Feasibility Study of Rainmaking in the Upper Ping River Basin

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Abstract

The objective of the present study is to assess the feasibility of a rainmaking process based on agricultural and hydropower generation purposes. The assessment method begins with calculating the amount of induced rainfall depths. The rainfall depths are then assessed; their feasibility using the criterion of benefit-cost ratio, and the internal rate of return. The procedure was used in the rainmaking application in the upper Ping river basin. Results have shown that the rainmaking process increases annual rainfall depths in the basin by 16 % (164 mm.). The location of moisture center is usually at the Nam Mae Khan sub-basin. Further, the assessment results have indicated that the rainmaking process is feasible when applied to agricultural purposes within the dry-spell period in the rainy season. It is also favorable economically for the hydropower generation purpose.

Key Words: Rainmaking, Nonstructural Measure of Drought, Feasibility Study.

1. Introduction

The phenomenon of drought has often damaged the production of agricultural activities in a region. For alleviating the drought problem, a number of structural and nonstructural measures are available. Structural measures are, for example, the diversion of available water from other river basins, the effective management of available water in existing reservoirs, and forest rehabilitation. These solutions can mitigate water deficit situations appreciably. However, they usually require large capital investments, a long time for implementation, and careful considerations on environmental impacts.

Another nonstructural solutions include the development of a water conservation program, implementation of drought signal warning, and the development of a rainmaking program. Currently, the rainmaking application has been the most popular measure for drought mitigation. This is because it uses a small amount of governmental budget and can relieve the localized drought problem promptly after the favorable conditions of rainmaking become available.

[1] evaluated the feasibility of rainmaking in the Ping river basin based on the criterion of benefit-cost ratio. The sum of hydropower generation benefit at the Bhumiphol Dam and agricultural one downstream of the dam were considered as the total rainmaking benefit. Results showed that the rainmaking application was feasible. However, unlike the recently popular situation, the use of rainmaking during this previous investigation was limited. Further, the purpose of its recent application is usually for the agricultural sector.

The main objective of the present study is therefore to assess the feasibility of rainmaking in the upper Ping River Basin. It can be concluded that the rainmaking is feasible for the agricultural purpose if its application is limited only for the period of dry spells in rainy season.

2. Economic Assessment Method of Rainmaking

Let $R_i(t)$ be an annual rainfall record at station i in year t and $\bar{R}_j(t)$ be an average rainfall of sub-basin j in a studied watershed area during year t. The proposed procedure calculates the average rainfall $\bar{R}_j(t)$ (j = 1, 2, ..., l; t = 1, 2, ..., m) using the Thiessen polygon method [2]:

$$\bar{R}_j(t) = \sum_{i=1}^{n} \frac{A_i}{A_1 + A_2 + \ldots + A_n} R_i(t) \qquad (1)$$

in which A_i = the enclosing polygon area of station i and n = the number of rainfall gauging stations used.

The sequence $\bar{R}_j(t)$ of average rainfall depths is then separated into 2 sub-series. The first one [$\bar{R}_j(t)$; t = 1, ..., p where $p < m$] has the total rainfall depth in each year considered to be purely natural. The remaining rainfall estimates $\bar{R}_j(t)$; for $t = p+1, p+2, \ldots, m$; are hence the combination of natural, and artificially-induced precipitation depths. Next, a linear regression model is applied to the series of natural rainfall as

$$\hat{R}_j(t+1) = a.\hat{R}_j(t) + b \qquad (2)$$

where $\hat{R}_j(t)$ = the computed value of $\bar{R}_j(t)$, a = the slope parameter and b = the intercept parameter. The parameters are estimated using the average rainfall $\bar{R}_j(t)$ for t = 1, 2, ..., p. This linear regression model in **(2)** is now used for computing the natural rainfall portions during $t = p+1, p+2, \ldots, m$. The amount of artificially induced precipitation $R'_j(t)$ is then given by

$$R'_j(t) = \bar{R}_j(t) - \hat{R}_j(t) \qquad (3)$$

Note that $R'_j(t) \geq 0$. If it is negative, it will be set equal to 0. In other words, there is no surplus for natural precipitation in year t.

Depending on the purpose of using $R'_j(t)$, the proposed evaluation can be described as follows.

2.1 Agricultural purpose

In this case, the rainfall depth $R'_j(t)$ is used in the j'th sub-basin only once. There is no return flow to drainage systems for further uses downstream. This rainfall depth $R'_j(t)$ is now linearly related to the amount of each agricultural commodity in the studied area [3]. That is,

$$Q'_k(t) = \left[\frac{R'_j(t)}{\bar{R}_j(t)}\right] Q_k(t) \qquad (4)$$

in which $Q_k(t)$ = the total commodity k produced (k = 1, 2, ..., c; where c = the number of agricultural products) and $Q'_k(t)$ = the k'th agricultural quantity due to $R'_j(t)$. The next step is to compute the net benefit $B_k(t)$ of each $Q'_k(t)$ as

$$B_k(t) = \frac{1}{m-p+1} \sum_{t=p+1}^{m} [P_k(t) - E_k(t)] Q'_k(t) \qquad (5)$$

where $P_k(t)$ and $E_k(t)$ = the market price and expense of each commodity respectively. The average value of net benefit during the period of rainmaking is used in **(5)** to avoid the variations in market price and expense for the analysis. Then, the total benefit in a year $B(t)$ is given by

$$B(t) = \sum_{k=1}^{c} B_k(t) \qquad (6)$$

The benefit of rainmaking is assessed using the ratio of benefit-cost (B/C) as

$$B/C = \frac{B(t)}{(1+r)C(t)} \qquad (7)$$

where r = the rate of interest in percent and $C(t)$ = the cost of rainmaking. If the ratio B/C > 1, it will be inferred that the rainmaking during year t is feasible for the considered purpose. The economical evaluation of rainmaking is further examined based on the internal rate of return, IRR, in percent:

$$IRR = \frac{[B(t) - C(t)]}{C(t)}.100 \qquad (8)$$

In this case, the feasibility of rainmaking is accepted if the criterion $IRR > r$.

The procedure described above yields the feasibility study of rainmaking during year t (e.g., rainy and dry cropping seasons). However, one may be interested in evaluating the rainmaking feasibility of the dry spells in rainy season since the water deficit consequently damages the agricultural products. In this circumstance, all agricultural lands within the studied area using rain-fed irrigation are considered. The net benefit of rainmaking $\tilde{B}(t)$ is hence the total profit of all commodities in the rain-fed area. The rainmaking cost during the spells $\tilde{C}(t)$ is proportionate to the total cost as

$$\tilde{C}(t)=\left(\frac{\tilde{A}}{A}\right)\left(\frac{L}{\omega}\right)C(t) \qquad (9)$$

where $\tilde{A}$ = the rain-fed irrigation area, A = the total studied area, L = the length of dry spells and ω = the total period of rainmaking. The benefit $\tilde{B}(t)$ and cost $\tilde{C}(t)$ are then evaluated using **(7)** and **(8)**.

2.2 Hydropower generation purpose

This economic assessment will be considered if there is at least one single or multipurpose reservoir storage within the studied area. Further, one of the primary purposes must be hydropower generation. In this case, the rainfall depth $R'_j(t)$ at the j'th sub-basin locating immediately upstream to the reservoir is used. The available water volume due to $R'_j(t)$, $V(t)$, is calculated by

$$V(t)=R'_j(t)S=R'_j(t)\mathbf{F}(G) \qquad (10)$$

where S = the average surface-water area of considered reservoir and $\mathbf{F}(G)$ = the function in terms of G in which G = the average storage level during the period of rainmaking. Its net benefit $B''(t)$ is given by

$$B''(t)=V(t)M(t)[P''(t)-E''(t)] \qquad (11)$$

in which $M(t)$ = the rate of hydropower generation per unit of available water in year t, and $P''(t)$ and $E''(t)$ = the market price and expense in each year respectively. The next step is to compute the cost of rainmaking $C''(t)$ as

$$C''(t)=\left(\frac{S}{A}\right)C(t) \qquad (12)$$

Finally, **(7)** and **(8)** are used to assess the feasibility of rainmaking.

3. Numerical Application

The upper Ping river basin was selected as the studied area. Forty-five series of 46-year (1952-1997) annual rainfall records were used. Figure 1 shows the locations of chosen rainfall stations, and the boundaries of all sub-basins in the considered area. The other relevant information; such as the cost of rainmaking, the market prices and expenses for various crops and hydropower generation, the rate of hydropower generation per unit of available water, and the pattern of cropping were also collected.

The assessment procedure described earlier was applied to the collected data. It was noted from the rainmaking cost data and discussed with W. Khantiyananta (October, 1999) that the rainmaking in the Ping river basin became popular in 1991. Table 1 shows the linear regression parameters of natural annual rainfall for each sub-basin. It appears that the natural rainfall trends can be classified into 2 groups. The first one decreases at the rate of 7 - 10 mm./year. While, the other is approximately constant. Graphical examples for the two cases are shown in Figures 2 and 3 respectively. Table 2 presents the computed depth of induced annual rainfall for every sub-basin. It can be seen that the amount of induced precipitation ranges from 70 to 490 mm. or 7% to 50% of natural rainfall depth. The center of humidity is usually located at the sub-basin code number 8 (Nam Mae Khan). The total mean of induced rainfall over the studied region is 165 mm. or 16% of virgin rainfall.

Table 3 illustrates the computed B/C and IRR of rainmaking for agricultural purposes in rainy and dry cropping seasons. In this study, the only principal crop (e.g., grain rice) was selected based on the preliminary investigation of collected cropping-pattern data. The discount rate of 9% was used in the evaluation. It is evident that the rainmaking application during the period is not feasible based on the criteria of B/C and IRR. The evaluation was further examined during the dry spells in the rainy season. As suggested in [4], the whole month of July was chosen as the dry spell period. Table 4 demonstrates the assessment results of rainmaking in the interval. It indicates that the computed two criteria support its feasibility during this period.

The assessment results for hydropower generation are presented in Table 5. As described earlier in the proposed method, the induced rainfall depths of sub-basins (e.g., Ping River part 3, Nam Mae Li and Nam Mae Tuen) locating immediately upstream to the Bhumiphol storage were used. It appears that the rainmaking used for the purpose is feasible, like the evaluation obtained by [1].

4. Conclusions

Rainmaking is currently accepted in practice as one nonstructural measure for alleviating the situation of water deficit. The main objective of this study is to assess the feasibility of rainmaking for agricultural and hydropower generation purposes. The assessment procedure consists of estimating the induced rainfall depths due to rainmaking, and evaluating economically the rainfall depths based on the criteria of B/C ratio and *IRR*. These criteria used the discount rate of 9%. The upper Ping River Basin locating upstream of the Bhumiphol dam was selected in this study.

The obtained results can be concluded as follows. The average value of induced rainfall depths is 16% of that of natural one. The center of rainmaking is located at the Nam Mae Khan sub-basin. The feasibility study of the additional rainfall amount shows that it is unfavorable for an agricultural purpose if one is interested in applying the rainmaking process throughout all cropping seasons. It is, however, feasible for supporting agricultural activities during the dry spells in rainy cropping season. In addition, the assessment results for hydropower generation have demonstrated that the use of rainmaking is also favorable.

5. Acknowledgments

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6. References

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7. Notation

The following symbols are used in this paper:

A_i = area enclosing station i;

$\tilde{A}$ = area of rainmaking within the dry spell period of rainy season;

a = slope parameter of linear regression for natural rainfall;

$B_k(t)$ = net benefit of crop k in year t;

$B(t)$ = total net benefit in year t;

$\tilde{B}(t)$ = total net benefit for the dry spell period L in year t;

$B''(t)$ = net benefit of hydropower generation in year t;

B/C = ratio of benefit and cost;

b = intercept parameter of linear regression for natural rainfall;

$C(t)$ = cost of rainmaking in year t;

$\tilde{C}(t)$ = cost of rainmaking for the dry spell period L in year in year t;

$C''(t)$ = cost of rainmaking for hydropower generation in year t;

c = number of crops;

$E_k(t)$ = expenses of k'th crop cultivation in year t;

$E''(t)$ = expenses of hydropower generation in year t;

$\mathbf{F}(G)$ = function of G;

G = average water stage in a storage reservoir;
IRR = internal rate of return;
I = index of rainfall gauging station;
J = index of sub-basin in a region;
k = index of crop type;
L = length of the dry spell period in rainy season;
L = number of sub-basins in a region;
$M(t)$ = rate of hydropower generation per unit of available water in year t;
m = number of available rainfall records;
n = number of rainfall gauging stations;
$P_k(t)$ = market price of k'th crop in year t;
$P''(t)$ = market price of hydropower in year t;
p = record length of purely natural rainfall in year;
$Q_k(t)$ = quantity of k'th agricultural commodity in year t;
$Q'_k(t)$ = quantity of k'th agricultural commodity due to rainmaking in year t;
$R_i(t)$ = annual rainfall record at station i in year t;
$\bar{R}_j(t)$ = average annual rainfall over j'th sub-basin;
$\hat{R}_j(t)$ = computed value of natural rainfall for sub-basin j in year t;
$R'_j(t)$ = artificially induced rainfall depth for sub-basin j in year t;
r = rate of discount;
S = average surface-water area of a reservoir;
$V(t)$ = available water volume due to rainmaking of a reservoir during year t; and
ω = total period of rainmaking.

Table 1 Linear Regression Parameters of Natural Annual Rainfall for Each Sub-basin.

Code	Sub-basin	Slope (mm/year)	Intercept (mm)
1	Ping River part top	-2.09	6560
2	Nam Mae Taeng	-0.31	2027
3	Nam Mae Ngad	-9.88	26001
4	Nam Mae Rim	-6.82	18266
5	Ping River part 2	-6.87	18360
6	Nam Mae Kuang	-6.98	18672
7	Nam Mae Chaem	-2.03	6114
8	Nam Mae Khan	-7.64	20341
9	Nam Mae Klang	-1.36	4339
10	Ping River part 3	-0.68	2704
11	Nam Mae Li	$\cong 0$	1035
12	Nam Mae Tuen	0.20	639

Table 2 Computed Depth of Induced Annual Rainfall for Each Sub-basin [mm and (% of natural rainfall)].

Code	Induced Annual Rainfall (mm, %)							Average
	1991	1992	1993	1994	1995	1996	1997	
1				113 (9)	172 (13)			142 (11)
2					183 (15)			183 (15)
3			178 (19)	465 (50)	345 (37)	234 (26)	242 (27)	293 (32)
4			209 (22)	362 (38)	455 (47)	169 (18)		299 (31)
5				369 (40)	183 (20)	119 (13)		224 (24)
6				161 (17)	48 (5)	28 (3)		79 (8)
7	26 (3)				108 (11)			67 (7)
8	178 (18)			1150 (120)	450 (47)	173 (18)		488 (51)
9					139 (16)			139 (16)
10		9 (1)				262 (27)		135 (14)
11		45 (4)		32 (3)		219 (21)		99 (10)
12	102 (9)	7 (1)		167 (15)	108 (10)	241 (21)		125 (11)
Average	29 (3)	7 (1)	14 (2)	189 (19)	138 (14)	129 (13)	12 (1)	164 (16)

Table 3 Computed B/C Ratio and IRR of Rainmaking for Rice Cultivation (rainy and dry cropping seasons)

Year	Q (ton)	$R'/\bar{R}$ (%)	Q' (ton)	B (10^6 baht)	C (10^6 baht)	B/C	IRR (%)
1991	430,243	3	11,692	5.9	7.7	0.7	-23.3
1992	387,501	1	2,441	1.2	24.6	0.05	-95.1
1993	331,365	2	4,848	2.5	.39	0.06	-93.7
1994	386,510	19	62,504	29.7	35.9	0.76	-17.2
1995	357,799	14	43,123	20.6	20.4	0.93	1.1
1996	309,056	13	35,224	17	26.8	0.58	-36.7
1997	334,597	1	4,552	2.2	68.8	0.03	-96.8

Note: The rate of discount is 9%.

Table 4 Computed B/C Ratio and IRR of Rainmaking for Rice Cultivation (the dry spells in rainy season).

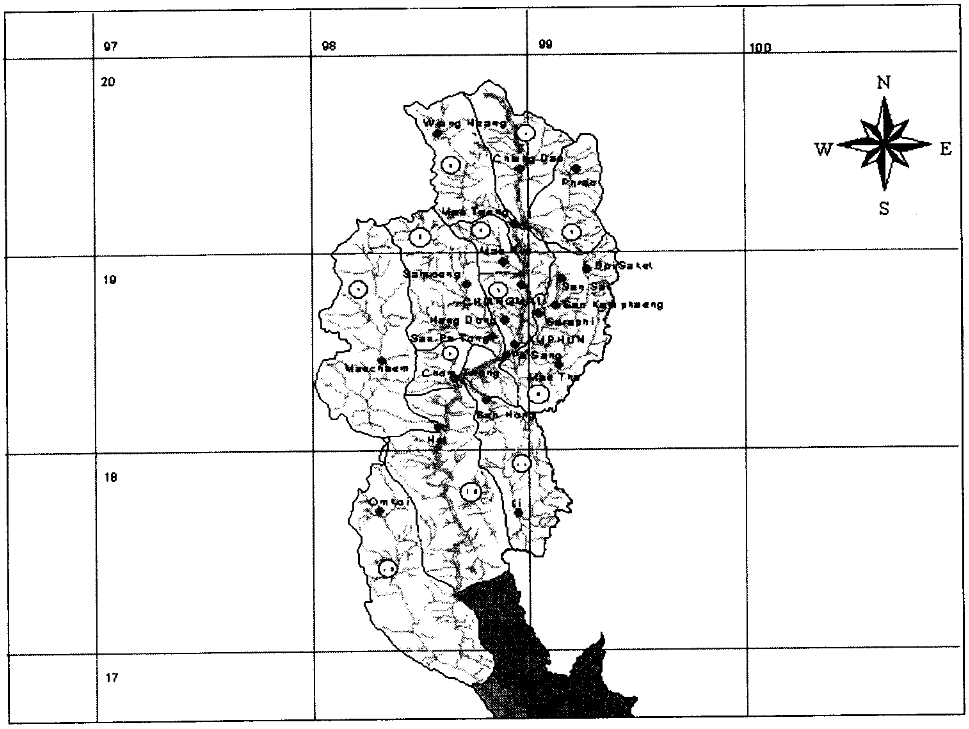
Year	$Q = Q'$ (ton)	$\tilde{B}$ (10^6 baht)	$\tilde{C}$ (10^6 baht)	B/C	IRR (%)
1991	68,163	31.9	2.5	11.9	1,201
1992	150,874	70.5	3.9	16.5	1,694
1993	134,089	62.7	6.3	9.2	902
1994	120,211	56.2	8.4	6.2	573
1995	99,294	46.4	5.8	7.3	697
1996	105,041	49.1	5.4	8.4	815
1997	92,709	43.3	13.8	2.9	215

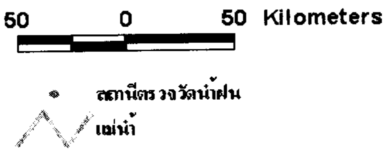
The rate of discount is 9%.

Table 5 Computed B/C Ratio and IRR of Rainmaking for Hydropower Generation

Year	R' (mm)	V (10^6 m^3)	B'' (10^6 Baht)	C'' (10^6 Baht)	B/C	IRR (%)
1991	35	7.9	0.6	0.07	7.6	728.6
1992	18	4.1	0.3	0.23	1.2	30.4
1993				0.36		
1994	65	15	1.1	0.33	3	233.3
1995	37	8.4	0.7	0.19	3.5	278.9
1996	243	55.6	5	0.25	18.4	1900
1997				0.63		

The rate of discount is 9 %. The average value of water surface area is 228.8 km^2.





Code	Basin	[illegible]
1	Ping river part top	2,045.3
2	Nam Mae Taeng	1,980.0
3	Nam Mae Ngat	1,288.3
4	Nam Mae Rim	556.4
5	Ping river part 2	1,750.2
6	Nam Mae Kuang	2,333.3
7	Nam Mae Chaem	3,405.6
8	Nam Mae Khan	1,781.9
9	Nam Mae Klang	611.1
10	Ping river part 3	3,645.9
11	Nam Mae Li	2,419.2
12	Nam Mae Tuen	3,3142.4

Figure 1. Locations of Rainfall Gauging Stations.

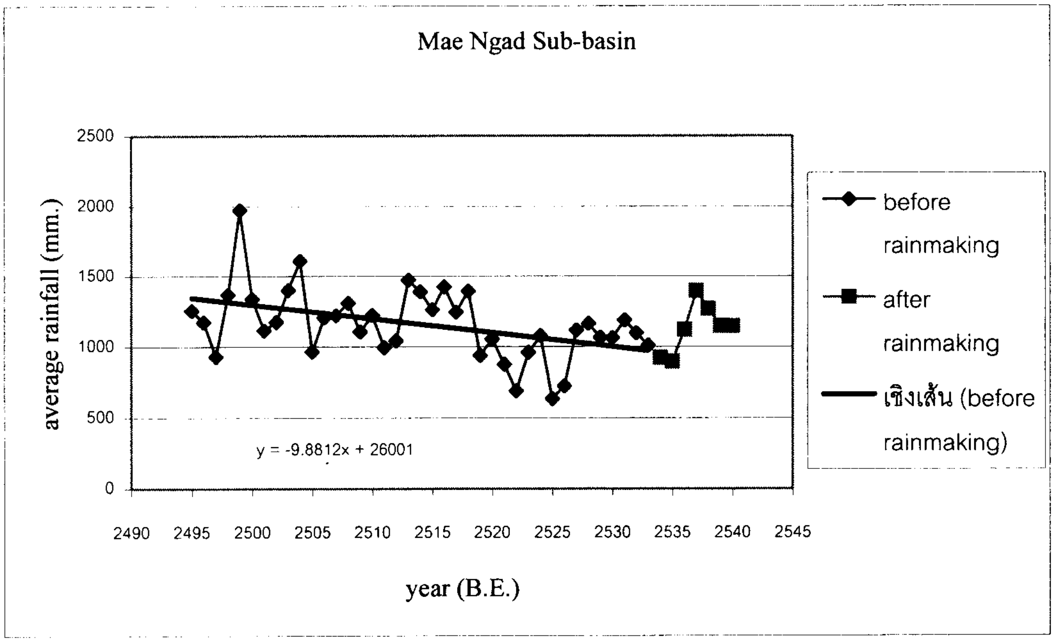


Figure 2. Average annual rainfall of Mae Ngad sub-basin

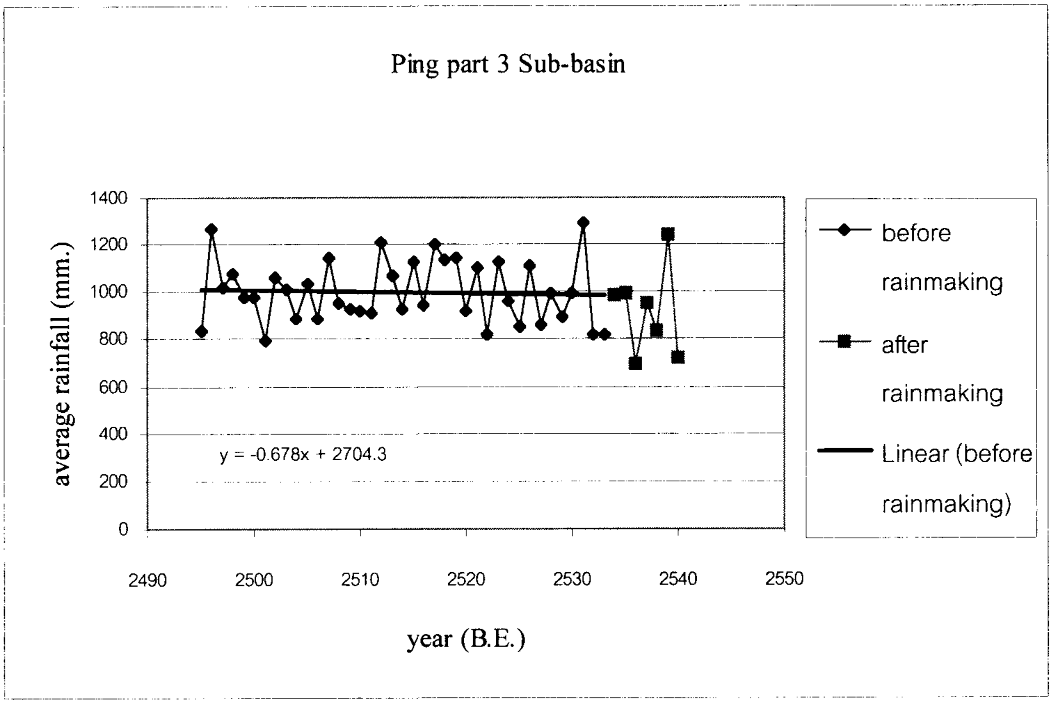


Figure 3. Average annual rainfall of Ping part 3 sub-basin