

Analyzing Flooding Impacts on Rural Access to Hospitals and Other Critical Services in Rural Cambodia Using Geo-Spatial Information and Network Analysis

Xavier Espinet Alegre
Zuzana Stanton-Geddes
Sadig Aliyev
Veasna Bun



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Abstract

Transport connectivity in Cambodia is challenged by its geography and exposure to recurrent flooding. Flood events create severe disruptions in segments of the transport network that undermine access to health, education, and work opportunities as well as create barriers to economic growth. Rural accessibility to emergency health facilities and delivery of medicines and basic food supplies is particularly critical in times of major health crises, such as the ongoing COVID-19 outbreak. This paper provides a method to quantify the impact of flooding on hospital access and other critical facilities, aiming to support governments on setting up health emergency mitigation plans for rural transport

in an environment with high flood risk. The method was piloted in three provinces in rural Cambodia, estimating that for 37 percent of the people on those provinces, it takes more than 60 minutes to reach an emergency health facility. During floods, 27 percent lose all access and 18 percent experience an increase of 30 minutes in travel time. In conclusion, this method introduces transparency and evidence-based support for prioritization of rural transport investment, identifies the social benefits (health and education) of rural infrastructure investments, and supports policy dialogue on rural development and resilience.

This paper is a joint product of the Transport Global Practice and the Urban, Disaster Risk Management, Resilience and Land Global Practice. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at <http://www.worldbank.org/prwp>. The authors may be contacted at xespinetalegre@worldbank.org.

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Xavier Espinet Alegre,¹ Zuzana Stanton-Geddes,² Sadig Aliyev,³ and Veasna Bun⁴

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¹ Senior Transport Consultant, SURLEA, World Bank Group, xespinetalegre@worldbank.org, +12024732994

² Disaster Risk Management Specialist, SCAUR, World Bank Group.

³ Senior Transport Specialist, IEAT1, World Bank Group.

⁴ Senior Infrastructure Specialist, IEAT1, World Bank Group

1. Introduction

Road connectivity in Cambodia is challenged by its geography, which includes the low-lying central plains of the Mekong and mountains in the northeast and southwest, and its exposure to recurrent flooding, particularly in the rainy season, which is between May and September, with regional variability. Cambodia is one of the most vulnerable countries worldwide to disaster risk and climate change, ranked the 12th most disaster-prone country in the 2018 World Risk Index of 172 countries by the Institute for International Law of Peace and Armed Conflict 2018. With 80 percent of the country within the Mekong River and Tonle Sap basins, Cambodia is especially vulnerable to floods, storms, and droughts. The infrastructure sector has seen significant damages due to disasters. For example, in 2014, the infrastructure sector bore some 86 percent of the total damages, predominantly roads and water and irrigation infrastructure (Royal Government of Cambodia 2014) with a cascading effect on local and regional economies due to disruption of infrastructure connectivity and supply chains and loss of market access for key economic goods. Looking ahead, climate change projections indicate temperature increase of 0.7°C–2.7°C by 2060 and increased intensity and frequency of extreme precipitation in the monsoon season and flooding (World Bank undated) which would only exacerbate current vulnerabilities.

The impacts of climate change are more noticeable in the rural parts of Cambodia. Higher levels of poverty compounded by poor infrastructure maintenance and limited access to all-season roads (only 5 percent of rural roads are paved) make the 79 percent of the Cambodian population living in rural areas (2016) highly vulnerable to the frequent disruptions of flooding events. The disrupted connectivity during flooding and other disasters greatly threatens the livelihood of those rural households and their access to basic services. In a context of health emergencies and pandemics, such as COVID-19, it is critical that the population has reliable and resilient access to health facilities to ensure rapid medical response and delivery of critical medical supplies.

Rural access to hospitals has been at the center of the discussion amid the COVID-19 health crisis (New York Times,⁵ Washington Post,⁶ and ABC News⁷). While most cases and outbreaks have taken place in densely populated areas (such as Northern Italy, New York, or Madrid), those areas tend to have good access to hospitals or have the availability to set up temporary hospitals. Rural areas are much worse equipped to face the impact of a health crisis, in terms of human, operational, and financial resources and capacity. Rural access to health care centers is low; the lengthy travel times to the nearest hospital with necessary emergency

⁵ <https://www.nytimes.com/2020/04/16/health/coronavirus-rural-hospitals.html>.

⁶ <https://www.washingtonpost.com/opinions/2020/04/06/covid-19-crisis-is-going-get-much-worse-when-it-hits-rural-areas/>.

⁷ <https://abcnews.go.com/Health/surprising-covid-19-hot-spots-coronavirus-threatens-rural/story?id=69940146>.

equipment to treat cases such as COVID-19 may become life-threatening for some of the most critical patients (Forbes⁸).

Additionally, rural accessibility may become critical to ensure social and economic recovery of rural areas post-crisis. Rural accessibility gains have a strong correlation with growth in agricultural production (Limi, You, and Wood-Sichra 2017), school attendance rate (Vasconcellos 1997), and child mortality rates (Gage and Calixte 2006). Strong evidence has motivated governments and financing institutions to prioritize interventions to enhance rural accessibility. In 2006, the World Bank Group developed the Rural Accessibility Index (Roberts, Shyam, and Rastogi 2006) as a metric to support the prioritization of rural roads investment with the aim to close the accessibility gap that most rural areas suffer from.

The methods and calculations used to determine the Rural Accessibility Index have evolved quickly since its inception, and in recent years, driven also with advances in analytics, availability of geo-reference data, and computing power, several new methods have been developed (Transport & ICT 2016; Mikou et al. 2019). To keep these methods simple and straightforward, the calculations of this index and the prioritization of interventions have been focusing on the origin of population, for example, where rural people live, but they do not consider the destination of that access and the facilities to which they are getting access. A few recent studies have demonstrated that calculating accessibility to specific facilities (for example, hospital, water sources, schools, or employment opportunities) using geo-spatial analysis is feasible to support the prioritization of rural investments (Andres et al. 2018; Krambeck et al. 2019; Quiros, Kerzhner, and Avner 2019). Currently, the World Bank is updating some of the methodologies for the Rural Accessibility Index and developing a toolbox to allow road agencies to calculate this index without the need of a geo-referenced Road Asset Management System.

There is evidence that disruptions of road infrastructure due to climate impacts have a tremendous impact on rural accessibility especially when communities lack alternative roads and accessibility is very poor even under non-disaster event conditions (Jenelius and Mattsson 2012; Taylor 2012). Transport disruptions are estimated to produce US\$107 billion economic impacts globally, not only on the loss of assets but also mostly because of disruption of trade and loss of business continuities (Rozenberg et al. 2019). Recent studies have scaled down this estimate to rural communities and have developed methods to prioritize interventions to reduce the impact and increase the resilience of the rural transport network (Alegre et al. 2018; Rozenberg et al. 2017). These methods are based on traffic flow and have not fully considered nonmotorized transport and the dramatic effect of disruption to the level of accessibility. In rural areas, where motorized traffic is low (for example, fewer

⁸ <https://www.forbes.com/sites/claryestes/2020/04/03/calm-before-the-storm-rural-hospital-workforce-pushed-to-the-breaking-point-when-treating-covid-19/#549dad573501>.

than 100 vehicles per day), new metrics and methods need to be developed to capture the social gains that an increase in resilient accessibility can bring.

The Institute for Applied Economic Research of Brazil has recently published (in April 2020) a technical note presenting the use of geo-spatial modeling to evaluate transport accessibility to hospitals for critical COVID-19 patients in the largest urban area in Brazil. The authors prove the relevance of evaluating the transport gaps on access to hospitals so that the government can target mitigation measures. Hallegatte, Rentschler, and Rozenberg (2019) already connected the concepts of accessibility, transport disruption, and climate impacts. A new method was proposed for the city of Kampala in Uganda (Rentschler et al. 2019) to quantify the loss of accessibility to referral hospitals due to the disruption of the urban roads network. This method serves as the foundation for the analysis described in this paper.

The analysis in this paper, piloted in three provinces in Cambodia (Kampong Cham, Kratie, and Tboung Khmum), quantifies the loss of accessibility to referral hospitals as well as calculates accessibility to schools and markets using methods similar to those described by Rentschler et al. (2019) but goes one step beyond to quantify the benefits of rural roads improvements and to develop a prioritization framework to select those investments that have the largest gains in resilience of rural accessibility. This analytical model was applied for the prioritization of rural roads under the Cambodia Road Connectivity Improvement Project (P169930).

The analysis proposed in this paper comprises three focus areas:

1. **Health emergency preparedness.** The analysis used data on location of hospitals to assess the accessibility of rural people to social services, as a key indicator to ensure effective response to health crisis of rural areas. This analysis detected which areas have lower rural accessibility and what would be the accessibility gains owing to the improvement of the rural road network. Accessibility was measured as the ability of people to reach hospitals in a given time frame. This analysis also includes schools as a critical point of interest for the broader human capital development interventions.
2. **Economic growth.** The analysis used agricultural production data (source: International Food Policy Research Institute [IFPRI]⁹) and location of regional markets (source: OpenDevelopmentCambodia website) to assess the accessibility of rural farmers to regional markets, as a key indicator to foster economic recovery of rural areas post-crisis. This analysis detected which areas have lower rural accessibility and what would be the accessibility gains owing

⁹ <https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/PRFF8V>.

to the improvements in the rural roads network. Accessibility was measured as the ability of agricultural products and farmers to reach local markets in a given time frame.

3. **Climate resilience.** The analysis for economic growth and human development was combined with climate resilience data, using flood risk maps already available through the Southeast Asia Disaster Risk Insurance Facility (SEADRIF) to assess the vulnerability of the roads to floods and the impact of such floods to accessibility to economic growth and human capital development. Using the water levels from the flood maps and the type and condition of roads, the analysis determined which roads would be impassable during flood events and then assessed which roads would require interventions to enhance climate resilient accessibility to economic growth and human development opportunities.

2. Methods

2.1. Accessibility Model

The underlying accessibility model¹⁰ follows different assumptions:

1. Two travel modes are modeled: vehicle and bicycle. Each mode has different travel speeds as reflected in Table 1. Based on local consultation, each mode is assigned to a different destination type.
2. Bicycles are used to access schools, high schools, and health centers. Vehicles are used to access markets and referral hospitals.
3. People can walk up to 2 km to road and/or to destination, modeling last-mile connectivity in addition to the main mode of transportation.
4. Roads become impossible to use with more than 0.5 m of water above road design levels for vehicles and 0.25 m for bicycles.^{11,12} Design standards are based on local construction practices (Table 1). Walking becomes impossible for any road under the flood zone regardless of water depths. The model does not consider specific design or location of bridges or culverts. Rather, it assumes that a water depth equal to or less than the hydraulic design would not damage the roads.

¹⁰ The model, written on python ArcGIS algorithms, uses raster-based Cost Distance function to estimate travel time to the closest destination – see Annex 1 for a sample code.

¹¹ These values reflect a conservative approach to accommodate uncertainties and lack of information on the road network attributes such as road vertical alignment, embankments or culverts (usual values are 20 to 30 cm).

¹² The model does not consider reduction of travel speeds for flood levels between 0 to 50cm. It only models passable or impassable.

The rural road network follows the assumptions described in Table 1. With the project intervention, travel time will be reduced (increase speed) and the road will become more resilient as drainage capacity (hydraulic design) will be larger (fourth and fifth columns in Table 1).

Table 1: Road Network Characteristics and Assumptions

Road type	Before Project		After Project	
	Speed (km/hour)	Hydraulic Design (years)	Speed (km/hour)	Hydraulic Design (years)
Primary	50	20	80	50
Secondary	40	10	60	20
Tertiary	30	10	60	20
Rural roads (cars)	10	5	40	10
Rural roads (bicycle)	10	5	20	10
Walking	4	—	4	—

The accessibility model has three main steps:

1. The travel time to the closest point of interest (schools, hospitals, or markets) is calculated for each cell in the project area.¹³ The cell resolution is 500 m.
2. The population and value of agricultural production are aggregated at the 500 m resolution.
3. The population and value of agricultural production are combined with travel time and aggregated for three thresholds (30, 60, and over 60 minutes). In some instances, some population or agriculture cells may not have road access to a certain point of interest (for example, some villages in the river islands); those populations are considered ‘isolated’ and would be counted as such. Isolation would increase in cases of flood impacts as some feeder roads, lacking alternative routes, would be disrupted.

2.2. Climate Resilience Analysis

To quantify the climate vulnerability, the accessibility model was used imposing the disruption of certain roads based on the flood levels and their hydraulic designs. The climate analysis is done as follows:

1. Intersect floods map with road network. Flood event model is a 50-year return event.
2. Disrupt road network based on hydraulic designs. For example, a main road will be disrupted if the difference between the 50-year flood and the 20-year flood is more than 0.5 m. This is calculated for each segment based on the design assumption.

¹³ In rural context, density of critical facilities is very low, and the population normally has only one choice based on distance, as it is the case in the pilot provinces. In urban context, this assumption may not be valid as people’s choices for critical facilities may depend on a wide range of factors (e.g. facility reputation, insurance, social network...).

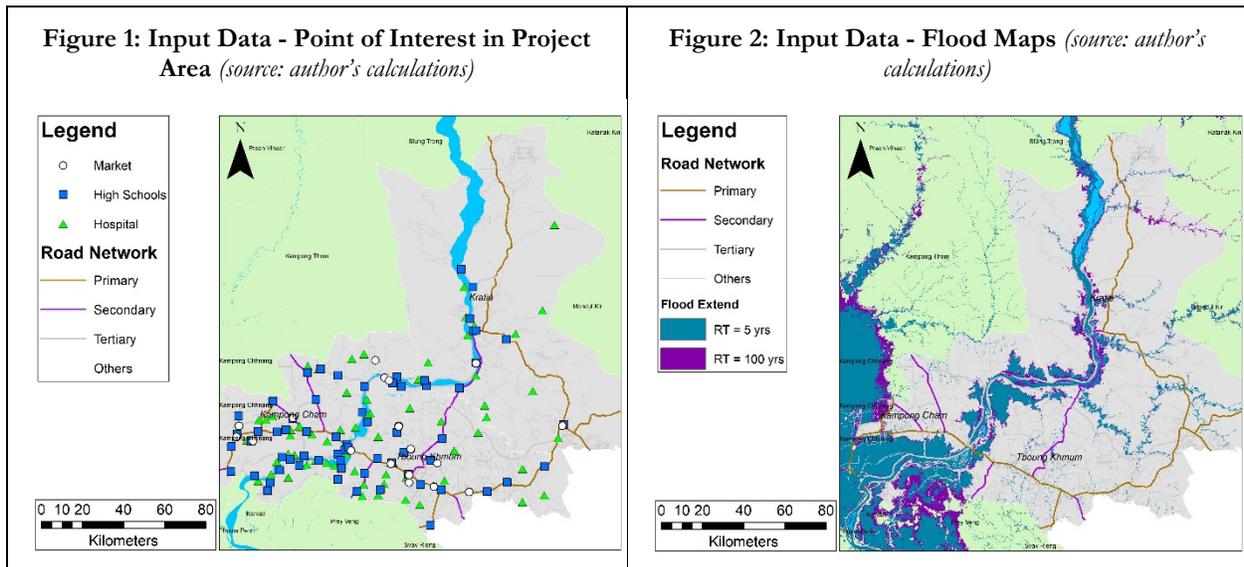
3. Recalculate travel times for each cell based on this new scenario.
4. Compare baseline with flooding scenarios and determine increased travel time (or loss of access) for non-isolated cells.
5. Combine loss of access with population/value of agricultural production and identify isolated cells.

2.3. Input Data

The model uses a set of databases combining open source data with government official data. Description and sources are detailed in Table 2 and displayed in Figure 1 and Figure 2.

Table 2: Data Inputs

	Description	Source
Population	United Nations (UN) estimates at 100 m resolution from 2015	AsiaPop
Points of interest	Geo-spatial location of schools (2015), hospitals (2018), and markets	Ministry of Rural Development, Ministry of Education, and Ministry of Health
Road network	OpenStreetMap + project-specific shapefile (Ministry of Rural Development) + additional roads to access all points of interest	OpenStreetMap and Ministry of Rural Development
Agriculture	Value of Crop Production (2010) at 10 km resolution	IFPRI Spatial Production Allocation Model (SPAM)
Floods	Flood water depth maps (5–100 years return period)	Deltares for SEADRIF



2.4. Evaluation and Prioritization of Interventions

Based on the assumption of speed and hydraulic design for roads after project interventions, new accessibility results were calculated. First, the road network was updated with new speeds to calculate gains in accessibility.

The climate resilience analysis was updated with new hydraulic design to calculate reduction of loss of accessibility during flood events. Four main scenarios are modeled: pre-project (non-flooded and flooded) and post-project (non-flooded and flooded).

To prioritize the interventions, the individual contribution of each road in terms of gains on accessibility and reduction of climate vulnerability (loss of accessibility) was calculated. The accessibility model was run for both non-flooded and flooded scenarios for each road under evaluation individually and assuming all other roads are not intervened. The pilot application considered 133 road segments, so in total, the accessibility analysis was computed for $134 \text{ (Baseline + 133 roads)} \times 3 \text{ points of interest} \times 2 \text{ (baseline and flooding)} = 804$ travel time scenarios.

3. Results

The model was used in the evaluation of more than 1,600 km of new investment in three flood-prone provinces in Cambodia: **Kampong Cham, Kratie, and Tboung Khmum**. The total population across these three provinces is over 2 million, Kampong Cham being the most populated province with the largest number of high schools and hospitals, Kratie being the least populated province, and Tboung Khmum being the province with the largest value of agricultural production among the three provinces.

3.1. Baseline Results

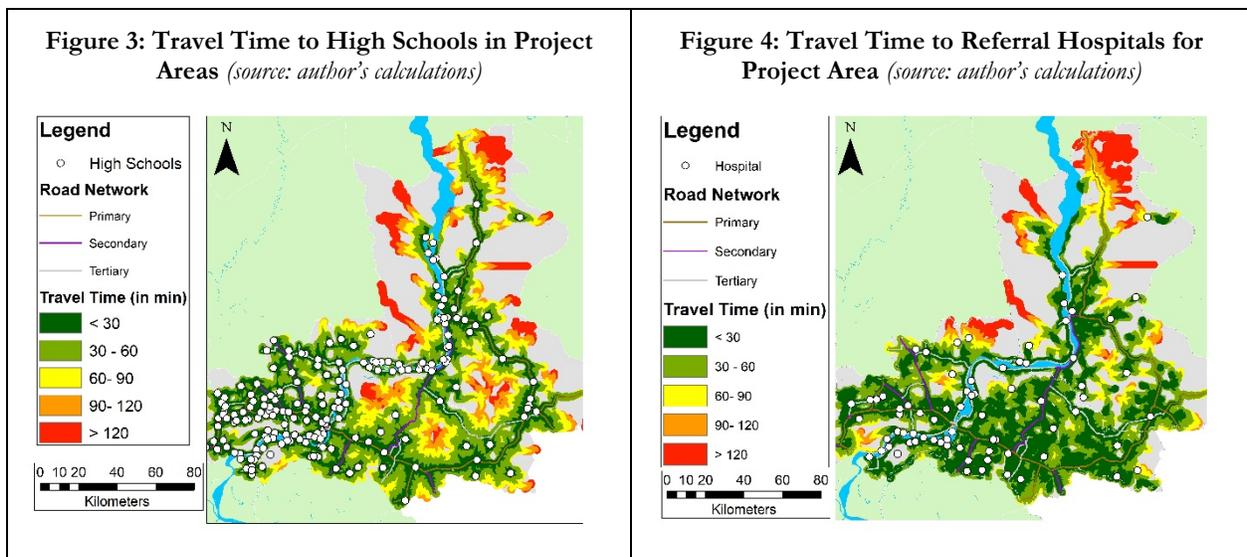
Table 3 and Table 4 show the results of the baseline accessibility and climate disruption analysis for the population across the three provinces (2.2 million people). Each row is the population and percentage of total population that can reach a certain destination in 0–30 minutes, 30–60 minutes, and more than 60 minutes. Value of agricultural production is not measured in population but rather in the value of agricultural production that can reach the regional market.

In terms of accessibility to education, constraints are high for high schools with only 55 percent of the population¹⁴ able to reach high schools in 30 minutes, making it suitable for an intervention (Table 3 and Figure 3). Accessibility constraints are high for referral and emergency medical facilities with only 32 percent of the population able to reach them in 30 minutes and about 37 percent at more than 60 minutes, therefore making it suitable for an intervention (Figure 4). Finally, in terms of accessibility to markets, about 28 percent of the value of agricultural production can reach a market within 60 minutes (Table 3).

¹⁴ The access to high-schools considers the whole population disregarding school-age. This assumption is made due to lack of undelaying georeferenced age population data.

Table 3: Results – Accessibility Baseline Scenario

Travel Time	Only High Schools (×1,000 people) and %		Only Referral Hospitals (×1,000 people) and %		Value of Agricultural Production (US\$, millions) and %	
All population			2,220		—	
At 2 km of any road			2,167		1,700	
0–30 minutes						
	1,199	55%	702	32%	166	10%
30–60 minutes						
	563	26%	609	28%	310	18%
More than 60 minutes						
	343	16%	794	37%	1,090	64%



The climate vulnerability scenario assumes flooded roads are impassable and recalculates accessibility analysis (Table 4) and loss of access (additional travel time required relative to baseline scenario - Table 5). The last row indicates the number of people who are either isolated (they cannot reach the facility) or flooded (located in the flood plain themselves).

The impact of floods is high. During heavy rains and floods, about 26 percent of the population lose access to critical facilities, health or education centers (Table 4), and 21 percent of the value of agricultural production loses access to markets (Table 4, Figure 5 and Figure 6).

Table 4: Results – Climate Vulnerability Scenario

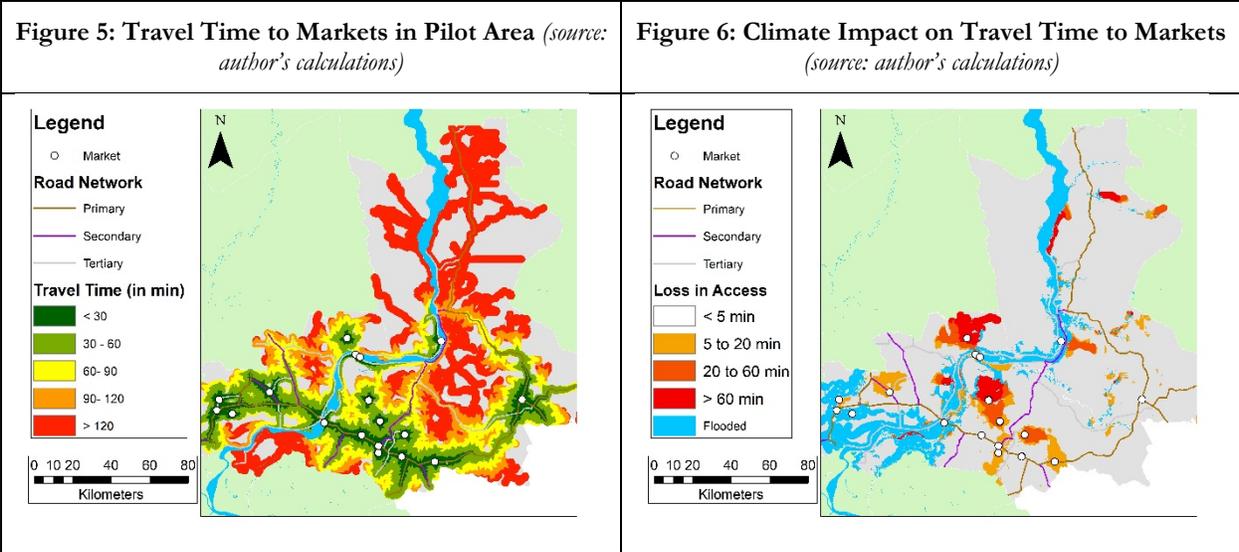
Travel Time	High Schools			Referral Hospitals			Value of Agricultural Production		
	(<i>×1,000 people</i>)	<i>% of Total</i>	<i>Diff</i>	(<i>×1,000 people</i>)	<i>% of Total</i>	<i>Diff</i>	(<i>US\$, millions</i>)	<i>% of Total</i>	<i>Diff</i>
All population				2,220			—		
At 2 km of any road				2,167			1,700		
0–30 minutes	834	39%	-16%	513	24%	-8%	129	8%	-2%
30–60 minutes	409	19%	-7%	435	20%	-8%	238	14%	-4%
More than 60 minutes	299	14%	-2%	579	27%	-10%	838	49%	-15%
Isolated	625	29% ¹⁵	26%	639	30%	27%	495	29%	21%

Looking at results from this climate disruption in more detail, Table 5 shows the losses in accessibility (measured as an increase in travel time) for each facility in terms of people impacted. Aside from people who become isolated because of flood disruptions, about 355,000 (16 percent of total) and 401,000 (18 percent of total) will require at least 30 additional minutes to reach a high school or referral hospital, respectively. For agriculture, about US\$210 million of value of production (10 percent of total) will need an additional 60 minutes to reach the closest markets. These values are different than in Table 3, as in this table all people with impacted access are accounted, rather than looking only at people who jump any of the three thresholds (30, 60 and more than 60 minutes).

Table 5: Results – Loss of Access

Loss of Access	High Schools (<i>×1,000 people</i>) and %		Referral Hospitals (<i>×1,000 people</i>) and %		Value of Agricultural Production (US\$, millions) and %	
0–30 minutes	659	30%	569	26%	461	22%
30–60 minutes	193	9%	178	8%	153	7%
More than 60 minutes	162	7%	223	10%	210	10%
Isolated	571	26%	587	27%	441	21%

¹⁵ The % of total and difference of isolated trips are not the same as there is approximately 2% of population in those provinces that is isolated in the non-flooded scenarios. The people lives on river islands without connection to road network and inland waterway transport is not modeled in this analysis.



3.1.1 Province Profiles

Accessibility and climate resilience diverge greatly among provinces. Kratie ranks the lowest in accessibility to a hospital with more than 44 percent of its population at more than 60 minutes from a referral hospital (see Table 6). Kratie is the least densely populated province with 30 people/sq. km compared to 170 and 227 in TBK and Kampong Cham, respectively. The low population density linked with the fact that the eligibility criteria to install health facilities depend on population (with an estimated average of 120,000 people served by a referral hospital), Kratie has the lowest number of referral hospitals with lowest population density leading to high travel time for its population to reach the closest facility. On the other side, Kampong Cham has fair accessibility to hospitals, with almost 70 percent of the population in the 60 minutes range.

Table 6: Accessibility to Referral Hospital by province

		Kampong Cham		Kratie		Tboung Khmum	
	Population Density (pop/sq km)	227		30		170	
	Referral Hospital Density (pop/hospital)	115,000		118,000		140,000	
	Travel Time	Population	%	Population	%	Population	%
Access to Hospitals	0–30 minutes	364,497	36%	93,266	31%	274,861	33%
	30–60 minutes	307,854	31%	54,693	18%	247,664	30%
	More than 60 minutes	306,297	31%	135,295	44%	297,839	36%

In terms of accessibility to markets and economic potential, Kratie has very low accessibility to markets, with more than 77 percent of its value of agricultural production at more than 60 minutes from a regional market (see Table 7).

Table 7: Accessibility to markets by province

	Travel Time	Kampong Cham Population and %		Kratie Population and %		Tboung Khmum Population and %	
		Population	%	Population	%	Population	%
Access to markets	0–30 minutes	59	15%	36	4%	72	15%
	30–60 minutes	106	27%	70	9%	134	28%
	More than 60 minutes	207	52%	619	77%	257	54%

3.2. Evaluation of the Benefits of Pipeline Project Investments

The proposed pilot area considers rehabilitation of some main roads and a large portion of the rural road network. There are more than 1,300 km of roads under intervention by the Cambodian government and other development partners/donors in those same provinces (Table 8 and Figure 7). For that reason, including the current roads under ongoing or planned interventions is critical to maximize the benefits in the area and avoid overlaps.

Table 8: Project Roads Length under Consideration				
Project Roads (km)	Total (km)	Kampong Cham	Tboung Khmum	Kratie
Main roads	173	47	97	29
Rural roads	1,688	465	500	723
Roads financed by various donors	1,312	487	319	506

Figure 7: Roads under Intervention in the Project Provinces (*source: author's calculations*)

The accessibility values to Referral Hospital, High Schools and Markets were recalculated based on improved travel speeds from project interventions. Results in Table 9 suggest that the number of people who needed more than 1 hour to reach a referral hospital will decrease 12 percent compared with baseline scenarios. In term of access to education, people with a high school at 30 minutes away will increase 6 percent up to 61 percent of total population and improvements of market access will see 10 percent reduction on agriculture values that need more than 60 minutes to reach markets.

Table 9: Results – Accessibility After Project Scenario

Travel Time	High Schools			Referral Hospitals			Value of Agricultural Production		
	(×1,000 people)	% of Total	Diff	(×1,000 people)	% of Total	Diff	(US\$, millions)	% of Total	Diff
All population				2,220			—		
At 2 km of any road				2,167			1,700		
0–30 minutes	1,318	61%	6%	892	41%	9%	234	14%	4%
30–60 minutes	549	25%	-1%	674	31%	3%	417	25%	7%
More than 60 minutes	238	11%	-5%	540	25%	-12%	916	54%	-10%

Looking at results from this scenario in more detail, Table 10, shows the gain in accessibility (measured as a reduction in travel time) for each facility in terms of people benefitted. Larger gains are seen in accessibility to high schools and referral hospitals with more than 541,000 and 911,000 people, respectively, experiencing a reduction of travel time thanks to project interventions (Table 10). More than US\$342 million of the value of agricultural production would see more than 45 minutes reduction in travel time to regional markets. All these values are larger than in Table 10, as in this case, all people with benefited access are accounted, rather than looking at only at people who jump any of the three thresholds (30, 60 and more than 60) in Table 9.

Table 10: Improvement of Accessibility from Project Interventions

Reduction in Travel Time	High Schools (×1,000 people)	Referral Hospitals (×1,000 people)	Value of Agricultural Production (US\$, millions)
5–20 minutes	372	358	210
20–45 minutes	142	308	265
> 45 minutes	27	245	342
Total	541	911	817

In terms of resilience, more than 152,000 and 393,000 people, respectively, will experience a reduction of more than 20 minutes travel time during rainfall events to access high schools and hospitals (sum of second and third rows in Table 11).

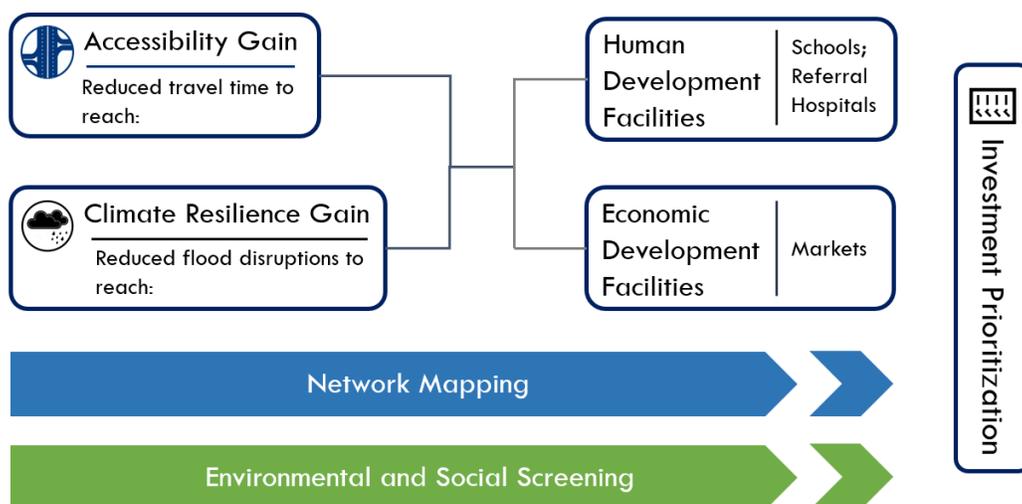
Table 11: Improvements in Resilient Accessibility from Project Interventions (during flooding events)

Reduction in Travel Time	High Schools (×1,000 people)	Referral Hospitals (×1,000 people)	Value of Agricultural Production (US\$, millions)
5–20 minutes	275	301	134
20–45 minutes	122	180	203
> 45 minutes	30	212	290
Total	427	693	627

3.3. Prioritization of Road Segments

The prioritization uses a multicriteria approach using the outputs of the accessibility analysis and the climate vulnerability analysis. Each criterion is based on absolute gains of accessibility by each individual road segment, calculated as the sum of the reduction in travel time in minutes for every person or the value of agricultural production. The values for each of the criteria are then normalized from 0 to 100 and then averaged out using equal weights. A value of 100 would indicate that the segment is the top segment in each of the criteria. Each road segment is then given a score from 0 to 100. These criteria and approach were discussed and agreed with the main stakeholders. After prioritization is done using this analysis, additional selection is done to select the final list of road candidates for improvement. Social and environmental safeguards screening further screens the list of identified roads to ensure that the proposed investment does not cause major negative environmental and social impacts and maximizes development gains for the beneficiaries. Finally, on this, a final short list of lifeline roads can be identified which are eligible for investment with a balanced representation of the targeted provinces (Figure 8).

Figure 8: Prioritization Framework



The highest scoring 300 km are shown in Table 12. Each row is a road segment. Columns 3–8 are the absolute gains in accessibility in minutes × persons or minutes × US\$, millions. Columns 9–12 are the normalized combined scores. The top road segment has a combined priority score of 55.

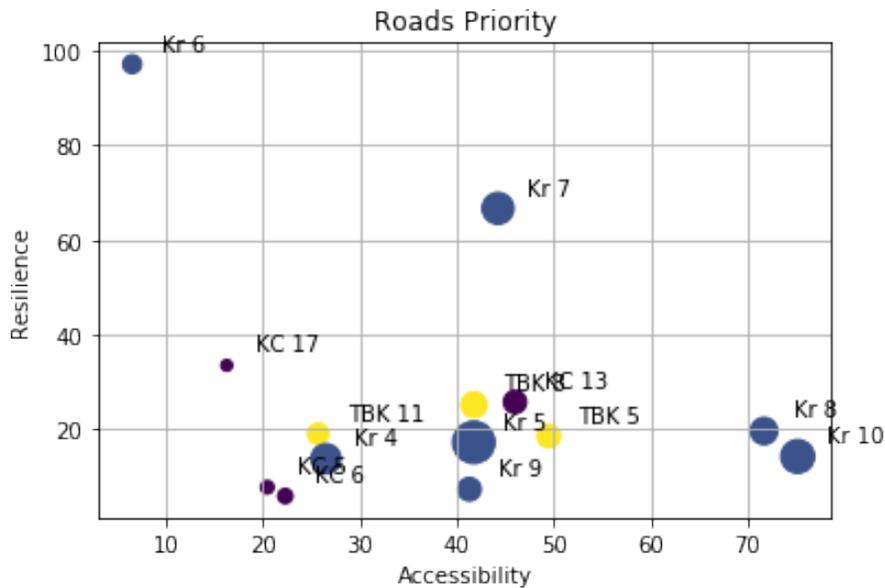
Table 12: Summary of Road Prioritization Results

Province	Map ID	Accessibility			Climate Resilience			Combined			Length (km)	Length Cumulative (km)
		School	Hospita 1	Market	School	Hospita 1	Market	Rank Access	Rank Climate Resilience	Rank Total		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Kratié	7	72,695	86,048	457	29,814	720,883	9,748	44	67	55	42	42
Kratié	6	4,722	7,335	367	142,295	845,934	10,196	7	97	52	14	56
Kratié	8	55,094	270,671	1,540	50,224	176,029	549	72	20	46	30	86
Kratié	10	83,802	72,925	2,854	35,239	49,598	1,409	75	14	45	47	133
Kampong Cham	13	62,782	168,176	116	99,195	90,269	245	46	26	36	22	155
Tboung Khmum	5	29,620	282,494	396	40,786	205,293	489	49	18	34	22	177
Tboung Khmum	8	48,477	176,374	163	95,403	77,460	471	42	25	33	28	204
Kratié	5	17,257	50,865	2,510	5,550	365,594	465	42	17	29	74	279
Kampong Cham	17	37,253	14,771	6	155,278	2,035	3	16	33	25	5	284
Kratié	9	53,732	131,931	392	24,142	44,007	83	41	7	24	23	307

Figure 9 is a representation of the values of Table 12, where the scores are plotted on the x- and y-axes. The size of each point is related to the length of the segment.

The four highest scoring roads are all in Kratié province. Kratié road segment 6 ranks the highest in resilience but low on accessibility, while Kratié road segments 8 and 10 rank the highest in accessibility gains but low on resilience. Kampong Cham roads rank lower compared to the other two provinces.

Figure 9: Road Prioritization Rank



3.4. Additional Use: Evaluation of Planned or Completed Projects

The analysis also has the potential of evaluating already selected/planned and/or completed road projects with assumptions on speeds and hydraulic designs collected from the field, to better understand the benefits of these investments from climate and accessibility perspectives.

This approach was piloted on 130 km for selected roads in three flood-prone provinces (**Siem Riep, Kandal, and Stung Teng**) as part of a World Bank Group-supported Cambodia Southeast Asia Disaster Risk Management Project (P160929) in rural roads of Cambodia. The methodology was used to evaluate the differences in accessibility between the baseline and the climate vulnerability scenario with and without the project. Based on this, the gains in rural accessibility during flood events were calculated, highlighting the increased resilience to those events. For example, in Siem Riep province, intervention in 51 km of resilient rural roads would mean resilient access to high schools for 23,000 students, resilient access to referral hospitals for 34,000 people, and resilient access to regional markets for more than US\$33 million of the value of agricultural production.

3.5. Limitations of the Analysis

This analysis has some limitations linked to data available or simplification of methodology that could eventually be addressed in future works. The main three limitations are described as follows:

1. **The model only considers road transport.** Although the model considers motorized and nonmotorized road transport, it does not model inland waterway nor public transport (like buses

or rail). Public transport is not an issue in the pilot provinces in Cambodia as it is rarely present and only serves for long-distance trips (for example, to the capital); however, if this method is to be applied in other regions (especially in the urban setting), this limitation may be important. At the same time, inland waterways are relevant in the pilot areas as there is evidence that villages depend on that mode of transport especially during rainy and flooding season. As data on inland waterways were not available, it was not possible to include it in the model at this point.

2. **Accessibility is estimated based on the shortest paths to the point of interest.** The model considers accessibility as the availability to reach the closest point of interest. For example, for agricultural production, it uses the provincial market as its destination regardless of the type of crops. This may not be always true as some products are sold locally, and some may be transported to the capital for international exports. This is a simplification as there are no available data on actual origin and destination or household surveys that would allow for that level of detail. Similarly, the model used assumptions of travel speeds rather than actual travel speeds (in the exception of the additional use case study in Section 3.4). This would require an intense data collection campaign that is beyond the scope of this study.
3. **Agricultural data have low resolution and have no distinction between seasons.** The values of agricultural production are taken from an open-source global model developed by IFPRI.¹⁶ Its resolution is 10 km by 10 km, and it provides an indication of high-productivity areas. The values used in our model are the estimated annual value of production. As such, we did not differentiate between crops that are grown during dry or rainy seasons nor if they are perishable or not. Therefore, the estimation for climate impacts may be over- or undercalculated. With more detailed information about crops, one could model the specific crops that would be affected by disruption during the rainy season, and it would allow for a more accurate sense of economic impacts.

4. Conclusion and Next Steps

Focusing on three pilot provinces, Kampong Cham, Kratie, and Tboung Khmum, the study has highlighted the urgent need to invest in resilient accessibility. For example;

- **Only 32 percent of its population can reach a referral hospital and emergency services in half an hour.** Even though there is an extensive network of community health centers in the rural areas, accessibility to a referral hospital with emergency services such as intensive care bed

¹⁶ <https://www.mapspam.info/>.

units is low. This may be critical in treating patients with severe and quickly deteriorating conditions such as in COVID-19. Investment in rural roads would bring large benefits with reduction of people who need more than 1 hour to reach a referral hospital from 37 to 25 percent.

- **Just over half of the rural population in the project provinces can reach a high school in half an hour.** That may be one of the factors limiting human development growth in rural areas. Investment in rural roads will increase this number to 61 percent.
- **Only about 28 percent of the value of agricultural production can reach a market within an hour,** and during floods, 21 percent of the value of agricultural production effectively loses access to markets. Lack of access to markets limits growth of income among the rural population, including women, who account for over 44 percent of employment in the agricultural sector, and may slow down economic recovery post a crisis. Investment in rural roads will increase that value by 11 points to 39 percent.
- **Investing in 1,300 km of rural roads toward climate resilient could bring large gains in accessibility,** with more than 390,000 people experiencing a reduction of more than 20 minutes travel time during rainfall events to access referral hospitals. Furthermore, more than US\$300 million of the value of agricultural production would see a reduction in travel time to regional markets of over 45 minutes.

The methodology presented in this paper aims to bring access to hospitals and schools, climate resilience, and economic growth to the prioritization and evaluation of rural transport projects. This data-driven analysis was able to provide the government with information and concepts that can guide their decision-making processes about new investments as well as an understanding of the benefits of existing interventions. This has various benefits, particularly in the context of limited data on the condition of rural roads, including:

- **Introduces transparency and evidence-based support for prioritization of new investments.** The method provides a framework to support decision making, prioritization, and selection on new investments in rural transport based on analytics and data. The approach can also support policy makers in the preparation of sectoral strategies and financing plans for rural roads investments and maintenance in countries that are exposed to floods and climate change uncertainties.
- **Provides a new set of metrics to evaluation of current investment.** The increase in accessibility during the dry season and the reduction in travel time to access human capital development and economic centers provide new insights on the evaluation of interventions already under development. The reduction of accessibility loss during the rainy season can be

used as a new metric for the monitoring and evaluation of the efficiency of investment and to better understand the benefits of improving accessibility and resilience of roads.

- **Identifies socioeconomic benefits of rural infrastructure investments.** Economic analysis of rural transport investments has traditionally focused on reduction of road user operating cost by improving road surface conditions. The framework presented here allows to bring social benefits to rural transport investment as gain in accessibility to human capital development centers such as for health and education. At the same time, introducing the gain in accessibility to markets by productive agricultural land, the method identifies a new metric for economic growth that goes one step beyond the more traditional methods focusing on measuring road operating cost.
- **Supports policy dialogue on rural development and resilience.** The data, maps, and results from this model engage decision makers, allowing them to identify areas with lower accessibility and high climate vulnerability. This information can inform strategic goals and action plans for the national and provincial governments.

The analysis has also identified the next avenues for further improvement of this model. The first is to include supply chain resilience, based on enterprise and business census. This will bring an additional dimension to the analysis as it will evaluate economic losses of business interruption. This method has already been developed in the context of Tanzania (Colon, Hallegatte, and Rozenberg 2019), and it is another step toward operationalizing some of the analysis included in the report of Hallegatte, Rentschler, and Rozenberg (2019). There is also potential to assess poverty impacts of road disruptions using the methodology by adding the results of the model to poverty maps. Another avenue is to scale up the analysis for all 27 provinces across Cambodia to produce whole-network analysis which can inform government strategies for closing the infrastructure and accessibility gaps.

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Annex 1: Accessibility Model - ArcGIS Python Sample Code

```

# Import system modules
import arcpy
from arcpy import env

## Road Network Input with Attribute with Travel Time per 100 m
inFeatures = "C:/Users/wb499012/OneDrive - WBG/Cambodia/GIS/RoadSpeeds_Scenarios_v7.shp"
## Population point shapefile with Attribute on Total Population and Ag Value per point
inPopPoint = "C:/Users/wb499012/OneDrive - WBG/Cambodia/GIS/Pop_Point_2km_v4.shp"
## Facilities point shapefile
inHSchool = "C:/Users/wb499012/OneDrive - WBG/Cambodia/GIS/MTR/HighSchools_ProjArea.shp"
inMarket = "C:/Users/wb499012/OneDrive - WBG/Cambodia/GIS/Market_ProjArea.shp"
inRHospital = "C:/Users/wb499012/OneDrive - WBG/Cambodia/GIS/Hospitals_ProjArea_v4.shp"
## Raster with walking travel time (90second per 100m) with waterbodies removed
inWalkbuf = "C:/Users/wb499012/OneDrive - WBG/Cambodia/GIS/twalk_buff_v3.tif"

for valField in ["Base_time", "Proj_time"]:

    outRaster = "RoadTime_" + valField[0:4] + "_vLE3"
    outCDS = "TTS_" + valField[0:4] + "_vLE3"
    outCDH = "TTH_" + valField[0:4] + "_vLE3"
    outCDM = "TTM_" + valField[0:4] + "_vLE3"
    outCDHS = "TTHS_" + valField[0:4] + "_vLE3"
    outCDRH = "TTRH_" + valField[0:4] + "_vLE3"

    outCDS_dr = "TTS_dr_" + valField[0:4] + "_vLE3"
    outCDH_dr = "TTH_dr_" + valField[0:4] + "_vLE3"
    outCDM_dr = "TTM_dr_" + valField[0:4] + "_vLE3"
    outCDHS_dr = "TTHS_dr_" + valField[0:4] + "_vLE3"
    outCDRH_dr = "TTRH_dr_" + valField[0:4] + "_vLE3"

    assignmentType = "MAXIMUM_COMBINED_LENGTH"
    priorityField = "Proj_speed"
    cellSize = 100
    arcpy.env.extent = "MAXOF"

    if len(arcpy.ListFields(inFeatures, valField)) > 0:

        ## By Bike - 20km and 0.25 m Climate Thre
        # Execute PolylineToRaster

        arcpy.PolylineToRaster_conversion(inFeatures, valField, outRaster, assignmentType, priorityField, cellSize)
        outRaster_1 = arcpy.sa.Con(arcpy.sa.IsNull(outRaster), inWalkbuf, outRaster)

        outCostDistance = arcpy.sa.CostDistance(inHSchool, outRaster_1)
        arcpy.sa.ZonalStatisticsAsTable(inPopPoint, "pointid", outCostDistance, outCDHS, "#", "SUM")

        ## Modeling climate disruption based on 3 types of roads (see assumption in paper)
        ## ratercals_sp are the difference between RT50 and RT (20, 10 and 5 - depending on road type) waterdepth rasters
        outRaster_Disr = arcpy.sa.Con(outRaster_1, arcpy.sa.Con("rastercalc_sp36", outRaster_1, "", "Value<0.25"), outRaster_1, "Value>35")
        outRaster_Disr = arcpy.sa.Con(outRaster_Disr, arcpy.sa.Con("rastercalc_sp9", outRaster_Disr, "", "Value<0.25"), outRaster_Disr, "Value>8")
        outRaster_Disr = arcpy.sa.Con(outRaster_Disr, arcpy.sa.Con("rastercalc_sp7", outRaster_Disr, "", "Value<0.25"), outRaster_Disr, "Value>5")

        outCostDistance_dr = arcpy.sa.CostDistance(inHSchool, outRaster_Disr)
        arcpy.sa.ZonalStatisticsAsTable(inPopPoint, "pointid", outCostDistance_dr, outCDHS_dr, "#", "SUM")

        ## By Car - 40km and 0.5 m Climate Thre
        # Execute PolylineToRaster
        ## Model higher speed for cars
        outRaster_1 = arcpy.sa.Con(outRaster_1, "9", outRaster_1, "Value = 18")

        outCostDistance = arcpy.sa.CostDistance(inRHospital, outRaster_1)
        arcpy.sa.ZonalStatisticsAsTable(inPopPoint, "pointid", outCostDistance, outCDRH, "#", "SUM")

        outCostDistance = arcpy.sa.CostDistance(inMarket, outRaster_1)
        arcpy.sa.ZonalStatisticsAsTable(inPopPoint, "pointid", outCostDistance, outCDM, "#", "SUM")

        outRaster_Disr = arcpy.sa.Con(outRaster_1, arcpy.sa.Con("rastercalc_sp36", outRaster_1, "", "Value<0.5"), outRaster_1, "Value>35")
        outRaster_Disr = arcpy.sa.Con(outRaster_Disr, arcpy.sa.Con("rastercalc_sp9", outRaster_Disr, "", "Value<0.5"), outRaster_Disr, "Value>8")
        outRaster_Disr = arcpy.sa.Con(outRaster_Disr, arcpy.sa.Con("rastercalc_sp7", outRaster_Disr, "", "Value<0.5"), outRaster_Disr, "Value>5")

        outCostDistance_dr = arcpy.sa.CostDistance(inRHospital, outRaster_Disr)
        arcpy.sa.ZonalStatisticsAsTable(inPopPoint, "pointid", outCostDistance_dr, outCDRH_dr, "#", "SUM")
        outCostDistance_dr = arcpy.sa.CostDistance(inMarket, outRaster_Disr)
        arcpy.sa.ZonalStatisticsAsTable(inPopPoint, "pointid", outCostDistance_dr, outCDM_dr, "#", "SUM")

        inPopPoint = "Pop_Point_2km_v4"
        arcpy.AddJoin_management(inPopPoint, "pointid", outCDRH, "pointid")
        arcpy.AddJoin_management(inPopPoint, inPopPoint + ".pointid", outCDM, "pointid")
        arcpy.AddJoin_management(inPopPoint, inPopPoint + ".pointid", outCDHS, "pointid")

        arcpy.TableToTable_conversion(inPopPoint, "C:/Users/wb499012/OneDrive - WBG/Cambodia/GIS/Results/V3/", "Pop_TTRHM_" + valField + ".csv")
        arcpy.RemoveJoin_management(inPopPoint)

        arcpy.AddJoin_management(inPopPoint, "pointid", outCDRH_dr, "pointid")
        arcpy.AddJoin_management(inPopPoint, inPopPoint + ".pointid", outCDM_dr, "pointid")
        arcpy.AddJoin_management(inPopPoint, inPopPoint + ".pointid", outCDHS_dr, "pointid")

        arcpy.TableToTable_conversion(inPopPoint, "C:/Users/wb499012/OneDrive - WBG/Cambodia/GIS/Results/V3/", "Pop_TTRHM_dr_" + valField + ".csv")
        arcpy.RemoveJoin_management(inPopPoint)

```