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Review

Flood Hazard and Management in Cambodia: A Review of Activities, Knowledge Gaps, and Research Direction

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Abstract: Cambodia is located in one of the most severe flood-vulnerable zones in mainland Southeast Asia. Flooding is the country's most recurrent and impactful hazard among other natural hazards. This hazard alone, observed in many river basins, has been inflicting huge damages on livelihoods, social infrastructure, and the country's economy. This study aims to review the current status of flood hazards, impacts, driving factors, management capacity, and future research directions on floods in Cambodia. The findings of this study suggested that there is still a lack of flood-related studies on flood hazard mapping, risk and damage assessment, and future flood analysis in Cambodia. The existing related studies mainly focused on the Tonle Sap Basin and its tributaries, the Lower Mekong Basin, the whole Mekong River Basin, and some of the tributaries of the Mekong River in Cambodia. The fundamental driving factors of the current flooding in Cambodia are impacts of climate change, land-use change, water infrastructure development, and weather extremes. The applications of mathematical and statistical tests and indices, conceptual and physically-based modeling, artificial intelligence and machine learning, and remote sensing are recommended to focus on future research directions on flood in Cambodia in the areas of land-use change, existing and planned operation of water infrastructure, flood hazard and damage assessment, and flood forecasting. The outcomes from these studies and applications would improve the understanding of flood hazard characteristics, reinforce flood management, and achieve flood damage reduction.

Keywords: flood hazard; driving factors; Cambodia

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1. Overview of Flood Hazard in Cambodia

1.1. Cambodia and Natural Hazards

Cambodia is a country located in Mainland Southeast Asia where most of its areas are in the low-lying plains. Topographically, the central plains, surrounded by high mountainous regions, cover almost three-fourths of the country's area of 181,035 km^2 (Figure 1a). The country is bordered by Thailand to the west and northwest, Lao PDR to the northeast, Vietnam to the east and southeast, and the Gulf of Thailand to the southwest. Freshwater bodies cover approximately 4520 km^2. In addition, Cambodia presents a miscellany of intrinsic features, including wetlands, long-stretching floodplains, fertile soil crucial for agriculture, coastal habitats with occupying mangroves, and flora and fauna enriching the ecosystems.

Lying between latitudes 10° and 15° North and longitudes 102° and 108° East, Cambodia is characterized by hot and humid climates governed by tropical monsoons that divide into two distinct seasons, namely the dry season (November–April) and the wet season (May–October). The driest period occurs in January and February, while approximately 80% of annual rainfall is accumulated during the wet season. The annual rainfall across the country ranges from 1200 mm to 2000 mm [1]. The average annual rainfall across the country was approximately 1350 mm between 1961 and 2015. Spatially, the coastal regions receive more rainfall than other areas with an amount of about 3000 mm/year. The rainfall in the central floodplain area is less than in the mountainous and coastal areas in the southwest and highly elevated regions in the east part of the country. Figure 1b shows the spatial distribution of annual rainfall from the Asian Precipitation—Highly-Resolved Observational Data Integration Towards Evaluation (APHRODITE) dataset which is based on gauged observation [2]. In line with the dry and wet seasons, the relative humidity is between 65–70% in January and February and increases up to 85–90% in August and September [1].

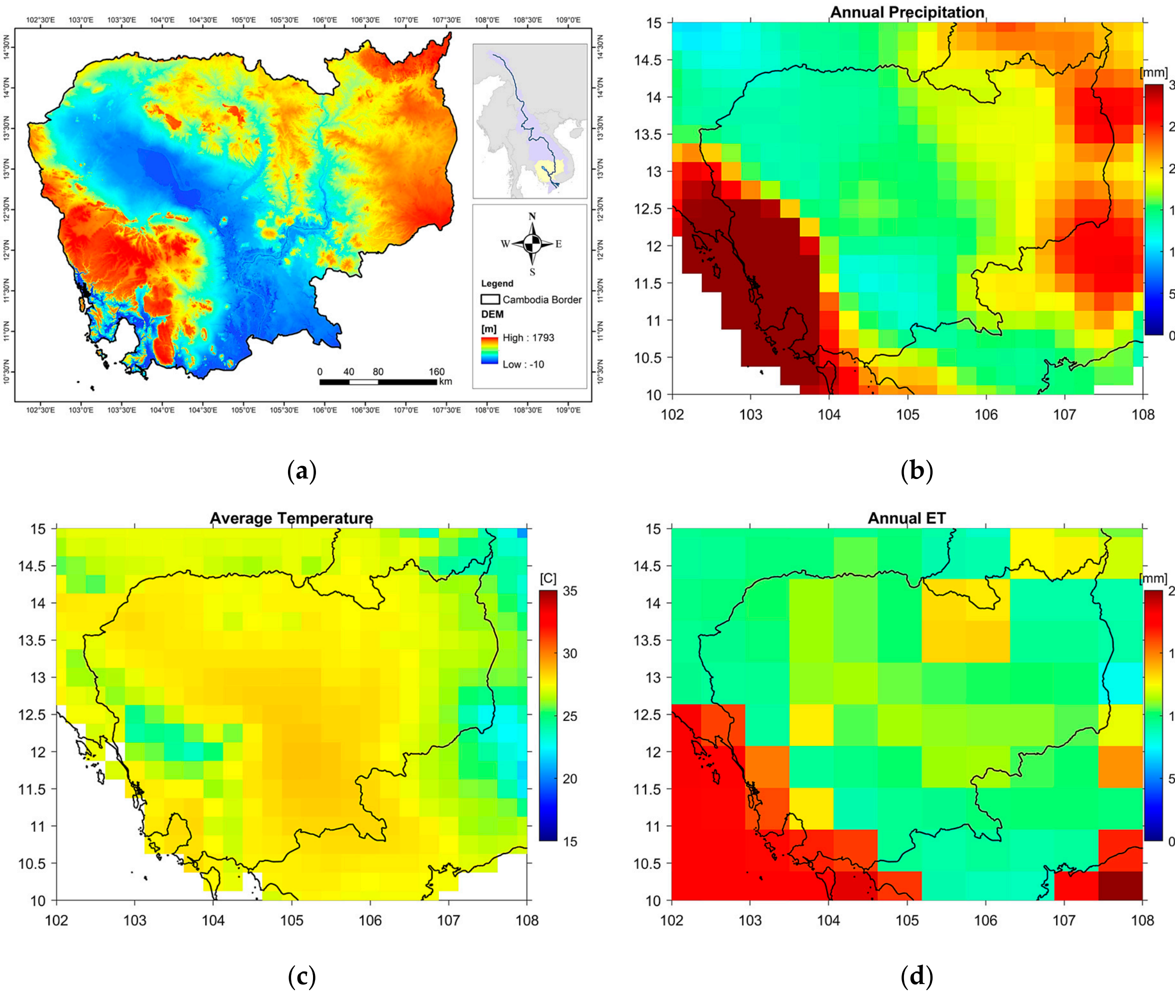

Figure 1. Map of Cambodia showing: (**a**) Digital Elevation Model; (**b**) Average annual precipitation over Cambodia from APHRODITE dataset; (**c**) Average annual temperature over Cambodia from APHRODITE dataset; (**d**) Average annual evapotranspiration over Cambodia from JRA−55 dataset.

The temperature and evapotranspiration in Cambodia also vary regionally and seasonally. For the temperature, from November to January occurs the cool weather with the lowest temperature of 22 °C in January, whereas the warmest month is in April, in which temperature can reach over 38 °C in the daytime [1]. Figure 1c displays the spatial distribution of average temperature from the APHRODITE dataset between 1961 and 2015 [3]. From this figure, the average annual temperature in the central plains and coastal region is between 28 °C and 29 °C, while the temperature in other regions ranges from 23 °C to 27 °C. Similar to the temperature, the coastal region has the highest average annual evapotranspiration while the value is higher in the central plains than in the rest of the country (Figure 1d), according to the Japanese 55-year Reanalysis (JRA-55) dataset [4]. The evapotranspiration in the coastal region ranges from 1400 mm/year to 1800 mm/year, in the central plains between 1100 mm/year and 1200 mm/year, and in other regions from 800 mm/year to 1100 mm/year. Overall, the average annual surface evapotranspiration over Cambodia during 1950−2014 amounts to approximately 1065 mm/year.

The whole country consists of five major river basins, namely Tonle Sap Lake (TSL), Lower Mekong, Upper Mekong, 3S (i.e., Sekong, Sesan, and Srepok), and coastal catchments [5]. The country's hydrology is fed by the Mekong River (MR) network, which traverses from the Tibetan Plateau crossing China, Myanmar, Thailand, Lao PDR, Cambodia, and Vietnam. The MR is intertwined with TSL via the Tonle Sap River (TSR), forming a unique flow reversal in the TSR that seasonally switches its direction relative to the MR flood pulse [6,7]. During the wet season, this flow reversal from the MR into TSL, together with the hydrological contribution from 11 tributaries of the TSL Basin, engenders seasonal flooding in the Tonle Sap floodplain [7]. Such characteristics make TSL a prominent hydro-geomorphological hallmark in the country as well as in the region. Figure 2 depicts the major river network in Cambodia and the frequency of water index between 1990 and 2020 acquired from Global Surface Water [8]. It is apparent from this figure that Cambodia experiences a large flood extent with a very high frequency of flooding, whose water index is from 50% to 90%, in the low-lying central plains (around TSL and along the lower part of the MR).

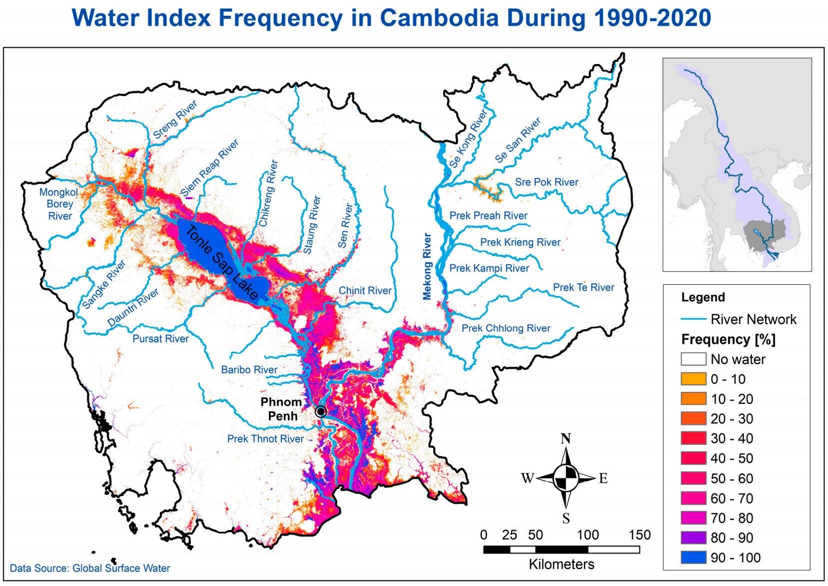

Figure 2. Water Index Frequency in Cambodia During 1990–2020.

To date, several notable natural hazards have occurred in Cambodia. The estimated consequences of socio-economic and environmental impacts have also been addressed. Flash and riverine floods, droughts, storms, and lightning have all struck the country to a worrisome degree. Drought, as a result of low annual rainfall, has hit the country at a frequent rate, and in turn, afflicted mainly the agriculture sector. That said, drought is a major threat to the sector, upon which the country's economy principally relies. Nonetheless, this hazard does not draw other major implications such as casualties or property damages. Typhoons, on the other hand, never hit the country directly. Yet, decaying typhoons still cause repercussions like torrential rainfall and flash floods on multiple occasions [9].

Flood is often deemed the most deleterious threat among all hazards, given its high frequency and its adverse impacts by the number of casualties, injuries, and cost of damages. For instance, between 1996 and 2013, there were 3564 flood disaster occurrences; this indicates that floods are way more frequent than droughts (1343) and storms (1585) combined [10]. The damages to rice paddy fields resulting from floods accounted for 67%

in comparison to only 31% from droughts [10]. Similarly, the reported deaths due to floods during the 18-year observation were over a thousand people, far higher than those due to other hazards [11].

These hazards and flooding, in particular, are set to intensify in the near future owing to the onset of climate change and other anthropogenic changes on land in the country [12]. In conjunction with the flood consequences which are more calamitous than other hazards, it thereby becomes the motivation that this review should delve into the flood status quo and management in Cambodia. Of great significance, this review will provide directions for future flood research.

1.2. Flood Hazard and Its Impacts

Cambodia is highly exposed to floods due to low-lying terrain and large floodplains [10]. The sources of flooding in the country stem mainly from water flow from upstream of the MR, in combination with the TSL annual seasonal flood, tributary flash flood, urban flood, and failure of water infrastructure [13]. Among these factors, flash and riverine floods are classified to characterize the country's flooding. During the monsoon season, Cambodia is subject to flash floods, usually after heavy rainfall. Several provinces such as Battambang, Kampong Chhnang, Kampong Speu, Kampong Thom, Kampot, Kandal, Pursat, Ratanakiri, Preah Vihear, and Oddar Meanchey are regularly hit by flash flooding [14]. The riverine flooding, which is the much slower but prolonged type, is caused by the overflow of the TSR and the MR's tributaries, inundating Kampong Cham, Kratie, Kandal, Prey Veng, Stung Treng, Svay Rieng, and Takeo [14]. In retrospect, severe flood events were recorded in 1961, 1966, 1978, 1984, 1991, 1996, 2000, 2001, 2002, 2011, and 2013, exerting considerable complications on the economic and social status of the country as a consequence [11,14]. Besides these severe events, other flood events in 2009, 2018, 2019, and especially, 2020 are also disastrous and worth mentioning as follows.

The year 2000 flood was the most severe of all in the past 70 years, leaving a huge sum of damage to the national economy [15]. It is worth noting that this event was particularly attributed to heavy rain, which preceded the last eleven days of July, thereby inducing the MR flooding [16]. The resulting agricultural damage was estimated at 402,940 ha [17], and the numbers of people killed and adversely affected were 374 and 2.7 million people, respectively. The total estimated cost of damages by flooding within all sectors (i.e., agricultural, social, education, health, rural development, water resources, public works, and transportation) was estimated at around US$156.7 million [18]. Unfortunately, amid recovering from the year 2000 massive flood, Cambodia once again confronted a devastating flood event in 2001, which adversely affected 18 provinces [19] and cost US$20 million in damages [14].

On 17 August 2002, the water level in Stung Treng rose to 10.70 m, surpassing the warning level, as a result of a medium-sized dam failure in Thailand, heavy rains in Laos, together with repeated rainfalls in the northeast region of Cambodia [20]. The estimated damages of the 2002 flood event were US$14 million [14]. The 2009 flood event, as a result of Typhoon Ketsana, left almost 4 dozen fatalities and 7 dozen injured with hundreds of houses and buildings harmed [21].

Another worst flood event ever recorded in 2011 was the consequence of storm rainfall which ravaged approximately 400,000 ha of agricultural land [22]. The flood on 10 August 2011, caused 250 fatalities, affected 1.6 million people, and damaged around 354,000 households [22]. This flood is the largest flood since 2000, although the capital city Phnom Penh was able to escape severe flood damages [16]. Moreover, the historical flood in 2011 affected many important sectors. Transportation (US$344.4 million or 57% of the total) and agriculture (US$179.6 million or 29% of the total) were the major sectors experiencing significant damages and monetary loss [22]. Other sectors entailed irrigation and water management, rural water, and sanitation. In total, Cambodia had to bear over US$500 million for all the aforementioned damages [22]. Compared to the event in 2011, the 2013 flood event appears to have been less extensive in scale [23]; however, the number of casualties was one of the highest ever recorded at almost 200 [14]. During the 2018 flood event, there were 16 fatalities, over 70,000 families affected, and 7000 of family evacuated [24]. Various provinces along the MR mainstem, including Phnom Penh, suffered from this event [24].

In 2019, the number of affected households rose by almost 20,000 from the previous year; most of them were in 10 provinces [25]. In early October 2020, the evacuation measures took place mainly in the northwest provinces bordered by Thailand, in which around 260 people were evacuated from their homes in Banteay Meanchey, over 1500 each in Pursat and Battambang, with collectively damaged 24,000 households [26]. As of 26 October 2020, about 176,000 households in 14 provinces, including Phnom Penh, were affected by flash floods; additionally, the death toll was 38 [27].

Flooding also leads to a myriad of indirect impacts. The hazard brings itself with certain water-borne diseases [15,28], and disruption of income-generating activities and services [10,29]. The financial state of each inundated household is by and large worsened further with years to recover and upcoming issues to curb. As the flood frequency portends the next flood occurrences, people already expect that their welfare will certainly be subject to such devastation again [29]. Flooding also induces inhabitants to migrate to better places in light of sustaining their livelihoods [10]. As for the substantive event of the 2000 flood, affected people had to migrate and indirectly experienced declining food security and increasing health risks due to water-borne diseases [15].

2. Existing Studies on Flood Hazard and Management in Cambodia

Recently, flood events have become more frequent and more extreme in many places because of the impacts of climate change, rapid urbanization, and other development activities [30]. This engenders many layers of constraint on Cambodia, a lower middle-income country thriving for socio-economic development. The 2011 flood, one of the historical extreme events, caused significant damage to rice production and was recognized as the worst flooding in terms of economic losses. During this flood, 18 of 24 provinces located along the MR mainstem and around TSL in Cambodia were inundated with exceeding warning levels at stations of both rivers [15]. According to the Mekong River Commission (MRC), large floods result from mainstream floods and combined floods caused by backwater effects around TSL and a combination of runoff and heavy rains [31]. Hence, the Cambodia Disaster Loss and Damage Information system (CamDi) has been developed to collect, store and analyze data, and visualize the risk and vulnerability. To substantiate such a system, studies on flood hazards and management in Cambodia must be taken into account.

Effective flood risk management is needed to reduce potential losses and damage. In so doing, conducting flood-related studies is of paramount importance as a precursor for science-based risk communication. A large body of research on flood risk assessment in Cambodia has been conducted based on various approaches and study sites. However, most of the river basins lack baseline data for investigating flood risk management, thereby luring more attention to only the areas around the TSL's floodplains and the MR mainstem [32,33]. Kim et al. [34] simulated flood extent and flood depth in the lower MR basin using HEC-RAS and GIS-based by considering discharges of return periods of 10, 20, 50, and 100 years, which were calculated from a 30-year peak discharge, to analyze flood hazards in Cambodia. The flood depth was classified in five intervals from <3 m to >12 m to produce flood maps which essentially served for understanding the potential severity of flooded areas. A review article by Koem and Tantanee [35] evaluated how the remote sensing (RS) approach has been applied to flood analysis and also assessed the RS gaps for flood studies in Cambodia. It focused on the 2011 flood impacts commonly located in the regions of TSL and along the MR. The main contribution of this review is the identification of broad and distinct patterns in terms of data source, method, spatial coverage, and result. Precisely, this article serves as a good foundation to develop the method of flood analysis with the help of RS which will lead to greater improvements in the field. Nevertheless, Koem and Tantanee [35] underscored the lack of flood studies using the RS approach in other flood-prone regions like areas in the northeast next to Lao PDR, whereas most RS studies are localized in TSL and the MR.

Additionally, Son et al. [36] carried out a study to develop an approach accommodating multi-temporal sequences of Moderate Resolution Imaging Spectroradiometer (MODIS) images for delineating flood-prone areas in Cambodia. The result indicated that the flood-prone areas were generally concentrated along the MR and TSL. Tangdamrongsub et al. [37] assessed total water storage and identified flood events over the Tonle Sap Basin in Cambodia using GRACE and MODIS satellite observations combined with hydrological models, while Siev et al. [38] mainly focused on seasonal changes in the inundation area and water volume of the TSR and its floodplain using a simple method of MODIS and Shuttle Radar Topography Mission (SRTM)-DEM. The results from both papers support an understanding of river connectivity in the TSL region in terms of water resources and flood management. Chung et al. [39] studied flood damage assessment on rice crops in the Stung Sen River Basin of Cambodia using the Rainfall-Runoff-Inundation (RRI) model to simulate flood characteristics (e.g., inundation depth, duration, and extent). The outputs are useful for key stakeholders at all levels, especially decision-makers, to comprehend the extent of agricultural damage attributed to flooding so that better risk reduction strategies are anticipated (e.g., appropriate flood control options to avert damages induced by future extreme flood events). Moreover, Thanh Son et al. [40] performed a study on flood risk assessment in the urbanized area of Phnom Penh using geospatial and remotely sensed data for the 1990–2005–2020 periods using the linear unmixing model (LUM), random forests (RF), and support vector machines (SVM). The outputs are the percentage of flood risks classified as high/very high and medium, and maps of flood-risk areas in relation to population density. In essence, this particular research introduced machine learning techniques to yield spatio-temporal flood risks and proved the effects of urbanization and climate change.

It is worth noting that flood risk assessment at small scales like river basins and provinces has not been given due attention. Several types of research including flood hazard mapping and damage assessment have been recently conducted at various study sites with different scenarios and methods as shown in Table 1. The abbreviations shown in Table 1 can be found in the list of abbreviations after the Conclusions section.

Table 1. Flood studies in Cambodia and its river basins.

Area	Method	Focus	Reference
Lower Mekong Basin	HEC-RAS model and AHP method	Flood hazard mapping and flood frequency	[34,41]
	HEC-RAS model	Flood map	[42]
	RRI model	Flood inundation and climate change	[43–45]
	RRI model and T-SAS method	Hydrograph separation and fluvial-pluvial flood	[46]
	SWAT model	Streamflow variability	[47]
Mekong River Basin	EVI or NDVI LSWI WFFI	Temporal change in annual flood	[48]
	Linear binary classifier and ROC analysis	Flood hazard mapping	[49]
	LOADEST method	Sediment load variability	[50]
	SWAT model	Hydrology and sediment yield	[51]
	RRI model	Evaluation of gridded rainfall products	[52]
Tonle Sap River Basin	NDVI index	Seasonal changes in inundation area and water volume	[38]
	Regression Monte Carlo simulation	Relationship between flood, precipitation, and deforestation	[53]
	GLDAS-NOAH ERA PCR-GLOBWB	Water storage and flood identification	[37]
	CAESAR-LISFLOOD model	Hydrological impacts on Tonle Sap Lake	[54]
Tonle Sap tributaries	SWAT model	Climate change and extreme flow	[55]
	RRI model	Rice crop damage	[39]
Whole Cambodia	NDVI Comparison Probability of flood	Multi-temporal flood mapping	[36]
Southern Cambodia, Along the Mekong	WFFI MNDWI	Spatiotemporal flood inundation and land cover change	[56]
Angkor Wat site	AHP	Flood hazard zonation map	[57]

3. Driving Factors on Flood in Cambodia

Flooding in Cambodia, divided into riverine and flash floods, is subject to a multitude of common driving factors. As the MRC rightly noted, flooding in the country can be aggravated by numerous factors, including but not limited to climate change, infrastructure development, dam construction, land cover/use change, or land clearing [31]. These factors, which have been observed based on scientific findings and reports, are elucidated as follows.

3.1. Climate Change

A growing number of researchers have been investigating the impacts of climate change on floods in major watersheds, that is, the MR and TSL basins. As strongly remarked by the Royal Government of Cambodia (RGC), this stems from the fact that Cambodia is highly susceptible to climate change, given the country's low adaptive capacity, yet high dependence on climate-driven resources [58]. The mean annual temperature will rise from 1.4 to 4.3 °C which induces an upward trend in average annual rainfall, especially during the rainy season [59] as well as spurs the unpredictability of weather patterns [60]. This unequivocal phenomenon will increase the frequency, duration, and severity of flood inundation, as a result of rising peak discharges in most streams, thereby leading to a more pressing future of flooding in Cambodia [60].

Oeurng et al. [55] and Try et al. [45] confirmed the alteration in peak discharge and flood inundation in the TSL Basin under certain climate change scenarios, whilst climate change will enlarge flood extent and increase water level [61]. Given that TSL is governed by the monsoonal flood pulse, major modifications in this basin have been anticipated along with its consequences on the whole ecosystem, including forests, wetlands, and aquatic ecosystems [7,62–65]. Other local watersheds are on course to deal with this climate change as flooding patterns diverge from the baseline and thus become more frequent and severe. For example, peak flows tend to rise dramatically in the 3S Basin by over 50% in the 2060s due to climate change [66]. Moreover, it is generally perceived that climate change triggers other factors such as failures of flood mitigation structures including dams and embankments, and more occurrences of extreme weather events [67].

3.2. Water Infrastructure Development

The construction of dams was cited to affect flood levels in the Cambodian lowland in an insignificant way; the annual flood extent between 1996 and 2000 saw a mean decrease of only 3–5%, compared with the baseline area of 38,200 km^2 [31]. In case of a dam collapse, flooding will turn into an unmanageable hazard, in which emergency response is of paramount importance, yet losses are woefully inevitable. The MRC also attested that should any dam failure occur along the MR, three provinces, namely Stung Treng, Kratie, and Kampong Cham, can be adversely threatened by flooding [67]. For instance, the major Xe Pian Xe Namnoy hydropower dam collapse in Laos in July 2018 left a devastating flash flood in the northeastern provinces of Cambodia along the MR by raising the water level in Stung Treng to 12 m, which is 0.5 m higher than the emergency level [68,69]. Thousands of Cambodians, over 100 km downstream, were displaced and forced to evacuate while rice crops were critically damaged [68,70]. Another study found that villagers in the 3S Basin incessantly suffered from floods of almost annual recurrence since 1996 due to water release in the wet season from dams in Vietnam and Laos [71]. The act is to keep dam levels below safe levels with respect to dam failure, especially during an extreme rainfall event [71].

Likewise, embankments were found to increase flooding depths as a result of the floodplain being replaced by those structures [31]. Notwithstanding flood risk management, which generally includes embankments, flooding is liable to occur as a result of floodplain loss. This is largely due to the capacity of flood water retention of the floodplain being depleted [72], which is otherwise crucial in maintaining hydrological regime and soil infiltration, reducing surface flow [73], and fostering a mosaic of ecological systems [74].

Rising water levels are inevitable when natural floodplain zones are substituted by such structures [72].

3.3. Weather Extremes

The unpredictability of future typhoons impacting Cambodia may be overlooked in the previous studies. This is largely because the country is never directly hit by typhoons and therefore, receives less severe effects from any typhoons that decay or transform into tropical storms, compared with the countries that are directly hit by typhoons. However, flash floods in over 14 provinces were logged as a result of decaying Typhoon Ketsana between the end of September and the beginning of October 2009 [21]. The aftermath left almost 4 dozen casualties, with other injuries and substantial property loss. 4 years later, two typhoons (Wutip on 26 September and Nari on 14 October) hitting the Lower Mekong Basin (LMB) transformed into significant tropical storms once they made landfall in Cambodia [15]. Almost 170 casualties were reported over the country as a result of flash floods due to these storms. That said, other than riverine flooding, flash flooding caused by tropical storms or typhoons is deemed perilous.

On top of that, the El Niño-Southern Oscillation (ENSO), comprising Neutral, La Niña, and El Niño phenomena, also plays an evident role in disproportionately affecting flooding situations globally, especially the duration of a flood event which was found to prolong [75]. Also, more intense precipitation and therefore extreme floods are attributed partially to La Niña [76]. In other words, above-average rainfall is usually expected during the La Niña period. However, some years are recorded as La Niña years or events while others are El Niño or Neutral years, both of which are of irregular occurrence, leading to another strain and uncertainty on climate variability over the region. Although La Niña often manifests as a factor in accruing flood risk, studies on these phenomena of flood inundation are not abundant enough in Cambodia [77]. Indeed, the years 2000 and 2011, during which two of the most severe flood events were well recorded in the LMB, were markedly influenced by the La Niña phase; Cambodia also underwent these two severest events, in which casualties and losses were insurmountable [78].

3.4. Land-Use Change

In addition to the said factors, flooding in Cambodian river basins is also attributed to land-use change, irrespective of any extent. The upstream part, usually occupied by forests, is central to regulating flow and averting flooding downstream. In other words, more land clearing in the upstream areas begets escalation of surface runoff, peak discharge, and flood magnitude [31]. Land-use change, usually from forests to agriculture and built-up area, brings about changes in surface roughness and a decrease in infiltration rates, which generally result in rising flood discharges [79]. The hydrological systems can be sustained unless major modifications of land cover in the highland take place. It is worth mentioning that this change is poised to continue in line with commonly known societal trends such as demographic transition, agricultural demand, and economic growth within the country. To illustrate, the transition from forest to agriculture and urban area is apparent in response to those aforementioned trends. For example, numerous forest types were transformed into agricultural and built-up areas at a rapid pace in the Stung Sangke catchment [80] and Battambang province [81]. The rates of such land conversion can be measured through in-situ and remotely sensed data, the RS and GIS approaches, and modeling to predict; however, the impact of those changes on hydrology and flooding remains to be seen. The uncertainty of hydrological response and flooding attributes becomes larger when the rapid land-use change is coupled with the aforementioned driving factors like climate change and infrastructure development.

4. Related Institutions and Efforts in Flood Management

The legal framework for Disaster Risk Management started when the National Committee for Disaster Management (NCDM) was set up in 1995 under sub-decree No. 54

ANKR.BK which was followed and supported by the sub-decree No. 30 ANKR.BK on the Organization and Functioning of the National and Sub-National Committees for Disaster Management [12,82]. Moreover, the lead administrator and coordinator of disaster activities formalized a comprehensive Law on Disaster Management which was passed in 2015 and was reinforced to secure the suitable implementation of disaster prevention, adaptation, mitigation, response, and recovery measures [83]. In 2008, the Strategic National Action Plan (SNAP) for Disaster Risk Reduction (DRR) was set to focus on vulnerability reduction and to set up a road map for the comprehensive DRR in Cambodia [14].

Framework for Disaster Management and cooperation on Flood Management in Cambodia has four levels of the Committee for Disaster Management. The top level is the NCDM, which is responsible for coordinating effective emergencies and developing preventive measures to avoid loss of life and property. The team of the NCDM is appointed by the authorization of the RGC. The NCDM is governed by the Prime Minister. Furthermore, the other three next levels are provincial and municipal, district, and commune committees, which are led by their respective leaders. The NCDM is working in close collaboration with many international and other organizations related to flood management in Cambodia, namely the International Federation of the Red Cross and Red Crescent Societies (IFRC), the Cambodian Red Cross (CRC), the United Nations Development Programme (UNDP), the World Food Programme (WFP), and various national non-governmental organizations (NGOs). The Ministry of Water Resources and Meteorology (MOWRAM) is mandated to undertake appropriate measures to ensure effective water resources management within international and national measures for addressing and mitigating floods and droughts [84]. The Cambodia National Mekong Committee (CNMC) is mandated by the RGC to coordinate flood transboundary at the national and regional levels.

5. Future Research Directions on Flood in Cambodia

As per future implications of the driving factors stressed in Section 3, flooding has never been more critical and volatile. This mere condition is objectively true not only in Cambodia but also in other flood-stricken countries and regions. Provided the coping capacity and the level of vulnerability in the country, a clear fundamental direction for prospective research must be established where researchers are urged to instigate further studies revolving around floods and related prospects. Upon the literature we have collated in this review, there are still major gaps and thereby flood management will not be able to overcome the shortcomings of future unpredictability.

On top of several previous research studies, further studies are needed to comprehensively address the flooding situations in Cambodia based on the latest scientific findings and available information and tools. It is noteworthy that the baseline or historical studies have not been ample in the country's watersheds; moreover, development and changes therein are ongoing, and yet, implications thereof with respect to flooding are not fully determined. Ultimately, the local flood management is reliant upon studies of all scales, in other words, from district to province to small and large basin scales.

Climate change, land-use change, extreme weather events, and dams and infrastructure development are fundamental instances to be investigated in relation to flooding in some locally significant watersheds. As previously mentioned, ignoring other watersheds is tantamount to the poor prediction of future disasters. Techniques involving the use of indices, mathematical and statistical tests, conceptual and physically-based models, machine learning, and remote sensing are all encouraged for any scholarships on and associated with floods in the country. Satellite data, likewise, should be emphasized in future studies since spatial and temporal scales matter. Collectively, the major future research directions are elucidated as follows.

5.1. Land Use/Land Cover

Even though there are studies dedicated to land use and/or land cover change in some parts of Cambodia, to the best of our knowledge, the abundance of the baseline, as well as future projections, is not rather substantial adding to the complexity of further investigations like dynamical changes in hydrology, flooding and water resources as a whole. In other words, it is useful to justify whether such change holds major significance on flooding in studied watersheds. Machine learning is gaining popularity in baseline and future land-use classification whose outputs feed other techniques to quantify hydrological and flooding responses to land-use change. As such, hydrologic models are widely applied when incorporating land-use change whose spatial and/or temporal resolutions can be coarse or fine [85,86]. These techniques are already freely available. Moreover, the country's rapid development manifests in population growth and incessant changes in land use/land cover. To this end, such changes should no further remain a limitation.

5.2. Water Infrastructure

Regarding the rising concerns about the MR Basin's future due to dam development and other water infrastructure including embankment, diversion, and irrigation, basin-scale, and local-scale studies technically support not only regional appraisal but also basin planning at all levels. A study involving reservoir operation and climate change in TSL concluded that the reduction in flood extent and duration by the operation was higher than the increase in those due to climate change [61]. Such is highly relevant when, in a similar manner, conducting this kind of study in other river basins in which existing and planned dam operations are currently and will be realized. As mentioned above, dam break is one of many flooding causes, albeit a rare occurrence. The simulation of this 'what if' scenario greatly assists action plans to avert or reduce serious damages. The simulation of dam operation during an extreme precipitation event is equally useful. Such scenarios make way for further necessary assessments to amplify preparedness and formulate an effective contingency plan for any possible flood-stricken areas. On top of that, studying the impacts of dam operation compounding with return periods, climate change, and land-use change on flood variables is of the future research trajectory in light of reducing uncertainties of projections while making such projections more robust.

5.3. Flood Forecasting

Flood forecasting is integral to contingency plans that involve emergency measures, and also a pivot to effective disaster management. The lack of flood forecasting in addition to current flood susceptibility and the onset of climate change worsens the socio-economic status and impedes the development of all kinds. The establishment of the early warning system EWS 1294, which uses smart sensing water level gauges, indicates a positive sign to alleviate the likelihood in the likely affected areas. Still, certain shortcomings of flood forecasting in Cambodia involve the employment of forecasting models [87]. More unpredictable and intense extreme weather events require the robustness of flood forecasting, which produces the most reliable warning information. Forecasting methods include hydrodynamic models [88], statistical models [89], ensemble forecasts [90], data-driven or machine learning [91], and hybrids of the said models like coupling machine learning with hydrodynamic models [92], all of which employed in different parts of the world; however, very little scholarship has been invested in forecasting floods in Cambodia thus far.

5.4. Flood Assessment and Surveys

Quantitative and qualitative flood assessments reveal the current situation of flooding across sectors and administrative divisions. Frameworks for disaster and flood risk reduction can greatly benefit from such assessments. Calculation, survey, and mapping of flood hazard, probability, vulnerability, and risk assist policymakers and relevant institutions to realize flood management strategies and mainstream them into development plans across sectors and administrative levels. In essence, effective decisions rely primarily on abundant evidence in which such assessments play a huge role. The assessments should be undertaken at all scales from country to river basins, provinces, and districts. Several studies have been conducted in some parts of the country such as flood vulnerability mapping [57,93], flood probability at the district level [36], flood vulnerability [94,95], flood damage assessment [39], and qualitative flood survey [96]. Effective management needs more assessments in other parts to pinpoint flood-prone regions and to buffer potential damages from future extreme events. Simultaneously, such studies are instrumental in raising local awareness as part of dissemination and outreach; the level of coping capacity will be understood as an alert to amend management strategies. Similarly, the assessment of the affected areas by recurrent floods should be conducted on a yearly or regular basis to form a monitoring system as recommended by the Food and Agriculture Organization (FAO) [97].

6. Conclusions

In this review, we investigated flood management and existing studies conducted in Cambodia. Flood is inherently complex and unpredictable through space and time. Flood management is even more complex when dealing with vulnerable people and limited capacity to curb. The breadth of existing research has been crucial to filling certain gaps. With the ongoing driving factors as described, however, more research into different flood aspects is of great demand and significance, which indeed capacitates national flood management. The future of the local water resources is expected to be more critical owing to major alterations to land, water, and climate; therefore, future research would shrink the unpredictability of flooding and disclose the response of each river basin and administrative level to flooding.

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Abbreviations

AHP	Analytic Hierarchy Process
APHRODITE	Asian Precipitation—Highly-Resolved Observational Data Integration Towards Evaluation
CNMC	Cambodia National Mekong Committee
CRC	Cambodian Red Cross
DEM	Digital Elevation Model
DRR	Disaster Risk Reduction
ENSO	El Niño-Southern Oscillation
ERA	European Centre for Medium-range Weather Forecasts (ECMWF) Reanalysis
EVI	Enhanced Vegetation Index
EWS	Early Warning System
FAO	Food and Agriculture Organization

GIS	Geographic Information System
GLDAS-NOAH	Global Land Data Assimilation System NOAH model
GRACE	Gravity Recovery and Climate Experiment
HEC-RAS	Hydrological Engineering Center—River Analysis System
IFRC	International Federation of Red Cross and Red Crescent Societies
JRA-55	Japanese 55-year Reanalysis
LMB	Lower Mekong Basin
LOADEST	LOAD ESTimator
LSWI	Land Surface Water Index
LUM	Linear Unmixing Model
MNDWI	Modified Normalized Difference Water Index
MODIS	Moderate Resolution Imaging Spectroradiometer
MOWRAM	Ministry of Water Resources and Meteorology
MR	Mekong River
MRC	Mekong River Commission
NCDM	National Committee for Disaster Management
NDVI	Normalized Difference Vegetation Index
NGOs	Non-Governmental Organizations
PCR-GLOBWB	PCRaster GLOBal Water Balance
RF	Random Forests
RGC	Royal Government of Cambodia
ROC	Receiver Operating Characteristics
RRI	Rainfall-Runoff-Inundation
RS	Remote Sensing
SNAP	Strategic National Action Plan
SRTM	Shuttle Radar Topography Mission
SVM	Support Vector Machines
SWAT	Soil and Water Assessment Tool
T-SAS	Time-Space Accounting Scheme
TSL	Tonle Sap Lake
TSR	Tonle Sap River
UNDP	United Nations Development Programme
WFFI	Wavelet-based Filter for detecting spatio-temporal changes in Flood Inundation
WFP	World Food Programme

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