Evaluating the budgeting approach of operation and maintenance of irrigation in Indonesia by using analytic hierarchy process

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Abstract: Currently, the Indonesian government calculates the operation and maintenance (O&M) budget by considering the size of the irrigation-area. The problem is that the O&M cost is not always proportional to the size of the area. In fact, infrastructure (such as irrigation channel and hydraulic structures) could be decisive in determining the amount of the required budget. This study will assess the difference in the O&M cost between the government's policy and the new approach using Analytic Hierarchy Process (AHP) method. The new method has been formulated by the observation in West Java, and this study will attempt to apply it to the various irrigation-area or farms in Central Java. As for the result, the direct application of the formula will yield unsatisfying result hence improvisation is required. Thus, it can be concluded that the usage of AHP-based formula is not meant to be applied directly, but it requires technical considerations based on the characteristics of irrigation-area. By conducting further analysis, the previously-derived equation exhibits the abnormality i.e. the unrealistically high budget for the irrigation area with many facilities. It is also much more logical to have the linear proportionality between the budget and the number of infrastructure. By evaluating the previous work and the results from this study, the conclusion also converges to the linear relationship. Thus, while the exact equation in this study is not meant to be applied universally, the most important finding is how the O&M budget is linearly proportional to the number of infrastructures and is not only depended on the size of the farms.

Keywords: O&M budget, AHP, irrigation infrastructure, area, channel, hydraulic structure

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1 Introduction

As for the diversity of agricultural systems, agriculture holds a paramount importance in Indonesia as it becomes the backbones of the national economy. From shifting cultivation to intensive crop farming, from rain-fed to intensive-irrigated paddy field, from vegetables mix farming to monoculture industrial plantations, from subsistence small-scale farming to large-scale commercial plantation, all of them are essential in providing food as well as becoming the nation's economic backbone. (Syuaib, 2016). The data from the World Bank (2014) shows that agriculture sector provides the job for 34% of the entire nation population. It also contributes a large share of its national revenue as the data from Badan Pusat Statistik (BPS). Additionally, Statistics Indonesia (2013) stated that agriculture had a share of 14.43% of Indonesia's gross domestic product.

By understanding its utter importance, government must exert full attention to the agriculture sector in order to improve its productivity. Unfortunately, it does not go

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unobstructed as the reasons are varied: (1) productivity tends to decrease; (2) the agricultural land is kept being converted into non-agricultural one; (3) there is restricted space for an agraric expansion; and (4) the population keeps increasing (Suhendrata, 2008). Out of these challenges, the land conversion and the space restriction are hardly counter-acted especially in Java. Hence, the focus must be shifted on intensification which is defined as an increased average inputs of labour or capital on a smallholding, either on cultivated land alone, or on cultivated and grazing land, for the purpose of increasing the value of output per hectare (Tiffen et al., 1994).

Agricultural intensification is also heavily associated with an increased frequency of cultivation, an increase in labour inputs, or an application of more advanced technology (Carswell, 1997). The effectiveness of intensification is proven by the data from the past that Indonesia managed to increase the productivity by 56.1% by the mean of intensification, compared to 26.3% by land expansion or extensification (Sembiring, 2007).

Irrigation infrastructure is also a part of the agricultural intensification (Matson et al., 1997), although it is often overlooked. Various studies have already proven that irrigation has an important role in increasing the productivity and even strengthening the national econmoyby Hussain and Hanjra (2004), Vaidyanathan et al. (1994), Lipton et al. (2003), and Hagos et al. (2009). Hence, establishing and running a well-designed irrigation system (and infrastructure) is very important to sustain the agricultural productivity.

Running an irrigation system requires money so government must allocate its budget for the operation and maintenance (O&M) of the system. Currently, the Indonesia government sets the value based on the total of the irrigation area. However, Hadihardaja (2005) and Hadihardaja et al. (2010) raised the concern regarding the policy's flawthat it does not take into account the presence of the irrigation infrastructure (here, defined as irrigation channel and hydraulic structure) which, in fact, contribute significantly to the O&M cost. Consequently, the vast irrigation-area with minimum infrastructure might receive the budget which exceed its requirement. On the other hand, the small irrigation-area which is equipped with the high amount of infrastructure might receive insufficient fund. Based on this problem, the fair O&M budgeting must be formulated in order to suffice the cost requirement which eventually is necessary to keep up the farm's productivity.

Thus, the new method to calculate the O&M budget is proposed by using the multicriteria analysis technique namely Analytic Hierarchy Process (AHP) which was developed and popularized by Saaty (1988). AHP is a popular method which is widely used for various works e.g. for water pring to improve water quality (Sachro, et al., 2013). This method has been used frequently for irrigation-related study field e.g. by Karami (2006), Montazar and Behbahani (2007), Montazar and Zadbagher (2010), Anane et al. (2012), Anjasmoro et al. (2017) and Bencheikh (2017). However, the topic on using AHP to determine the irrigation O&M budget was firstly proposed by Hadihardaja and Grigg (2011). In their work, they found that the budgeting index for each irrigation area can be correlated to the channel length and the number of hydraulic structures. The plot between the budgeting index and the sum of channel and hydraulic structures is depicted in Figure 1. As expected, the more infrastructure equipped in an irrigation area, the higher is its budgeting index. Soentoro et al. (2014) attempted to use such approach for their case in West Java as well as they agreed that the method yielded better budgeting.

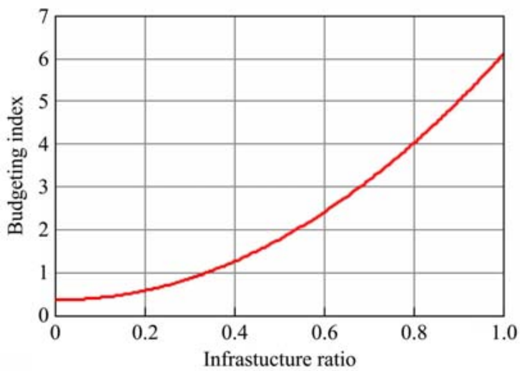

Figure 1 The plot between the infrastructure ratio and its corresponding budgeting index

In this study, the very similar method is tried on 8 samples of irrigation area in Central Java to see if the O&M budgeting solely depends on how vast is the farm's area. Furthermore, this study is also aimed to assess if the relation between the budgeting index and the infrastructure index (Hadihardaja and Grigg, 2011) can be applied and not limited only in West Java.

2 Method

2.1 Bugeting index

This study will determine the budget distribution by taking into account the irrigation infrastructures at each irrigation area and it will be calculated with the AHP method. In the first stage, the budgeting index in Central Java, Indonesia was computed by the formula which was derived from the previous study in West Java, Indonesia (Hadihardaja and Grigg, 2011). In the second stage, the budgeting index will be calculated by the AHP method.

The relation between infrastructure density and budgeting index in West Java can be formulated as Equation (1).

$$B_{Ii} = 7.42(P_{ICi} + P_{HSi})^2 - 1.19(P_{ICi} + P_{HSi}) + 0.5 \qquad (1)$$

where, B_{Ii} is the budgeting index for area i; P_{Ici} is the channel index for area i which is defined as $D_{ICi}\,P_{IC}$ (here, P_{Ic} is assumed as 1); P_{Hsi} is the hydraulic structure index of area i which is defined as $D_{HSi}\,P_{HS}$ (P_{HS} is assumed as 1); D_{ICi} is the index of irrigation canal for area i and D_{HSi} is the index of irrigation hydraulic structure for area i. D_{ICi} and D_{HSi} can be presented as follow:

$$D_{ICi} = \frac{L_i}{\sum_{i=1}^{N} L_i}$$

$$D_{HSi} = \frac{H_i}{\sum_{i=1}^{N} H_i}$$

Equation (1) is a simplified relation between the infrastructure ratio and the budgeting index (B_{Ii}). Originally, B_{Ii} is computed with AHP method which is expressed by Hadihardaja and Grigg (2011) as Equation (2).

$$B_{Ii} = C_w W_i \qquad (2)$$

C_w is the global weight coefficient for all irrigation region which is determined as 6.63 in the previous study. Meanwhile, W_i is the weight priority derived from AHP. From the derived B_{Ii} , either by Equation (1) or (2), the new value for O&M budget per hectare can be determined as Equation (3).

$$NB_i = B_{Ii}\overline{B} \qquad (3)$$

In which, NB_i is the new O&M budget per unit area (Rupiah per hectare), $\overline{B}$ is O&M budget allocated from the Indonesia government i.e. Rp. 200,000.

2.2 Site of the study

Here, various irrigation area in province of Central Java, Indonesia will be assessed. This province has a significant contribution in Indonesia's agriculture. For rice sector, BPS recorded that Central Java had 952,525 ha of rice field in 2013 (which was 11.74% of Indonesia's rice field) and it also produced 11,045,494 ton of rice in 2015 (which was 14.73% of Indonesia's rice production). From this data, it is very clear that the agriculture (especially rice production) in Central Java is very important to Indonesia.

The characteristics of the assessed irrigation-area, i.e. area and facilities, are shown in Table 1 (the infrastructure performance and the investment cost/benefit are out of the study's scope thus are not included). The definition of most of the parameters are quite self-explanatory. As for the number of hydraulic structures, it indicates the amount of weirs, diversion structures and sills in each area in 2015. There are several aspects of uniformity regarding the selected irrigation area:

- All selected farms have precisely similar cropping pattern i.e. rice – rice – field crops and rice – field crops – field crops with weir as a main infrastructure.
- All the farms are under similar climate condition.
- The farming system in Indonesia is still labour intensive, hence, there is barely any difference in infrastructures throughout the farms. It is safely assumed that all the farms have uniform infrastructures.
- The uniformity is not only in physical aspects (such as climate and infrastructures), but also in cultural aspect as the demography of the farmers in the Central Java province is quite homogeneously.
- The only notable difference is the geographic difference as the farms are spread throughout various terrains. The farms on the lowland are implied by the vast area, but equipped with minimum infrastructures. Conversely, the farms on the highland have small area, but require relatively long channel and many hydraulic structures.

Table 2 indicates the ratio of the each parameter relative to the sum of all the irrigation-area. The definition is quite self-explanatory as the ratio compares the scale of each irrigation-area's properties to the sum of all the irrigation-area. There are 3 parameters which are compared i.e. area, channel length, and the amount of hydraulic structures.

Table 1 Physical characteristic of assessed irrigation area (Central Java Water Resources Management Agency, 2015)

Irrigation area	Symbol	Area (ha)	Channel length (km)	Number of hydraulic structures (unit)
Pemali Bawah	PB	26952	204.67	844
Cacaban	Ca	7439	97.66	599
Rambut	Ra	7634	45.23	135
Glapan	Gl	18740	176.16	730
Kedungasem	Ke	4353	60.32	583
Waduk Sempor	WS	6478	122.09	580
Wadaslintang	Wa	31853	453.53	2782
Progomanggis	Pr	3633	79.60	535
Sum		107082	1239.26	6788

Table 2 The ratio of irrigation-area's characteristic relative to their respective sum

Irrigation area	Area ratio	Channel ratio	Structure ratio
Pemali Bawah	0.25	0.17	0.12
Cacaban	0.07	0.08	0.09
Rambut	0.07	0.04	0.02
Glapan	0.18	0.14	0.11
Kedungasem	0.04	0.05	0.09
Waduk Sempor	0.06	0.10	0.09
Wadaslintang	0.30	0.37	0.41
Progomanggis	0.03	0.06	0.08

3 Results and discussion

3.1 The budgeting index, calculated with Equation (1)

The derivation of P_{ICi} and P_{HSi} can be referred to the study of Hadihardaja and Grigg (2011). The values of both variables are depicted in Figure 2. After several steps, these variables will be converted into the budgeting index (denoted as B_{Ii}) by Equation 1 and their values are shown in Figure 3.

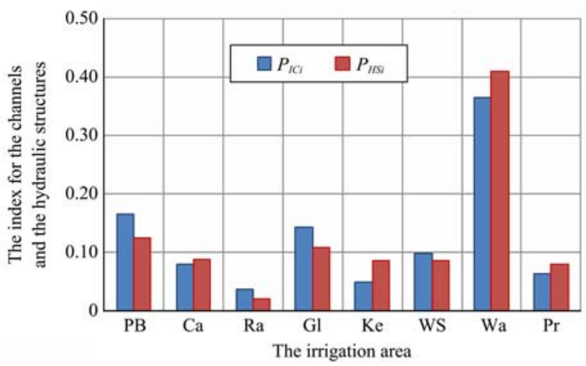

Figure 2 The value of P_{ICi} and P_{HSi} for each irrigation area

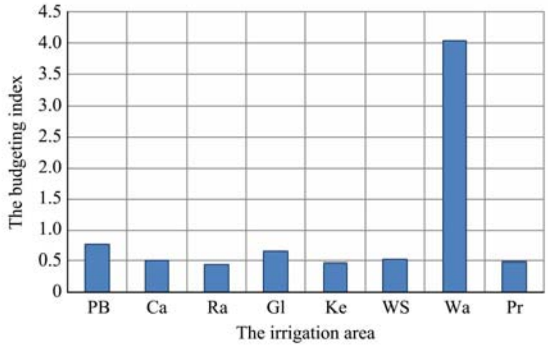

Figure 3 The value of budgeting index per irrigation area

The computation of the new budget (NB_i) formulated by AHP approach is explained in Equation (2) and its value will be compared with the budget allocated by the government (uniform budgets for each irrigation region). The comparison between both approach is depicted in Figure 4. There, the difference between both approach is obviously shown. It shows that PB, Gl, WS, and P, which have high amount of infrastructure in a small area (can be consulted to Table 2), receive a small amout of budget.

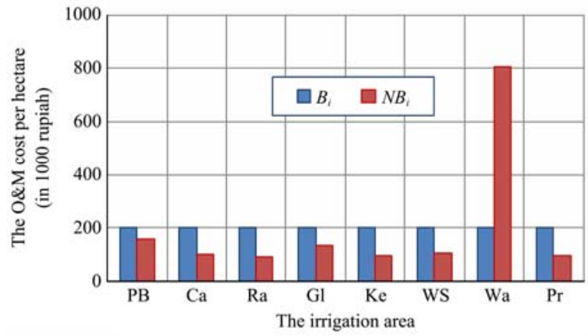

Figure 4 The comparison of O&M budget per hectare (P_{ICi} = 1 and P_{HSi} = 1)

The calculation of the new budget tends to be lower than the value determined by the government ($\bar{B}$). Such behavior is different with the expectation as NB_i should be higher than $\bar{B}$ if there is high amount of hydraulic infrastructure (channel and hydraulic structure) in the irrigation area. As NB_i is generally lower than $\bar{B}$, the modification must be performed on the AHP method i.e. on Equation (1). Here, the proposed solution is by adding the coefficient to both P_{ICi} and P_{HSi} (denoted as C_{IC} and C_{HS}). Thus, Equation (1) can be re-expressed as:

$$B_{Ii}=7.42(C_{IC}P_{ICi}+C_{HS}P_{HSi})^2-1.19(CICP_{ICi}+CHSP_{HSi})+0.5 \quad (4)$$

This approach (adding C_{IC} and C_{HS}) is taken because it is the simple way to solve the problem of undershooting/overshooting the computation of B_{Ii}. Their values can be estimated from the sum of channel length and hydraulic structures of all samples. For instance, in this case, the sum of the channel length and the hydraulic structures is 1239.26 m and 6788 units respectively. Meanwhile, for the West Java case, both are 432.70 m and 1421 units respectively. Currently, there is no guidelines about how to pick the values of C_{IC} and C_{HS}, but it is only reasonable that higher amount of infrastructure should have higher values. By a couples of trial-and-error attempts, C_{IC} = 2 and C_{HS} = 2 seems to yield the best estimation. It is proven by $NBi > \overline{B}$ when the hydraulic infrastructure (channel and structure) is plenty (PB, Gl, WS, Wa, and Pr) and $NBi < \overline{B}$ when the hydraulic infrastructure is few (Figure 5).

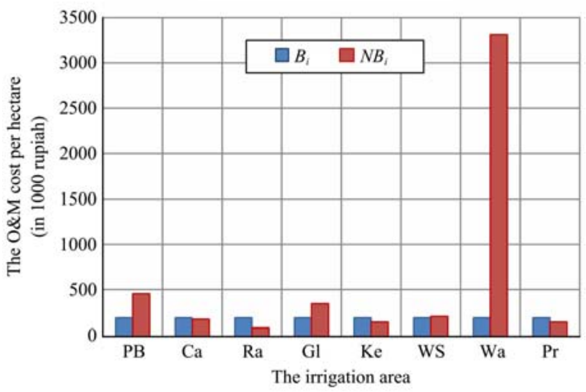

Figure 5 The comparison of O&M budget per hectare using C_{IC} = 2 and C_{HS} = 2

It turns out that the modification is necessary for Equation (1) in order to be used in other area. However, the equation also raises a question as the O&M budget is unrealistically high when the irrigation area has many infrastructures (Wa in this case) i.e. 800000 rupiah (before modification) and even 3.3 million rupiah (after modification). It is because Equation (1) has a quadratic relation which yields extremely high B_{Ii} when the infrastructure ratio is high. In order to understand if such relation is indeed true, the form of the equation will be re-evaluated with AHP method again.

3.2 The budgeting index calculated with the AHP method

For the calculation of the AHP, the goal is set by using the channel length and the hydraulic structures as the criteria. For the start, it is assumed that both carry the same priority to the AHP i.e. 0.5 each. Then, the matrix for each criterion is shown in Table 3 and Table 4.

The value in the matrix is based on the ratio between two corresponding irrigation areas. For example, the top left of Table 3 has a value 2.10 which is derived by dividing the channel length of PB (204.67 km) with Ca (97.66 km). The process is repeated for all the locations.

Table 3 Pairwise table for the channel length criteria

	PB	Ca	Ra	Gl	Ke	WS	Wa	Pr
PB		2.10	4.53	1.16	3.39	1.68	0.45	2.57
Ca			2.16	0.55	1.62	0.80	0.22	2.57
Ra				0.26	0.75	0.37	0.10	0.57
Gl					2.92	1.44	0.39	2.21
Ke						0.49	0.13	0.76
WS							0.27	1.53
Wa								5.70
Pr								

Table 4 Pairwise table for the hydraulic structures criteria

	PB	Ca	Ra	Gl	Ke	WS	Wa	Pr
PB		1.41	6.25	1.16	1.45	1.46	0.30	1.58
Ca			4.44	0.82	1.03	1.03	0.22	1.12
Ra				0.19	0.23	0.23	0.05	0.25
Gl					1.25	1.26	0.26	1.36
Ke						1.00	0.21	1.09
WS							0.21	1.08
Wa								5.2
Pr								

Table 5 The values of the infrastructure ratio, the budget distribution, and the budget allocation which are derived by AHP method

	PB	Ca	Ra	Gl	Ke	WS	Wa	Pr
$P_{ICi}+P_{HSi}$	0.58	0.33	0.11	0.50	0.27	0.37	1.55	0.29
Budget distribution by AHP	0.15	0.11	0.03	0.12	0.07	0.09	0.37	0.07
Budgeting index by AHP (B_{Ii})	0.97	0.72	0.19	0.78	0.44	0.62	2.47	0.44

Now that all components are available, the priority of each location can be computed with AHP method and the values are listed in Table 5. The weight of the priority can be converted into the budgeting index by Equation (2). Then, B_{Ii} is matched with the infrastructure ratio (P_{ICi} + P_{HSi}) and the relation between them is shown in Figure 6.

$$B_{Ii}=1.57(P_{ICi}+P_{HSi})+0.04 \tag{5}$$

The derived relation, Equation (5), has a linear relation which is extremely different with the quadratic relation of Equation (1) which is derived by Hadihardaja and Grigg (2011). Unfortunately, there is no data available from the field to justify which relation approaches the real situation better. However, the linear relationship should be more logical than the quadratic one. Logically, doubling or tripling the amount of the infrastructure will make the O&M cost 2 times or 3 times respectively, not making it 4 times or 9 times higher. So, the linear relationship should be more reasonable rather than the quadratic one.

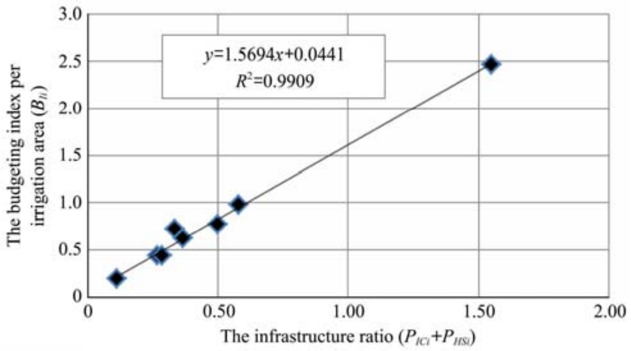

Figure 6 The plot between the infrastructure ratio and its respective budgeting index

3.3 Comparison between the BIi from Equation (1) and (5)

Figure 7 depicts the comparison of Equation (1) and Equation (5) with the data from this case (Table 1). For Wa irrigation-area which has high infrastructure ratio, the quadratic relation gives an unrealistically high B_{Ii} i.e. approx. 16 compared to the linear one which has the value of approx. 2.4. From this figure, it can inferred that the linear relationship is more realistic to be applied especially in the case of highly facilitated irrigation-area.

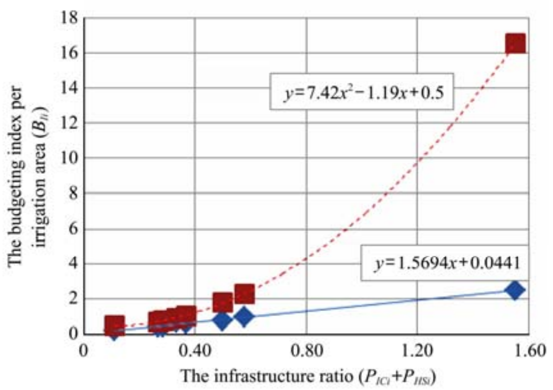

Figure 7 Comparison between the B_{Ii}

Figure 8 illustrates the total O&M cost per hectare calculated by the current policy, the unmodified quadratic equation, and the unmodified linear equation.The figure demonstrates that the linear equation also needs a modification as it tends to undershoot the O&M budget especially for lowly-facilitated irrigation-area. But, the most important point is the linear proportionality between the O&M budget per hectare and the number of infrastructure. As for the coefficients, they will depend on the analyzed samples.

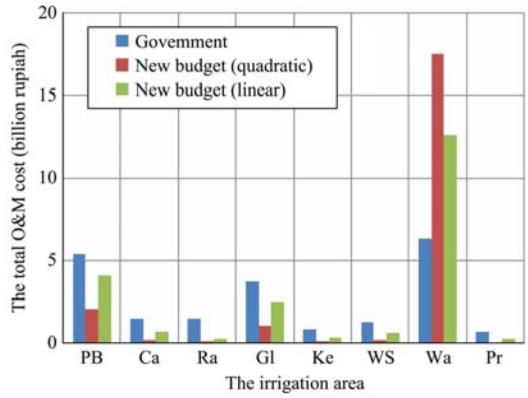

Figure 8 The total O&M budget per irrigation area

The massive difference in B_{Ii} formula between this case (Central Java) and the previous one (West Java) comples the authors to probe the derivation of the quadratic relationship. By replicating the process in this study with the data from West Java, the equation is expressed by Equation (6) and graphically depicted in Figure 9.

$$B_{Ii,\ West\ Java}=2.81(P_{ICi}+P_{HSi})+0.15 \quad (6)$$

Again, the re-calculation yields a completely different correlation between the budgeting index and the infrastructure ratio. It produces another linear relationship which agrees with the finding from Central-Java's case. It also agrees with the reasoning that the O&M budget should have linear proportion to the number of infrastructures, not quadratic. As why the previous case found the quadratic correlation, one can speculate if it used different criteria (e.g. inclusion of area size) or it used different weight for each criteria. All in all, the compilation of the studies converges to the conclusion that the budgeting index (and O&M budget) is linearly proportional to the amount of infrastructure.

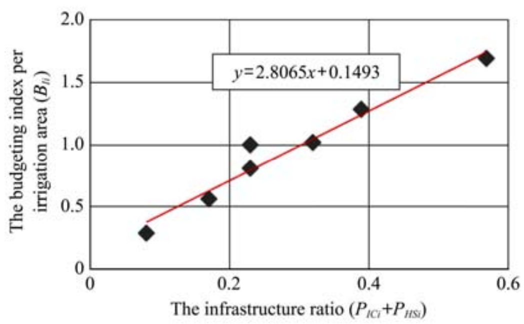

Figure 9 Comparison between the B_{Ii} derived from Equation (1) and (5) using the data from West Java case

The Equation (1) which was formulated by Hadihardaja and Grigg (2011) based on AHP method for the study case in West Java, was tested for various irrigation-area in Central Java. When it is applied directly (which means it uses exactly identical variable values), it does not produce satisfying result as the new budget (NB_i) is too low. It implies that it does not consider the infrasturucture aspect sufficiently into the calculation hence the low value. Furthermore, the new budget is also extremely high for the irrigation-area with high amount of infrastructure. Hence, it can be concluded that the formula cannot be applied universally without any modification. Here, it is suggested to add the coefficients (C_{IC} and C_{HS}) to produce reasonable budget. In this case, the value is 2 for both of them although it might be different for different cases.

However, the linear reliationship is found to be more realistic to be applied. The linear relationship is also found when the previous case is re-calculated by Equation (6). Furthermore, it is logical that the O&M budget should increase/decrease linearly relative to the amount of infrastructure. Both equations are linear, but they have different forms. Hence, it can concluded that the coefficients for the equation will differ depending on the researched sites, but the trend will be likely to be linear.

One way to improve the accuracy of the budget calculation is by specifying the values of each infrastructure. Here, the considered infrastructure is channel and hydraulic structures. The cost of O&M for each of them is different yet it is assumed equal in this study. Another recommendation is by having the survey to estimate the real required budget. Then, the theoritical budget can be compared and calibrated to the real budget. Unfortunately, both methods are not performed in this study due to the limited resources.

4 Conclusions

In this study, the O&M budget was determined by the AHP method for various farms in the province of Central Java, Indonesia. The following points are the conclusion of this study:

- The cost of O&M budget for irrigation depends on the characteristics of irrigation infrastructures such as channel length and the number of irrigation channel.

- The cost of O&M for irrigation tends to correspond linearly with the number of irrigation infrastructures. The linear function is different with the conclusion of the previous study which gave the quadratic function as its result. It is argued that the linear proportionality makes more sense as the budget will increase/decrease linearly on the number of infrastructures instead of quadratic. Each area or region has its own budgeting characteristic thus there is no single equation/function which can be applied universally.

- As there are different conclusions regarding whether the relation should be linear or quadratic, the further investigations are required to understand the underlying condition in using either functions.

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