times higher than that in the Osaka Plain when rain cloud encountered directly the Ikoma Mountains from the Osaka Bay.

Table. 1 shows altitude effect [6]-[8]. Amount of precipitation increased by 5 to 10 % for every 100 m altitude in some site. The result of this study coincided with the maximum rate for altitude effect in previous study as increasing by about 40 % for 400 m altitude. It was thought that the maximum rate were indicated when vapor-rich air encountered

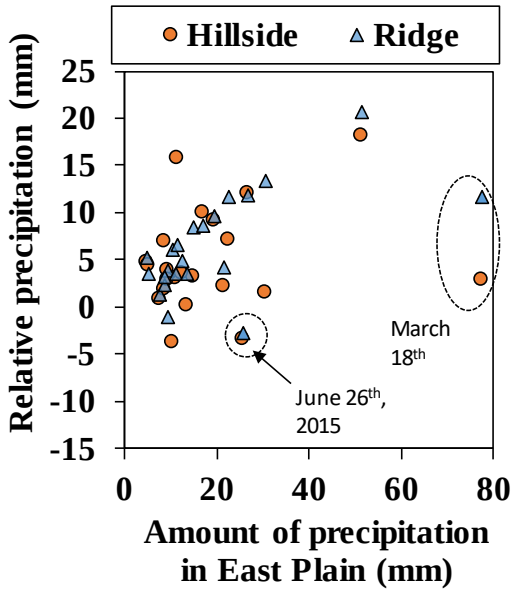

Fig.8 Relationship between relative precipitations for the sampling points Hillside or Ridge and amount of precipitation in the sampling point East Plain under the condition of west direction cloud

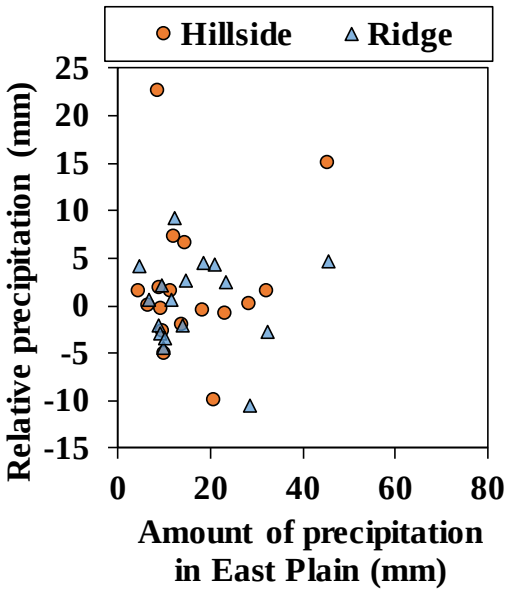

Fig.9 Relationship relative precipitation in the Ridge or Hillside and amount of precipitation in sampling point East Plain under the condition of rain clouds crossing the surrounding mountains

Table.1 Rate of amount of precipitation increase with altitude

Site	Per 100m altitude	400 m altitude difference
Mt. Yubari Mt. Gozaisyo	4.7 to 10 %	
On JR Shinonoi Line On JR Koumi Line	5 to 10 %	
On JR Ou Main Line	Several percent to 20 %	
Mt. Ikoma (This study)		41 %

a mountain from sea directly. Therefore, it was thought that rate for amount of precipitation with altitude in this study were applicable to other mountainous area when rain cloud encountered mountain from sea directly although for the other directions wind after crossing mountain, altitude effect did not occur.

4. CONCLUSION

To compare altitude effect for precipitation, amounts of precipitation for mountainous area and plain area at the foot of mountain, rain sample between from the Osaka Plain to the Ikoma Mountains was collected.

It was found that when rain clouds from the Osaka Bay directly migrated west to the Ikoma Mountains before crossing other mountains, amounts of precipitation in the Ikoma Mountains were higher than those in the Osaka Plain. Direct wind brought out upstream air at the Ikoma Mountains and then orographic clouds were thought to be easy to occur because rain clouds keep wet.

On other hand, rain clouds from other directions firstly encountered the Hokusetsu Mountains, the Rokko Mountains or the Kongo-Izumikatsuragi Mountains before crossing the Ikoma Mountains. When rain clouds crossed the Ikoma Mountains, rain clouds were dry and upstream air at the Ikoma Mountains was hard to occur because surrounding mountains disturbed wind and upstream air or orographic clouds did not always occur efficiently, then amounts of precipitation in the Ikoma Mountains were not higher than that in the Osaka Plain.

As a result, when rain clouds encountered the Ikoma Mountains directly, amounts of precipitation in the Ikoma Mountains were observed to be 41 % higher than in the Osaka Plain. The altitude difference between the Ikoma Mountains and the Osaka plain is about 400 m. These results coincided with the maximum values of previous results [6]-[8].

Therefore, it was thought that rate for amount of precipitation with altitude in this study were applicable to other mountainous area when rain cloud encountered mountain from sea directly although for the other directions wind after crossing mountain, altitude effect did not occur.

5. REFERENCES

[1] Patuti I.M., Ahmad R, K. B. Suryolelono, “Mechanism and Characteristics of The Landslides in Bone Bolango Regency, Gorontalo Province, Indonesia”, International Journal of GEOMATE, Vol. 12, Issue 29, pp. 1-8, 2017.

[2] Suzuki Y., Nakakita E. and Ikebuchi S., “Study on the Dependence Properties of Rainfall Distributions on Topography Based on the Altitude Dependence Line”, Annual journal of Hydraulic Engineering, Vol.45, 2001, pp. 302-306.

[3] Fujimoto M., Watanabe K., and Moriwaki, R. “Space-Time Characteristics of Diurnal Rainfall Variation in Matsuyama Plain”, Journal of JSCE Ser.B1, Hydraulic Engineering, Vol.67, No.4, 2011, pp. I_451-456.

[4] Yabusaki S., Kono T., “Characteristics of stable isotopes in precipitation at Kyoto basin”, Bulletin of geo-environmental science, Vol. 14, 2010, pp. 23-30.

[5] Smallshaw J., “Some Precipitation-Altitude studies of the Tennessee Valley Authority”, Eos, Transactions American Geophysical Union. vol.34, No.4, 1953, pp.583-588.

[6] Suzuki H., Nakakita E., “Analysis of Dependence of Heavy Rainfall on Elevation Using Data Observed at Railway Stations and Meteorological Stations”, Annual journal of Hydraulic Engineering, Vol.51, 2007, pp. 283-288.

[7] Suzuki H., Nakakita, E., “Dependence of Heavy Rainfall on Elevation Along Railroad in Mountainous Area”, Annual journal of Hydraulic Engineering, Vol.54, 2010, pp .337-342.

[8] Yamada T, Hibino T, Araki T, “Statistical Characteristics of Rainfall in Mountainous Basins” Journal of Japan Society of Civil Engineers, No. 527, 1995, pp 1-13.

[9] K. Saito, L. Thanh, and T. Takeda, “Airflow over the Kii Peninsula and its Relation to the Orographic Enhancement of Rainfall” Papers in Meteorology and Geophysics, Vol. 45, Issue 2, 1994, pp. 65-90.

[10] Kikuchi, K., Ohguchi, O., Uyeda, H., Taniguchi, T., Kobayashi, F., Iwanami, K. and Shirooka, R. Rainfall Characteristics Around Mt. Yotei, Hokkaido, Geophysical Bulletin of Hokkaido University, Sapporo, Japan, Vol., No.57, 1994, 35-59.

[11] Takeda T., N. Moriyama and Y. Iwasaka "A Case Study of Heavy Rain in Owase Area", Journal of the Meteorological Society of Japan. Ser. II, 54(1), 1976, pp. 32-41.
[12] Houze R.A., Jr., "Cloud Dynamics", Vol. 53, Academic Press, 1998.
[13] Japan Meteorological Agency, https://www.data.jma.go.jp/obd/stats/etrn/index.php
[14] Japan Weather Association, https://tenki.jp/past/