Analysis of the Causes of Damage to Canals and Structures Related to the Pattern of Tertiary Networks

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INTRODUCTION

IN THE LAST 20 years, the Government of Indonesia made massive investments in the irrigation sector in an effort to achieve self-sufficiency in rice production. With respect to the targets for total irrigated area and self-sufficiency in rice, the irrigation development program was successful. The total irrigated area in the country increased from 3,388,000 hectares (ha) in 1969 to 4,779,000 ha in 1985 (IIMI 1987). Rice production increased at a rate of 5.6 percent per year. Since 1985, Indonesia has changed from being one of the world's largest importers of rice to become self-sufficient in it (Damardjati et al. 1987).

On the other hand, criticism, comments, and recommendations have been directed toward the implementation process that is part of the irrigation-development program. The existing irrigation networks were considered too complicated to be operated by irrigation-agency personnel at the main system level, and too complicated for the farmers to operate at the tertiary level (Horst 1984; IIMI 1987). As a result, several newly developed irrigation schemes were ineffective and inefficiently used. Most of them were also poorly managed so that they became inoperative within a short time (The Jakarta Post 1988; The Jakarta Post 1989; Kompas 1984; Kompas 1988). In an attempt to overcome the weaknesses of these irrigation schemes, Horst (1984) recommended simplifying the existing irrigation networks. In particular, he recommended that the water-division structures, water-measurement structures, and offtake structures at the tertiary level be simplified. Purba and Bhuiyan (1982) reported that before physical improvements could improve

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the effectiveness and efficiency of the irrigation system it is necessary to improve the capacity of the farmers (through water users' associations) to manage the tertiary system.

According to the Indonesian Irrigation Act, the responsibility for the development, operation, and maintenance of tertiary-level irrigation facilities rests with the water users' associations. The ability of the farmers to operate the network is a key factor for achieving a sustainable irrigation system at the farm level. By knowing the relationship between the complexity of the irrigation infrastructure and the causes of damage to the infrastructure, alternatives for simplifying the tertiary network pattern which match the ability of the farmers to operate the network can be formulated.

THEORETICAL BACKGROUND

Characteristics of Tertiary Irrigation Network Patterns

At present, tertiary networks in Indonesia do not follow any particular standard design. Guidelines issued by the Department of Public Works only mention the tertiary block size (50-100 ha), maximum tertiary canal length (less than 1,500 meters), and criteria related to structural specifications (DPU 1986). Since no standard criteria exist for classifying tertiary networks it is difficult to determine the level of complexity of a system.

To describe the characteristics of an irrigation network whose main function is to convey and distribute water, this study draws on an analogy to a transportation network. Two criteria were used:

1. The density of irrigation structures per unit service area (unit/ha), and the canal length per unit service area (unit/ha) were examined.
2. The complexity of the interconnections among the canal segments at the division box was examined using Kansky's (1963) terms: U-index, β ratio, μ ratio, and Ω ratio. Kansky defined these terms as follows:

   $U = e - v + p$
   $\beta = e/v$
   $\mu = M/e$, and
   $\Omega = M/v$, where
   e = the number of canal segments,
   v = the number of division boxes,
   M = total canal length in a tertiary block
   p = the number of tertiary offtakes; usually $p = 1$

The simplest tertiary network has $U = 1$, and $\beta = 0$. In this case, the tertiary network consists of only one offtake without any distribution canal. Irrigation water is distributed throughout the entire block from plot to plot. Both the β ratio and the Ω ratio express the dependency of the tertiary network on the function of the division box. With respect to the complexity of a tertiary network, the ratio expresses the complexity of water division. The higher the value of the β ratio, the more complex is the network in terms of dividing water. On the other hand, a high Ω ratio merely indicates characteristics about conveying or distributing water throughout the blocks. A low ß ratio and high Ω ratio indicate that water division in the tertiary block is simple but that the conveyance canal is longer than average. Therefore, the tertiary network is characterized as having a higher probability of water-conveyance problems despite being a network with simple water division.

Structural density is commonly used to indicate the level of complexity of a tertiary network based on the assumption that the work load, difficulties, and cost for operation and maintenance of the tertiary network are positively related to the structural density of that network. A similar assumption is applied to canal density (which is similar to the expression of the ratio -- the length of the canal divided by the number of division boxes).

RESEARCH METHOD

Site and Description of Sample Areas

Research was conducted in four irrigation schemes: Keyang Bawah of Ponorogo District and Andong of Ngawi District, East Java Province, and van der Wijk and Sorogenen of the Yogyakarta Special Territory Province.

The tertiary blocks were selected to represent different approaches to irrigation development: the van der Wijk and Sorogenen irrigation systems were developed by government personnel, Keyang Bawah was rehabilitated using a farmer-participatory approach, and the Andong irrigation system was rehabilitated through the efforts of the water users' association.

Where tertiary development is implemented by the government the water users are not involved in the process. However, after the project is completed the water users are trained to operate and manage the network in accordance with the operation and maintenance manual issued by the Irrigation Office. Typically, problems arise soon after management of the tertiary network is transferred from the government to the water users.

Where the farmer-participatory approach to irrigation development is used the water users' association is involved in all activities from designing the network to the trial-run stage. The tertiary network is constructed by a contractor after the proposed design (made by both the government and the water users) is approved by the water users' association. The water users' association acts as the counterpart to the government in supervising the construction. At the trial-run stage, the government personnel train the water users to operate and maintain the network according to the standard manual of operation and maintenance.

The most independent approach to the development of tertiary irrigation networks occurs when the project is fully implemented by the water users. In this case the government only acts as a technical consultant in the design and construction stages upon the request of the farmers. The government remains responsible for providing training in operation and maintenance of the network.

Categorization of Causes of Damage to Irrigation Networks

It is hypothesized that a relationship exists between the level of complexity of an irrigation network at the tertiary level and the water users' satisfaction with the system and their ability to manage it. Pusposutardjo et al. (1985) reported that in three newly rehabilitated irrigation schemes the farmers were not able to manage the tertiary network because they did not know the technical functions or purpose of some of the structures. Based on the above hypothesis, the causes of damage to irrigation structures were categorized.

Damages to irrigation structures were categorized as: 1) damages caused by natural forces such as landslides and floods; 2) damages due to improper design and construction, often indicated by unused structures; 3) damages resulting from improper operation and poor maintenance; or 4) damages caused by the farmers. The second classification relates to an irrigation network that does not meet the needs of the water users. The last two categories are related to either the dissatisfaction of the water users with the performance of the irrigation facility or their inability to manage the network. The last three classifications interact, e.g., farmers may destroy a structure that was not designed to meet their needs or ceased to be of use. Improper design and construction are often found in tertiary networks that were developed by government agencies.

In the field, a structure was considered damaged when it could not perform its functions without any measure of improvement. The degree of the damage observed was not classified, although the degrees were different.

It was often difficult to distinguish the exact cause of the damage observed because of the interaction among the different causes. When a structure did not perform well the farmers tended to neglect it. Moreover, the farmers might try to modify the structure to get it to perform according to their needs or they might destroy it because it was of little or no use to them. As a result, the damaged structure appeared to be poorly maintained, improperly operated, and destroyed. This research categorized the cause of damage according to the suspected primary cause.

RESULTS AND DISCUSSION

The Effects of Tertiary Rehabilitation on Irrigation-Network Patterns

Significant changes in the tertiary network patterns occurred after rehabilitation (Tables 1 and 2). The number of tertiary structures and the total canal length in the tertiary blocks increased as did the structure density and canal density. However, the function of the division structures became simpler because the number of canal segments to be fed decreased. Therefore, after rehabilitation, water distribution in a tertiary block tended to change from plot-to-plot distribution to distribution from canals, reducing the interdependence between adjacent plots.

The tertiary networks in Keyang Bawah and Andong were designed according to the farmers' preferences. This indicates that the farmers preferred to receive water from a canal with simpler

Table 1. General description of tertiary block samples.

Sample descriptor	Irrigation schemes					
	Keyang Bawah		Andong		van der Wijk	Sorogenen
	a	b	a	b		
No. of tertiary samples	5	5	4	4	3	5
Area of tertiary blocks (ha)						
average	25	25	212	212	74	13
maximum	50	50	265	265	85	22
minimum	14	14	176	176	60	3
No. of canal segments per block						
average	5	11	53	92	11	3
maximum	12	17	75	91	13	4
minimum	3	7	20	60	8	2
No. of division boxes per block						
average	2	5	23	3	5	1
maximum	5	8	36	39	6	1
minimum	1	3	9	26	3	0
Total length of canal per block (m)						
average	1,278	1,580	4,681	15,563	5,295	1,101
maximum	3,165	2,200	9,000	23,500	7,229	1,877
minimum	660	800	1,750	10,900	3,473	459
No. of tertiary intakes per block						
average	1	1	2	2	1	1
maximum	1	1	4	4	1	1
minimum	1	1	1	1	1	1
Procedure of tertiary development	Govt	FPart	Govt	Frmrs	Govt	Govt

Notes:
a = before rehabilitation
b = after rehabilitation
Govt = development conducted by the government
FPart = development using farmer participation
Frmrs = development by the farmers

Table 2. Parameters of network patterns for tertiary block samples.

Parameters of network patterns	Irrigation schemes					
	Keyang	Bawah	Andong		van der Wijk	Sorogenen
	a	b	a	b		
U- Index						
average	4	4	29	41	7	3
maximum	5	6	40	53	8	4
minimum	4	3	12	34	6	3
ß Ratio						
average	2.5	2.3	2.1	2.2	2.3	3.5
maximum	3.0	2.5	2.3	2.4	2.6	4.0
minimum	2.2	2.2	2.1	2.0	2.2	0
μ Ratio (m/unit)						
average	398	178	102	213	667	379
maximum	633	367	154	258	695	469
minimum	133	118	24	173	648	230
Ω Ratio (m/unit)						
average	662	342	217	477	379	1,583
maximum	992	550	50	603	469	1,877
minimum	330	200	342	395	230	0
Canal density (m/ha)						
average	45	71	26	82	90	113
maximum	91	93	42	109	117	185
minimum	18	41	7	66	49	73
Structure density (unit/ha)						
average	0.12	0.33	0.07	0.13	0.65	0.43
maximum	0.20	0.42	0.07	0.20	1.00	0.91
minimum	0.04	0.15	0.05	0.09	0.15	0.09

water division in the tertiary block rather than use plot-to-plot distribution where the control of water division was more difficult. As the interdependence between adjacent plots for water supply decreased the farmers were more able to control the water supply according to their needs.

Relationship between the Causes of Damage to the Tertiary Networks and the Values of Kansky's Parameters

Three parameters of Kansky's, ß ratio, u ratio, and Ω ratio, were adopted to test the relationship between the causes of damage to tertiary networks and the characteristics of the network pattern. The U-index was not used because it did not show a significant value for distinguishing differences among the characteristics of the tertiary network pattern in the research sample.

Kansky's parameters were applied to test the relationship between the characteristics of the tertiary network and the causes of the damages. Statistically, all tests showed that the different classes of tertiary network parameters were related to the different causes of damages at the 95 percent level of significance. Results from the test also confirmed the hypothesis that the most preferable tertiary network (as characterized by Kansky's parameters) would have the least damage (Table 3).

Table 3. Damages observed in the tertiary network samples as classified according to the primary cause of the damage.

A. Parameter: ß ratio = (no. of canal segments/division boxes)

	No. of samples	Value of ß ratio	Causes of damages observed					
			DF	O&M	D&C	Nat	Total	Percent
	6	<2.20	25	23	9	17	74	29
	5	2.21-2.50	8	15	0	1	24	10
	5	>2.50	68	54	18	16	156	61
Total	16		101	92	27	34	254	100
Percent			40	36	11	13	100	
Chi square		17.30						

B. Parameter: µ ratio = (canal length in block/no. of canal segments)

	No. of samples	Value of µ ratio	Causes of damages observed					
			DF	O&M	D&C	Nat	Total	Percent
	5	<250	16	14	0	10	40	16
	6	250-500	14	24	5	10	53	21
	5	>500	71	54	22	14	161	63
Total	16		101	92	27	34	254	100
Chi square		18.26						

Table 3 (Continued)

C. Parameter: Ω ratio = (canal length in block/division boxes)

	No. of samples	Value of Ω ratio	Causes of damages observed					
			DF	O&M	D&C	Nat	Total	Percent
	6	<500	20	14	0	12	46	18
	6	500-1000	25	27	8	8	63	27
	4	>1000	56	51	19	14	140	55
Total	16		101	92	27	34	254	100
Chi square		13.96						

Notes: DF = destroyed by farmers
O&M = operation and maintenance
D&C = improper design and construction
Nat = damaged by natural causes

Table 3 shows that destruction by farmers and improper operation and maintenance are the two main causes of tertiary network damages. Further analysis (Table 4) indicates that 172 out of 254 cases of the damages to tertiary networks were damags to the canal from: 1) illegal offtakes (91 cases or 52 percent), 2) poor canal maintenance (46 cases or 27 percent), 3) improper design and construction (19 cases or 11 percent), and 4) damage due to natural causes (16 cases or 9 percent).

Table 4 also indicates that water measuring devices, especially the Romiyn and Cipoletti weirs, have not yet been accepted by farmers.

Table 4. Distribution of damages to tertiary network structures in the block samples.

Tertiary structure	Total	Damaged	DF	O&M	D&C	Nat	Percent of damage
Tertiary offtake	16	6	1	3	0	2	38
Water measuring devices							
Romiyn type	4	4	3	1	0	0	100
Cipoletti	1	1	1	0	0	0	100
Others	12	8	1	4	0	3	75
Quaternary division box	40	23	4	8	4	7	58
Road crossings	40	33	0	28	1	4	83
Elevated flumes	2	0	0	0	0	0	0
Others	14	7	0	2	3	2	50
Total	129	82	10	46	8	18	

Relationship between the Causes of Tertiary Network Damages and the Values of Canal Density and Structure Density

Using a similar procedure of analysis on Kansky's parameters, canal density and structure density were classified according to their values in the networks designed by farmers. The Asian Development Bank claimed that a canal density of 62 meters (m) per ha would be sufficient to achieve good water management in tertiary blocks (Anonymous 1988). Therefore, the canal density of 50-100 m/ha used in the hypothesis is a reasonable value.

Results of the analysis (Table 5) indicate that tertiary networks with a canal density of 50-100 m/ha and structure density of 0.1-0.4 unit/ha (1-4 structures per ha) were observed to have been damaged the least. The differences between the incidence of damage and canal density, and the incidence of damage and structure density were significant at the 95 percent level. Therefore, it can be concluded that both canal density and structure density can be used as reliable parameters, similar to Kansky's parameters.

Table 5. Number of damages in tertiary network samples classified according to cause of the damage.

A. Parameter: Canal density (m/ha)

	No. of samples	Value of canal density	Causes of damages observed					
			DF	O&M	D&C	Nat	Total	Percent
	7	<50	46	31	8	21	106	42
	5	50-100	16	20	0	2	38	15
	4	>100	39	41	19	11	110	43
Total	16		101	92	27	34	254	100
Percent			40	36	11	13	100	
Chi square		20.40						

B. Parameter: Structure density (unit/ha)

	No. of samples	Value of density	Causes of damages observed					
			DF	O&M	D&C	Nat	Total	Percent
	7	<0.11	27	22	9	21	79	31
	5	0.11-0.40	24	23	4	4	55	22
	4	>0.40	50	47	14	9	120	47
Total	16		101	92	27	34	254	100
Chi square		18.89						

Notes: DF = destroyed by farmers
O&M = operation and maintenance
D&C = improper design and construction
Nat = damaged by natural causes

Characteristics of the Most Preferable Tertiary Network Pattern

Summarizing the results from the analysis of Tables 3, 4, and 5, the most preferable tertiary network pattern should have the following characteristics:

1. Canal density between 50-100 m/ha.
2. Structure density between 0.1-0.4 units/ha, or 1-4 structures per ha. Road crossings create maintenance problems. Therefore, it is recommended that the number of road crossings be kept to a minimum.
3. Each quaternary division box serving only 2-3 canal segments (ratio = 2.21-2.50) with only 2-4 division boxes per ha.
4. The optimum length for lower-level canal segments ranging from 250 to 500 m. Shorter canal segments are technically possible but may reduce the cropping area and increase the number of canal segments that have to be fed per division box.
5. The optimum length of a distribution canal served by one division box between 500-1,000 m.

   The results of the research indicate the possibility for improving irrigation-management performance through improvement in the tertiary network pattern. Also, within the parameters given above, an irrigation network can be simplified.

CONCLUSIONS

The pattern of a tertiary network of an irrigation system can be characterized using Kansky's network parameters of β ratio, μ ratio, and Ω ratio. Canal density and structural density parameters are also reliable for this purpose, keeping in mind that the value of structure density sometimes does not represent the actual irrigation requirements because some structures such as road crossings are related to functions other than irrigation.

Based on their accumulated experience, farmers have the ability to design tertiary networks suitable to their needs as demonstrated by the value of the parameters of the farmer-designed networks in Keyang Bawah and Andong irrigation systems. In order to obtain the most preferable design for a tertiary network, the farmers' experiences related to water management at a particular site need to be considered in the irrigation design, especially for layout of the network. However, technical assistance is still needed for drawing and designing special structures such as siphons, elevated flumes, and water-measuring devices.

An additional observation related to the irrigation-development approach used for rehabilitation is that the existing design standards for tertiary networks as prescribed by the government must be revised to allow the flexibility necessary when the water users are partners or leaders in the rehabilitation effort.

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