FLOOD INUNDATION ANALYSIS IN LACLO RIVER BASIN MANATUTO MUNICIPALITY, TIMOR LESTE FOR EFFECTIVE COUNTERMEASURES

Ligia Mediadora Amaral Soares* **MEE22716**

Supervisors: Dr. Daiki KAKINUMA**
Associate Prof. MIYAMOTO Mamoru***
Prof. OSANAI Nobutomo****

ABSTRACT

Flooding remains a significant natural hazard in many regions worldwide, including the Laclo River Basin (LBR) in Manatuto Municipality, Timor Leste. The increasing frequency and severity of flood events have raised concerns about vulnerability of communities, infrastructures and ecosystems in the basin. To address these pressing issues, a comprehensive flood inundation analysis was conducted to identify countermeasures for mitigating flood impacts. The Laclo river basin (LRB) is the second-largest river in Timor Leste. It is located in Manatuto Municipality and experiences near-annual flooding, which causes damage and interferes with everyday life. Flood damage occurs every year and flood countermeasures are insufficient. Structural countermeasures, such as embankments, have been implemented at several locations in the downstream area to reduce the impact of flooding; however, nonstructural countermeasures, such as flood early warning systems, are not yet well established in LRB. Flood inundation maps are essential for effective flood risk management. The hydrological method used in this study was the rainfall-runoff-inundation (RRI) model, which was employed for simulation to develop an inundation map, analyze the effectiveness of existing countermeasures, and propose new mitigation measures for future development. Flood simulations were conducted for various flood scales based on stochastic rainfall to understand how the spatiotemporal distribution of rainfall influences the extent of flooding and inundation depth. Flood events on April 4, 2021, were used in this study. Flood control with structural countermeasures should be implemented to prevent and reduce socioeconomic losses. To develop a new rainfall-runoff inundation model and perform a risk analysis, in addition to calculating statistical rainfall, considering future rainfall prediction data.

Keywords: Laclo River Basin, Flood Inundation, RRI Model, Risk Analysis, Countermeasures

INTRODUCTION

The Republic Democratic of Timor Leste (RDTL) is one of the tropical countries located in Southeast Asia with a population of 1.34 million people (Population Census Timor Leste 2022) and a total area of 14,874 sq. km. The topography is generally steep and the climate is tropical, hot, and humid, with distinct rainy and dry seasons. The rainy season extends from December to May, whereas the dry season extends from June to December. A notable flood impact was experienced in 2021 when the Tropical Cyclone Seroja made its way into Australia and Indonesia, resulting in 46 fatalities and an estimated damage of US$ 300 million (The Interpreter, 2021). The country is highly vulnerable to water-related disasters such as floods, tropical cyclones, landslides, and droughts. Among these, floods are one of the most frequent and have the most severe impact on lives, livelihoods, and the economy in Timor-Leste.

* National Directorate of National Directorate of Construction and Roads under the Ministry of Public Works (MPW), Timor Leste.

** International Center for Water Hazard and Risk Management (ICHARM), PWRI Tsukuba, Japan.

*** Professor, National Graduate Institute for Policy Studies (GRIPS), International Center for Water Hazard and Risk Management (ICHARM), PWRI Tsukuba, Japan.

**** Professor, National Graduate Institute for Policy Studies (GRIPS), Tokyo Japan.

Figure 1. shows that the study area of the LRB covers approximately 1,386 sq. Km. The major population centers in the Laclo River catchment, from southwest to northeast, are Aileu, Liquidoe, Remexio, Laclo, and Manatuto. The catchment land is mainly mountainous, with urban and agricultural areas. In 2021, LRB overflowed, resulting in two fatalities, four cases of missing people, and damage to around 791 households (source: Ministry of Solidarity Social Timor Leste) and agricultural land. Therefore, we selected 2021 events as a case study to analyze the effectiveness of existing countermeasures and propose new countermeasures. The study aims to calculate the damage assessment based on the flood extent and inundation depth for flood disaster mitigation and develop flood inundation maps for flood risk management.

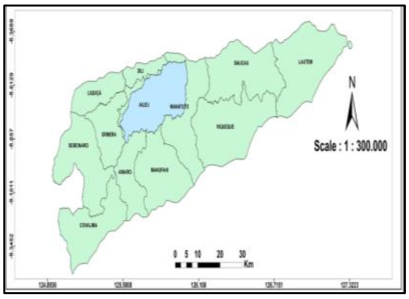

Figure 1: Location of Study Area

THEORY AND METHODOLOGY

The research methodology adopted in this thesis follows an end-to-end approach, as depicted in Figure 2, which links science, technology, engineering solutions, socioeconomic considerations, and decision-making based on evidence-based approaches. The study's methodology utilizes the rainfall-runoff-inundation (RRI) model for hydrological analysis, which is divided into five parts: model setup, identification of high flood risk areas, development of flood scenarios, identification of necessary countermeasures, and propose effective control measures. The simulation was done by using the inundation map due to the lack of the hydrologic data (water level and flow rate). By calibrating the model, historical inundation maps for the flood event in 2021 were developed. Subsequently, extreme value for design rainfall were calculated based on the recorder data.

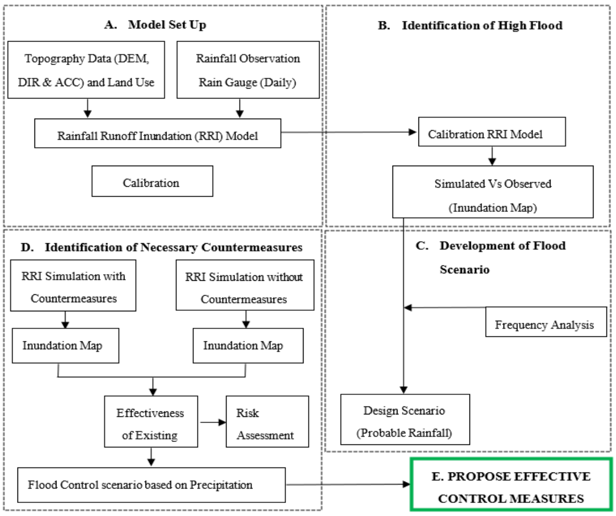

Figure 2: Methodology framework

Using this calculated rainfall pattern for designing the return period and calibrated model parameters, flood inundation scenarios with and without countermeasures were developed. The effectiveness of these countermeasures was evaluated by comparing the inundation extent and inundation flood depth. Additionally, damage information important to analyze risk assessment and the effectiveness of mitigation measures were assessed. New additional countermeasures useful for inundation scenario results were compared to determine the effect of these countermeasures. Then selected and proposed the most appropriate project for flood mitigation in the near future.

DATA

For the purpose of this study, daily meteorological data were obtained from 2010 to 2022. The dataset was obtained from the National Authority of Water and Sanitation (Autoridade Nacional Agua e Saneamento, Impresa Publico). Additionally, topographic data were obtained in the form of a Digital Elevation Model (DEM) and land-use data. The locations of the meteorological stations are shown in Figure 3. The DEM used in this study had a resolution of 100 m and was obtained from a Lidar survey conducted in 2019 and land cover data were obtained from a survey conducted in 2020 by the Institute of Petroleum and Geology (IPG) Timor Leste.

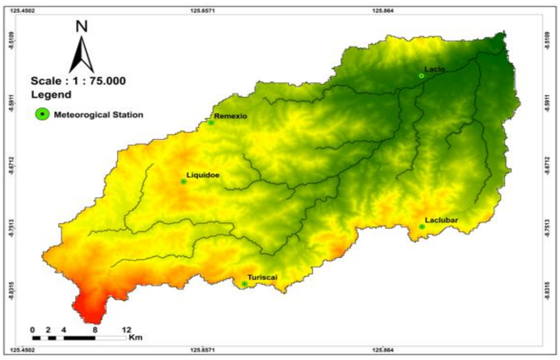

Figure 3: Location of Meteorological station

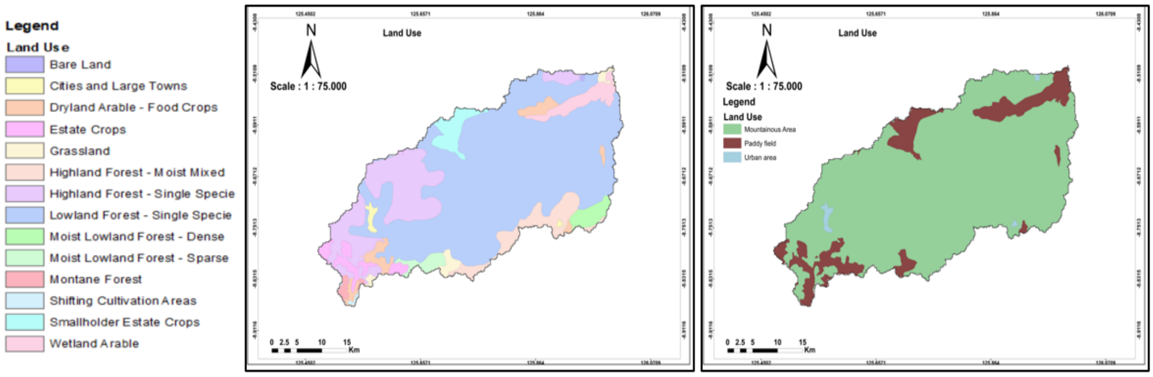

Figure 4: Original Land Use had 14 Classifications, as shown on the left side and was reclassified into 3 Classifications as shown on the right side

Figure 5: Countermeasures used for 25-year return period and 200-year return period.

The structural countermeasures used for this study case are embankments with an assumption of a bank height of 2 m for the Laclo main river in the downstream area Manatuto for distances about 4 Km. Further validation and improvement in the method employed in this study using updated data is warranted.

RESULTS AND DISCUSSION

1. RRI Model for 2021 Events and Calibration Compared to the Actual Measurement

The result of the inundation area calculation by the model generally represents the actual inundation area. In this study, the target location was a downstream area. The effectiveness of the existing countermeasures in terms of inundation against the 2021 food events is shown in Figure 6. According to the inundation analysis, the 2021 flood events is shows in the right side of figure 6. The result of the inundation area calculation by the model generally represents the actual inundation area.

This figure displays the observed flood map on the left and the simulated inundation map on the right, both obtained from the calibrated model using the flood event of 2021.

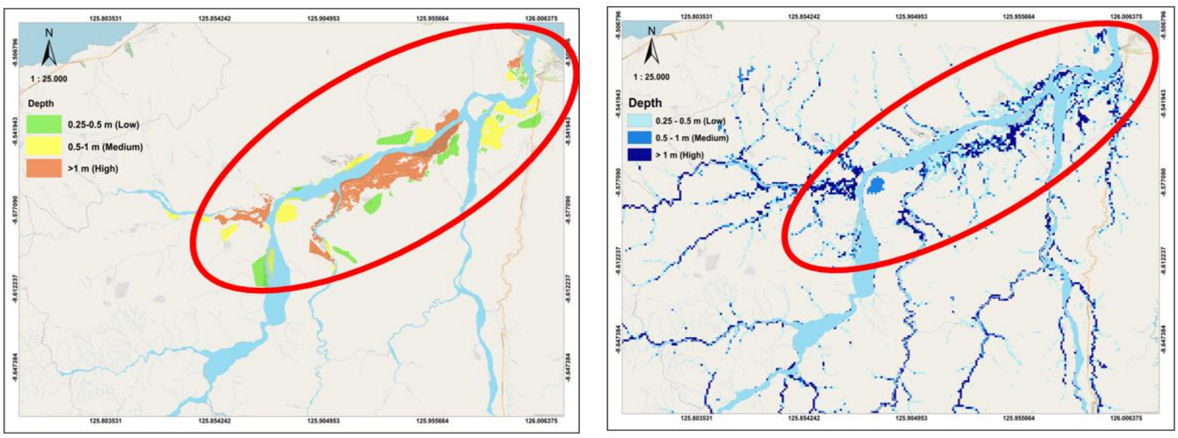

Figure 6: Comparison between the observed flood map for the year 2021 on the left side and the simulated inundation depth map on the right side. These maps were utilized for model calibration

2. Calculated statistical rainfall result (with return period for the 2021 event)

For the design proposal of the structural countermeasures, 2-day average maximum rainfall was considered. The table displays the rainfall values for the 5-, 25-, 50-,100- and 200-year return periods based on the Gumbel and GEV methods using the recorder data for 2-day maximum rainfall. Furthermore, the figures illustrate the relationships between extreme values, return periods, and non-exceedance probabilities. The Gumbel distribution is represented by a straight line and the GEV method is represented by a curved line. In this study, the Gumbel Distribution was used to analyze the designed rainfall pattern.

Return Period	2-day Max rainfall (mm)	
	Gumbel – PM	GEV
5-year	147.8	99.2
10-year	188.8	133.0
25-year	240.6	207.7
50-year	279.1	301.9
100-year	317.2	449.8
200-year	355.3	682

The table shows the 2-day Max rainfall (mm) for 5-, 10-, 25-, 50-, 100- and 200-year return periods.

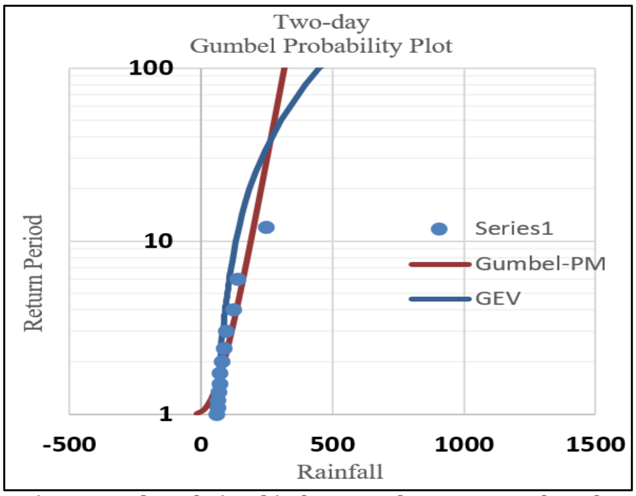

Figure 7: The relationship between the extreme value, the return periods and the non-exceedance probability

3. Results when using statistical rainfall (25- and 200-year periods)

The main purpose of this study was to develop a flood hazard map for flood risk management using RRI model simulation. The other purpose was to examine the effectiveness of existing countermeasures constructed in recent years, which was proven by comparing the inundation extent and inundation depth based on the different conditions with and without countermeasures. In this study, simulated to 25- and 200- years return periods. Here is why 25- and 200-years return period. Events of a 25-year return period are relatively less severe than 2021 flood event due to 2021 flood event 2-day maximum annual rainfall is 315.5 mm/day and Events of 200-year return period is higher than 2021 flood event. These two events have significant damage to infrastructure, human live and agriculture land.

1. 25-year return period (a) with and (b) without countermeasures

   (a) with countermeasures (b) without countermeasures

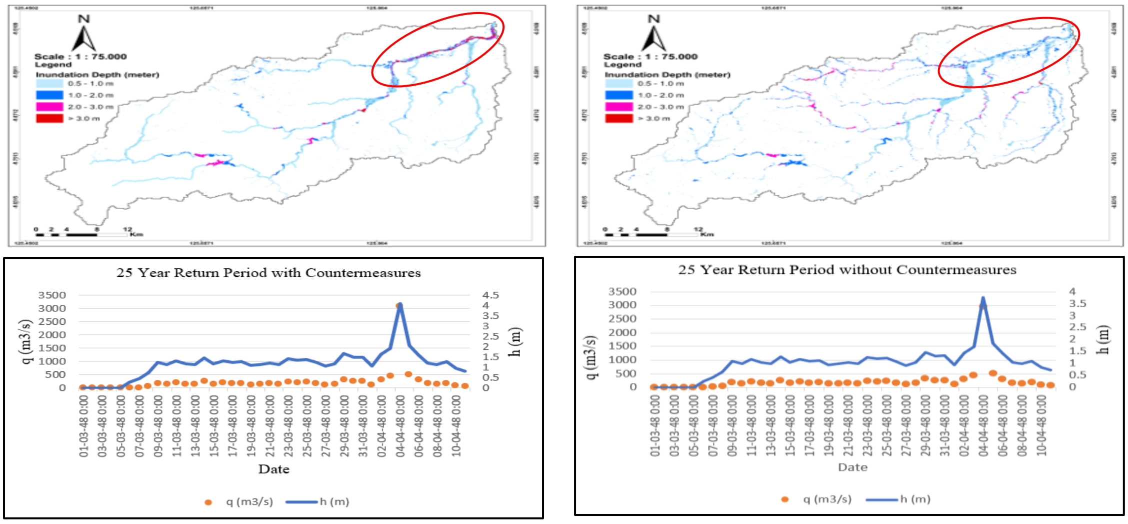

Figure 8: Simulation inundation extent and inundation depth for (a) 25-year return period with countermeasures and (b) 25-year return period without countermeasures

2. 200-year return period (a) with and (b) without countermeasures

(a) with countermeasures (b) without countermeasures

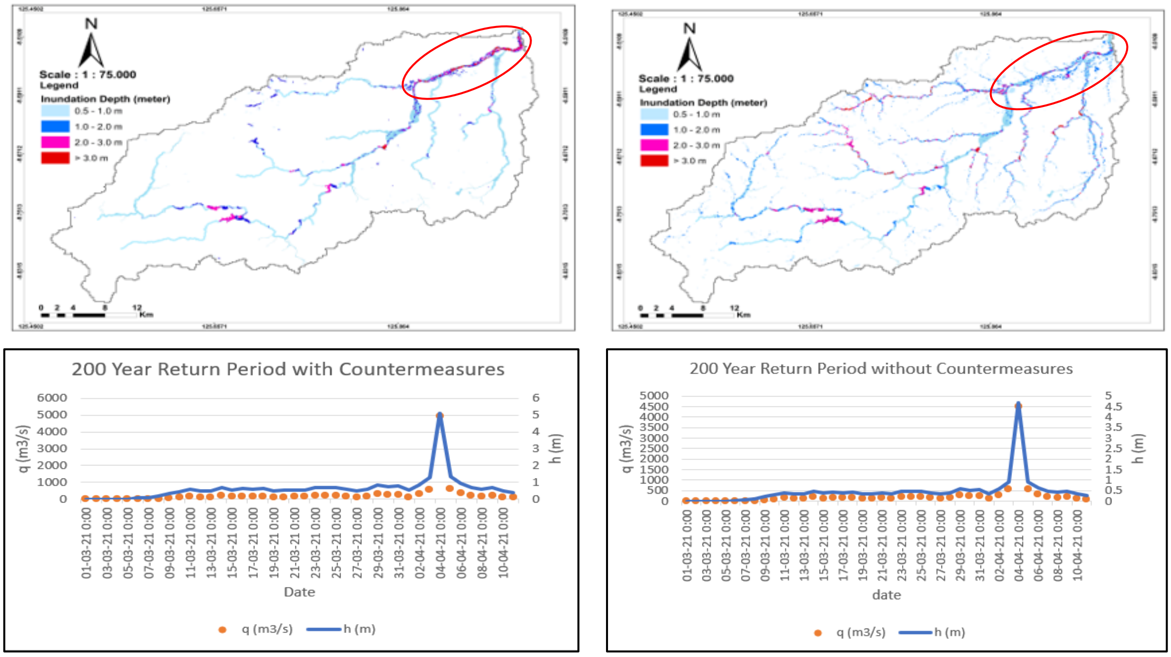

Figure 9: Simulation inundation extent and inundation depth for (a) 200-year return period with countermeasures and (b) 200-year return period without countermeasures

4. Risk Assessment

In this study, the risk assessment focused on estimating flood losses by considering damage to agricultural paddy fields and household. According to the inundation analysis, the 2021 flood event could reduce the flooding area and proposed that it could be reduced with countermeasures for 25- and 200-year return period floods. The analysis aimed to calculate the potential impact of flood with 25-year and 200-year return period design rainfall in the basin area.

1. 25-Year Return Period with and without Countermeasures

25- Year Return Period with Countermeasures				
Inundation Depth	Inundation Area (Km2)	Houses Affect	Population Affect	Agriculture (Paddy Field) (Km^2) Affect
0.50 – 1.0 m	4.1	65	260	1
1.0 – 2.0 m	1.2	25	100	0.4
2.0 – 3.0 m	0.5	5	20	0
3.0 – 4.11 m	0	0	0	0
Total	**5.8**	**95**	**380**	**1.4**
25-Year Return Period without Countermeasures				
Inundation Depth	Inundation Area (Km2)	Houses Affect	Population Affect	Agriculture (Paddy Field) (Km^2) Affect
0.50 – 1.0 m	8.25	133	532	1.2
1.0 – 2.0 m	3.15	70	280	0.68
2.0 – 3.0 m	1.5	15	60	0.03
3.0 – 3.76 m	0	0	0	0
Total	**12.9**	**218**	**872**	**1.91**

2. 200-Year Return Period with and without Countermeasures

200-Year Return Period with Countermeasures				
Inundation Depth	Inundation Area (Km2)	Houses Affect	Population Affect	Agriculture (Paddy Field) (Km^2) Affect
0.50 - 1 m	4.9	58	232	1.85
1-2 m	2.5	22	88	0.5
2-3 m	1.9	7	28	0
3-5.0 m	0	0	0	0
Total	**9.3**	**87**	**348**	**2.35**
200-Year Return Period without Countermeasures				
Inundation Depth	Inundation Area (Km2)	Houses Affect	Population Affect	Agriculture (Paddy Field) (Km^2) Affect
0.50 - 1 m	10.2	650	2600	3.25
1-2 m	5.4	350	1400	2.8
2-3 m	3.7	52	208	0.5
3-4.70 m	0	0	0	0
Total	**19.3**	**1052**	**4208**	**6.55**

This table shows that the risk assessment for the 25-year return period with and without countermeasures and the 200-year return period with and without countermeasures are significantly different and reduce.

CONCLUSIONS AND RECOMMENDATIONS

LRB is important for agriculture because farmers cultivate paddy fields using its water. However, during the monsoon season, severe floods inundate flood-prone areas due to heavy rainfall. The capacity of a river to carry excess water is insufficient, leading to flooding along its banks. This study aimed to analyze the effectiveness of existing flood mitigation measures, propose new countermeasures, and create flood inundation maps to manage flood risk. The RRI model was calibrated to represent the conditions of the study area. The designed rainfall patterns were developed for 25- and 200-year return periods. The model was also simulated with and without countermeasures, especially targeting the 25- and 200-year return periods for extreme rainfall. The results of the inundation areas were compared to evaluate the effectiveness of the mitigation measures. We estimated flood damage, especially agricultural and household losses. New structural countermeasures were proposed for the river system, and flood scenarios were simulated to select the most suitable mitigation measures for future development. This study emphasizes the importance of damage assessment for effective disaster management and the development of new countermeasures. Flood control measures should be implemented to mitigate flood risks in the LRB, including the rehabilitation of existing countermeasures in downstream, the construction of levees in the downstream, and the construction of a dam for flood control in the upstream area. The reliability of the study results depends on the accuracy of the data, proper model setup, calibration, and validation. Enhanced inputs and additional information are crucial to ensure highly accurate and realistic outputs. The findings of this study can be valuable for local and national governments involved in planning river management and policymaking related to flood disaster management; however, it is recommended that the study be reevaluated with updated and more reliable data for a better and more realistic assessment. Structural (infrastructure) and nonstructural (planning control) approaches are essential for future flood mitigation. Structural measures include rehabilitating existing embankments and constructing levees and dams for flood control. Non-structural measures involve installing effective early warning systems, especially in the Laclo and Manatuto areas; installing stations such as water levels and discharges in the LRB, and enforcing proper land use management and forest and watershed protection. Regular updates on flood hazard maps and the promotion of flood disaster risk awareness campaigns and education can enhance community resilience. Additionally, conducting field observations and damage surveys after flooding is critical for accurately assessing the determined damage ratios. Finally, this study can be used as a reference for understanding the situation of the basin area and for studying other similar basins. The methods used in this study can be replicated or improved to address various objectives in another basin.

ACKNOWLEDGEMENTS

I express my sincere gratitude to my respected supervisors Dr. Daiki Kakinuma, Associate Professor Miyamoto Mamoru and Professor Osanai Nobutomo for their valuable advice and guidance during this thesis. My gratitude extends to Aida sensei, the Professor for the innovative comments and to all researchers from ICHARM for their remarks.

REFERENCES

SAYAMA, Takahiro. Rainfall-Runoff-Inundation (RRI) Model User’s Manual. Tsukuba International Center for Water and Risk Management (ICHARM), 2012.

Sayama, T., Ozawa, G., Kawakami, T., Nebesaka, S., & Fukami, K. (2012). Rainfall-runoff-inundation analysis of the 2010 Pakistan flood in the Kabul River basin. Hydrological Sciences journal.

Tessema, S. M. (2011). Hydrological modeling as a tool for sustainable water resources management: a case study of the Awash River basin (Doctoral dissertation, KTH Royal Institute of Technology).

Almeida, R. A., Pereira, S. B., & Pinto, D. B. (2018). Calibration and Validation of the SWAT hydrologicalmodel for the Mucuri River Basin.

Center for Excellence in Disaster Management & Humanitarian Assistance CFE-DM-DMRH-Timor-Leste2022 www.CFE-DMHA.org.

TLDD Base de Dados Disasters Timor Leste http://tldd.mss.gov.tl/

The study on community-based integrated watershed management in Laclo and Comoro River basins in the Democratic Republic of Timor-Leste: Final report; Vol. 2. -Watershed management planning guideline s (jica.go.jp)

David R. Maidment,” Handbook of Hydrology Chapter 18 Frequency Analysis of Extreme Events

Cunnane, C.,” Statistical Distribution for Flood Frequency Analysis, Operational Hydrology Report No. 33, World Meteorological Organization WMO No. 718.