The analysis of water loses in the secondary channels of Bissua irrigation

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Abstract. This research aims to analyze the correlation between water efficiency, water losses, and channel density in the secondary channels of Bissua irrigation and figure them spatially. Channel was sampled purposively for different dense of a channel in the area based on irrigation channel map. The water inflow and outflow were measured in the selected segmented channels. Discharges, evaporation, and seepage data were used to determine water losses and their efficiencies. Spatial mapping was processed using ArcGIS 10.4 to figure the location of channels with their value of efficiencies and losses. The result shows that losses and efficiency range from 1.2 to 4.7 x10^-4 m^3/s/m and 40 to 90%, respectively. The variation of channel density from 0.03 to 0.25 km/km^2 found a negative exponential correlation between water efficiency, water losses, and channel density. In addition, water losses also have a positive correlation to the width of channels.

1. Introduction
Water is the most important requirement for agricultural crop production. Water application is essential for growing plants because it supplies moisture essential for seed germination and other physiological processes during plant growth, washes out or dilutes salts in the soil, enables efficient fertilizers, and prevents water deficit.

To provide efficient use of water resources, conservation techniques should be applied at all stages of the irrigation system, from the storage reservoir to field application. Two of the most important ways to increase the efficiency of water diverted for irrigation are by introducing reforms in irrigation districts' operation and using good agronomic techniques, including water-conserving crop varieties.

The conveyance and distribution systems consist of canals transporting the water through the whole irrigation system. Canal structures are required for the control and measurement of the water flow. An open canal, channel, or ditch, is an open waterway whose purpose is to carry water from one place to another. Channels and canals refer to main waterways supplying water to one or more farms. Field ditches have smaller dimensions and convey water from the farm entrance to the irrigated fields [1].

Water losses are one factor that determines efficiency through conveying water in irrigation schemes. Water conveying efficiency is used to evaluate the effectiveness of the watering system in the irrigation area. Losses during conveying can be caused by surface water evaporation, percolation,
unlawful exploitation by pumping, and seepage. Seepage in Bissua was caused by the physical condition of its 33 secondary canals along 115,464 m in 10,758 ha [2].

Water losses occur during flowing water from the primary canal to the rice field. It was predicted that a third to a quarter of water is a deficit. Efficiency and losses have best-fit correlations. The amount of water losses have a negative correlation to the level of efficiencies. The different water volume between allocated or flow in and water used or flow out is called water efficiency [3,4,5]. Mapping water losses of the secondary canal in irrigation schemes caused by seepage, canal condition, and evaporation is beneficial to operate and maintain irrigation facilities and minimize water losses or increase the water conveying efficiency at secondary canals in particular.

2. Methods

2.1. Location and secondary data

This study was conducted in the Bissua irrigation scheme. The location is situated in the boundary of two regencies: Gowa and Takalar regencies, about 21.5 km to the south of Makassar City. Bissua dam, as a water source of irrigation geographically, is located at 5°18′14″ S and 119°31′59″ E at Jenneberang river. Data related to the irrigation scheme was collected from the Jenneberang River Basin Board, including a map of the irrigation scheme, the physical condition of the secondary irrigation channel, and daily evaporation [2]. The situation of the Irrigation is presented in figure 1.
2.2. Field data
Primary data was collected from the field during February-March 2020 using the purposive sampling method to select the appropriate location to measure discharge properly. Five secondary channels with 16 nodes/segments were chosen to measure the inlet and outlet velocity using current meter type FL-01. The dimensions of the channel were measured using stuff-gage to calculate the cross-section of the channel. Discharges as inflow and outflow have been determined by multiplying the velocity and the cross-section of the channel. Water losses are defined as the difference of inflow and outflow at each selected node. The losses are then categorized into seepage and evaporation. Seepage was determined using a monograph based on the channel width and physical condition of the channel [6,7].

Water conveying efficiency, \( Ef \), is the ratio of the quantity of water flow in a node (inflow) and the quantity of water flow out a node (outflow). Good secondary channels have the efficiency of conveying water about 80-90% [8,9]. The efficiency is determined using equation 1.

\[
Ef = \frac{Q_{in}}{Q_{out}} \times 100\% 
\]  

Where:
- \( Ef \) is water conveyance efficiency, %
- \( Q_{in} \) is water flow in a node at a section (m\(^3\)/s), and
- \( Q_{out} \) is water flow out a node at a section (m\(^3\)/s)

Drainage density or channel irrigation density as the length of the channel for a certain area is calculated using the following equation:

\[
Dc = \frac{ln}{A} 
\]  

Where:
- \( Dc \) is channel density (km/km\(^2\)),
- \( Ln \) is the total length of the secondary channel (km), and
- \( A \) is a covered area of the secondary channel (km\(^2\)).

2.3. Analysis and mapping
The primary and secondary data were calculated to determine all nodes/sections of selected secondary channels. The correlation analyses between the three parameters, density, efficiency, and water losses, were done in a spreadsheet using Microsoft Excel. The density, efficiency, and water losses data were plotted in the irrigation scheme map to describe the situation of the secondary channel spatially using ArcGIS software version 10.4.

3. Results and discussion
3.1. Discharges
Bissua Irrigation Scheme irrigates a 10,758 ha rice field with 17,304 m length of the primary channel, 115,464 m length of the secondary channel. There were measure the discharges of 16 sections of five secondary channels (SC), which are Lauwa, Dingau, Mallewang, Kaci-kaci and Bilacaddi channels. The highest discharge was at Dingu and following by Lauwa channel. Both secondary channels were flowed at maximum discharge (gate opened maximumly) during measurement, while other channels in the position of low discharge. The detailed value of discharge measurement at all sections can be seen in table 1.
Table 1. Discharges at all sections secondary channel of Bissua Irrigation Scheme.

| Channel's Name | Sections       | Discharge (m³/s) |
|----------------|----------------|------------------|
| Lauwa          | BMA 2 – BLW 1  | 0.3052           |
|                | BLW 1 - BLW 2  | 0.3501           |
|                | BLW 2 - BLW 3  | 0.0987           |
|                | BLW 3 - BLW 4  | 0.0591           |
|                | BLW 4 - BLW 5  | 0.0300           |
| Dingau         | BMA7-BDG1      | 0.4776           |
|                | BDG1-BDG2      | 0.4565           |
|                | BDG2-BDG3      | 0.4710           |
|                | BDG3-BDG4      | 0.4684           |
| Mallewang      | BPL 2- BML 1   | 0.0513           |
|                | BML 1-BML 2    | 0.0561           |
| Kaci-Kaci      | BPL 7- BKC 1   | 0.0427           |
|                | BKC 1-BKC 2    | 0.0475           |
| Bila Caddi     | BPL 7- BBC 1   | 0.0781           |
|                | BBC 1-BBC2     | 0.0600           |
|                | BBC 2-BBC3     | 0.0141           |

3.2. Water losses
Water losses in the channels were presumed affected mainly by evaporation and seepage. The highest value of water loss was about $4.7 \times 10^{-4}$ m³/s/m length of the channel at Dingau secondary channel, while the lowest value of water loss was about $1.2 \times 10^{-4}$ m³/s/m length of the channel at Bilacaddi secondary channel. Losses were caused mainly by seepage, evaporation, or inappropriate water from the channel without permission from the irrigation authority. The physical condition of the channel was the main factor of water losses through seepage. Water losses at all sections are provided in Table 2.

Table 2. Water losses and efficiency of secondary channels at Bissua irrigation area.

| No | Secondary Channel | Efficiency (%) | Water losses (x $10^{-4}$ m³/s/m) |
|----|------------------|----------------|-----------------------------------|
| 1  | Lauwa            | 75.36          | 4.100                             |
| 2  | Dingau           | 89.47          | 4.700                             |
| 3  | Mallewang        | 39.99          | 1.800                             |
| 4  | Kaci-kaci        | 49.70          | 1.500                             |
| 5  | Bila Caddi       | 49.36          | 1.200                             |

3.3. The efficiency of conveying water
Even the Dingau channel flowed at the maximum level. It has had the highest efficiency value at about 89% due to the good condition of the physical lining. On the other side, the lowest value of efficiency was in Mallewang channel at around 40% because of the bad condition of lining along the channel. The detail value of efficiency of conveyance for all sections is shown in table 2.

3.4. Channel density
Bissua irrigation has a medium-class dense of channels (0.25-10 km/km^2). The density of the channel in the upper, middle and lower of irrigation area were 0.78, 0.71 and 0.63 km/km^2, respectively. Densities of secondary channels were classified as low dense, ranging from 0.03 km/km^2 at Lauwa and Dingau to 0.25 km/km^2 at the Kaci-kaci channel. Table 3 provides a summary of the density of five secondary channels.

| Secondary Channels | Length of the channel (km) | Covered Area (km^2) | Density of channel (km/km^2) |
|--------------------|----------------------------|---------------------|-----------------------------|
| Lauwa              | 2.90                       | 109.87              | 0.03                        |
| Dingau             | 2.42                       | 78.06               | 0.03                        |
| Mallewang          | 0.75                       | 4.26                | 0.18                        |
| Kaci-kaci          | 0.63                       | 2.53                | 0.25                        |
| Bila Caddi         | 2.81                       | 16.93               | 0.17                        |

3.5. Correlation of seepage, water losses, efficiency, channel width, and channel density
The densities of secondary channels have had a significant correlation with seepage in the Bissua Irrigation Area. It was found that negative exponential relation was the best fit for them with R-square about 0.97, as shown in figure 2. This indicates that the denser channels can reduce water losses through seepage in the area because denser channel developed larger saturated area compared to the area with a sparser channel. Specifically, figure 2 shows the relation function of both variables, shape of the trendline and the R-square of the graph.

Water losses also have a significant correlation with channel widths. It was a linear correlation between them with an R-square of 0.95. It is clear that the large wetted perimeter increased the opportunity of water to lose through seepage, while the larger surface channel will have a higher value of evaporation from the surface water of the channel. The correlation was a positive linear correlation, as shown in figure 3.
The relation between the efficiency of conveying water and channel density has a similar pattern with water losses and channel densities. The correlation has an R-square value of about 0.87 with the exponential equation. The efficiencies have a tendency to be higher in the area of the denser channel. If the water losses are smaller, then efficiencies will higher.

4. Conclusion
The level of water losses in the secondary channel of Bissua irrigation area depends on the physical condition of the channel. The losses have influenced the capacity of conveying water and their efficiencies. There were significant correlations between seepage, water losses, efficiency, width of the channel, and secondary channel density in the Bissua irrigation area.

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