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FLOOD ASSESSMENT OF BENGAWAN SOLO RIVER

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ABSTRACT

Bengawan Solo river has the largest river basin in Java Island. This river flows from upstream in Central Java Province to downstream in East Java Province and empties into the Madura strait. Big flood of Bengawan Solo river occurred in 1966, then in 1974, 1995, 2002, 2005 and 2007. Flood disaster has resulted in an impact on losses of people and possessions. In this study, flood disaster assessment of Bengawan Solo river was conducted to obtain information and detailed pictures of flood causes, condition during flood, problem solutions of flood, and losses because of it. Flood assessment was carried out by analyzing flood causes, inundations, flood losses, flood handling programs and recommendations to manage flood in the future. The result of flood assessment shows clear pictures of flood and they can be used to determine flood prone area, the risk of flooding and to create an evacuation route in order to minimize losses due to flood disaster in the future.

Keywords: flood assessment, inundations, flood disaster, losses, Bengawan Solo.

INTRODUCTION

Bengawan Solo river has a river basin area of 16,000 km^2.This river basin is located on latitude of 110^{0}18 E - 112^{0}45 E and longitude of 6^{0}49 S - 8^{0}08 S. It is divided into 3 sub-basins namely: Bengawan Solo upstream,Kali Madiun and Bengawan Solo downstream. Bengawan Solo river flows through 17 regencies and 3 cities in Central Java and in East Java. These regencies are :Boyolali, Klaten, Sukoharjo, Wonogiri, Karanganyar, Sragen, Blora, Rembang, Ponorogo, Pacitan, Madiun, Magetan, Ngawi, Bojonegoro, Tuban, Lamongan and Gresik. Whereas the cities are: Surakarta, Madiundan Bojonegoro.

Big flood of Bengawan Solo river which took place in 1966flowed peak discharge reached 4,000 m^3/s in Wonogiri dam, 2,000 m^3/s in Surakarta and1, 850 m^3/s in Ngawi. This flood caused high inundation in Surakarta reached 1 – 2 meter. This flood left 90 people died [1]. Big flood also occurred in the end of 2007. It caused Bojonegoro city was flooded up to 2 meters high. As the levee of Bengawan Solo river broke, Widang area was covered by water for quite along time.

Recently, Bengawan Solo flood frequently happened in rainy season. Bojonegoro, Tuban and Lamonganregencies were regions that were flooded quite often. Flood inundated settlements, farming lands and roads. It caused damages on infrastructures such as bridges, irrigation structures, and other structures. Due to flood, transportation was disrupted, economy was hampered, and losses of community's materials as their possessions were flooded.

To minimize losses due to flood disaster and bad impacts as a result of flood, flood assessment was badly required. The purpose of assessment was to understand the main problems of flood, efforts that had been accomplished, the level of its success rates, obstacles faced by flood, and to propose solution of flood handling to reduce losses due to disaster in the future.

LITERATURE REVIEW

The impact of flood disaster increased gradually accompanied by the increase number of flood events and bigger flood discharge. Flood disaster raised real impacts on cultures, religions, geography and losses of life. It also disturbed community and business, damaged properties and assets, caused stress and annoyed people's health [2].Indonesia country is located in tropical area having fairly high rainfall so that flood disaster easily takes place. The condition of river basin tends to reduce its ability to absorb water, to decrease water stream capacity and also to increase the vulnerability of flood event. As it happens on rivers in developing countries, the river basin in Indonesia only possesses limited data both its quantity and its quality. However, flood problems must be solved by existing resources so that losses due to flood disaster can be minimized accordingly. Initial step to get flood handling solution was conducting flood assessment.

Based on assessment guideline of disaster emergency response, assessment is a series of activities on both data identification and data analysis and situation which is useful to execute intervention [3]. To obtain complete pictures, the assessment is carried out in each step of disaster cycle: prior to disaster (preparedness phase), post disaster (emergency response phase) and recovery phase. On each phase, assessment can be carried out several times and in different forms as required to get the increasing number of information.

On assessment prior to the event, its purpose is to describe disaster potency, community status, availability of competency and resources to encounter flood event etc. The purpose of post event assessment, in emergency response phase, is to reveal damages, social function changes of community and the needs of affected community (gap between their needs and availability). The next assessment can be done several times during the process of emergency response and continued throughout the recovery process (rehabilitation and reconstruction). It

is carried out to obtain information of affected community's condition who are processing for recovery from their condition prior to disaster [4].

After prevention has been completed, handling action has also been designed (response/intervention) during the flood disaster. Handling action of flood disaster among others are : announcement and information dissemination of flood forecasting (flood forecasting information and dissemination),emergency response, assistance of logistic equipment for flood handling(flood emergency response and assistance), and fighting against flood (flood fighting). Recovery from flood condition was carried out by improving transportation lanes which are disconnected by flood hit, cleaning up dwellings from the rest of sediment and mud which are carried away by flood etc.[4].

Flood risk assessment according to SEPA (Scotissh Environment Protection Agency) 2011, is assessment which entirely depends on and pays attention to physical, social, economic and environment factors. Expected result, therefore, is in accordance with the expectation i.e. it can be easily accessed, presented information is easily read and identification of regions which are severely affected by flood can be informed [5].

In identifying flood, the following data are required such as: history of flood, flood duration in each easily affected region, inundation height, climate changes, and river discharge to ease in making further assessment which can help in emergency response process to encounter flood. In addition, infrastructures in easily affected disaster and its surroundings are also needed. Further required information are: the location of energy generators, hospitals, telecommunications, high ways, railways, airports etc. They are made in spatial maps to construct evacuation routes and further policies of past disaster and the coming one [5].

Mitigation strategy of flood disaster must be based on a comprehensive evaluation of flood risk combined with thorough investigation of an uncertainty related with risk evaluation procedure [6]. Flood risk can be reduced by mitigation to minimize impacts generated by flood or improve the ability of community in facing flood disaster. Flood assessment is also related with estimation of flood disaster (that is related runoff and probability) and consequences of flood (that is property damage and damage to people etc.) [7].

European Commission proposed a guideline to evaluate and manage flood which aims to manage basin and reduce the risk of flood for people's health, environment, infrastructure and property [8]. Its country members are obliged to perform the following activities for basins and sub-basins:

1. Assessing an initial flood risk
2. Making a flood risk map
3. Planning flood risk management

Based on ANCOLD guideline 2003, common methodology to assess risk should follow the following stages:

1. risk identification: in this stage, carrying out identification on danger source.
2. risk analysis or risk estimation :in this stage, conducting estimation of probability level for dangerous phenomena, estimation of actual consequences and estimation of susceptibility of a system affected to selected danger scenario.
3. risk evaluation : in this stage, executing identification of risk policy accepted by local community and criteria as well as understanding of local community on danger impact perception by decision makers.
4. risk assessment : referring to accepted risk estimation based on accepted criteria of local community.

METHODS

The study of flood assessment of Bengawan Solo river was conducted with some activities, among others were:

1. Secondary data collection from various previous studies, measurement data of water level/discharge, rainfall data, flood event data, inundation data, topography data, basin maps and river cross section data.
2. Location survey to collect information of flood event and impact inflicted.
3. Data analysis, both secondary data and survey result data by calculating flood discharge in some locations of observation and compared them with river flow capacity, flood spread calculation, land use analysis, analysis and design of existing river capacity, 1D flood modeling, sedimentation analysis, and flood causes identification.
4. Evaluation of Bengawan Solo flood management plan based on existing master plan and implementation of this plan in location.
5. Giving suggestions based on assessment result that must be executed to minimize losses due to flood disaster in the future.

Disaster risk assessment is a tool to assess the likelihood and magnitude of losses due to disaster threats [9]. The assessment was conducted to determine the likelihood and magnitude of losses, the focus of the planning and integration of disaster management in order to become more effective. Thus, disaster risk assessments can be used as a basis to ensure alignment and effectiveness in the implementation of disaster management in the region. Therefore flood assessment needs to be done in order to flood disaster management Solo River.

RESULTS AND DISCUSSIONS

Flood took place as rainfall on land surface could not pass through and flowed directly so that it caused inundation. To know the flood causes of Bengawan Solo river, analysis of rainfall during the rain and that before flood occurred. Figure-1 is aIsohyet map of daily rainfall

in Bengawan Solo river basin on December 25, 2007. This map shows that daily rainfall in sub-basins of Bengawan Solo upstream and Kali Madiun reaches maximum 250 mm (equals to return period rainfall of 80 years). Further to downstream, daily rainfall reaches 200, 150, and 100 mm. These rainfalls are categorized as high rainfalls in Java Island. At the same time, rainfall spreads evenly in both sub-basin Bengawan Solo upstream and sub-basin Kali Madiun as well as confluence area from these sub-basins. Meanwhile the development of Bengawan Solo is only planned for 10 years repeated period of flood discharge. Therefore, high rainfall can be said as one cause of Bengawan Solo river flood.

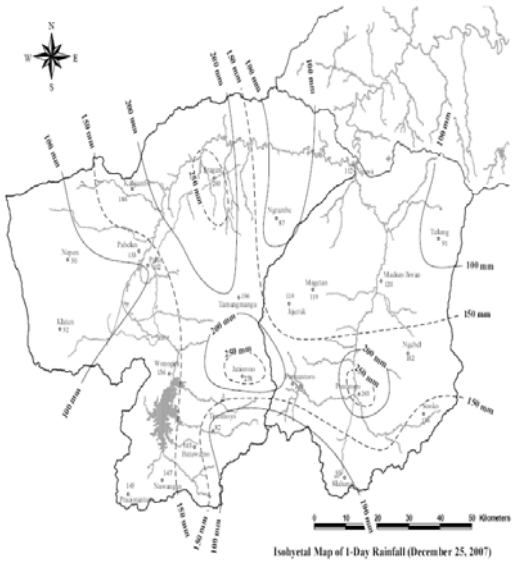


Figure-1. Isohyet map of 1-day rainfall in December 25, 2007.

Rain that dropped over river basin then flowed to Bengangan Solo river. There were some monitoring locations for surface water i.e. Sub-basin Bengawan Solo uptsream : Wonogiri, Jurug (Solo city), and Kajangan, in Sub-Basin Kali Madiun : Sekayu and Ahmad Yani (Madiun city), whereas in Sub-Basin Bengawan Solo downstream : Ketongo, Napel, Karangnongko, Cepu, Bojonegoro, Babat, Karanggeneng and Kuro. Monitoring result of surface water elevation in some locations is presented in Figure-2. From 4 flood events in 1993, 2002, 2005 and 2007, shows that the flood event in 2007 had been the biggest flood event since 1993.

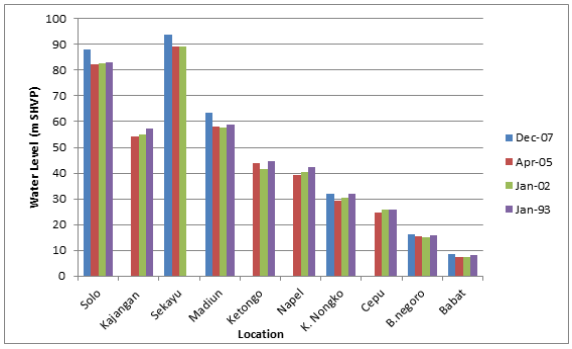


Figure-2. Water level of Bengawan solo during flood.

Flood discharge that fllowed into Bengawan Solo river in Solo city was not only from Wonogiri dam outflow but also from tributaries which emptied into Bengawan Solo river. In river segment between Wonogiri dam and Solo city, there were 8 tributaries which total catchment area 1979 km^2 and their flood discharge flowed to Bengawan Solo river. Therefore, even some of rain water had been acommodated in Wonogiri dam and their flows to downstream had been limited, their discharge in Solo city was still high due to water from tributaries. At the moment of flood event, measurement result revealed that river discharge in Solo city could reach 2.000 m^3/s (Figure 3), in fact outflow from Wonogiri dam was only 250 m^3/s from a maximum outflow 400 m^3/s.

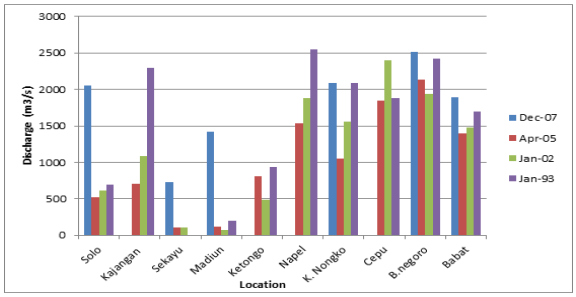


Figure-3. Discharge in some monitoring locations in Bengawan solo river during flood.

In Figure 3 can be seen that measured discharge in Napel and Bojonegoro stations reached 2500 m^3/s, meanwhile flow cross-section capacity of Bengawan Solo river from Cepu to Bojonegoro only 1250 m^3/s. So overflow took place due to river cross-section capacity of existing river was smaller than running discharge.

Flood discharge can be chanelled without having overflow if capacity of river cross-section had been increased in accordance with planned river cross-section capacity (Table-1). And so does, existing capacity of Bengawan Solo river cross-section located in Bojonegoro downstream which now cross-section still has capacity less than 2500 m^3/s. It means that it isless than the capacity of discharge that flows. It makes river overflows. Existing capacity and plan for each river cross-section can be seen in Table-1.

Table-1. The flow capacity of Bengawan solo river cross-section.

River Reach	Length (km)	Existing capacity (m^3/s)	Design capacity (m^3/s)
Nguter-Jurug	55	400-600	700-1500
Jurug-Tangen	50	600-1100	1500-1600
Tangen-Kajangan	55	1100-1600	1600-1700
Kajangan-Ngawi	35	1600-2300	1700-1800
Ponorogo-Madiun	35	400-500	800-1000
Madiun-Kwadungan	29	500-700	1000-1400
Kwadungan-Ngawi	30	500-700	1400-1600
Cepu-Bojonegoro	68	1250	2490
Bojonegoro-Babat	62	1400	2530
Babat-Karanggeneng	35	1250	2530
Kr.geneng-Sembayat	33	1450	2530
Sembayat-Muara	26	1800	2530

River cross-section in Solo city was only designed for discharge 1500 – 1600 m^3/s from nowdays cross-section which has capacity 600-1100 m^3/s. Designed capacity of river cross section has not been realized yet in location. The same things happened with river segments in other places such as in Madiun, Ngawi, Bojonegoro and Babat where all river capacity are smaller than flood discharge. This small river capacity becomes one of water overflow or flood.

From observation result, water surface in some monitoring locations can be seen flood spread from upstream to downstream of river. Heavy rain occured on 26 December 2007, causing water surface of Bengawan Solo river in Solo city and Kali Madiun in Madiun city reached their peak. Flood discharge from Bengawan Solo upstream and Kali Madiun met caused river water surface increased and in Karangnongko reached its peak on 28 December 2007. Flood discharge continued to flow to downstream and some overflowed and inundated land in left and right sides of river. Record of river water surface monitoring in Bojonegoro city revealed its peak on 30 December 2007. And on 31 December 2007 flood peak was recorded in Babat monitoring location. Flood peak in Babat station kept quite long time and just subsided few days later because it happened at the same time with tide down. This caused inundations for long time in Babat and its surroundings.

Flood spread could be seen from rain dropped and one day later flood peak took place in Solo city and in Madiun. The next three days flood peak reached Karangnongko. Five days later, it reached Bojonegoro. The next six days it hit Babat. Changes of flood water surface in some mon

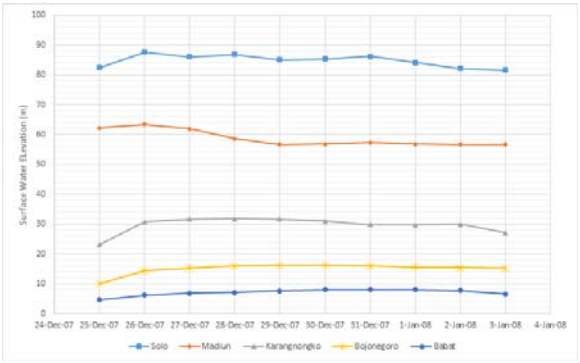


Figure-4. Elevation of river water surface in some monitoring locations.

Simulation of 1 dimensional flow model using software Hec-RAS showed the river water level has exceeded the high embankment in particularly cross-section of the river in Bojonegoro and Babat so that rivers overflow and inundate the land. The overtopiing ocation of flood can be seen in Figure-5.

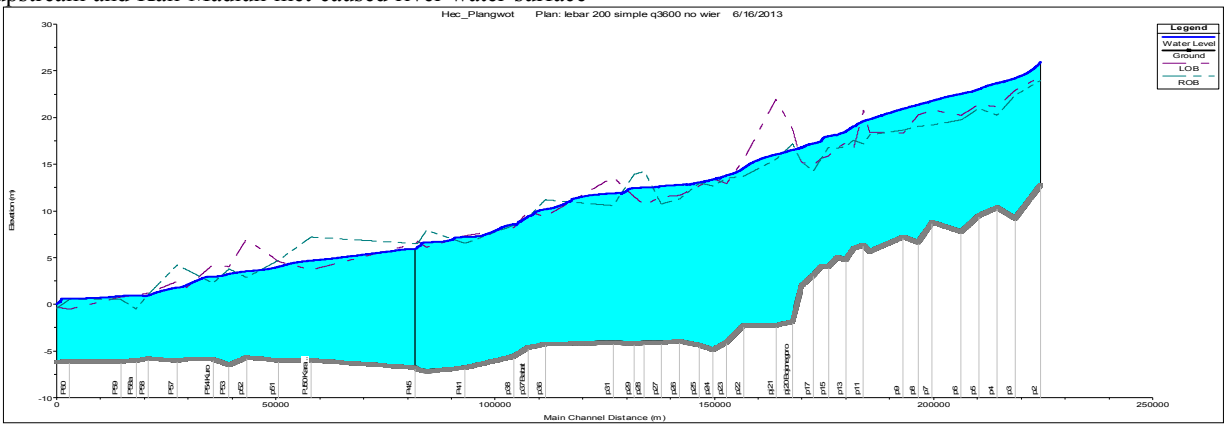


Figure-5. Flood water level profile of Bengawan solo river.

Figure-6. shows inundation areas as a result of Bengawan Solo river flood in 2007. From this figure shows that the flood inundation area along the Bengawan Solo river is the city of Solo, Madiun, Ngawi, Bojonegoro, Lamongan, Babat and area of district Lamongan and Gresik.

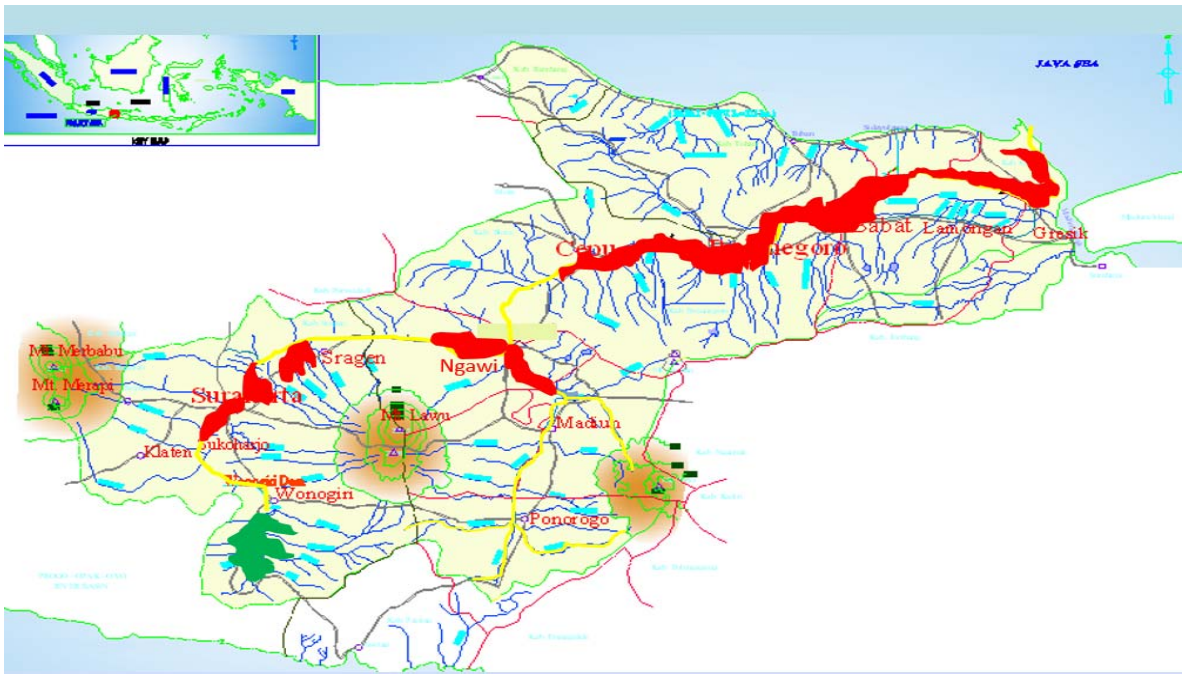


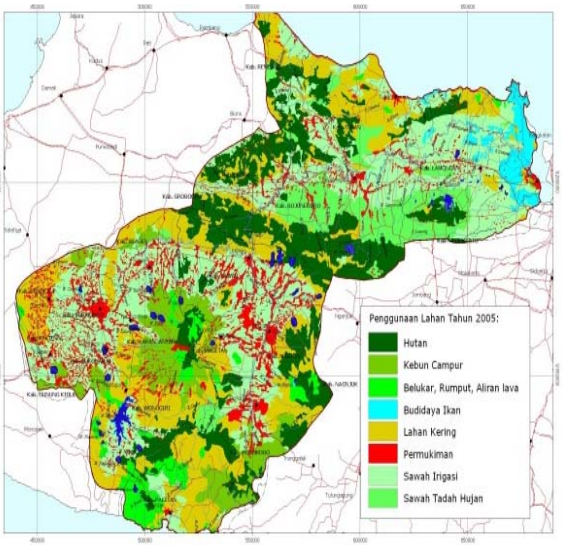
Figure-6. Inundation area of Bengawan solo river.

Assessmed of land use aspest was carried out by analyzing changes of land use in Bengawan Solo river basin. By employing satelite image map in 2005 and 2007, land use changes which had potency to change surface water flow could be calculated.

Figure-7. reveals comparison of land use in2005 and in 2007. The largest land use in upstream of Bengawan Solo river basin was for forest, paddy field and dry land. Changes of land use from 2005 to 2007 reduced paddy field from 38% to 35.4%, forest from 18% to 16.7% and dry land from 22% to 21.9%, and other land uses from 6% to 2.2%. On the other hand, there was an increase of mixed garden from 5.14% to 7% and residential land use from 9% to 14.6%. These land use changes caused decrease land which had high water absorptiond and otherwise increased land area which had low water absorption. So that water absorption in river basin decreased causing increase surface runoff. Increase runoff would increase flood discharge and also sediment flowed into river or dam due to land erosion.

Land use changes from forest to farming land caused increase of land erosion which was brought by water to river and dam. Result of sedimentation forecast in Wonogiri dam as a result of land changes from 1980 to 1993 caused sedimentation amounting to 5.9 millions m^3/year, whereas in period of 1993-2005 sedimentation was 3.1 millions m^3/year [10]. As a result of sedimentation, dam reservoir volume decreased so that abundant flood discharge from dam increased.

The result of flood survey and data analysis of Bengawan Solo river flood, some factors as flood causes in Bojonegoro City/Regency, Ngawi, Tuban, Gresik and Lamongan could be obtained. Especially, flood causes in each region can be identified and presented in Table-2.



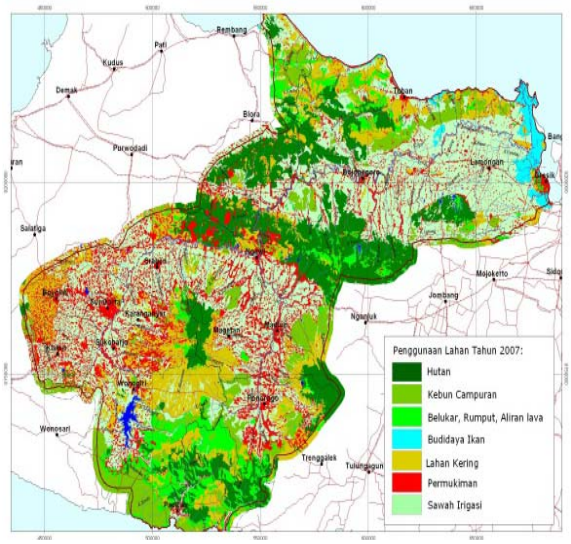


Figure-7. Land use change from 2005 (above) to 2007 (bottom)[9].

Table-2. Flood primary causes in each region.

Ngawi	Bojonegoro	Tuban, Lamongan & Gresik
High rainfall in upstream cacthment	Flood discharge from upstream	Flood discharge from upstream
Low topograhy	River cross-section has no levee	Levee breach
Flood discharge from upstream	Levee breach in Bojonegoro	River cross-section has no levee
Confluence of Bengawan Solo upstream and Kali Madiun	Settlement inside levee	Backwater due to tide up
Backwater from Bengawan Solo river to Kali Madiun	Levee and levee gates leakage	

Development of flood control infrastructure inBengawan Solo river basin has been initiated by Dutch government since 18th century by planning and constructing Solo Werken Valley canal and Plangwot-Sidayu Lawas floodway but not all of them has been realized due to lack of fund. After big flood in 1966 which inundated Solo city, Indonesia Government started to construct infrastructure to control Bengawan Solo flood. In 1974Indonesia Government made Master Plan to develop Bengawan Solo river basin with technical assisstance from Japan Government. In 2001 review in the form of Comprehensive Development and Management Plan (CDMP) was carried out. The result of master plan review suggested 29 activities and they were grouped into 5 components [11]. They were:

- Water resource development, consisted of constructing long storage in Bengawan Solo upstream, developing raw water supply for Drinking Water Local Company (PDAM) Solo city, raw water supply to Rembang, constructing 9 small dams for irrigation in Bengawan Solo sub-basin upstream, constructing 3 small dams for irrigation in Kali Madiun sub-basin, constructing 16 small dams for irrigation in Bengawan Solo sub-basin downstream, constructing Kedungombo irrigation dam, rehabilitating system for irrigation network, constructingBendo and Badegan multipurpose dams, constructing Pidekso dam, and rehabilitating Ngebel lake.
- Strengthening river basin area management with some activities : handling Wonogiri dam sedimentation and river basin area, and rehabilitating critical land.
- Strengthening framework for water quality management by management improvement program for water quality in Bengawan Solo river basin and study to remove water waste in Bengawan Solo river.
- Strengthening for flood control management by improving activities of Bengawan Solo upstream stage 2, improving development for Kali Madiun stage 2 and 3, rehabilitating water constructions located along river and developing flood forecasting and flood disaster early warning.
- Strengthening institutional framework to manage natural resources through – Empowerment agency for water resource Central Management in Bengawan Solo River Basin

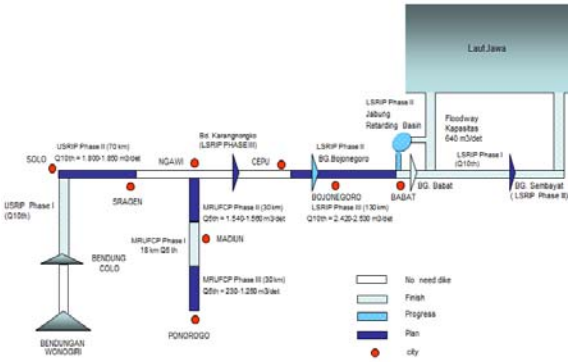


Figure 8. Scheme of flood management of Bengawan Solo (11).

Nol all 5 component programs above were realized. Some realized programs were construction of Babat Barrage andPlangwot-SedayuLawas floodway , Rehabilitationof irrigation infrastructure, dam rehabilitation, installation construction for Maron raw

water uptake, irrigation network operation and maintenance, river and dam, taking action on emergency response of Wonogiri dam sedimentation, pattern preparation for natural resource management in Bengawan Solo river basin, formation of team coordinator to manage water resource of Bengawan Solo basin and implementation of National Partnership Movement Water Rescue.Whereas, construction of Jipang dam had not been realized yet. Actually, this dam was very important to accommodate water from upstream so that flood discharge run to downstream was reduced.

Suggested flood control of Bengawan Solo river for short term was improvement of flow capacity for Cepu – Babat segment so that it could channel flood discharge 10 years return period, river capacity improvement from Jurug to Sawur (70km) so that it could flow flood discharge 10 years return period, capacity improvement for Kali Madiun from Kwadungan to Ngawi and from Ponorogo to Catur so that they could channel flood discharge 5 years return period, and flow capacity improvement of tributaries such as Dengkeng river, Jerowan river and Ponorogo river. In long term, Bengawan Solo river down stream capacity improvement from Cepu to Tanjung Kelapa (220 km) to channel flood discharge 5 years return period, Bengawan Solo river upstream capacity improvement from Nguter to Sawur (120 km) to channel flood discharge 5 years return period, as well as capacity improvement for Kali Madiun from Ponorogo to Ngawi (80km) to channel flood discharge 5 years return period.

Some flood control programs of Bengawan Solo river had been planned and some of them had been realized. Levees of Bengawan Solo river upstream and downstream had been planned to channel flood discharge every 10 years, whereas Kali Madiun levee had been planned to channel flood discharge every 5 years. In CDMP, levee had been planned to be built in Nguter-Jurug segment as long as 128 km, however only 32 km had been built. In Kali Madiun (Kali Catur – Kwadungan), 78 km levee had been planned but only 18 km had been able to be constructed. Whereas in Bengawan Solo downstream, Babat – Tanjung Kepala levee segment had been planned for 240 km but only 110 km had been constructed. However, only Floodway Plangwot-Sedayu Lawas levee had been able to be completed.

Levee segment from Babat Barrage to Plangwot floodway and Plangwot floodway segment to Ujung Pangkah had been built on the left side of river but they had been incomplete yet. There were still 5 locations of river cross-setion which did not have levee yet. In these locations, water river overflowed to land. So did, some of planned levee on the right side from Bojonegoro to Lamongan and from Lamongan to Unjung Pangkah had been built but some locations did not have any levee yet. The primary constraint in constructing levees was land acquisition from community. Levee construction plan on the right side of river from Bojonegoro to Babat and levee improvement on the left side of river from Rengel to Babat Barrage had been completed.

Levee construction around Jabung swamp had been finished. It could holdwater of 31 million m^3. Improvement plan for water flow capacity of Plangwot floodway from 640 m^3/s to 1800 m^3/s by adding more doors and enlarging floodway channels had not been completed.

Land along Bengawan Solo river, between Cepu and Bojonegoro was planned as flood prone area to hold some of flood discharge so that water flow to downstream could be reduced. Therefore, in this river segment, levee was not planned to be built.

Construction of water reservoir that could be realized was Badegan and Bendo dams. Construction of Bojonegoro Barrage had been completed and put into operation, while Sembayat Barrage was in the stage of completion for construction work.

Based on infrastructure construction assessment for flood control, not all planned infrastructures were able to be realized so that these infrastructures were unable to function optimally in reducing flood disaster.

Flood disaster of Bengawan Solo river and based on its water resources, excessive water/flood could be categorized into three categories: (a) Flood caused by high rainfall so that discharge of river exceeded system distribution which consisted of natural river systems and man-made drainage system, (b) flood caused by river discharge along with tide up as well as high ocean wave due to storm; and (c) flood due to failure of man-made water construction such as dams, levees and flood control structures.

The largest damage or loss caused by Bengawan Solo river flood were:

- Kanor sub-district, Bojonegoro regency : levee breach, 7000 ha of productive rice fields and neighborhoods inundated.
- Widang-sub district , Tuban regency: Levee breach and 2 villages inundated (450 families).

In addition, there were also losses due to flood experienced by people living in Lamongan and Madiun regencies.

CONCLUSIONS

Based on the results of this study it can be concluded that flood on Bengawan Solo river due to daily rainfall up to 250 mm in the upstream catchment, increases discharge flowing to the river was greater than flow capacity of the river, there was stillriver segment between Cepu to Bojonegoro had not been levied, weak levees, drainage problems aroundlevees area, backwater flow caused by tide up as well as major rivers andless optimal function of flood control infrastructure.Changes in land use were likely to increase in land area which was not easy absorbing water which led to increase runoff so that flood discharge was escalating.Land erosion occurred in river basin was carried by river flow causing sedimentation in rivers and dams so that declining their capacities.

Mathematical modeling produces inundations locations, depth and area along the Solo River. This information can be used to determine areas prone to

inundate, the risk of flooding and create an evacuation route.Floods occurred in the towns along the river Bengawan Solo occur sequentially from upstream to downstream with a sufficient period of time to perform early warning.

Management of flood structurally with infrastructure development plans to reduce Bengawan Solo river flood was not entirely successful to be realized due to limited costs and social problems so that it was suggested to have non-structural flood management approach such as river basin conservation, flood early warning and flood mitigation to reduce losses due to flood disaster.

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