FLOOD AND DROUGHT RISK ASSESSMENT ON EFFECTIVENESS OF PROPOSED INFRASTRUCTURES IN THE BA RIVER BASIN, FIJI

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ABSTRACT

Fiji is subjected to frequent water related hazards and requires implementation of preventive measures to reduce potential damages that may be caused by these events. The Ba River basin, selected for this study, is located in the Western part of the main island, Viti Levu, and has experienced severe floods and droughts, especially 1993 flood and 1998 drought. To assess the effectiveness of infrastructures on flood and drought reduction, past flood and drought hazards were investigated using numerical models with proposed infrastructure in the Ba River basin. Using the Block-wise TOP (BTOP) model, the simulated BTOP river discharges were calibrated with observed discharge data at the past flood events. From long-term calibrated BTOP model simulation, flood peak discharges of selected return period were estimated with flood frequency analysis and flood inundation simulations were conducted with Flood Inundation Depth (FID) model and compared with the flood inundation extent simulated by the Rainfall-Runoff-Inundation (RRI) model. The estimated flood inundation area and flood exposure with and without infrastructure were utilized for the flood risk estimation of 1993 flood damages. In 1993 flood, the flood inundation and affected people were estimated and found comparable with the historical flood inundation depth and records data. The result of investigating the two proposed flood retention dams with the 1993 flood event, which was 6-year return period flood indicated that the capacity of these two small scale dams are not effective for flood peak reduction at the downstream location near the Ba Town. For the drought assessment, the historical rainfall record at two rainfall gauging stations were utilized to estimate the Standardized Precipitation Index (SPI) and compared with the Standardized Precipitation Evapotranspiration Index (SPEI) to indicate precipitation deficit for the rainfed sugarcane agriculture. Investigating the alternative option proposed by JICA with BTOP model, the results show that a dam with 200 million cubic meter (MCM) capacity will be adequate in maintaining low flow during 8-month period of the 1998 drought.

Keywords: BTOP model, RRI model, flood peak discharge, SPI, SPEI.

INTRODUCTION

Fiji, which comprises of over 320 islands with a total land area of approximately 18,333 km^2, lies at the heart of the Pacific Ocean between 12° and 22° latitude South and 174° and 178° longitude West (Fig. 1a). The two largest islands are Viti Levu and Vanua Levu. The Ba River basin is situated on the north western part of Viti Levu and drains an area of 957 km^2 (Fig. 1b). The main river, Ba River, flows in a northwesterly direction, originating from the central mountainous parts of Viti Levu and discharging into the South Pacific, about 15 km downstream of Ba Town (Fig. 1c). The Ba River basin is home to approximately 18,500 inhabitants where 37 percent of the population are living in urban areas (i.e. Ba Town area) and the other 63 percent in the peri-urban areas, mostly settlements and villages (Fiji Bureau of Statistics, 2015). Flooding has been a common problem in Fiji, happening almost on annual basis. The Ba River has a long history of flood record dating back to 1871 occuring about 127 times from 1871 – 2009. Some of the disastrous floods in the Ba River basin were recorded in 1931, 1956, 1993, 1999 and 2009 (McGree et al., 2010). Reported damage during the 1993 flood amounted to FJ$17 million. Drought, on the other hand, is closely associated with the El Niño Southern Oscillation (ENSO) events. The worst

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drought recorded in Fiji's history was experienced during the ENSO phenomena of 1998 with many parts of the country recording 20% to 50% below average rainfall (Lightfoot, 1999). The national production loss of rain fed agriculture was estimated to be around 50% (FJ$104 million). The location of the Ba River basin, in the leeward side of Viti Levu, makes it susceptible to drought events. Agriculture has been always affected when there is a prolonged dry period in the basin. The severe drought in 1998 affected the population of Ba town and caused damages to agriculture, particularly sugarcane production. The Rarawai Mill in Ba recorded a loss of 21.80 km^2 of sugarcane, which was usually supplied by farms in the Ba River basin (Kaloumaira and Rokovada, 1998). Over the years the government of Fiji have implemented flood and drought counter measures such river dredging, construction of small check dams, early flood warning system for flood and supply of water and food rations, ENSO monthly outlook and supply of rainwater tanks for drought. Recently, proposal have been for the construction of 2 flood control dams as countermeasures for flooding in the Ba River basin. A study by JICA (1998) also proposed two multipurpose dams for flood reduction as wells as providing water supply during drought period. The main objectives of this study were to assess flood and drought risk in Fiji using global and locally available information and investigate the effectiveness for proposed infrastructure in reducing flood and drought risk.

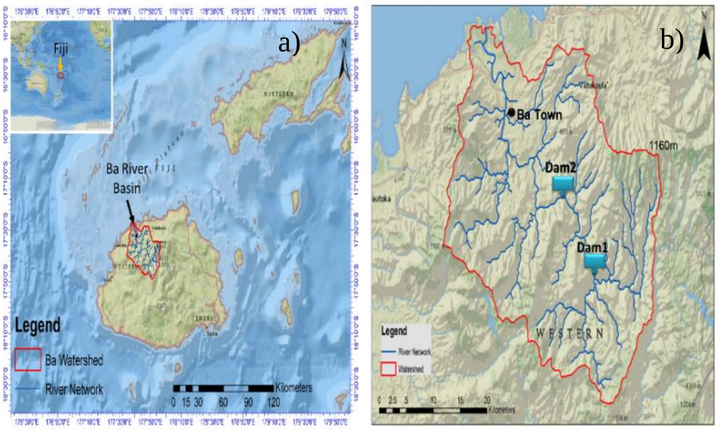

Figure 1: a) locality of the Ba River basin and b) the Ba River watershed. INSERT: geographic location of Fiji.

THEORY AND METHODOLOGY

The general approach of this study is based on quantifying the flood and drought hazard and investigating the effectiveness of proposed infrastructures on flood risk reduction using numerical model. The methodology was divided into two major components, flood risk assessment and drought risk assessment (Fig. 2). In flood risk assessment, the BTOP model was used to simulate long-term discharges in the Ba River basin, while RRI and FID were used for flood inundation. Using the simulated discharges of the calibrated BTOP model, the flood frequency analysis was generated to estimate the flood discharges for a 10-, 25-, 50, 100-, 200-, 500-, and 1000-year return period floods. The estimated flood inundation area and flood exposure with and without infrastructure was utilised for flood risk estimation. For drought risk assessment, the monthly historical rainfall record at selected station was utilised to estimate the Standard Precipitation Index (SPI). The computed SPI was compared with the global Standardized Precipitation Evapotranspiration Index (SPEI).The SPI and SPEI quantifies the risk of precipitation deficit which correspond to the affected agriculture in the Ba River basin during the drought period. Infrastructures were also investigated for maintaining low flow during drought.

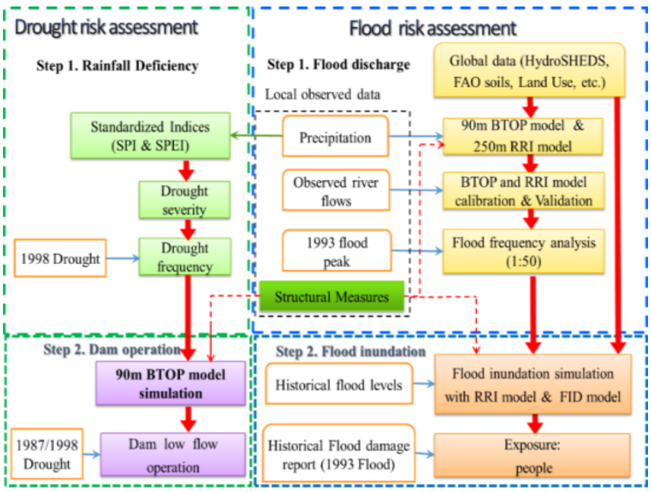

Figure 2: Methodology for flood and drought risk assessment in the Ba River Basin.

Drought Indices

Drought indices are quantitative measures that characterize drought levels by adjusting data from one or several variables such as rainfall, snowpack, stream flow as indicators, into a single numerical value. Such indices are more useful to drought planners than raw data (Zargar et al., 2011). Some drought indices are better suited for certain region. The SPI and SPEI, were used in this study as drought indices. Monthly rainfall data is required as input for the estimation of SPI, whereas SPEI requires both rainfall and evapotranspiration as input.

Hydrological Model (BTOP and RRI)

The BTOP and RRI models are utilized to perform simulations of rainfall-runoff, soil moisture and river discharge processes on different basin scale. The BTOP model uses a redefined topographical index by Takeuchi et al. (2008) for river discharge simulations and is suitable for the investigation of dam infrastructure effectiveness in various basins (Gusyev et al., 2015).

The RRI model is a two-dimensional distributed model that can simulate rainfall runoff and flood inundation concurrently (Sayama, 2014). The model calculate flow and inundation parameters such as discharge and height of water at each grid cell within the river basin. The RRI model simulates flows on land and in the river and their relation at a river basin scale, where Two-Dimensional diffusive (2D) wave model is used to calculate flow on a slope, while channel flow is calculated with One-Dimensional (1D) diffusive wave model.

DATA

The setup of the hydrological models such as BTOP and RRI requires topographical data of the river basin such as digital elevation model (DEM), flow direction (FD), flow accumulation (FACC), land classification data (e.g. land cover and soil classification) as well as hydro-meteorological data like precipitation, evapotranspiration and observed discharge. The topographical data of the Ba River basin was obtained from HydroSHEDS (Fig. 4a), while land cover (Fig. 4b) and soil classification (Fig. 4c) were extracted from the Global Land Cover Characterization (GLCC) and Food and Agriculture Organization (FAO) global soil database, respectively. The daily precipitation data, from the 1984 – 1999, were obtained from seven gauging stations. The observed discharges, used for the BTOP and RRI calibration and validation were obtained from Toge and Navala stations (Fig 4a). The population dataset, downloaded from the Fiji Bureau of Statistics website, is based on the 2007 population census.

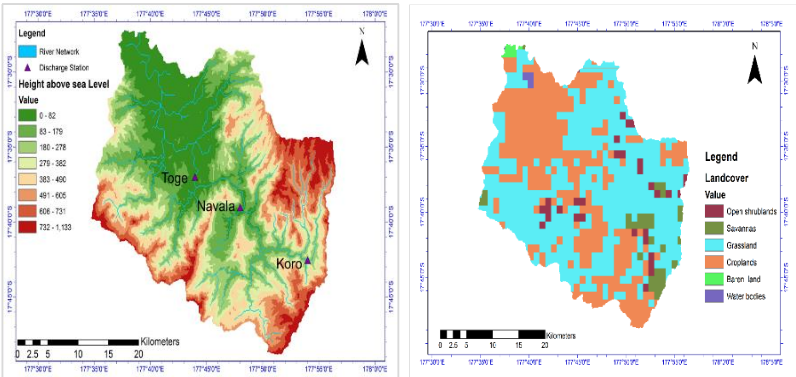

Figure 3: a) DEMand b) land cover classification.

RESULTS

Long-term River Discharge Simulation

The river flow at the Ba River basin was simulated for a period of 15 years, from January 1984 to December 1999. Within these simulation period, the observed discharges were recorded from 1984 to 1992. The 1984 flood event was selected for short-term calibration of BTOP and RRI model (Fig. 4). The long-term the calibration period was from 1984 -1987, for BTOP and RRI, while 1988–1992 was selected as validation period (Fig. 5). The BTOP model was able to simulate both high and low flow discharges. The annual flood peak discharges from the BTOP simulation was used for flood frequency analysis to determine the return period of 1993 flood as well as design discharge for 1 in 25-, 50-, and 100-, 200-, 500- and 1000-year flood (Table 1).

Table 1: Frequency Analysis at Toge station.

Return Period	Flood Discharge (m^3/s)
25	1983
50	2260
100	2573
200	2812
500	3176
1000	3451

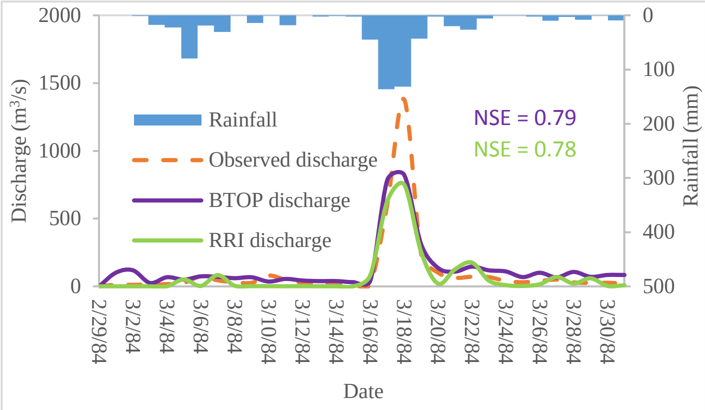

Figure 4: Short-term calibration at Toge station for 1984.

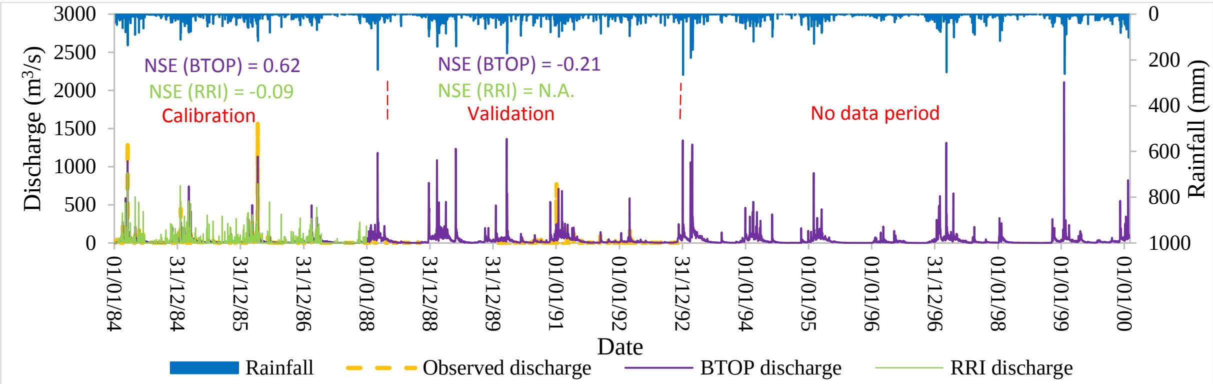

Figure 5: Long-term simulation of BTOP model at Toge station from 1984 to 1999.

Flood Inundation and Exposure in 1993 Flood

Using the BTOP simulated discharges as boundary conditions, the RRI model was used to simulate flood inundation for 1993 flood (Fig. 6a) and the results were validated with Landsat image (Fig. 6b) as well as observed flood inundation depth (Fig. 6c) at Rarawai mill (2.16 m) and Ba town (2.13 m). The FID model was simulated with flood peaks of 25-year return period and resulted in a similar flood inundation extent produced by RRI model. However, additional cross-checking with field data is needed for the estimation of flood hazard maps of different return periods. Therefore, the RRI flood inundation was used for estimation of flood exposure in the Ba River basin. The simulated flood exposure in terms of affected population (12,426 people) in the 1993 flood compares reasonably well with the past record of affected people (10,585 people) derived from the JICA study (1998).

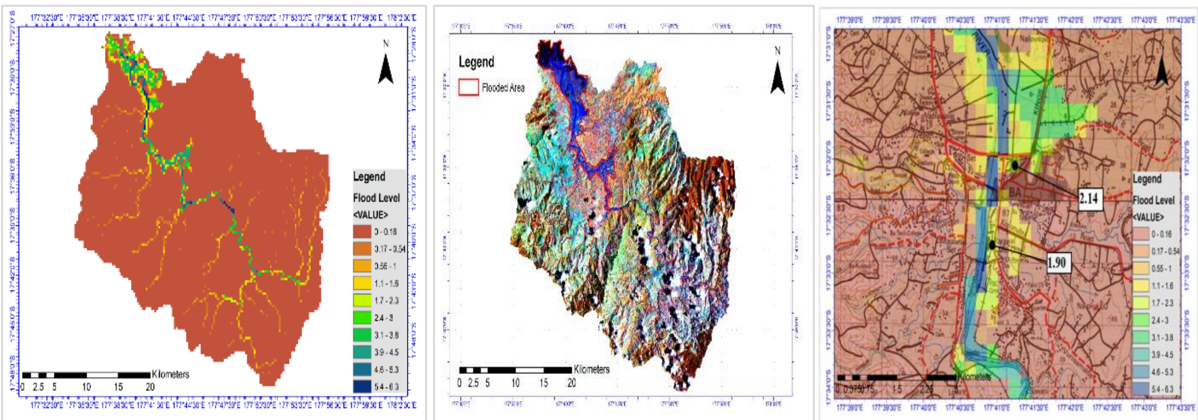

Figure 6: a) RRI simulated flood inundation, b) Landsat image flood extent and c) simulated inundation depth at Rarawai mill and Ba Town.

Quantification of Drought Hazard

The SPI have similar behavior as the SPEI, especially during drought historical drought period in Fiji. The SPI values, for different timescale at Ba Filter station can identify the type of agriculture that is likely to be affected. The 1998 drought, was well represented by the 3-month SPI & SPEI values (< -2) for Ba Filter station (Fig. 7). The 1998 drought is categorized as an extreme drought with the 1 in 48 years return period.

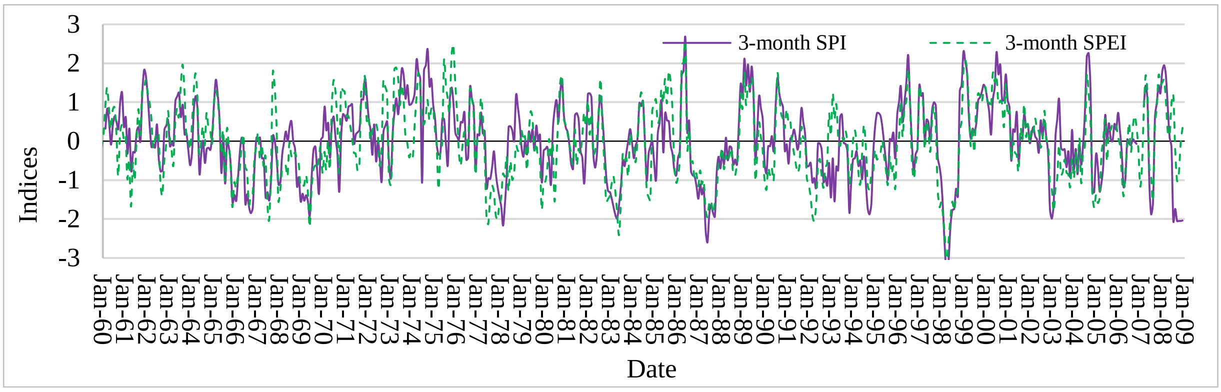

Figure 7: 3-month SPI and SPEI at Ba Filter station.

Effectiveness of Proposed Infrastructures

Flood Peak Reduction: The simulated dam inflow and outflow of the proposed 0.95 MCM capacity dam are able to reduce flood peaks of less than 2-year flood peak as shown in Fig. 8a. This indicate that the government proposed infrastructures are not effective for flood control in the Ba River basin.

Drought Water Supply: Two multipurpose dams proposed in the JICA (1998) was also considered in this study as a possible alternative design, with the purpose of flood control as well as providing water supply during drought period. Simulating different dam capacities with the assumed outflow of 9.23 m^3/s, it was found that the 200 MCM dam capacity will be suitable for maintain low flow during an extreme drought period similar to that of 1998 drought in the Ba River Basin (Fig. 8b).

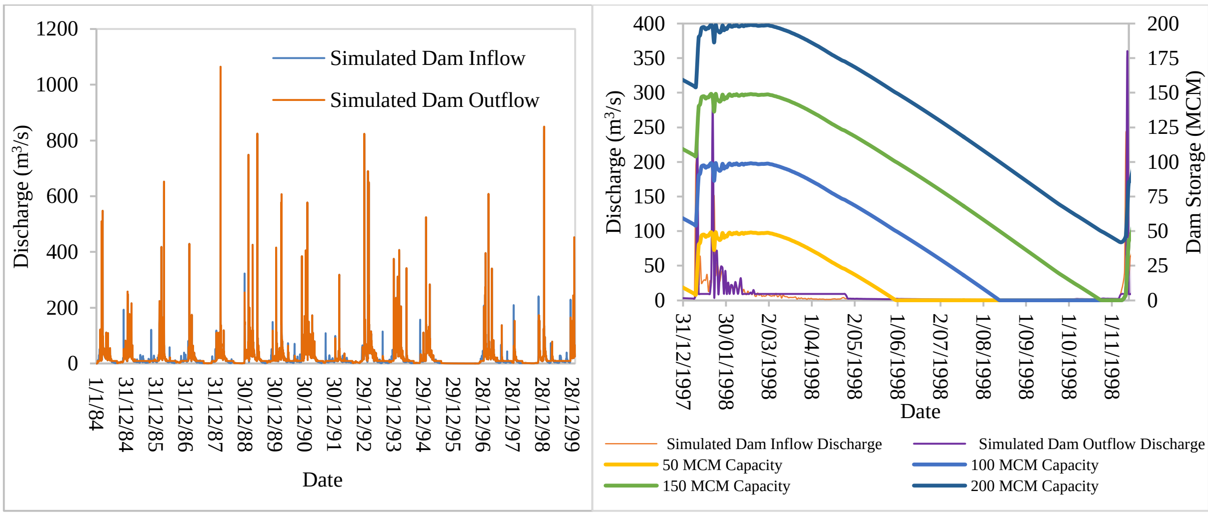

Figure 8: a) Flow through dam (proposed) and b) storage capacity of water supply dam (option).

CONCLUSION AND RECOMMENDATIONS

In the absence of long-term historical flood discharge for quantifying flood hazards in the Ba River basin, the numerical simulation models such as BTOP, RRI, and Standardized Indices (SPI and SPEI) provide a suitable alternative in quantifying flood and drought hazards in the Ba River basin. The BTOP is suitable for flood forecasting in the Ba River basin, the RRI model can be used for near real-

time flood inundation simulation. the current capacity (0.95 MCM/dam) of these two small scale dams are too small and are not effective for flood control in the Ba River basin as these two dams are only effective in reducing small flood peaks with 2 year return period. The 200 MCM capacity dams will be suitable for maintaining low flow during drought period. This study has also shown that the numerical simulation models can be a useful cost effective tool for the government of Fiji in assessing the effectiveness of proposed infrastructures for flood and drought risks reduction in the Ba River basin.
Further studies are required for assessing flood and drought risk with regards to damages to agriculture in the Ba River Basin, investigating the effectiveness of cascading small dams and analysis of other flood and drought countermeasures. Further improvement of the FID model is also necessary for the production of static flood hazard maps.

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