FLOOD MITIGATION RECOMMENDATIONS
Report

STRENGTHENING CLIMATE INFORMATION AND EARLY WARNING SYSTEM IN CAMBODIA TO SUPPORT CLIMATE RESILIENT DEVELOPMENT AND ADAPTATION TO CLIMATE CHANGE

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Acknowledgement

The present report is developed by People in Need (PIN) Cambodia as part of the ongoing project *"Strengthening Climate Information and Early Warning Systems in Cambodia to Support Climate Resilient Development and Adaptation to Climate Change"*. This Action falls under the Cambodia Climate Change Alliance (CCCA) – Phase 3. CCCA is a joint initiative of the Royal Government of Cambodia and development partners to address climate change in Cambodia. It provides a unified engagement point to pool resources for the mainstreaming of climate change into national and sub-national policies and programmes.

People in Need (PIN) would like to sincerely thank all those who facilitated the work and research behind the development of this study, including the Battambang Municipality; the Provincial Committees for Disaster Management (PCDM) working under the National Committee for Disaster Management (NCDM); the Department of Water Resources and Meteorology of Battambang (PDWRW) working under the Ministry of Water Resources and Meteorology (MOWRAM).

All of them have always supported PIN and facilitated first and secondary data collection, while proving useful insights and inputs for developing the present study through a participated and informed approach at all stages.

Executive Summary

Cambodian cities are highly underprepared to forecast, adapt and respond to these hazards, where the effects are further exacerbated by growing urbanization; a process that perturbs the natural hydrological cycle and enhances flood peaks by additional rainfall-runoff. Climate change is intensifying natural hazards, as higher temperatures lead to more sporadic weather patterns, predicted to increase the frequency and magnitude of extreme hydrometeorological events. **Flooding events can harm sustainable development** because of their recurrent and cyclical negative impacts. When inappropriately mitigated, floods damage investments in infrastructure, harm economic prosperity of those living in at-risk areas, cause deaths and can lead to the spread of water-borne diseases.

The present paper presents the key findings of the study conducted by PIN under CCCA funds and includes recommendations to Cambodian duty bearers on how to improve flood management in Battambang, supporting the decision-making process.
Specifically, to support the scientific calculation of disaster risk, the mentioned study produced **high-resolution topographic data, Digital Elevation Models (DEMs)** to predict the spatial distribution of impacts caused by natural hazards flood through a process known as **flood modelling**. Prek Preah Sdach, Rottanak, Wat Kor, Toul Ta Ek and Chomkar Somraong communes resulted to be the areas of greatest absolute flood hazard among the 9 at-risk communes that were object of the study.

Preliminary findings of the study informed PIN's identification of the most suitable sites where to install early warning infrastructures such as **fixed public speakers in Battambang**, being the first urban early warning system created in the country.

Based on project's achievements and lessons learned as well as on findings from the study, the paper finally presents a set of actionable recommendations focusing on two ways to protect lives and properties from flooding: *keep floodwater away from people* (mainly through structural measures or urban green measures); *keep people away from floodwater* (mainly through non-structural measures). Both ways are incorporated in feasible solutions with the ultimate goal of supporting disaster management decision makers in controlling the overall flood disasters (in the sense of being prepared for a flood, and to minimize its impact) in Battambang city.

Contents

Acronyms

CCCA: Cambodia Climate Change Alliance

CCDM: Commune Committee for Disaster Management

DCDM: District Committee for Disaster Management

DEM: Digital Elevation Model

DSM: Digital Surface Model

DTM: Digital Terrain Model

FRM: Flood Risk Management

GNSS: Global Navigation Satellite System technology

MoWRAM: Ministry of Water Resources and Meteorology

NCSD: National Council for Sustainable Development

PCDM: Committees for Disaster Management

PDWRM: Department of Water Resources and Meteorology Battambang province

RTK: Real-Time Kinematic

SP: Spatial planning

UNDP: United Nations Development Programme

VDMG: Village Disaster Management Group

Section I. Floods in Cambodia

Cambodia is one of the most disaster-prone countries; floods are amongst its greatest hazards. Dam-induced floods are becoming more frequent in Cambodia. These types of floods are caused by water being released without warning or dam failures (Center for Excellence in Disaster Management & Humanitarian Assistance [CFE-DM], 2020). Also, floods in Cambodia are exacerbated by deforestation, urbanization and changes in precipitation patterns under climate change. Land use change, urbanization and underdevelopment of systematic water resource management practices and facilities leads to a hazardous environment (CFE-DM, 2020). According to PMPSWG (2011), agro-industrial cash crops substitute to forest cover and internal immigration movements of people coming from lowland fuels contributed to the increase in deforestation (Heang et.al, 2013). Climate changes intensify floods and influence the exposure component of risk (World Bank, 2021).

Over the past 30 years, Cambodia has recurrently experienced flooding events. On average, a flooding event causes the death of around 100 people in Cambodia (data including events from 1991 to 2019), as presented in figure 1. Major cities located in alluvial plains have been damaged every year (JICA, 2015). Flash floods and central area large scale floods affect different parts of Cambodia (Asian Development Bank [ADB] 2018). A study conducted by ADB explained that heavy rain downpour upstream on the Mekong River causes flash floods which affect provinces along the Mekong River and the south-eastern area of country. A combination of runoff from the Mekong River and heavy rains around the Tonle Sap Lake causes central area large scale flooding, affecting the provinces around the lake and the southern province.

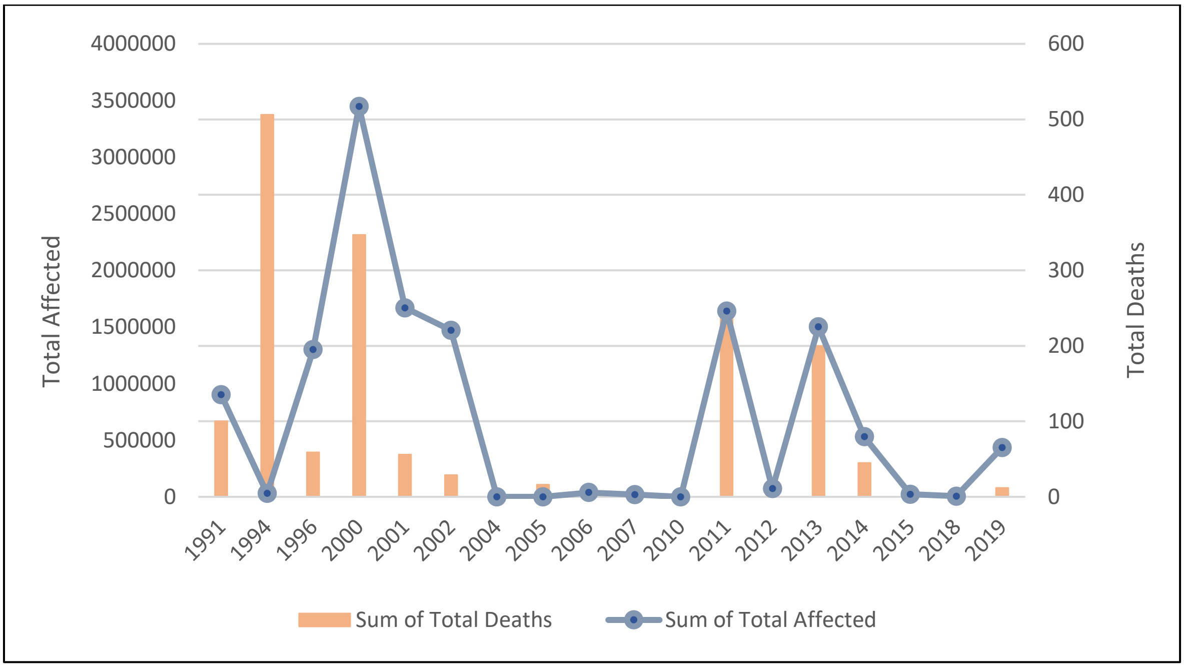


Figure 1: Total death and affected caused by floods
Source: EM-DAT: The OFDA/CRED International Disaster Database (Archived in 2021)
(Note: zero is unavailable data in database)

Section II. Flooding in Battambang city

Battambang province is situated in the northwest of Cambodia. Battambang City is the second largest urban area in Cambodia, with a population of 163,400 (2020) and density of 1,414/km_2 (ESCAP, 2020). Battambang province borders to the North with Banteay Meanchey, Siem Reap, Pailin and Pursat Province, to the West with Thailand and to the North-East with the Tonle Sap Lake. The population of Battambang Province is expected to reach around 70,000 people by 2030 (World Bank, 2018). More than half of the land area in Battambang province is agricultural (596,497 ha) and around 25% of agricultural land is forest land and half of which is flooded (Try et al., 2015). 75% of the total agricultural land is jungles and mountains having mostly tropical climate. Battambang is a part of the greater natural landscapes of the Cardamom region, where natural habitats form a complex network of interconnected landscapes and watersheds providing important ecosystem services to the region (Killeen, 2012).

The Sangkae river is categorized under Basin Group 4 (Tonle Sap) based on river basin management sub-degree. It is a main river in Battambang Province with the catchment area is 3,459 km^2. Its length is approximately 250 km. The Sangkae river originates in the Elephant and Cardamom Mountain which presents an elevation of 1,391m above the mean sea level (MSL). It flows from South-West to North across Krong Battambang and joins Stung Mongkol Borey river at Bac Prea village about 40 km downstream. Then, it flows further 10 km downstream before flowing into the Tonle Sap lake. It flows across 6 districts and 27 communes in Battambang into the Tonle Sap lake. Rainfall inside the catchment is also highly varied, with distribution following a similar pattern to elevation. In the south-west, mean annual rainfall reaches 2,900 mm whereas lower in the catchment closer to the Tonle Sap, around the study area of Battambang City, mean annual rainfall is much lower at 1,350 mm.

The geographic features of Battambang Province are favorable for economic development, but they also pose a threat regarding floods. As a matter of fact, its geographical condition, exacerbated by climate change and degraded natural environment represent an additional threat for flooding events[1]. Heavy rain downpour upstream on the Mekong River causes flash floods which affect provinces along the Mekong River and the south-eastern area of country. A combination of runoff from the Mekong River and heavy rains around the Tonle Sap Lake causes central area large scale flooding, affecting the provinces around the lake and the southern province. PIN developed displays Sentinel-2 composite images that show the relative expansion and contraction of the lake during the wet and dry season respectively in 2018. Comparing this expansion to the Sangkae catchment and Battambang city. The seasonal flow in and out of the Tonle Sap has a strong impact on its water level, which in turn can affect the water level along the lower reaches of its tributaries, including the Stung Sangkae (figure 2).

Battambang Province has experienced flooding and periodic inundation during the rainy season period (NCDM & UNDP, 2014). Flooding frequently occurs in the town center among other types of disasters. It affects traffic flow and movement of people in the major thoroughfares, and disrupts economic services accessibilities (Try et al., 2015). This province experienced severe pluvial floods caused by speedy urban growth. Based on a Cities Development Initiative for Asia Report & ADB (2010), flooding also happened along the rail line because capacity reduction of drainage canals was blocked by new constructions and filled with sediment, and several national roads have been built without proper drainage systems (Try et al., 2015).

[1] The Ministry of Environment (MoE) showed that forest cover data in Battambang province was reduced by 20% for 10 years (UNDP, 2019).

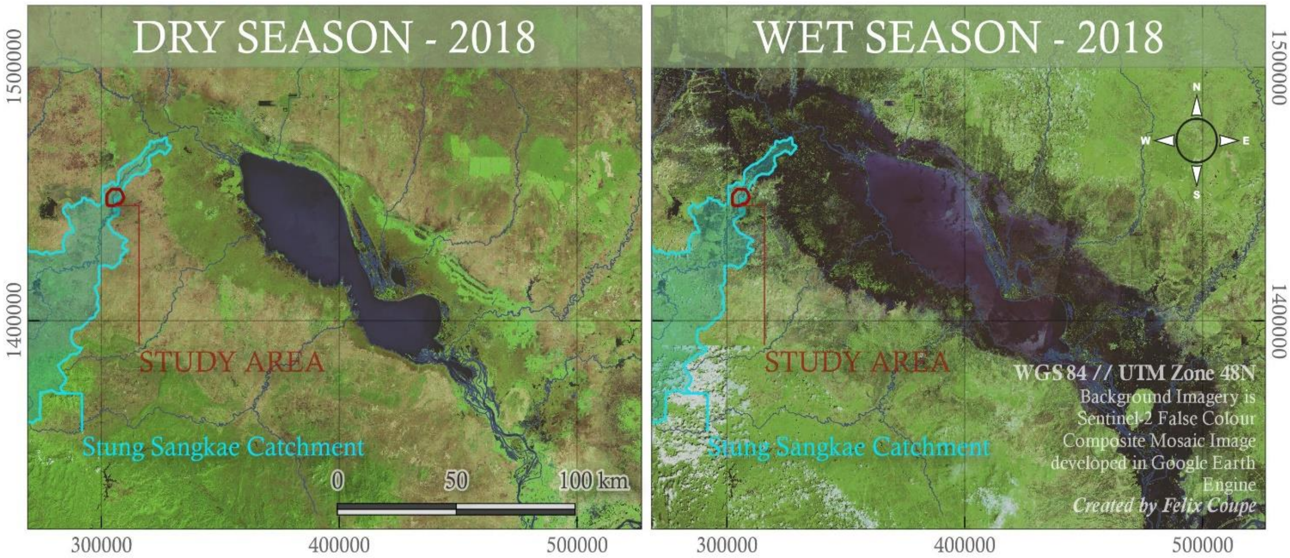


Figure 2: The relative expansion and contraction of the lake during the wet and dry season respectively in 2018 map.

2.1 Flood Modelling in Battambang City

2.1.1 Rationale of the study

The adverse impacts of hazards often cannot be prevented fully, but their scale or severity can be substantially lessened by various strategies and actions. Mitigation measures encompass engineering techniques and hazard-resistant construction as well as improved environmental policies and public awareness. Disaster preparedness consists of a set of measures undertaken by governments, organizations, communities or individuals to better respond and cope with the immediate aftermath of a disaster, whether it be human-made or caused by natural hazards.

Depending on their use, flood hazard maps can be meant in a twofold way, both to reduce exposure of lives and capital stocks, and to strengthen preparedness of the at-risk communities.

Risk knowledge is important to deal with flooding issues (Mills, 2019). Flood hazard maps are necessary to increase coping capacities, planning, and awareness raising (Ministry of Water Resource and Meteorology [MoWRAM], 2020). The output produced through the flood modelling will be critical to strengthen the reliability and accuracy of the flood hazard mapping process in the target areas. As such, it is necessary to have a proper estimation of flood extent and flood hazard for the different flow conditions, so that proper flood evacuation and disaster management plans can be prepared in advance in Battambang city.

By incorporating the findings from the flood hazard maps with knowledge of historical flooding in Battambang city, Digital Elevation Models (DEM) produce the most up-to-date to reflect changes in the flood zone in Battambang city.

2.1.2 Methodology and approach

- **Data collection**

PIN worked with a consultant company to collect data covering Battambang topographic and aerial space. Surveys were undertaken in June 2021. The data collection process followed 4 main steps/activities, such as identification of benchmark; road and topographic survey; aerial survey of 3600 ha; cross section of the Sangkae river and historical flood level survey. PIN's project team selected nine communes in Krong Battambang to pilot this project, namely Sla Ket, Chamkar Samroang, Ou Char, Rottanak, Tuol Ta Ek, Svay Por, Preak Preah Sdach, OMal and Wat Kor. Communes were selected based on proximity to the Sangkae River and on prior flood impacts (communes that were flooded in 2013). Seven communes except O Mal and Wat Kor communes were categorized as urban communes in Krong Battambang because they were impacted by flood in 2013.

The DEM and cross section data collection process was coordinated with Battambang Municipality; simultaneously, local authorities – namely, communes' officials and village chiefs - and inhabitants in the targeted areas were engaged to provide historical information.

Identifying benchmark points: 2 benchmark points were determined. Concrete monuments were taken as control points. Benchmarks were located in Sophi 2 village in and Num Kieb village. Global navigation satellite system (GNSS) technology was used to conduct benchmark survey. Horizontal (X, Y) datum was connected to national coordinate system benchmark (Datum WGS84, Zone 48N). Vertical (Z) datum was connected to national leveling network (from Hon Dau, Viet Nam, MSL).

Road and topographic survey and aerial survey of 3600 ha: Road level survey was undertaken for 90 km in total using real-time kinematic (RTK) as input for digital evaluation model. Three sets of GPS receiver with RTK continues survey method for every 10 meters. One set of GPS receiver were setup on two known point BM1 and other two sets of GPS receiver were set up as rover on two different cars (one car each) for measure road level. Tuk-tuks was utilized as a vehicle for data collection. Ground control point (GCP) survey was designed based on boundary shape of study area where was about 3600 ha. 10 GCP were marked and survey before UAV fly. The eBee X RTK was applied for aerial survey about 1700ha with a Geo-base on a known point.

Cross section of the Sangkae river and historical flood level survey: Four sets of GNSS receiver with RTK survey method was applied for cross section survey of Sangkae river. One of set GPS receiver was set up on a known point and 3 sets of GPS receiver were set up as rover for measure topographic points along river (left bank, right bank and in water). Longitudinal profile was nor surveyed only every 50m points on center canals and dykes but also where the changing slope and turning points surveyor was surveyed more points. Cross section was surveyed along river and cross length in every approximately 150m – 200m every depend on situation. All the features in side area 100m both sides were survey and drew on plan view. The 12 points of history of maximum flood level of water mark were surveyed and recorded. The flood level of water mark were survey based on RTK survey (X,Y, Z) and data collecting from location people.

PIN worked with technical flood modelling consultant for studying the flood dynamics and hazard impacts within Battambang city. To produce an accurate 2D flood model, it is required to have additional data to first hand data. Time series data for rainfall, evapotranspiration, water level and discharge were required for creating an accurate flood model. Gauge data was available from both the Mekong River Commission (MRC) and PDWRAM. Data such as drainage networks, in-channel structures such as weirs and bridges, canals, and flood defenses, gauge data meteorological, rainfall, evapotranspiration were collected. Hydrological discharge is another input for flood model that controls river level and velocity. Time series data for rainfall, evapotranspiration, water level and discharge are required for creating an accurate flood model. Gauge data was available from both the MRC and PDWRAM.

- **Data processing**

In line with the inputs of the first-hand data, PIN produced an urban elevation profile, through the use of real-time kinematic (RTK) positioning and global navigation satellite system (GNSS) technology, utilizing tuk-tuks as a vehicle for data collection. The elevation profile is verified and integrated with high-resolution surface data collected by PIN's eBee Plus drone, contributing to the creation of a comprehensive urban DEM. DEM model was processed to a form of Digital Surface Model (DSM) and a Digital Terrain Model (DTM). The elevation from road level survey, river cross-section survey and aerial survey shall be integrated as the elevation model to support flood modeling of Battambang provincial town.

HECRAS, hydraulic software program is used for producing the 2D flood modelling for this project that provided values such as elevation, wetted perimeter, area, roughness, and others. This enables the use of larger cell sizes without losing finer details, which can help accelerate model computation times. A new land cover layer was developed using machine-learning Random Forest Classification methods and semi-automatic classification tools. The imagery used was the RGB optical image processed from the survey was low (only 3-band RGB). The high spatial resolution meant that a good quality land cover layer could be produced, using the Google Earth imagery and assessment tools to evaluate the success of the classification. The method, spatial analysis and final land cover are presented in the data analysis section. This analysis suggests that, of the years with available data, 2011 would be a suitable year to use for calibration. Additional years could include any others that exceed flood hazard level, particularly 2006 and 2019.

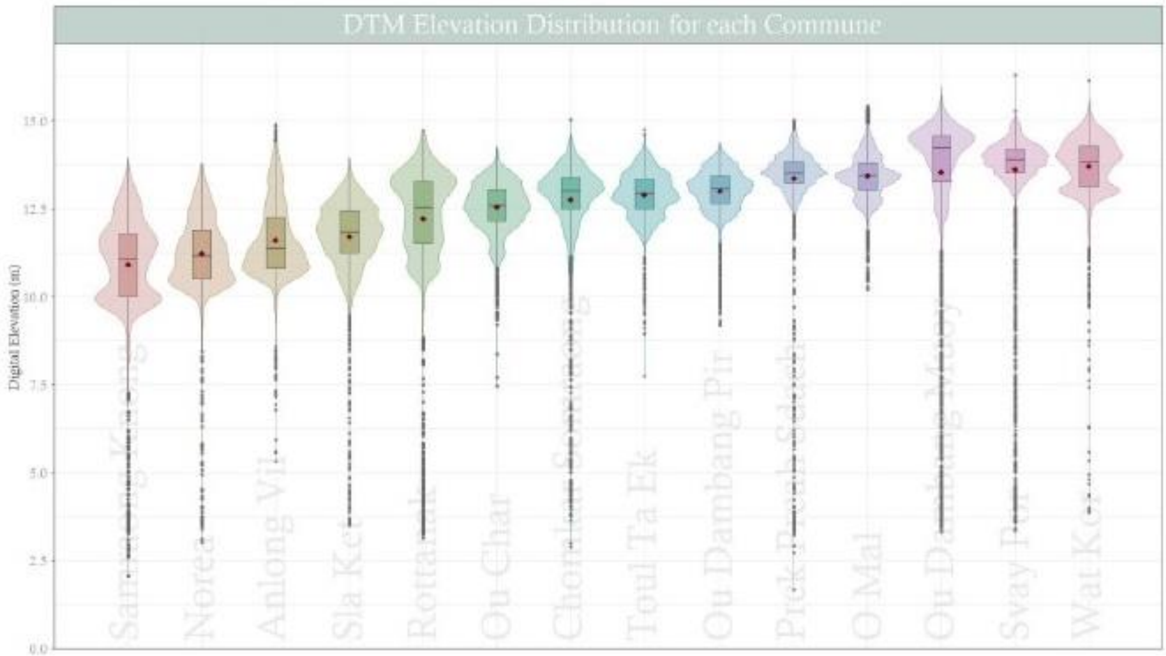
The main limiting factors affecting model accuracy are data consistency and availability of data. Rainfall and water level gauge data for peak historic flood events was missing. A lack of discharge data and the absence of calibration data in overbank flooded areas also represented limitations to the accuracy of the study.

2.1.3 Key Findings: Flood impact in Battambang city

Finding 1: Communes with the lowest relative building elevations, an indicator of flood hazard, include Sla Ket, Prek Preah Sdach and Svay Por.

The elevation distribution of all points per commune, order from the lowest, Samraong Knong, on the left to the highest, Wat Kor, to the right (see figure 3). Most communes feature large ranges from approximately 3m to 15m, with those communes exclusively on the flood plain having much lower elevation ranges. This figure provides a simple summary of elevation distribution across the study area and can give insight into the general direction of surface runoff. Water elevation distribution is dependent on whether the commune contains any area of the Sangkae River, with the peripheral communes only identifying smaller and shallower ponds or channels.

Communes with the lowest relative building elevations, an indicator of flood hazard, include Sla Ket, Prek Preah Sdach and Svay Por. In terms of absolute area in km^2, Rottanak contains the largest surface area of buildings, followed by Svay Por, Toul Ta Ek and Prek Preah Sdach. It should be noted however that these 'relatively lower areas' refer to only a small portion of all the buildings in these areas and could possibly be an error carried over from the land cover layer development. Central area of the city is the highest region reaching 16.3 m, with this level dropping lower towards 10 m in the periphery of the city and towards the agricultural land. Annex 1 topography map includes significant information about the different evaluation of Battambang city namely Sla Ket, Chamkar Samroang, Ou Char, Rottanak, Tuol Ta Ek, Svay Por, Preak Preah Sdach, OMal and Wat Kor.


DTM Elevation Distribution for each Commune
Digital Elevation (m)
15.0
12.5
10.0
7.5
5.0
2.5
0.0
Samrong Knong
Norea
Anlong Vil
Sla Ket
Rottanak
Ou Char
Chomkar Somraong
Toul Ta Ek
Ou Dambang Pir
Prek Preah Sdach
O Mal
Ou Dambang Muoy
Svay Por
Wat Kor

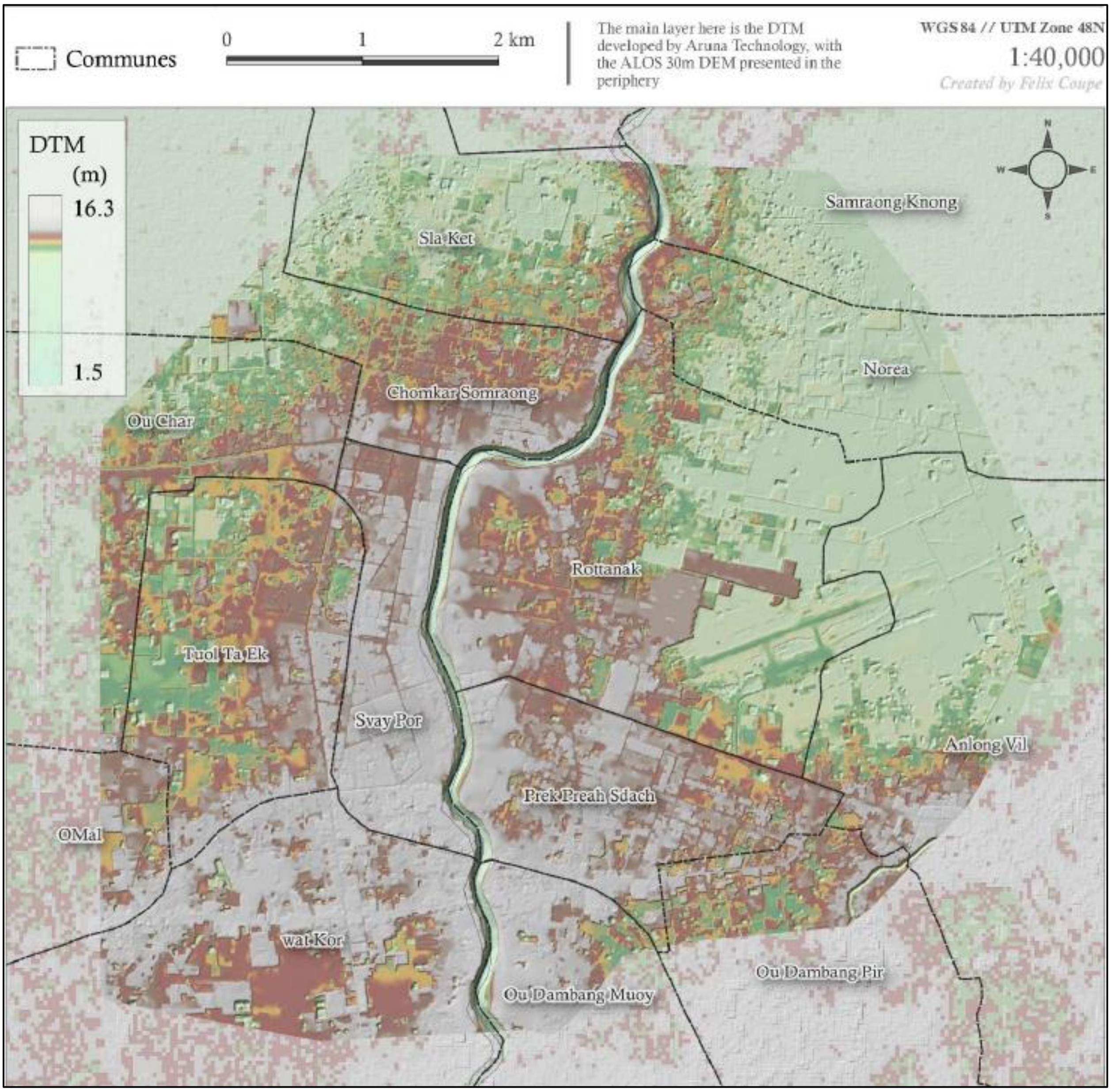


Figure 3: DEM Elevation distribution per commune

Finding 2: A bank-full capacity is 13.9 meters and 13.6 m will hereafter be considered flood hazard level. 12.25 meters will hereafter be considered flood warning level.

Daily rainfall intensity has 2 peaks through the year, one being in late dry season occurring in April and May, and another higher peak in the wet season occurring in September and October. September and October are the months that feature both the rainiest days on average, and the greatest mean rainfall intensity on these days (figure 4). Linear regression analysis based on the gauge rainfall monthly from 1920 to 2020 shows the annual rainfall to be increasing over the data series, with wet season showing the same trend. Dry season mean rainfall appears to decrease however, suggesting that annual rainfall distribution shifts towards a stronger seasonal pattern, with dryer dry seasons and wetter wet seasons.

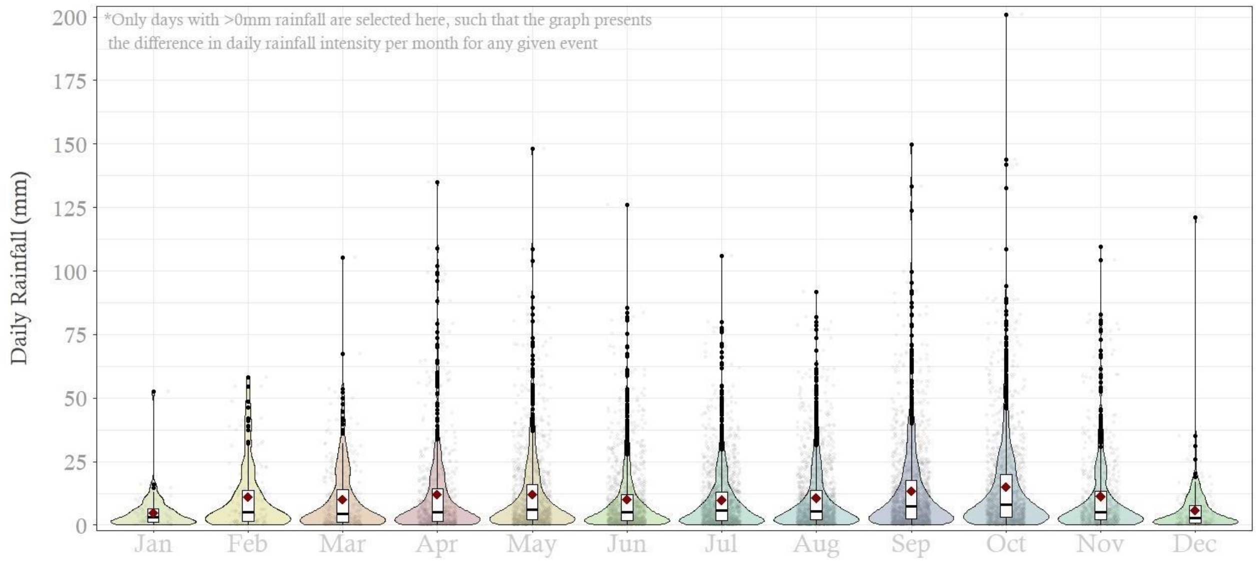


Figure 4: Battambang Gauge Daily Rainfall Frequency (combined Daily Telemetry and Manual Datasets from 1920 to 2021)

Water level analysis focusses on the wet season period, extending from June 1st – November 1st. Data provided by the MRC are for the Battambang City gauge, recorded manually daily from 1982 – 2012, and automatically in 15-min intervals from 2009 – 2021. Some years in the MRC data are only partially complete or contain erroneous data for the wet season, including 1986, 1987 and 1988 for manual data and 2010, 2013, 2018, 2019 and 2020 for telemetric. These years were therefore omitted during trend analysis, but peak water levels provided by PDWRAM are presented where available. 2021 data is also thus far incomplete and therefore has been removed also. The raw annual water level data for all years provided by MRC, including the omitted. After modifying, the bank-full capacity is 13.9 m.

Considering variations in channel dimensions and bank development along the study reach, a conservative value of 13.6 m will hereafter be considered flood hazard level. As there is no quotable figure for flood warning level, this report will use 90% of flood hazard level, an arbitrary value selected based on review of the cross-section. This value is 12.25 m.

Frequency analysis for all days over 12m level is also presented on the right to help identify high level years that can be used for model calibration events (figure 5). On both plots, provisional flood warning and hazard level thresholds are marked. Gauge bank-full level is also shown, to identify any years where water level exceeds the bank level in the centre of the Battambang City area. Mean wet season water levels range from 7.8 – 9.6 m, with ± standard deviations ranging from 5.4 – 11.9 m. Years experiencing flow higher than the provisional flood warning level include 1983, 1997, 1999, 2000, 2003, 2005, 2006, 2011, 2012, 2014 and 2019. The highest water level identified in the recorded data series is 13.96 m, which occurred in 2011. Despite this, flood events with >13 m peak water level have been recorded in every month from July to November.

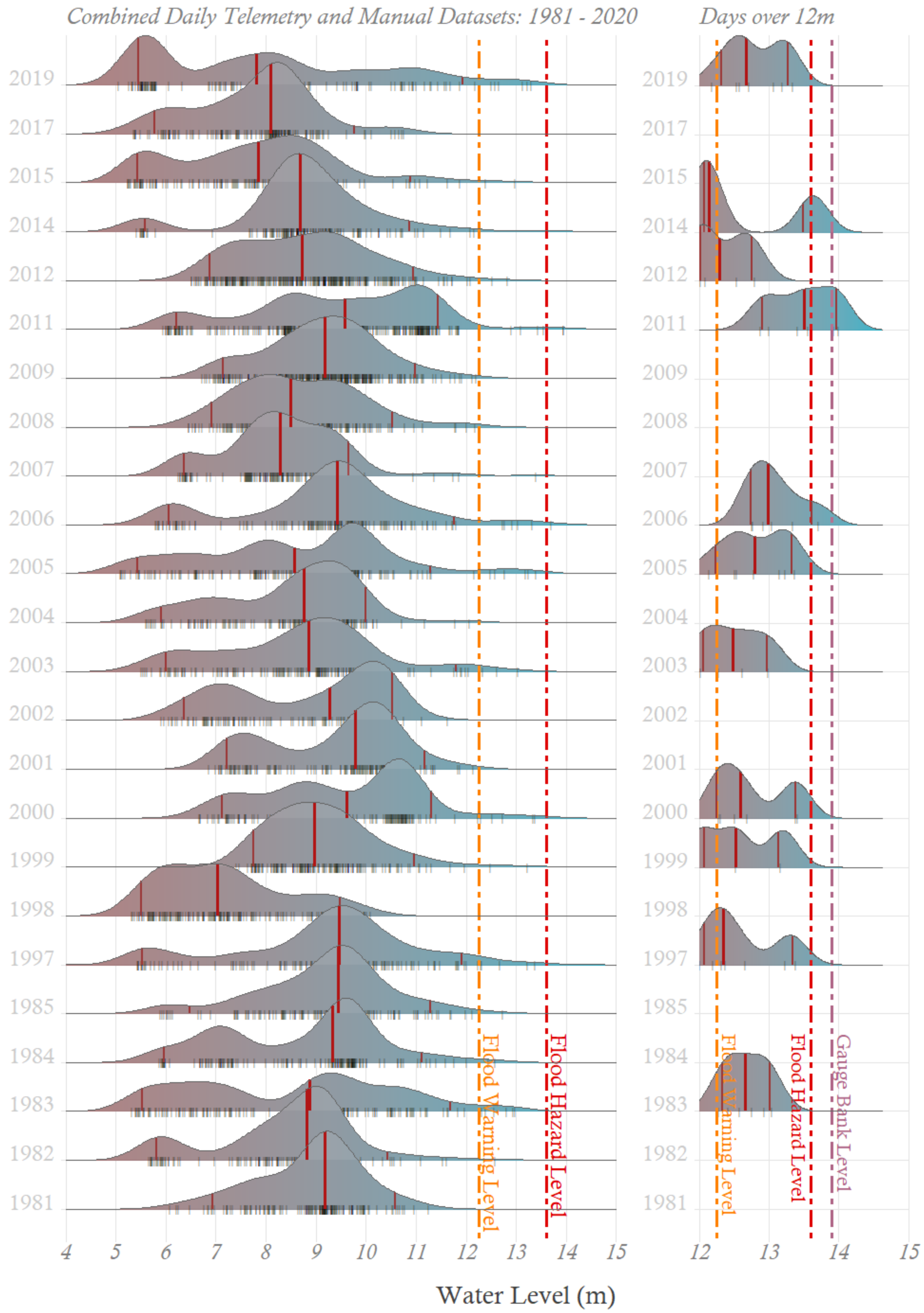


Figure5: Battambang wet season water level (combined Daily Telemetry and Manual Datasets from 1981 *to 2020)*

Finding 3: Most flooding occurs to the east of river, draining north eastward through the agricultural low land and artificial drainage channels. Some inundation does occur within the urban areas along the roads, although this is primarily under 25 cm depth.

The flood depth and calculated hazard for the modelled 2019 calibration and 2011 validation flood events. In both events, channel overflow occurs in both Prek Preah Sdach, in the upstream area of the reach, and the north of Rottanak, in the downstream area of the reach. Most flooding occurs to the east of river, draining north eastward through the agricultural low land and artificial drainage channels. Some inundation does occur within the urban areas along the roads, although this is primarily under 25 cm depth. Beyond the channel itself, flood hazard is greatest at the locations of bank overflow, again in Prek Preah Sdach and Rottanak, as well as in the deep storage areas located throughout the model extent.

Rottanak contains the largest surface area of buildings, followed by Svay Por, Toul Ta Ek and Prek Preah Sdach. As percentage of commune, Svay Por contains the most relative buildings at 60.2%, followed by Chomkar Somraong at 43.5% and Prek Preah Sdach at 39.4%. Over time the town has been built up in the centre, creating a watershed forcing rainwater to flow to the west and east. The exception was at a point to the south of the city where the river tended to breach its banks exposing lower-lying areas to both river overtopping and pluvial flooding. This is extremely important information and the hypotheses from the ADB study, and it is aligned under this project through the flood modelling process.

Plotted return periods are at intervals 1, 5, 10, 20, 50, 100, 200, 500 and 1000 years, peaking at a water level of 15.19 m and a discharge of 1,724 m3/s. Also derived are the return periods of flood hazard and gauge bank-full levels, which are 5.5 and 14.7 years respectively. Another important clarification to be made is the term 'return period'. A return period of, for example, 10 years does not strictly mean that this event will occur every 10 years, but more indicates the average probable time interval between these events. A 10-year return period could also be expressed as a 10% chance of occurring every year.

Under this premise, this event could occur in consecutive years although the probability of this decreases over time (2 consecutive years – 1% chance, 3 consecutive years – 0.1% chance etc.). It should be noted that certain years within the data range have not been included due to partial or missing data, particularly referring to the high-level flooding of 2020. Because of this, estimations of return period based on the flow of the last 40 years, from 1980 – 2020, may be slightly mis-represented.

Finding 4: The areas of greatest absolute flood hazard are Prek Preah Sdach, Rottanak, Wat Kor, Norea, Anlong Vil, Toul Ta Ek and Chomkar Somraong.

The flood depth and calculated hazard for the modelled 2019 calibration and 2011 validation flood events can be seen in Figure 6. In both events, channel overflow occurs in both Prek Preah Sdach, in the upstream area of the reach, and the north of Rottanak, in the downstream area of the reach. Most flooding occurs to the east of river, draining north eastward through the agricultural low land and artificial drainage channels. Some inundation does occur within the urban areas along the roads, although this is primarily under 25 cm depth.

A low flood hazard zone is characterised by shallow flowing water or deep standing water. In moderate hazard zones, flooding is considered more dangerous with deep or fast flowing water. These zones are considered dangerous for some individuals, such as children. Significant hazard zones are dangerous for most individuals and are characterised by deep fast flowing water. Finally, extreme hazard zones are considered very dangerous to all individuals and feature deep fast flowing water. 0 refers to no hazard; <0.75 refers to law hazard; 0.75-1.25 refers to moderate hazard; 1.25-2.5 referes to significant hazard and >2.5 referes to extreme hazard. The areas of greatest absolute flood hazard within the study area include Prek Preah Sdach, Rottanak, Wat Kor, Norea, Anlong Vil, Toul Ta Ek and Chomkar Somraong. When considering the location of populations in the area, the areas with the greatest likely flood risk include Prek Preah Sdach, Wat Kor, Rottanak, Chomkar Somraong, Toul Ta Ek, and Svay Por.

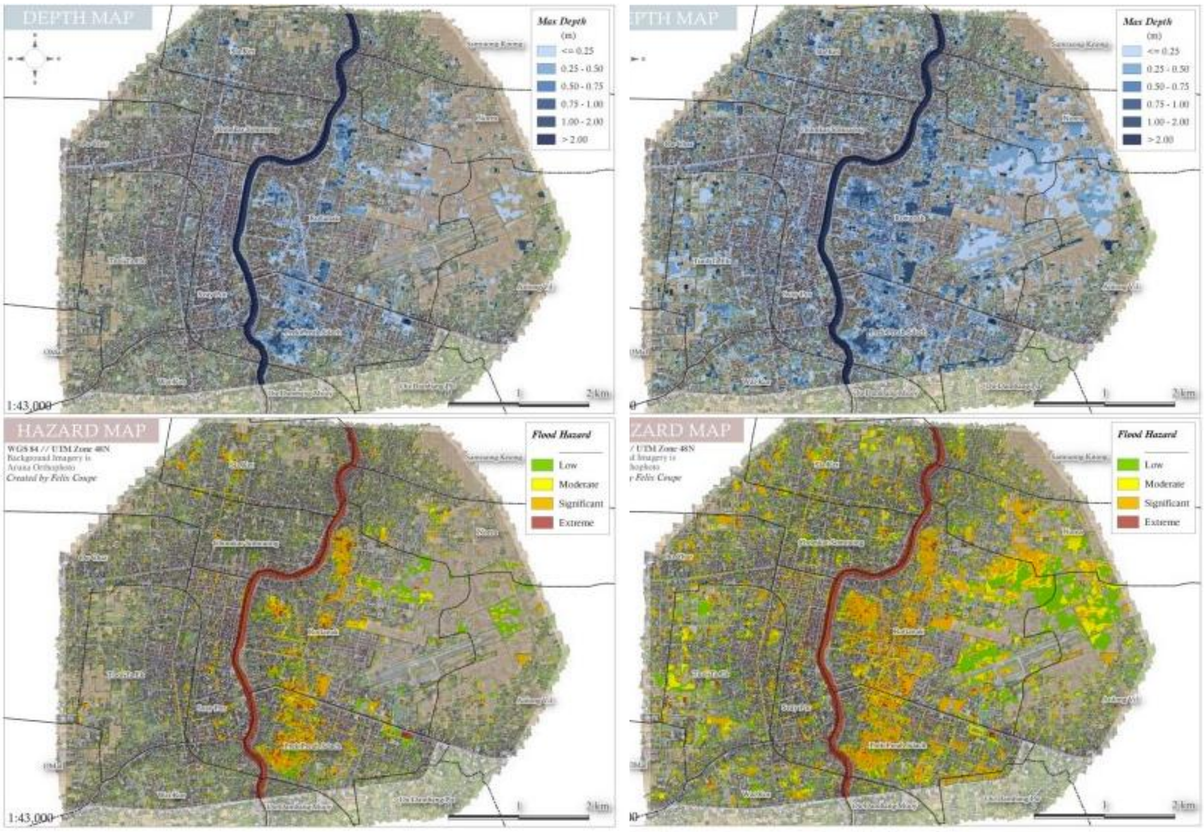


Figure 6: Flood Model result- depth and hazard 2019 and Flood Model result- depth and hazard 2011 map

Finding 5: In the higher frequency design floods (RP5 to RP50) Svay Por tends to feature lower hazards, but during the larger events (RP500 and RP1000) when the bank overtops here, hazard increases rapidly.

The flood warning, flood hazard, and gauge location bank-full capacity water levels were plotted in return period for comparison. From this data all return period floods exceed the flood warning level, with all events over a 10-year return period exceeding flood hazard level and all events over 20-year return period exceeding gauge bank-full capacity for some duration. During a mean 1000-year return period event, water level is estimated to exceed gauge bank-full capacity for almost 36 hours. It is important to reiterate that the following flood scenarios feature the 24-hour rainfall and the discharge estimated for each return period, creating a 'perform storm' scenario that aims to estimate maximum likely inundation, depth and hazard per return period. This ensures that hazard for any given return period is not under-estimated, but may slightly over-estimate.

The maximum inundation of each model flood can be seen in Figure 7. The high level of rainfall prior to hydrograph peak leads to widespread inundation across the study area in all scenarios, although in the lower return period events such as RP5 and RP10, this inundation is primarily focused in storage areas within agricultural land. As the return period increases, this encroaches more into the residential areas, particularly in Toul Ta Ek, Chomkar Somraong, and Rattanak.

The maximum inundation of each model flood can be seen in Figure 8. The high level of rainfall prior to hydrograph peak leads to widespread inundation across the study area in all scenarios, although in the lower return period events such as RP5 and RP10, this inundation is primarily focused in storage areas within agricultural land. As the return period increases, this encroaches more into the residential areas, particularly in Toul Ta Ek, Chomkar Somraong, and Rottanak.

Maximum flood depth for both RP5 and RP10 is <= 0.25 m in most of the overbank agricultural areas (in figure 8). In both RP50 and RP100 this tends to increase to between 0.25 – 0.50 m, and in RP500 and RP1000 this rises to 0.50 – 0.75 m, with some areas reaching over 1.00 m deep. In terms of maximum flood hazard, overbank areas for RP5 and RP10 tend to be low or moderate with some significant areas in storage zones where depth increases. From RP50 to the RP500 hazard level tends to increase from low to moderate and significant, with more extreme hazard levels occurring in some isolated areas. In RP1000, hazard level increases drastically to primarily extreme, with some lower hazard zones in the peripheral areas of flooding.

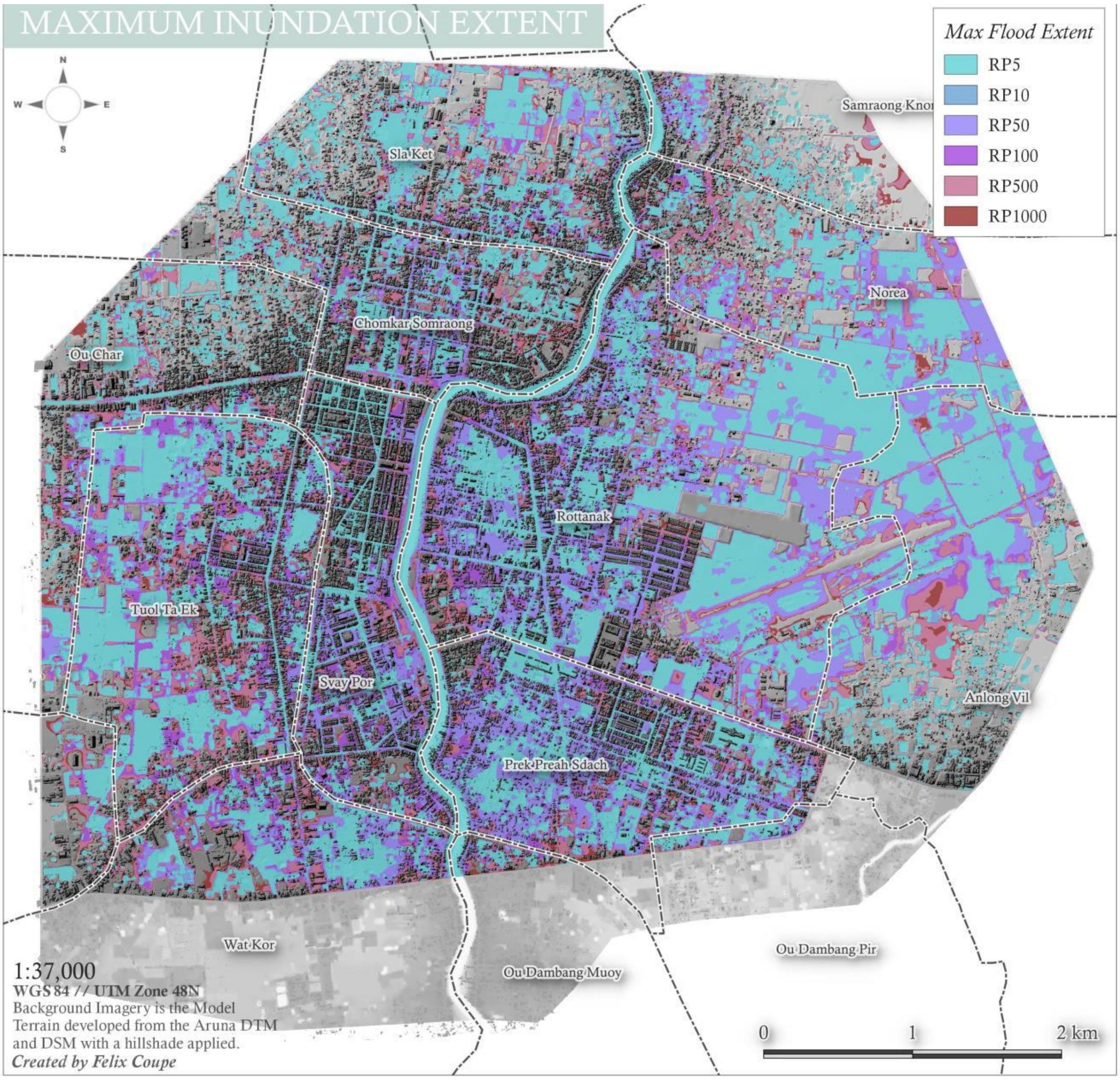
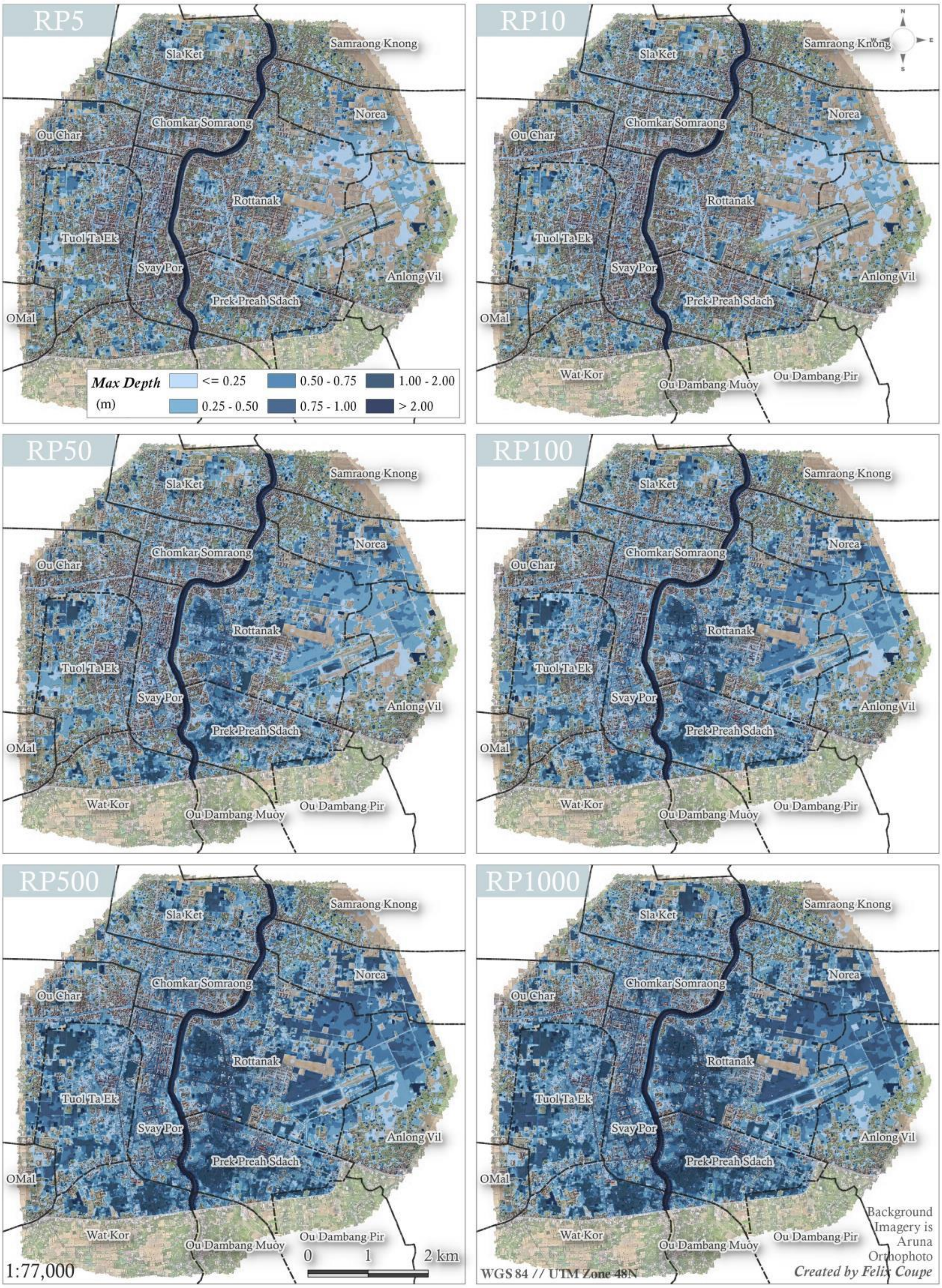


Figure 7: Maximum inundation extent map


RP5
RP10
RP50
RP100
RP500
RP1000
Sla Ket
Samraong Knong
Chomkar Somraong
Norea
Ou Char
Rottanak
Tuol Ta Ek
Svay Por
Anlong Vil
Prek Preah Sdach
OMal
Wat Kor
Ou Dambang Muoy
Ou Dambang Pir
Max Depth
(m)
<= 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 2.00
> 2.00
1:77,000
0
1
2 km
WGS 84 // UTM Zone 48N
Background
Imagery is
Aruna
Orthophoto
Created by Felix Coupe

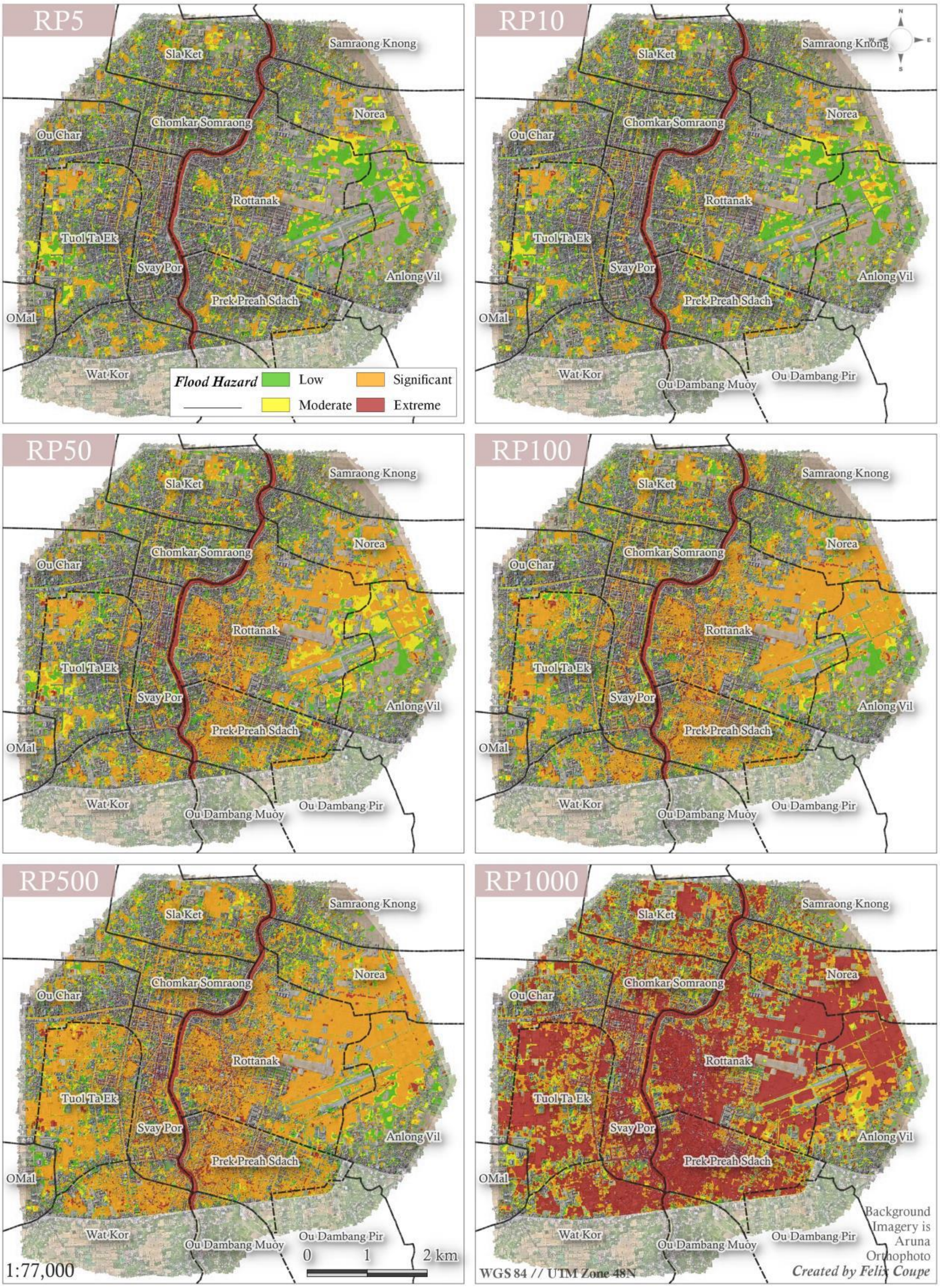


Figure 8: Modeled design maximum flood depth and hazard and extent map

Section III. Flood Management Recommended Actions

Flooding in Battambang city happens almost every year. Flood affects and threatens human life, property, infrastructures presenting as an obstacle for sustain urban development. Along with the recent changes in land use, mass urbanization, the underdevelopment of systematic water resource management practices and facilities, these have led to a hazardous environment to human health. The risks of flood events faced by poor and vulnerable people in Battambang city deepens poverty, therefore, strategies and practices unfolding flood impacts is a build back better.

The sets of recommendations in this report aims at emphasizing on controlling the overall flood disasters in the sense of being prepared for a flood, and to minimize its impact as much as possible for Battambang city. There are two ways to protect lives and properties from flooding: keep floodwater away from people (mainly through structural measures or urban green measures[2]); Keep people away from floodwater (mainly through non-structural measures). Both ways are incorporated in the below suggested actionable solutions.

The recommendations are built from flood modelling findings and reflections conducted by PIN during the project implementation. Specifically, 2 areas of suggested actionable recommendations (both short-term and longer term) were identified and are detailed below: *strengthening flood mitigation measures* and *increasing flood preparedness and early action.*

The recommendation set is applicable specifically to Battambang city, but can be replicated as part of the disaster mitigation strategy in a broader context.

Action 1. Strengthening Flood Mitigation Measures.

- **Integrated Flood Risk Zones to Urban Development plan**

In Battambang city, the flood modelling study found that Prek Preah Sdach, Rottanak, Wat Kor, Toul Ta Ek and Chomkar Somraong communes are the areas of greatest absolute flood hazard. Svay Por commune tends to feature lower hazards, but during the larger events (RP500 and RP1000) when the bank overtops here, hazard increases rapidly. Those communes except Toul Ta Ek commune are located along the Sangkae river.

- Settlement plan should consider to **limit human presence and properties** in the mentioned hazardous areas, while providing practical alternatives for those already settled there, in line with the principle of *doing no harm*.
- **Infrastructural development.** Structural flood control measures such as embankments can reduce to flooding probability in at-risk areas, especially alongside the Sangkea river, provided that technical and quality standard are taken into account.

Whilst the urbanization process of Battambang city is ongoing, a gray infrastructures' rehabilitation plan shall be pre-financed to be ready to face a flooding event and safeguard properties and individuals. Nature-based solution alone cannot depend on to prevent floods in the city. Gray infrastructure interventions such as storm water drainage and cross-channels shall be created to

[2] Various types of greening can be considered such as street trees, gardening, waterfront and rooftop and wall greening

control and divert the flood flow. Rehabilitating wastewater drainage and elaborating standards for wastewater treatment can mitigate floods.

Besides **hard structural interventions, soft structural methods and green alternatives can be explored** (e.g. improve soil cover with plants along the river can slow down water).

Action 2. Increasing Flood Preparedness and Early Action

- **Disaster Responsive Social Protection**

The study of ADB "Cambodia Post-Flood Relief and Recovery Survey 2012" shows that 40 percent among the people in debt contracted new loans due to the flood for reconstructing house and for business recovery purposes (ADB,2012). The reported data does not only indicate individual struggles, but it is also related to increasing economic losses from government's side. Comparing a trend in 2009, the case of Typhoon Ketsana was loss of US$ 132 million while it was increased during flood event 2011 and 2 times increasing during flood event in 2014 (World Bank, 2017). Social protection programs should be reinforced to help marginalized and vulnerable people to cope with natural disaster impacts. The Cambodia social protection program is limited (e.g. ID Poor) and does not fully considers how to address social vulnerability caused/exacerbated by natural disaster. **Focusing on the facilitation/strengthening of access to ID Poor in the more at-risk areas of Battambang** would provide more resources for the vulnerable population to protect themselves as well as to cope with the aftermath of flood events. An extensive awareness on ID poor is required to support families and individuals living in flood-prone areas.

- **Community-based approaches to flood management**

A combination of top-down and bottom-up methodologies is indispensable to reinforce the coordination mechanisms in emergency assistances. Engaging the community throughout the project cycle of flood management (assessment, design, implementation, monitoring and evaluation) is also a prerequisite to ensuring that the measures undertaken are equitable and effective and that the needs and priorities of the entire affected population are met in the long term.

Setting up a reporting and feedback mechanism to flood management assuring the concerns, complaints and suggestions from the vulnerable communities are gathered and properly addressed requires a comprehensive plan and standard operation procedure (SOPs). The feedback channels, for instance, can include phone feedback, survey, SMS or offline feedback channel. Being those channels available all the time (before, during, after the rainy season and possible flood events) will give time and space to Provincial and Municipal authorities to consider and, if appropriate, address concerns and include suggestions in their actions and future planning.

- **Enhancing Urban Early Warning System**

Under the project implementation, four communes lying along the Sangkae river (Preak Preah Sdach, Ratanak, Slaket, Kdol Doun Teav commune) have been provided with automatic fixed public speakers which are a last-mile communication channel of the first Urban early warning system. **Wat Kor, Chamka Samroung and Svay Por commune should be considered as prioritized areas to expand and improve the last-mile communication channel infrastructure.** Specifically, it is recommended to:

- Installing additional speakers in more areas at high risk of flooding;
- Plan financial resources carefully to support the operational and maintenance costs of the system;

- In the medium-term, enhance the technological capacities of the system (e.g. optimize the broadcasting system allowing the software to notify and confirm back the operator when a warning system is successfully disseminated);
- Support the EWS with awareness-raising programs (e.g. information sessions at community level) to ensure population's understanding of the correct actions/behavior to adopt upon an alert message.

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Annex 1: Battambang Topography map