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El-Nino effect on reservoir capacity reliability: Case study of Sumi dam, Sumbawa Island, Indonesia

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Abstract

Reservoirs have a very important function in providing multi-sector water requirements. In the future, reservoirs not only serve to store and available water can also be used as disaster mitigation instruments. The completeness of hydrological measurements in reservoirs can be expanded more widely for climate change mitigation. The reliability of the reservoir capacity varies greatly depending on the El-Nino character that occurs among them El-Nino is weak, moderate, strong and very strong. The El-Nino characteristic is very influential on the period of water availability, the increase of evaporation capacity and decrease of reservoir capacity. Analysis of the reliability of the reservoir volume due to El-Nino using the Weibull equation. The deficit reservoir was calculated using the concept of water balance in the reservoir that is the relationship between inflow, outflow, and change of storage at the same time. Based on the results of the analysis showed that the evaporation increase and the decrease of reservoir capacity had a different pattern that is when the evaporation capacity started to increase at the same time the reservoir capacity decreased significantly. The correlation coefficient between evaporation capacity increase and decrease of reservoir water capacity are consecutively –0.828, –0.636, and –0.777 for El-Nino weak, moderate and very strong respectively. At the reservoir capacity reliability of 50% reservoir has a significant deficit. When weak El-Nino the deficit is $2.30 \cdot 10^6$ m^3, moderate: $6.58 \cdot 10^6$ m^3, and very strong $8.85 \cdot 10^6$ m^3.

Key words: *capacity, El-Nino, evaporation, reliability, reservoir*

INTRODUCTION

Global climate change occurring around the world has affected the water availability condition of a regions [IPCC 2007]. The availability of water is very difficult to predict, thus affecting the multi-sector water supply allocation pattern. The El-Nino phenomenon adds to the reduced volume of surface water availability and subsurface water. The river flow becomes very small, the capacity of reservoirs are reduced by a very extreme volume and are unable to supply for irrigation water requirements. The effect of climate change on hydrological events not only runoff, and diverse hydrological characteristics of the entire basin to reveal the response mechanism of hydrological factors to potential climate change and determine their role in the water management [OKAFOR, OGBU 2018].

The El-Nino phenomenon lasts so long that it causes the failure of the agricultural production process. Climate variability also may affect water quality as seen in pollutants, although these concerns are often overlooked in favour of focusing on stream flow amounts and timing. However, volumes of stream flow, reservoir capacity, flow may not be the most important factor if water quality is lowered to a point where the utility in natural or manmade ecosystems is compromised [KEENER *et al.* 2010]. Climate change due to El-Nino causes reservoir volume deficits to be very extreme. A decrease in reservoir volume can reach a dead storage [YASA *et al.* 2018]. Re-charge the reservoir capacity until it reaches normal storage conditions due to climate change requires a very long period [WONDIMAGEGNEHU, TADELE 2015]

The ENSO phenomenon is recognized as having an approximate periodicity of 3–7 years [RASMUSSON, WALLACE 1983], which has various affect. on global climate. The relationships shown in other locations between observed precipitation, stream flow, and the ENSO index [LABAT 2008; RAJAGOPALAN, LALL 1998]. Furthermore, the existence of climate change affects all the hydrological processes in the reservoir, namely the flow of rivers into reservoirs, evaporation, and capacity in the reservoirs [ADELOYE *et al.* 1999]. Base on NOAA/National Weather Service [NOAA 2017], climate change has occurred since 1950 until the year 2017 in the form of El-Nino and La-Nina events. El-Nino is a low-intensity rainfall below average and La-Nina is a high above average rainfall. El-Nino and La-Nina were reviewed based on anomalies of sea surface temperature (SST anomalies). Events are defined as five consecutive overlaping 3-month periods at above the +0.5° anomaly for warm events (El-Nino) and at or below the –0.5° anomaly for cold (La Nina). There are several types of El-Nino and La-Nina which include weak (with the 0.5–0.9 SST anomaly), moderate (1.0–1.4), strong (1.5–1.9) and very strong (≥2.0) as shown Figure 1. The potential impacts of climate change have been a major concern in the management of water resources. Climate change is indicated by the increasing of temperature of the earth's surface with a more extreme tendency.

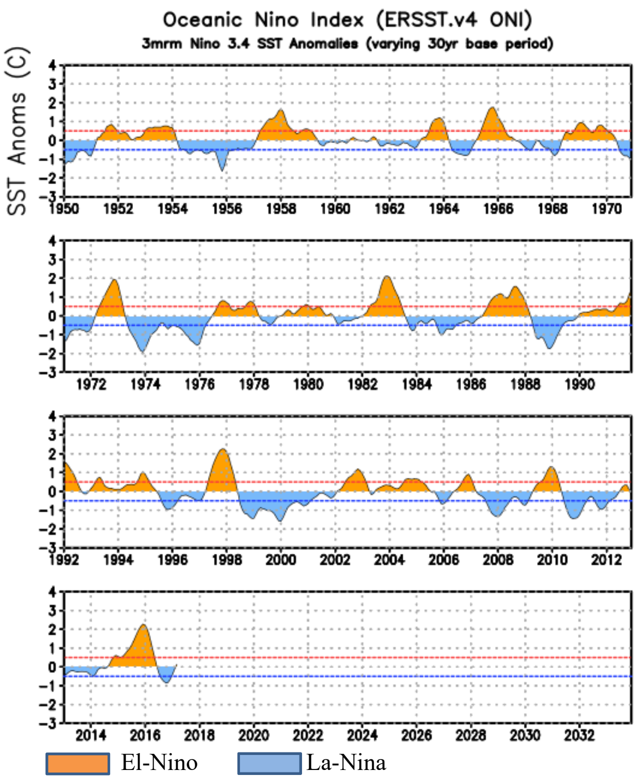

Fig. 1. El-Nino and La-Nina years SST = sea surface temperature; source: Golden Gate Weather Services [undated]

BHUVANESWARI and GEETHALAKSHMI [2013] reported that El-Nino occurred in 1972, 1982, 1987, 1991, 1997, 2002 and 2004. KEENER *et al.* [2010] stated that El-Nino has implications for the increasing uncertainty of water supply that affects the regulation of the allocation of water resources into complexes. One of the ways in which the construction of reservoirs is expected can be used as an anticipatory effort [CHIANG, TSAI 2012]. Reservoir is a very important facility in the water supply system and has many functions to collect water during the rainy season.

The reservoir function is not only limited to the physical side such as capacity and flow but also depends on the needs and operating patterns. Further, SHIAU [2003] noted that reservoir is an important facility in multi-sector water supply system with the main function is to regulate the fluctuating surface water flow. Reservoirs have many benefits, such as flood control, recreational activities, hydroelectric and water supply, which may conflict each other [FRANCISCO *et al.* 2016 ADJIM, DJEDID 2018], water reservoir management must consider natural variability, especially climate change and land use change. Several studies have shown that climate change affects the performance of reservoirs due to the extreme reduction of reservoir capacity [BURN, SIMONOVIC 1996; FOWLER *et al.* 2003; LI *et al.* 2010; LOPEZ *et al.* 2009; NAWAZ, ADELOYE 2006].

Table 1. Recorded El-Nino events during 1950–2017

Occurring year of El-Nino type			
week	moderate	strong	very strong
1952–1953	1951–1952	1957–1958	1982–1983
1953–1954	1963–1964	1965–1966	1997–1998
1958–1959	1968–1969	1972–1973	2015–1016
1969–1970	1986–1987	1987–1988	
1976–1977	1994–1995	1991–1992	
1977–1978	2002–2003		
1979–1980	2009–2010		
2004–2005			
2006–2007			
2014–2015			

Source: Golden Gate Weather Services [undated].

METERIALS AND METHODS

STUDY AREA

This research was conducted in Sumi dam of Bima Regency of West Nusa Tenggara Province, Indonesia. Sumi dam was built between 1995 and 1996 with a catchment area of 78 km^2, the average annual flow rate of $39.21 \cdot 10^6$ m^3. The reservoir area of Sumi dam is 155 ha with an $18 \cdot 10^6$ m^3 gross capacity and $16 \cdot 10^6$ m^3 net. Utilization of Sumi dam water that is to supply water land of 2272 ha and to water population around the dam.

DATA

The data collected were daily data such as reservoir inflow, outflow, high water level, reservoir volume, and evaporation from 1996 to 2016. In the analysis of the reliability capacity using the average data of reservoir volume in the event of El-Nino.

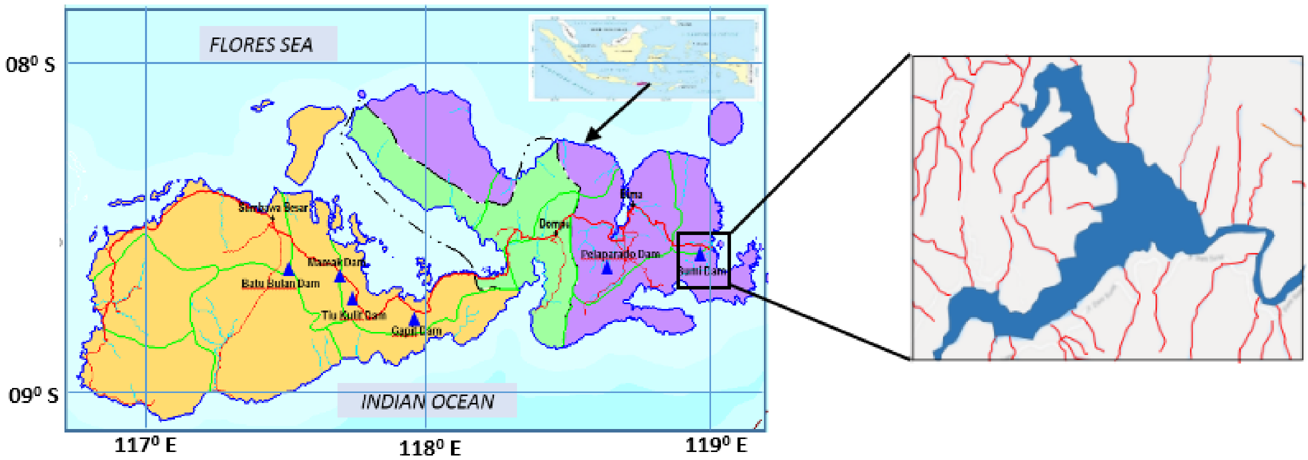

Fig. 2. Location map of Sumi dam; source: own elaboration

STUDY METHODS

The deficit reservoir was calculated using the concept of water balance in the reservoir that is the relationship between inflow, outflow, and change of storage at the same time. Inflow is water into the reservoir from the river and precipitation while outflow in the form of irrigation water coming out from the reservoir. The hydrological drought index is a deficit of the capacity of the reservoir under normal conditions. Normal condition reservoirs is the water level of the reservoir is the same as the height of the spillway.

$$I - O = \Delta S \qquad (1)$$

Where: I = inflow (m^3); O = outflow (m^3); ΔS = change of storage (m^3).

The magnitude of the reliable value of a hydrological drought index can be determined using the following equation:

$$P = \frac{m}{n+1} \qquad (2)$$

Where: P = probability, n = amount of data, m = serial number of data.

Food and Agricultural Organization (FAO) modified the original Penman equation [PENMAN 1963]. This method uses mean daily climatic data, with an adjustment for day and night time weather conditions. The modified equation used in this method [DOORENBOS, PRUITT 1977].

RESULTS AND DISCUSSION

RESERVOIR CAPACITY AND EVAPORATION CORRELATION

Reservoir capacity and evaporation during the weak El-Nino period

The weak El Nino phenomenon occurred in 2004 and ended in 2007. At the time of weak El-Nino period there is a decrease in the rain intensity and the evaporation rise but not significant. Figure 3 shows that at the beginning of March there has been a decrease in reservoir capacity and reached its peak in October. The correlation coefficient of decrease of reservoir capacity with the increase of evaporation value is –0.828. It shows the opposite relationship between the hydrological parameters at the time of El-Nino where the reservoir capacity decreases while the evaporation value increases. Based on 50% reservoir reliability at the time of weak El-Nino reservoir suffered a deficit of –2.30·10^6 m^3.

Reservoir and evaporation capacity during moderate El-Nino period

Figure 4 shows a decrease in reservoir volume and evaporation increase during El-Nino moderate. There is a negative correlation the coefficient of –0.777. The increase in evaporation capacity and decrease of reservoir volume have occurred at the end of February until December. The average evaporation capacity occurring at a moderate El-Nino is 0.0090·10^6 m^3 and precipitation intensity is very low.

Reservoir and evaporation capacity during very strong El-Nino period

El-Nino's very strong events occurred in 1982–1983, 1997–1998 and 2015–2016. In the El-Nino event this decline in reservoir capacity and increase in evaporation capacity is very extreme (Fig. 5). The volume of the reservoir water is so small that the water capacity of the reservoir can reach the minimum capacity. At the time of very strong El-Nino the reservoir cannot supply for irrigation water requirements because the water level of the reservoir is under the intake elevation. The correlation coefficient between decrease of reservoir volume and evaporation value is 0.636. Evaporation capacity increased from January to December on average of 0.0095·10^6 m^3, while reservoir deficit volumes of 50% reliability reached 8.85·10^6 m^3.

RELIABILITY

The existence of reservoirs is expected to provide multi-sector water requirements throughout the year. The reservoir is built with certain reliability based on the capacity of the storage and available to the irrigation water, domestic water, fisheries, tourism and water conservation. The

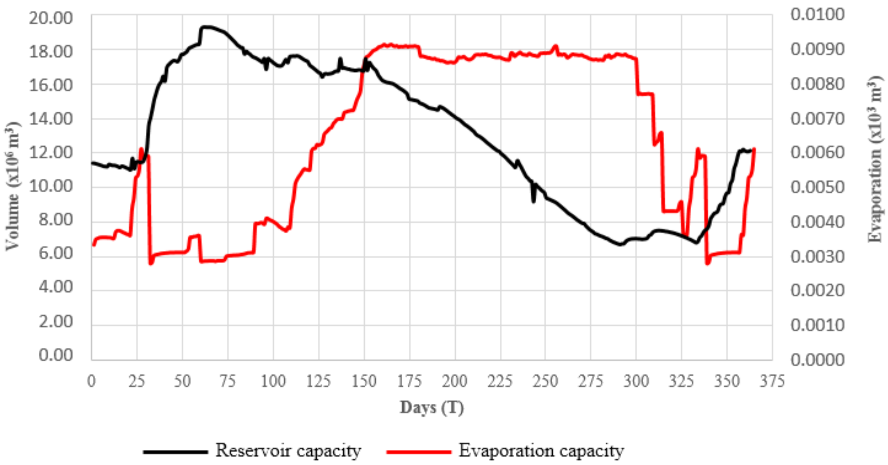

Fig. 3. The relationship between reservoir and evaporation capacity during weak El-Nino period; source: own study

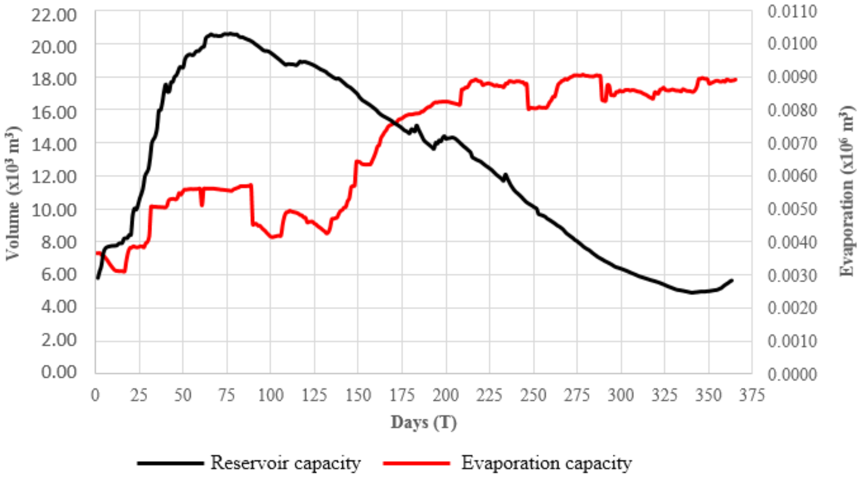

Fig. 4. The relationship between reservoir and evaporation capacity during moderate El-Nino period; source: own study

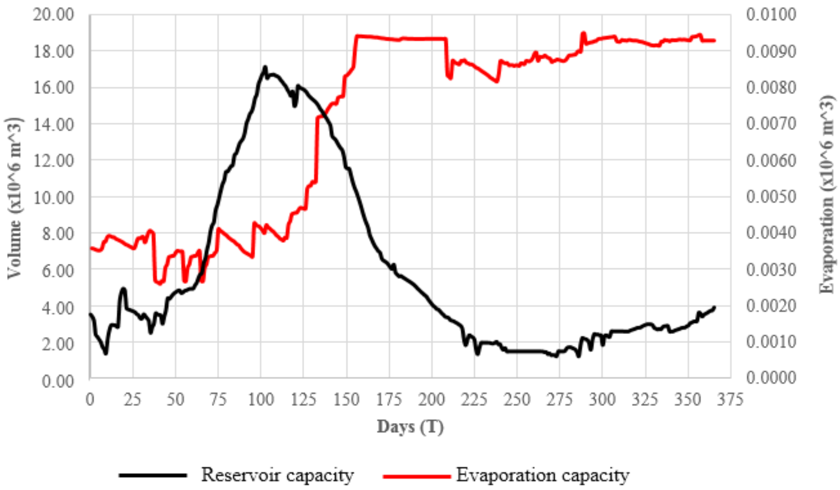

Fig. 5. The relationship between reservoir capacity and evaporation during very strong El-Nino; source: own study

occurrence of global climate change greatly affected the function of the reservoir mainly due to the El-Nino phenomenon. The reservoir capacity has a very extreme deficit due to unbalance between inflow and outflow from the reservoir. At 50% reliability there is a significant volume deficit of $-2.30 \cdot 10^6$ m^3: $6.58 \cdot 10^6$ m^3, and $8.85 \cdot 10^6$ m^3 for weak, moderate and very strong El-Nino.

Reliability of the reservoir during weak El-Nino

As shown in Figure 6 during weak El-Nino, the reservoir capacity with a 50% reliability did not have a significant deficit capacity. Decrease in reservoir volume occurs slowly but still exists at the limit of normal reservoir capacity. At 50% reliability, the reservoir capacity shows surplus from January to June and from July to December reservoir capacity deficit of $2.30 \cdot 10^6$ m^3.

Reliability of the reservoir during moderate El-Nino

Figure 7 shows, the condition of reservoir capacity during moderate El-Nino volume reservoir of surplus and deficit are almost balanced. On the reliability of 50% reservoir the surplus condition of $6.38 \cdot 10^6$ m^3 decreased slowly until June. The decrease in reservoir volume start in early July and the maximum deficit in December at $6.58 \cdot 10^6$ m^3.

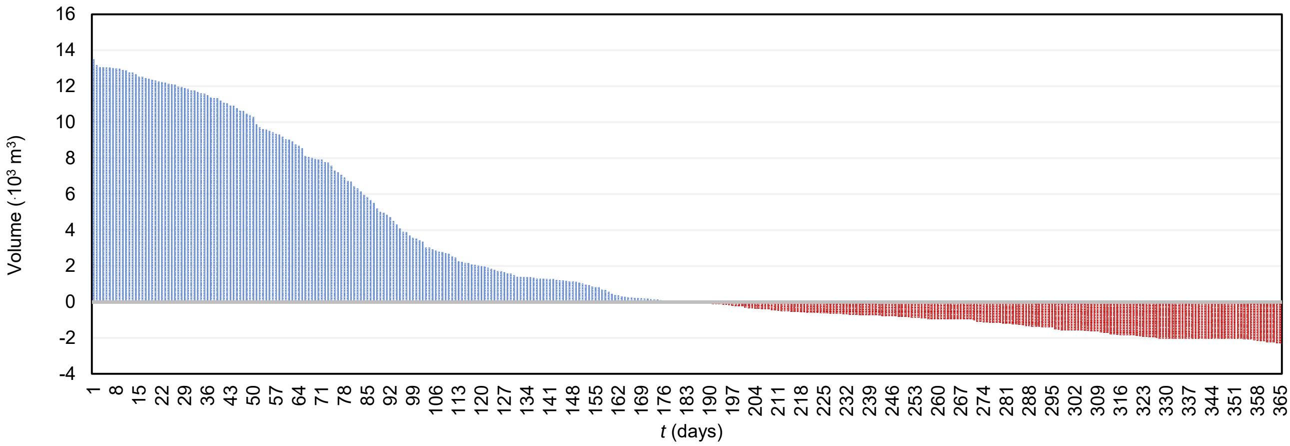

Fig. 6. Reliability of reservoir capacity during weak El-Nino; source: own study

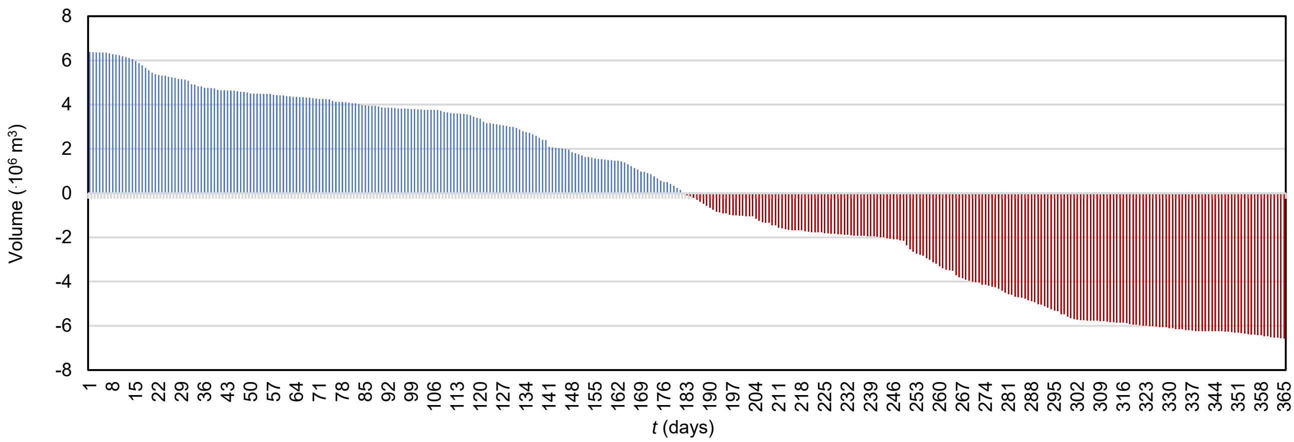

Fig. 7. Reliability of reservoir capacity during moderate El-Nino; source: own study

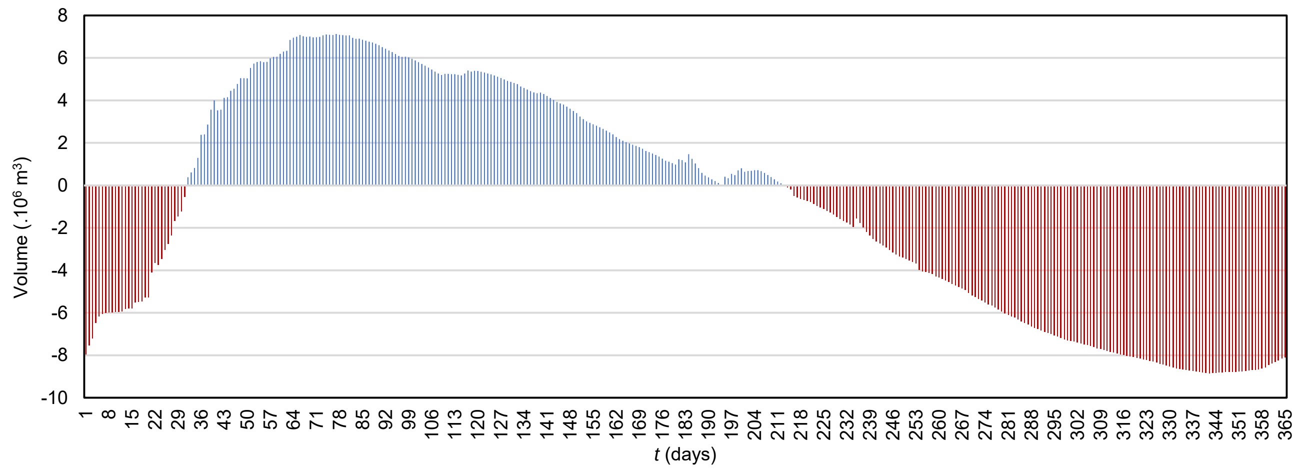

Fig. 8. Reliability of reservoir volume during very strong El-Nino; source: own study

Reliability of the reservoir during very strong El-Nino

Figure 8 shows reservoir capacity in the event of very strong El-Nino. Availability capacity and deficit on 50% reservoir reliability occur very extreme. Under these conditions, the dam has a maximum deficit of $8.85 \cdot 10^6$ m^3 in January and November. When the reservoir has a maximum deficit, the capacity reservoir is nearing dead storage capacity, so that the reservoir cannot supply for irrigation water requirements. The hydrological component occurring at that time is the maximum evaporation, minimum inflow and low precipitation.

CONCLUSIONS

Based on the analysis, El-Nino events have an impact on the hydrological component of evaporation, river flow and rainfall. There is a very strong correlation between the increase in evaporation and the decrease volume of the reservoir. El-Nino's characteristics greatly affect the period and value of evaporation and decrease of reservoir capacity. Increased evaporation and decrease of reservoir capacity showed the same pattern that when evaporation value began to increase at the same time the reservoir capacity decreased significantly. The correlation coefficient between evaporation value increase and decrease of reservoir volume are consecutively 0.828, 0.636, and 0.777 for El-Nino weak, moderate and very strong. At 50% reliability there is a significant volume deficit of $2.30 \cdot 10^6$ m^3: $6.58 \cdot 10^6$ m^3, and $-8.85 \cdot 10^6$ m^3 for weak, moderate and very strong El-Nino.

Based on these results, El-Nino events have a significant impact on decreasing the reliability of the reservoir especially if there is a moderate and very strong El-Nino. The supply of irrigation water requirements from reservoirs is very limited, so that there is a failure of the agricultural production process. The reliability of reservoir capacities in the period of El-Nino can be used for anticipation, especially the regulation and allocation of reservoir capacity.

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