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Mapping Irrigation Networks with Geographical Information Systems Using Satelite Imagery Data: A Case of Brebes Regency, Indonesia

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***Abstract*—Water resources are important factors in food production. Those are very vital and strategic to meet food needs and food security. As water is scarce both in terms of volume and distribution throughout the year, reliable water management is needed. To support this water management, the accurate data is needed. However, the complete tabular data is not enough. It is because the existing tabular data does not provide the various activities and events based on time and place spatially and detail enough for planning purposes at the sub-district level. The researchers use high-resolution satellite imagery data that have been pre-processed with the geometric and radiometric corrections. They are used as one of the layers in the working map, so it is easier to provide the depiction of irrigation network objects, to find out the location of rice fields that have not been irrigated and the location of damaged irrigation networks. The depiction of the working map can also be used to map irrigation networks and their network conditions. Through this work, it has been shown that the researchers can map irrigation networks in detail for operational planning at a sub-district level with the help of technology, in particular for developing countries that is difficult or even impossible to do in the past.**

***Index Terms*—Satellite Imagery Data, Geographic Information System (GIS), Irrigation Network**

I. Introduction

WATER resources are important factors for food production. Those are very vital and strategic to meet food needs and food security [1]. The decreasing availability of water supply is due to the increasing damage of some watersheds ‘Daerah Aliran Sungai’ (DAS), global climate change, and increasing damage of irrigation infrastructure. In 2015, it was reported that watersheds had significant damage due to global climate change and irrigation infrastructure damage. From 458 watersheds in Indonesia, there are 108 watersheds (23.5%) that had been damaged in Java and outside Java [2]. Watershed damage reduces water availability especially in the dry season and increases water intensity which causes flooding in the rainy season. This watershed damage management is very important for food security because it is the main source of water for the irrigated rice in the country. It is amounted to about 58.4% of the 8.186.469 Ha of total paddy fields in Indonesia [3].

One of the government efforts in anticipating the increasing damage of the watersheds and the increasing damage of the irrigation infrastructures is by fulfilling the water needs. It is done by conducting water management through building irrigation channels network from various water resources or ponds (both natural and human-made ponds). The function of this irrigation channel network is to ensure availability of water supply during the dry season so that the farmers can continuously utilize their available land.

Accurate data are needed to support this water availability program. To obtain the accurate data, complete tabular data is not enough because the existing tabular data cannot see various activities and events based on time and place. Therefore, the researchers use satellite imagery. It can monitor large areas in almost the same time and continuously including areas that are difficult to explore and can record dynamic water conditions

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in a short time [4]. Moreover, to support the data accuracy, spatial data are needed to see the spatial patterns according to time and place [5]. Both spatial and tabular data of the irrigation condition are very useful in irrigation operations, maintenance, repair, and development [6]. Spatial data on irrigation networks are also very useful in water resource management and agricultural development planning [7].

Geographic Information System (GIS) is a computer-based information system for storing, managing, analyzing, and retrieving spatial data [8]. The benefits of GIS are to provide an easy way for users or decision makers to determine policies related to spatial aspects. With the existence of GIS technology, the mapping of water irrigation networks is easily facilitated and supported.

The availability of spatial data is now relatively easier to obtain because of the many types of images with various spatial resolutions. Satellite imagery has been widely publicized. With the development of information technology, many people take advantage of satellite imagery for the benefit of mapping, especially in making thematic maps [9]. Using a combination of aerial photography, satellite image, topographic maps, the identification of changes in land use and land cover has been carried out for 50 years in Thailand, Vietnam, Cambodia, and Laos [10]. By using Landsat Image and applying the maximum likelihood supervised classification and post-classification change detection method, Ref. [11] conducted a study to map land use and land cover changes in the Egyptian region. Using ancillary data, visual interpretation and expert knowledge of the area through GIS refined the classification results.

Studies for utilizing satellite imagery data related to the agricultural sector have been widely carried out. Several studies that have been carried out include Ref. [12] who used Landsat Thematic Mapper (TM) imagery to predict microclimatic parameters based on the initial land surface data and an estimation of the change in vegetation and urban coverage. To evaluate land use, land cover changes and urban expansion in greater Dhaka, Bangladesh. Reference [13] used satellite images and socio-economic data and using the post-classification change detection technique in GIS.

Using improved radiometric normalization techniques, Ref. [14] conducted a land cover change analysis using three Landsat-5 TM images for three different years (August 1986, 1987, and 1991). The update on land use and land cover data in China had been carried out by Ref. [15] using a medium spatial resolution satellite images with a resolution of 30 m and accuracy about 95%.

Brebes Regency, one of the regency in Central Java province, has a very prominent potential in the agricultural sector. The area has extensive agricultural land. However, it has problems in the water distribution sector. Therefore, to make Brebes Regency more developed in the agricultural sector, the researchers can optimize the water irrigation network using GIS applications. The application of this GIS can make it easier for policy makers and farmers to obtain information of area with proper irrigation. In the application of GIS, there is a map that knows which paths to make effective irrigation.

Collecting data through satellite images is faster and more practical in the field especially in the mapping of the irrigation network. Hence, with this background, the study on the mapping of irrigation networks with satellite imagery data based on GIS in Brebes Regency is conducted.

A. *Research Problem*

To plan the rehabilitation program and develop irrigation networks to support the food production development program, it requires spatial and tabular irrigation data. However, the availability of existing irrigation spatial data is still limited. Thus, it is necessary to map the irrigation network. One alternative in mapping irrigation networks is to utilize satellite image data. With satellite data, collection and mapping irrigation will be easier, faster, and more practical. The research problems can be formulated as follows:

1) How can satellite image data be used to map irrigation networks?
2) How can GIS be used to support the creation of spatial data on irrigation networks?

B. *Research Objectives*

There are two purposes in this research. First, it is to utilize satellite image data in mapping irrigation networks. Second, it is to make spatial data on irrigation networks using GIS. Moreover, the benefits of this research are to provide an easier tool to develop activities and program on planning and rehabilitation of irrigation networks and to help facilitate the management of water resources operationally in the field.

II. Research Method

A. *Framework*

Before utilizing satellite image data, image preprocessing should be done. Image pre-processing is an activity of pre-analyzing satellite image data. The purpose of image data pre-processing is to sharpen geographical data in digital form into a more meaningful display. It can provide quantitative information of an object. Sensor recorded image data are strongly

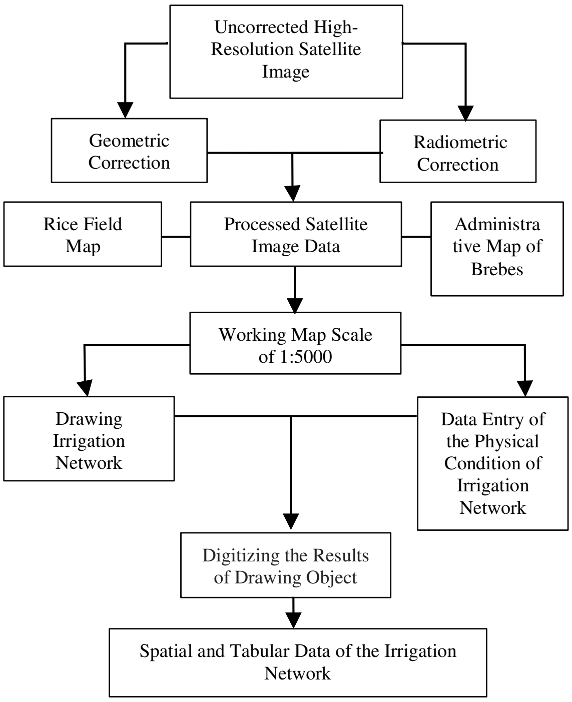

Fig. 1. Research framework.

influenced by atmospheric conditions, angle of data retrieval from the sensor, and data retrieval time. The framework is in Fig. 1.

This condition causes satellite image data to have a biased value of information that must be corrected [16]. The stages in the image processing will reduce bias caused by the factors mentioned. There are several activities in image processing [17]. Those are as follows:

1) Radiometric Correction.
This type of correction is useful for improving the visual quality of the images that do not match the reflection value or the actual spectral beam of the object. When a sensor in an aircraft or spacecraft observes the emitted or reflected electromagnetic energy, the observed energy does not coincide with the energy from the same object observed from a short distance. This is due to the sun's azimuth and elevation and atmospheric conditions such as fog, aerosols, or sensor's response. Therefore, to obtain the real irradiance or reflectance, those radiometric distortions must be corrected [18]. Radiometric correction is classified into three types.
   a) Radiometric Correction due to Sensor Sensitivity.
   In the case of optical sensors, with the use of a lens, a fringe area in the corners will be darker compared to the central area. This is called as vignetting. Vignetting can be expressed by the cost that is the angle of a ray according to the optical axis. The n is dependent on the lens characteristics even though n is usually taken as 4. In the case of electro-optical sensors, the measured calibration data between irradiance and the sensor output signal can be used for radiometric correction.
   b) Radiometric Correction for Sun Angle and Topography.
   The solar radiation will be reflected diffusely in the ground surface. It results in lighter areas in an image called as a sunspot. The sunspot with vignetting can be corrected by estimating a shading curve determined by Fourier analysis to extract a low-frequency component. Then, there is also shading. The shading effect due to topographic relief can be corrected using the angle between the solar radiation direction and the normal vector to the ground surface.
   c) Atmospheric Correction.
   The solar radiation is absorbed or scattered by the atmosphere during transmission to the ground surface. Meanwhile, the reflected or emitted radiation from the target is also absorbed or scattered by the atmosphere before it reaches the sensor. The ground surface receives not only the direct solar radiation but also skylight or scattered radiation from the atmosphere. In addition, the sensor will receive not only the direct reflected or emitted radiation from a target but also the scattered radiation from a target and the scattered radiation from the atmosphere which is called as path radiance. Atmospheric correction is used to remove these effects.

2) Geometric Correction.
The correction of errors in remotely sensed data such as errors caused by satellites or aircraft that does not stay at the constant altitude or by sensors deviating from the primary focus plane. Images are often compared to ground control points on accurate basemaps and resampled. Then, the exact locations and appropriate pixel values can be calculated. Correction is done to adjust the analyzed image of the coordinate system. In this type of correction, the coordinate system is adjusted to the coordinate system used in each country. The steps for geometric correction (Murai, 1993) are as follows:
   a) Method Selection.
   After consideration of the characteristics of the

geometric distortion and the available reference data, a proper method should be selected.

b) Parameter Determination.
Unknown parameters, which define the mathematical equation between the image coordinate system and the geographic coordinate system, should be determined with calibration data or ground control points.

c) Accuracy Check.
The accuracy of the geometric correction should be checked and verified. If the accuracy does not meet the criteria, the method or the data used should be checked and corrected to avoid the errors.

d) Interpolation and Resampling.
The resampling and interpolation technique should produce geo-coded image. Processing satellite image data is by covering paddy field standard maps, and Brebes Regency administration maps to create a 1:5000 scale working map. Overlaying paddy fields is to distinguish which area is categorized as rice fields. Overlaying administrative boundaries is to limit the Brebes area over the other areas. Working map of 1:5000 is used to draw physical objects of irrigation networks in accordance with the factual conditions in the field and fill in the irrigation network conditions. Working maps and irrigation network conditions that have been described and filled out will be digitized by using ArcGIS software to obtain spatial and tabular data on the irrigation network. This spatial and tabular data is the input for making a map of the irrigation network of Brebes Regency.

B. Data Collection

The used data are primary and secondary data. Primary data are from the depiction of irrigation network objects and data from a field survey using the form of irrigation network conditions. Meanwhile, the secondary data are very high-resolution image data (Quickbird, Geoeye, Worldview) in 2013 from National Institute of Aeronautics and Space-LAPAN, a map of the rice field year in 2013 from the Ministry of Agriculture, and the 2015 Brebes district administration map from the Geospatial Information Agency.

C. Developing Irrigation Network Maps

The first stage is processing satellite image data. Processing satellite image data must go through the preparation stages before being analyzed. Pre-processing of satellite image data is absolutely necessary so that there are no errors during digital image analysis [19]. This

Fig. 2. The sample of field work maps.

pre-processing image consists of cutting image data according to the study area, geometric correction and radiometric correction using ArcGIS 10.5 software.

The second stage is the preparation and printing of fieldwork maps. At this stage a working map with a scale of 1:5000 is prepared using ArcGIS 10.5 software. The map consists of several layers, namely: satellite image data, paddy field, and administrative boundaries. The example can be seen in Fig. 2.

The third stage is the description of physical objects of irrigation networks. At this stage, delineation (border) of physical objects of primary, secondary and tertiary irrigation networks is also carried out. It provides information on the types and physical conditions of the irrigation network, main irrigation, carrier irrigation, divider and tapping irrigation, water level control, waster irrigation and drains, and supporting infrastructures (inspection roads, embankments, pedestrian bridges, and others) on working maps based on satellite imagery maps in each village using permanent markers. The description of physical objects of irrigation networks is red for primary irrigation networks, blue for secondary irrigation networks, yellow for tertiary irrigation networks, and black for buildings around the irrigation network. In addition, it marks the damaged irrigation network.

The fourth stage is completing the irrigation network condition form. It fills in the form of the irrigation network conditions to provide information on the network.

The fifth stage is the processing of field activity results. The digitization process is carried out in this stage. It digitizes the irrigation network as a result of field working maps and data entry forms for irrigation network performance using ArcGIS 10.5 software. In

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this last stage, spatial and tabular data of the irrigation network will be obtained.

III. Results and Discussion

A. Utilization of Satellite Image Data in Mapping Irrigation Networks

Brebes regency satellite imagery data that have been corrected using geometric and radiometric corrections are used as the base layer in the working map. To complete the working map, a paddy field and administrative boundary layer are added. Working maps are drawn using permanent markers according to the type of irrigation (primary, secondary, or tertiary). The high-resolution satellite imagery data as the base layer will help interpreting the irrigation network in accordance with the facts in the field.

B. Developing Spatial Data on Irrigation Networks by Using Geographic Information System (GIS)

After drawing the irrigation network objects on the working map and filling the physical condition form of the irrigation network, the next step is to digitize those using one of the GIS applications, ArcGIS. The results of filling the physical condition form of the irrigation network are included in the attributes of digitizing the irrigation network to provide additional information of the irrigation network. From the spatial data digitization process of this irrigation network, the length of the primary, secondary, and tertiary irrigation networks in each sub-district in Brebes Regency are estimated.

Figure 3 shows the results of the overall digitization of irrigation networks in the Brebes Regency. The blue line is the irrigation network, and the green line is the wetland polygon.

Moreover, Fig. 4 explains the results obtained. Those are the spatial data of irrigation networks start from primary, secondary, and tertiary levels. The dark blue line is the primary irrigation network. It can be seen that the primary irrigation network flows into the secondary irrigation network. Then, the secondary irrigation network flows into several tertiary irrigation networks.

Tables I and II are the results of the calculation in the geometry process from spatial data of the irrigation networks using GIS. Table I shows that Banjarharjo Sub-District has 114.58 km length of irrigation network. It consists of 25.29 km of primary irrigation network, 3.91 km of secondary irrigation network, 57.52 km of tertiary, quarterly 3.08 km and 4.07 km of the irrigation type that has not been identified. Moreover, Bantarkawung Sub-District has the length of 97.98 km in irrigation network including 1.39 km of primary irrigation network, 24.09 km of secondary irrigation network, and 72.50 km of tertiary irrigation network.

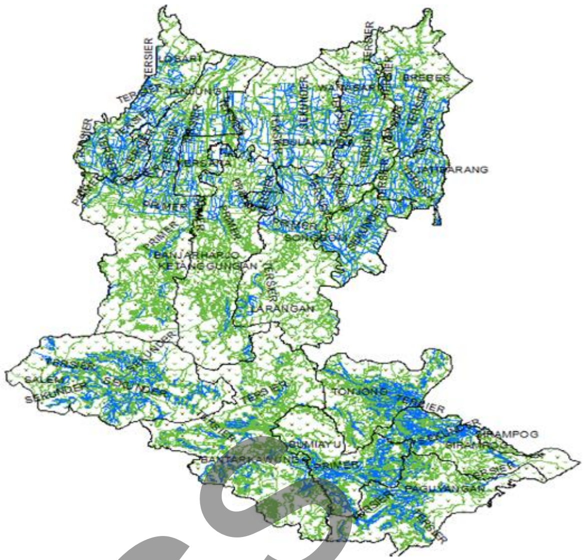

Fig. 3. The results of digitization of primary, secondary, and tertiary irrigation networks in Brebes Regency.

Fig. 4. Spatial data of irrigation network.

Then, Brebes Sub-District has a length of irrigation network about 232.13 km. It shows 121.70 km of primary irrigation network, and 110.42 km of secondary irrigation network. Next, Bulakamba Sub-District has an irrigation network about 198.91 km. It consists of 4.47 km of primary irrigation network, 39.87 km of secondary irrigation network, 154.04 km of tertiary irrigation network of, and quaternary irrigation network of 0.52 km. Next, Bumiayu Sub-District has 171.85 km of irrigation networks. Those are 13.43 km of primary irrigation networks, 52.06 km of secondary irrigation networks, and 106.37 km of tertiary irrigation networks.

Jatibarang Sub-District has 93.08 km of irrigation network length. It includes 1.43 km of primary ir-

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rigation network, 19.42 km of secondary irrigation network, and 72.24 km of tertiary irrigation network. Moreover, Kersana Sub-District has 47.19 km of irrigation network consisting of 0.41 km (primary irrigation network), 0.45 km (secondary irrigation network), and 46.32 km (tertiary irrigation network).

Ketanggungan Sub-District has 88.02 km length of irrigation network. Those are 6.91 km (primary irrigation network), 6.76 km (secondary irrigation network), and 74.35 km (tertiary irrigation network). Larangan Sub-District has 154.41 km of irrigation network consisting of 9.74 km (primary irrigation networks), 35.62 km (secondary irrigation networks), 107.13 km (tertiary irrigation networks), and 1.91 km (quaternary irrigation networks). Losari Sub-District has 182.9 km of irrigation networks. It has 18.41 km of secondary irrigation network, and 164.49 km of tertiary irrigation network. Then, Paguyangan Sub-District has 135.04 km of irrigation network including 134.70 km of tertiary irrigation network, and 0.34 km of irrigation type that has not been identified. Moreover, Salem Sub-District has 239.10 km of irrigation networks. Those are 2.77 km (primary irrigation network), 158.26 km (secondary irrigation network), 53.42 km (tertiary irrigation network), and 24.66 km areas that are not identified.

Sirampog Sub-District consists of 153.94 km for the length of irrigation network. It has 20.76 km of primary irrigation network, 60.11 km of secondary irrigation network, and 73.66 km of tertiary irrigation network. Songgom Sub-District consists of 126.32 km length of irrigation networks with 7.50 km (primary irrigation networks), 15.12 km (secondary irrigation networks), and 103.69 km (tertiary irrigation networks).

Moreover, Tanjung Sub-District covers 149.94 km length of irrigation networks. It has 31.45 km of secondary irrigation networks and 118.5 km of tertiary irrigation networks. Tonjong Sub-District has 138.35 km of irrigation networks. It consists of 1.74 km (primary irrigation network), 55.72 km (secondary irrigation network), and 80.90 km (tertiary irrigation network). Then, Wanasari Sub-District has 160.61 km of irrigation network length consisting of 26.20 km (secondary irrigation networks) and 134.41 km (tertiary irrigation networks).

In Fig. 5, it illustrates the results of digitizing irrigation networks. The blue line shows the spatial data of irrigation networks, and the red lines are spatial data of damaged irrigation networks. Moreover, Table II shows the length of the broken irrigation network. In Banjarharjo Sub-District, there are 401.8 m of broken tertiary irrigation network. Bulakamba Sub-District has 5 859.91 m of broken tertiary irrigation netwoks. Meanwhile, Bumiayu Sub-District has 8 684.4 m of

TABLE I
TYPE AND LENGTH OF IRRIGATION NETWORK.

No	Sub-Districts	Irrigation Network Length (km)		
		Primary	Secondary	Tertiary
1	Banjarharjo	25.29	20.71	57.52
2	Bantarkawung	1.39	24.09	72.50
3	Brebes	0	121.7	110.42
4	Bulakampa	4.47	39.87	154.04
5	Bumiayu	13.43	52.06	106.37
6	Jatirabang	1.43	19.42	72.24
7	Kersana	0.41	0.45	46.32
8	Ketanggungan	6.91	6.76	74.35
9	Larangan	9.74	35.62	107.13
10	Losari	0	18.41	169.49
11	Paguyangan	0	0	0
12	Salem	2.77	158.26	53.42
13	Sirampog	20.76	60.11	73.06
14	Songgom	7.50	15.12	103.69
15	Tanjung	0	31.45	118.50
16	Tonjong	1.74	55.72	80.90
17	Wanasari	0	26.2	134.41

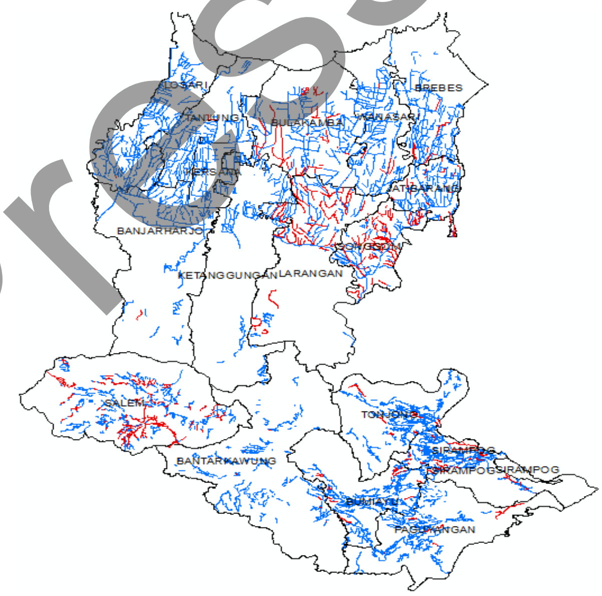

Fig. 5. The results of digitization of broken irrigation networks in Brebes Regency.

broken irrigation network. It consists of 568.7 m of primary irrigation network, 3 126.09 m of secondary irrigation network, and 4 989.64 m of tertiary irrigation network.

Jatibarang Sub-District has 3 629.7 m of broken irrigation networks consisting of 977.8 m in secondary irrigation network and 2 714.9 m in tertiary irrigation network. Then, Ketanggungan Sub-District has 25 397.8 m of broken irrigation networks. It consists of 309.5 m (primary irrigation network), 3 785.4 m (secondary irrigation network), and 21 302.8 m (tertiary irrigation network). Next, in Larangan Sub-District, there are 6 394.5 m of broken irrigation network con-

TABLE II
THE LENGTH OF BROKEN IRRIGATION NETWORK.

No	Sub-Districts	Broken Irrigation Network (m)		
		Primary	Secondary	Tertiary
1	Banjarharjo	-	-	401.83
2	Bantarkawung	-	-	-
3	Brebes	-	-	-
4	Bulakampa	-	-	5 859.91
5	Bumiayu	568.70	3 126.09	4 989.64
6	Jatirabang	-	977.81	2 714.86
7	Kersana	-	-	-
8	Ketanggungan	309.54	3 785.43	21 302.83
9	Larangan	1 683.54	-	4 711.01
10	Losari	-	-	2 285.15
11	Paguyangan	-	-	72.44
12	Salem	326.31	797.19	435.21
13	Sirampog	109.07	-	436.25
14	Songgom	-	-	12 705.44
15	Tanjung	-	-	5 834.49
16	Tonjong	-	-	-
17	Wanasari	-	627.08	2 772.49

sisting of primary irrigation network (1 683.5 m) and tertiary irrigation network (4,711 m).

Losari Sub-District has 2 285.2 m of broken tertiary irrigation network. Meanwhile, Paguyangan Sub-District has 72.4 m of broken tertiary irrigation network. Then, in Salem Sub-District, there are 1 558.7 m of broken irrigation networks. It consists of primary irrigation network (326.3 m), secondary irrigation network (797.2 m), and tertiary irrigation network (435.2 m). Then, Sirampog Sub-District has 545.3 m of broken irrigation networks. It covers 109.1 m of primary irrigation network and 436.3 m of tertiary irrigation network. Songgom has 12 705.4 m of broken tertiary irrigation network. Tanjung Sub-District has 5 834.5 m of broken tertiary irrigation networks. Next, Wanasari Sub-District has 3 399.6 m of broken irrigation network consisting of secondary irrigation network (627.1 m) and tertiary irrigation network (2 772.5 m).

C. Follow-up Plan with Irrigation Network Spatial Data

By obtaining spatial data on irrigation networks, it is expected that the Brebes Regency government can plan the cost budget. Knowing the location of the irrigation network that is in good or damaged condition is very useful in irrigation operations, maintenance, repair, and development. Moreover, it can review the field so that it can capture the conditions that are happening in the field.

It can also monitor wetland area that does not have an irrigation network to make irrigation drain or pumps for the need for water in paddy fields. Last, it can conduct socialization or training to another district to have spatial data on irrigation networks.

IV. CONCLUSION

High-resolution satellite imagery data that has been preprocessed with the geometric and radiometric corrections can be used as one of the layers in the working map. Thus, it is easier to provide the depiction of irrigation network objects, to find out the location of rice fields that have not been irrigated, and to find out the location of the damaged irrigation networks. The depiction of the working map can also be used to map irrigation networks and their network conditions.

GIS can assist in the digitalization of spatial data on irrigation networks starting from the stage of image pre-processing and creating working maps to creating spatial data on irrigation networks. The detailed mapping of irrigation networks will be almost impossible without being facilitated by GIS satellite imagery data.

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