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Determining water flow efficiencies at Kah Pulo Geto primary irrigation channels, Bengkulu, Indonesia

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Abstract Unproperly functions from the irrigation channels and networks cause inefficiently water distribution to supply rice fields for the paddy growth demand. The results showed that the water loss from the primary canal with whole channel length of 800 m at Kah Pulo Geto Bengkulu around 13.76% and at the same time the water efficiency in this channel amounted to 86.24%, slightly below the theoretical efficiency limit value, 90%. From 10 primary canals, 7 canals conveyed water inefficient to next channel networks. The water loss resulting inefficiency water supplies in the irrigation canals were caused by seepage, 1.351 x 10^{-4} m day^{-1} while the water loss through evaporation was about 0.0207 mm sec^{-1}. Cracks and concrete damage occurrences causes the water seepage in the irrigation channel because of lack of maintenance.

Keywords: Primary irrigation channels, Seepage, Soil cracks, Water efficiencies

Introduction

Water scarcity and the increasing global demand for water in many sectors, including agriculture, has become a global concern. Today, water availability for agriculture continues to decline due to socioeconomic demands and climate change. The rapid growing world population and the adverse impacts of climate change led to growing competition for water use by industrial and urban users for agriculture to secure enough food. Around 70% of all freshwater withdrawals mostly through irrigation channel were used for food production in agriculture. Unfortunately, many scientists stated irrigation for agricultural cultivation has long been considered to be wasteful because of the unnecessary high amount of water loss. Water loss is considered one of the most important problems of water irrigation infrastructures and a huge amount of water is lost from earth canals during transportation and distribution, hence, it is necessary to tackle the problem of inefficient water use because of the water losses in irrigation canals and search for modern sustainable solutions (Abuzeid, 2021). The primary cause of the

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inefficiency in irrigation systems was the capacity of the irrigation channel to distribute water degraded leading to large water loss during distribution to irrigated areas (Akhavan *et al*., 2022). Many irrigation structures under improper operation led to huge water loss during delivery causing significant water distribution unbalance (Tandiono *et al*., 2024). Earthen irrigation structures experience significant water losses, including through seepage, evaporation, and evapotranspiration, which significantly reduce water supplies (Ashour *et al*., 2023). Water loss from the earthen irrigation causing inefficient water supplies was affected by several factors such as cracks, percolation, seepage and physical damages of the canals (Sen *et al*., 2018). Furthermore, the water losses through the earthen irrigation structures while conveying it from the source to the fields in irrigation channels could waste up between 30% and 50% of the total volume of water transported from the whole level of canals. The water loss from the primary canals was lower than secondary and in secondary canals was lower than the tertiary canals (Mohammadi *et al*., 2019). It is well recognized that irrigation water application efficiency is relatively higher in the primary channels than in the secondary canals and the tertiary ones in fact the water loss during the water flowing at many primary channels for watering agricultural areas were much below the theoretical efficiency limit value, 90%.Many studies have evaluated the effect of water loss in the irrigation for rice cultivation related to the irrigation efficiency during the irrigation water conveyed. In Indonesia, the overall irrigation efficiency is generally used at 65% determined based on distributed and conveyance efficiency in main, secondary, and tertiary channels namely 90%, 90%, and 80%, respectively (Rizalihadi *et al*., 2022). A study at Cubo irrigation in Pidie Jaya District, Indonesia to observe the efficiency of primary and secondary channels resulted the efficiency of the primary channel was 59.41%, the efficiency of the secondary channel was 56.04% with the average channel efficiency is 57.73 % (Akmal *et al*., 2019). Also, the other study in Aceh, at Krueng Baro irrigation scheme, a rice field area about 11.950 Ha, divided into Baro Kanan irrigation (8,920 Ha) and Baro Kiri irrigation (3.030 Ha) reported that the distribution efficiency of the Baro Kiri primary channel was 74,1% and the Baro Kanan was 86,8% (Yanita *et al*., 2020). Another study in Bissua irrigation, South Sulawesi showed the water losses and efficiency from the secondary channels range from 1.2 to 4.7 x10-4 m^3 sec^{-1} m^{-1} and 40 to 90%, respectively (Achmad *et al*., 2021). Therefore, based on some studies in Indonesia, the water supplies during flowing in the irrigation channels for agricultural food production lost in high amount in all channel schemes; the main-, secondary, and tertiary channels. Furthermore, the physical condition of the channel was the main factor of water losses through seepage.

Looking at current and future trends of agriculture food production in Indonesia especially in Bengkulu Province, it is clear that water irrigation efficiencies are essential to be evaluated to meet the effort in reaching food self-sufficiency and food security. When reviewing the current circumstance of the irrigation channels in Bengkulu, many irrigated agricultural lands were previously as rice fields today changing the land functions as industrial perennial crops and intensive fish ponds. The water supplies limited to food cropping lands because of water loss in high amounts during water conveyances in all channel levels triggered the land use changes to other functions. Therefore, an evaluation of the efficiencies of the channel levels from some irrigation channels in Bengkulu Province is needed. The study was focused on the primary canal at Kah Pulo Geto irrigation area.

Materials and methods

The research locations were in the Kah Pulo Geto irrigation areas, Kepahiang District, Bengkulu Province covering 380 ha. Geographically, this area is located at 03^0 30’ 35” alt. and 102^0 32’ 12” long with altitude about 700 m above sea level. Good climatic conditions and landscapes covering the irrigated rice fields favour for intensively rice farming systems. Rainfall average 233.5 mm $month^{-1}$ with number rain day of 23.2 days $month^{-1}$ in 9 months of wet season and number rain day of 14.6 days $month^{-1}$ in 3 months of dry season. Maximum temperatures at 29.87°C and minimum temperatures at 19.65°C and the average daily temperature at 23.87 °C with relative humidity in around 85.21% (Mawaddah *et al*., 2020).

The study focused on water irrigation efficiency based on water input and water output at 8 primary channels having 800 m length. Several data were needed for analysis the efficiency of the irrigation channels involving primary and secondary data. The primary data were in the form of measurement on the dimensions of channel appearance and water flow velocities at each primary channel while the secondary data were irrigation network maps taken from the Public Work Department of Bengkulu Province and last rainfall data from the closed climatology station for the study area taken from Meteorology and Geophysics Agency (BMKG) in Bengkulu.

Generally, the water irrigation efficiency is based on the water input and output principle drawn in Figure 1.

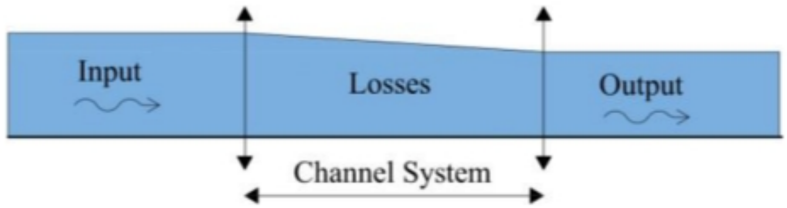

Figure 1. Water loss based on input and output principle (Murtaqi *et al*., 2023)

The water flow velocities at the upstream and downstream channels at each channel schemes using a portable Current Meter, F.1 Propeller type with Pitch of 0.25 m then calculated the water input- or the water output volume at the channels followed a formula:

$$Q = A \times V$$

Q = water discharge ($m^3\ sec^{-1}$), V = flow velocity ($m\ sec^{-1}$), A = cross sectional area of the channel (m^2). The water loss from the channels were determined through water inflow volume reduced by water outflow volume:

$$Q = Q_{in} - Q_{out}$$

which Q = the water loss ($m^3\ sec^{-1}$), Q in = water inflow volume ($m^3\ sec^{-1}$), Q out = water outflow volume ($m^3\ sec^{-1}$). Due to many factors causing the water loss from the irrigation channels, only evaporation and seepage as physical factors affected the water loss was studied.

The evaporation value was calculated for its value over the entire length of each channel. Secondary evaporation data measured by an evaporimeter pan collected from BMKG was converted to the evaporation value through formula as follow:

$$E = k \times Ep$$

Which E = evaporation from water body ($mm\ day^{-1}$), k = pan coefficient, (0,8), Ep = evaporation from pan ($mm\ day^{-1}$). Then, to calculate the evaporation from each canal surface used a equation:

$$E_{loss} = E \times A$$

Which E_{loss} = water loss because of evaporation ($mm^3\ day^{-1}$), A = channel surface wide (m^2), E = evaporation from water body ($mm\ day^{-1}$).

Water loss due to seepage in irrigation channels is a serious problem in water use efficiency for agricultural activities therefore estimated water loss through seepage along the irrigation canal needs to be calculated. The formula estimated seepage as follow:

$$q = kr \times (B - 2h)$$

which q = seepage ($mm\ day^{-1}$), kr = seepage coefficient with value of 6.8×10^{-7} $cm\ sec^{-1}$, B = water surface width (m), h = water depth (m).

Furthermore, the water irrigation channel efficiency at each measurement section was calculated as:

$$Ec = (Q_{out}/Q_{in}) \times 100\%$$

Ec = water irrigation channel efficiency (%), Q_{out} = actual discharge, water out flow volume ($m^3\ sec^{-1}$), Q_{in} = theoretical discharge, water inflow volume ($m^3\ sec^{-1}$). The research flow chart is revealed in Figure 2.

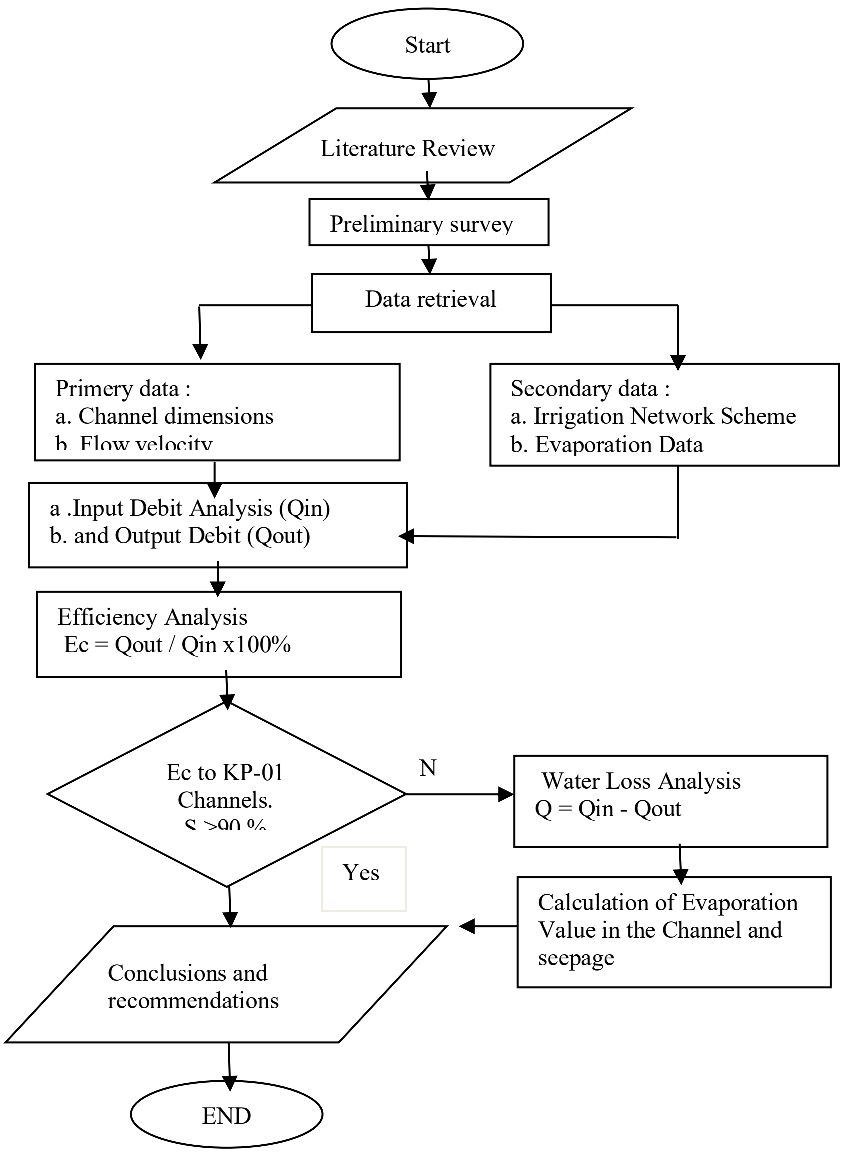

Figure 2. Research flowchart

Results

Water flow velocity and discharge

Water flow velocities and discharges from 10 sections of the primary canals of the Kah Pulo Geto irrigation structure showed values in high differences. The detailed values of water flow velocities and discharges at all sections could be seen in Table 1.

Table 1. Discharges at 10 primary channels, Kah Pulo Geto irrigation structure

Canals code	Cross sectional area (m^2)		Flow velocity ($m\ sec^{-1}$)		Discharge ($m^3\ sec^{-1}$)	
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
BK0	1.610	1.540	0.411	0.387	0.662	0.595
BK1	0.938	0.980	0.603	0.536	0.565	0.525
BK2	0.630	0.630	0.823	0.706	0.519	0.445
BK3	0.600	0.600	0.678	0.530	0.407	0.318
BK4	0.720	0.668	0.411	0.371	0.296	0.248
BK5	0.420	0.420	0.576	0.472	0.242	0.198
BK6	0.315	0.315	0.586	0.519	0.185	0.164
BK7	0.820	0.800	0.187	0.173	0.153	0.138
BK8	0.345	0.483	0.388	0.257	0.134	0.124
BK9	0.270	0.218	0.573	0.555	0.155	0.121

The widest vertical cross-sectional area of all irrigation channels at the Kah Pulo Geto irrigation facilities was BK0 canal as consequence the water supply at the upstream canal and the water discharge at BK0 was also the highest volume.

Evaporation and seepage

Water losses in the channels were presumed affected mainly by evaporation and seepage. The water losses because of the evaporation determined by the evaporation pan with the pan coefficient value, 0.8 and monthly evaporation reference at the same study period, 3.1 mm day^{-1} released by Meteorology and Geophysical Agency, Bengkulu are shown in Table 2. The highest evaporation value was found at BK0 canal with volume 2.076 x 10^{-5} m^3 sec-1 while the lowest one at BK6, 1.575 x 10^{-6} m^3 sec^{-1}, and with the average evaporation value, 6.935 x 10^{-5} m^3 sec^{-1}.

Seepage losses reduce the quantity of irrigation water, extend the irrigation time, and reduce the irrigation efficiency. Seepage causing water loss on the irrigation channels was determined by water surface width (B) and water depth

(h) then the water loss because of seepage should be corrected with coefficient value of 6.8 x 10^{-7} cm sec^{-1}.

Table 2. Evaporation at 10 primary channels, Kah Pulo Geto irrigation structure

Canals code	Canal dimension			Evaporation	
	Wide (m)	Length (m)	Surface area (m^2)	(m3 day^{-1})	(m3 sec^{-1})
BK0	3.70	202	747,2	1.794	2.076E-05
BK1	1.40	84	117,6	0.282	3.267E-06
BK2	2.50	53	132,5	0.318	3.681E-06
BK3	2.60	49	127,4	0.306	3.539E-06
BK4	2.60	56	145,6	0.349	4.044E-06
BK5	1.05	159	166,95	0.401	4.638E-06
BK6	1.05	54	56,7	0.136	1.575E-06
BK7	2.85	62	176,7	0.424	4.908E-06
BK8	2.05	44	90,2	0.216	2.506E-06
BK9	1.75	37	64,75	0.155	1.7986E-06

Based on the previous formula, the water losses from the channels due to seepage are shown in Table 3.

Table 3. Seepage at 10 primary channels, Kah Pulo Geto irrigation structure

Canal code	B (m)	h (m)	Seepage (m day^{-1})
BK0	3.6	0.7	1.351 x 10^{-4}
BK1	1.4	0.6	1.175 x 10^{-5}
BK2	2.5	0.35	1.058 x 10^{-4}
BK3	2.6	0.3	1.175 x 10^{-4}
BK4	2.6	0.4	1.058 x 10^{-4}
BK5	1.05	0.4	1.469 x 10^{-5}
BK6	1.05	0.3	2.644 x 10^{-5}
BK7	2.85	0.4	1.204 x 10^{-5}
BK8	2.05	0.3	8.519 x 10^{-5}
BK9	1.75	0.2	7.931 x 10^{-5}

The highest water loss through seepage was found at BK0 with value of 1,351 x 10^{-4} m day^{-1} with the average seepage value from all canals around 6.936 x 10^{-5} m day^{-1}. One of the primary canal conditions could be seen in Figure 2.

Water loss and efficiency

Water loss is considered one of the most important problems of water infrastructures. Based on the differences between the water discharge at the upstream (Q_{in}) and downstream (Q_{out}) canals, the water losses and efficiency during flowing at the Kah Pulo Geto primary canals could be seen in Table 4.

Figure 2. Canal condition at the Kah Pulo Geto irrigation

Table 4. Water loss and efficiency at 10 primary channels, Kah Pulo Geto irrigation structure

Canal code	Water loss (m^3 sec^{-1})	Water loss (%)	Efficiency (%)
BK0	0.067	10.11	89.89
BK1	0.040	7.07	92.93
BK2	0.074	14.24	85.76
BK3	0.088	21.74	78.26
BK4	0.048	16.24	83.76
BK5	0.044	18.03	81.97
BK6	0.021	11.37	88.63
BK7	0.015	9.74	90.26
BK8	0.009	7.07	92.93
BK9	0.034	21.98	78.02

The highest water loss from the Kah Pulo Geto primary canal was at BK3 with value of 0.088 m^3 sec^{-1} (Table 4). The average water loss from all primary canals in this irrigation area was about 13,759%. The highest water efficiency at the primary canal in this irrigation area was shown at BK8 with percentage value of 92.933% while the lowest efficiency was found at BK9 with value of 78.019%. Comparing to theoretical water irrigation canal efficiency, ≥ 90%, there were 3 canals involved in the efficiency criteria such as BK1, BK7, and BK9 while BK0 a little closed to the efficiency criteria.

Discussion

Canals continue to be major conveyance systems for delivering water for irrigation in the agricultural cultivation systems however the water loss from irrigation canals constitutes a substantial percentage of the usable water (Swamee *et al*., 2010). From the 10 primary canals in this study, there were 7 canals that receive sufficient water flow but lose a lot of water along the flow to the end of the primary canals such as BK0, BK2, BK3, BK4, BK5, BK6 and BK9, and only 3 canals such as BK1, BK7 and BK8 were efficient enough in delivering water flow to secondary channels which then flow to tertiary channels which ultimately flow to agricultural land activities. In this case, the water lost from the primary canals due to seepage was much higher than the water lost because of evaporation. The water loss in irrigation canals mainly is due to seepage (Eltarabily *et al*., 2023). Furthermore, the water seepage could be severe if the soil through which the canal passes is porous and the canal is unlined. A large part of the water was lost during its travel through the canal system mainly due to seepage (Shah *et al*., 2020). Seepage is the most serious cause of water losses and reducing canals conveyance efficiency (Samir *et al*., 2023).

The amount of water loss due to evaporation at the open surface should be properly quantified (Nguyen *et al*., 2020). Accurate quantification of water loss from irrigation canals due to evaporation was significantly important for developing sustainable strategies of water resource management, particularly in arid regions with limited water resources (Wang *et al*., 2019). In fact, this study conducted at tropical region with high rainfall, the water conveyance loss because of evaporation on the study area with the highest value found at BK0 with value of 0,0000207 m^3 sec^{-1} or 0.0207 mm sec^{-1}, and the loss of water through this natural phenomenon was considered very small. Evaporation loss in irrigation networks was generally not taken into consideration (Omar *et al*., 2019). Typically, the losses due to evaporation are considerably less significant than the other two types; seepage and operational losses. As a result, the main losses associated with agricultural water distribution systems were considered to be seepage and operational losses (Avargani *et al*., 2023). Therefore, considering minimising irrigation losses through evaporation, it may be equal as or better making optimal use of existing soil water and maximising rainfall effectiveness (Carter *et al*., 1999).

Paddy farming activities in the Kah Pulo Geto irrigation area have been cultivated intensively because this area is located in the medium altitude with high rainy climatic zone in Bengkulu therefore at three decades before the Public Work Department built this agricultural paddy area with concrete irrigation canal facilities. As time goes by, the irrigation network facilities at Kah Pulo Geto are not maintained properly so that the condition of the irrigation canal network is getting more and more damaged and the water flowing in the canal is experiencing leaks, causing a decrease in the efficiency of transporting water entering the canal upstream to the downstream of the irrigation canal. In other word, many cracks were found in this irrigation canal due to lack of maintenance as shown in Figure 2. Seepage losses include a significant portion of losses due to earthen canal systems or systems with poor lining and cracked concrete. The presence of cracks in the channel concrete is the main cause of water loss in irrigation channels through leaks (Qian *et al*., 2012). The main factor affecting canal seepage was the channel damage conditions (Han *et al*., 2021). Thus, It is important to prevent or to control canal seepage loss for improving water resource utilization efficiency.

Some irrigation network in Indonesia showed inefficiencies supplied water due to poor operation and maintenance of the irrigation channels and network (Wardi *et al*., 2024). Almost half of the whole irrigation infrastructures in Indonesia were moderately to heavily damaged causing the irrigation facilities in poor operational performance (Tirtalistyani *et al*., 2022). The low level of efficiency in irrigation canals was caused by the age factor of the canals therefore regular and periodic maintenance of irrigation and drainage channels needed to be done to keep the canals in good condition (Hakim *et al*., 2022). The maintenance of the irrigation channels and network were ones of some important operations that help in raising the efficiency of irrigation because with periodic maintenance of primary irrigation channels to ensure that they worked with high efficiency in order to avoid water loss during operation (Mansour *et al*., 2022).

In short, 7 irrigation primary canals of whole 10 ones at the Kah Pulo Geto irrigation area Bengkulu were under inefficiency flowing water mainly because of cracks or concrete construction damage. The cracks in concrete-constructed irrigation channels could allow water leaking through the channels into the soil, especially in soils with high porosity and permeability. Concerning on efforts to maintain rice production in high yield at the Kah Pulo Geto irrigation area, rehabilitation and maintenance of all canals schemes and canal networks followed by improving water use management working together with water-using farmer groups must be carried out immediately. If these irrigation channels are not continuously repaired and maintained, there would be a chance that the land could be converted to other agricultural commodities or even converted to the non-agricultural sector.

Conflicts of interest

The authors declare no conflict of interest.

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