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指導教員　横張真 教授
飯田晶子 特任講師
山崎嵩拓 特任助教

都市化と気候変動の複合的効果の分析を通じた レジリエントな太平洋島嶼のための選択可能な道筋の提案

Analyzing the combined effects of urbanization and climate change to develop alternative pathways for resilient Pacific Islands

37-186864　David Lowell Mason

The escalating risks of coastal flooding and water shortage in Pacific Island Countries (PICs) are usually attributed to climate change hazards. This ignores the other components of risk to which urbanization contributes. We investigate whether urbanization increased risk using the Republic of Palau as a case study. This research developed a simplified model to perform analyses that can be applied to other PICs. By dividing coastal flooding and water shortage into hazard and exposure components we determine how urbanization contributed to the present-day risks and then predict how climate change may increase risk in the future. Results showed that urbanization is responsible for nearly all buildings exposed to coastal flooding today, while a projected sea level rise only led to 0.5% increase in exposed buildings. The water scarcity index illustrated how urbanization alone caused 3 water shortages between 1980 and 2018. Analysis of projected future rainfall predicted more than double the number of water shortages. The results illustrate the necessity to prioritize urbanization in the design of climate risk policy in PICs. Urban planning strategies that make best available use water and land resources gives PICs the potential to manage their long-term risk even in the face of climate change.

Introduction

The IPCC recognizes Climate Change-induced sea level rise and changing rainfall patterns as “key climate and ocean drivers of change" in island nations (Nurse, et al. 2014). These synergistic hazards pose a particularly high threat to very exposed Pacific Islands Countries (PICs), characterized by vast ocean territory and small landmasses and it can only be expected to worsen as Climate Change continues at unprecedented rates (Nurse, 2014).

Just as these Climate Change studies evaluated how hazards have and will increase (IPCC 2019) in number and severity, the nature of their analysis means they do not explore exposure and vulnerability. Since risk is defined as a function of hazard (natural weather or geological events), exposure (how likely one is to be affected by such hazards) and vulnerability (one's inability to cope with exposure to hazards) a complete risk assessment requires and analysis of socio-geographic factors as well (ADRC 2009). Traditionally, vulnerability in the Pacific is very low due to strong social and community ties, which foster strong resilience in the face of naturally occurring and anthropogenic environmental changes (Campbell 1990, Firth 1959, Lessa 1964, Marshall 1979, Rappaport 1963). However, even though it is recognized that urbanization increases exposure, and possibly vulnerability (UNISDR 2015), increases to coastal flooding and water shortage risk are still often attributed to Climate Change as efforts to separate Climate Change hazards and urbanization exposure are sparse. In PICs, if exposure has significant impacts on risk it means that urban management can potentially act as an adaptation method to future Climate Change. Urbanization is known to increase exposure and vulnerability to coastal flooding and water shortage (ADB 2013), but there is no research in PICs to determine the degree to which it has increased risk. This research seeks fill that gap and suggest urban management as a tool to reduce coastal flooding and water shortage risk and act as a Climate Change adaptation strategy.

Methodology

Palau sits in the Western Pacific just north of the equator and consists of 16 local state governments spread over more than 300 volcanic and limestone islands and sand atolls. While nine of these states are located on the biggest island, Babeldaob (see figure 1). However, most residents (65%) live in the urban center upon the island of Koror, which is connected to southern Babeldaob via a bridge (Republic of Palau 2015). Since World War II, Koror's population has grown from almost 700 people in 1946 to 11,444 at present, representing two thirds of the total population today (Republic of Palau 2015), while a further 13% of the population reside in the neighboring state of Airai, which holds the international airport and the sole water source for the two states, which compose Palau's formal urban area (Republic of Palau 2015).

Examining Climate Change-induced sea level rise and urbanization is equivalent to two objects moving closer to each other until they meet and eventually push into one another. As sea levels moved further inland, population growth pushed the urban footprint towards and into the mangroves and reefs. In Koror we measured both of these movements through local tide gauge data (NCDC) and using GIS data to determine which was a more significant factor in current coastal flooding.

This analysis was limited to reliable tide gauge data and only allowed us to use map data from 1983 and 2018. Sea levels from these two periods were then extracted to GIS elevation contour layers. Buildings touching or lying below these elevations are considered to be exposed to coastal flooding.

If a building is only touching the 2018 sea level elevation it is considered to be exposed because of Climate Change because without the sea level rise that occurred from 1983 to 2018 it would not be at risk of coastal flooding. However, if a building is touch or below the 1983 sea level elevation it is considered exposed due to urbanization because removing sea level rise still leaves the building exposed to coastal flooding. We then counted all the buildings exposed because of Climate Change and, separately, urbanization to determine which was the bigger factor in today's coastal flooding. This methodology allows us to use the available data and separate increases to coastal flooding risk into hazards from Climate Change and exposure from urbanization.

Similar to the coastal flooding analysis, this seeks to separate contributions to water shortages from changes in Climate Change-induced rainfall patterns and increased water demand caused by urbanization. However, differences in data type and availability require a completely different approach to water shortage analysis. The case study area was also expanded to include the entire urban area, Koror and Airai, because they use the same water source and together hold almost all of Palau's tourism.

To separate changes to rainfall and water demand we create a water scarcity index (WSI) dividing predicted demand, population growth dependent, by water supply, rainfall dependent, which is shown by the following equation:

$$\boldsymbol{WSI} = \frac{\Delta Predicted\ Monthly\ Water\ Demand}{\Delta 5\ Monthly\ Average\ Rainfall} \qquad (1)$$

This index enables us to manipulate population growth to simulate how urbanization contributed to the reported water shortages and estimate if these events would have happened in the absence of this urbanization.

We use per person water consumption estimated in 2007 (ADB 2007). These rates will be multiplied by the number of tourists and residents and days in the respective month to calculate the predicted monthly water demand (PMWD), which is shown by the following equation:

$$\boldsymbol{PMWD} = d(xP_t + yP_r) \qquad (2)$$

where d is the number of days in the given month, Pt is the population of tourists, Pr is the population of residents. The value of x and y represent the water use in liters person^{-1} day^{-1}, 1,366 and 443 respectively (ADB 2007). For the WSI to predict a water shortage it must have a point where if it goes higher it is considered a water shortage. To calibrate the model, we use the same government reports and newspapers to set a water shortage threshold (WST) that makes the WSI most accurately recreate actual water shortages by using Palau's water shortage history.

Once the WSI and WST were set, we ran the same model with removed population growth after 1980, while maintaining the same number of tourists. Taking away urbanization after 1980 shows how the increase in population contributed to water shortages that occurred over the study period. After, we counted the reduction in number of months over the WST to better understand how urbanization not only contributed to more water shortages but also increased their severity.

Results

Post-WWII Koror experienced substantial building growth as shown in figure 6. As land in the urban center became scarce buildings moved closer to and in some cases past the coastline, already demonstrating urbanization's role in increasing exposure to coastal flooding. A detailed plan and section of Sechemus, Koror in figure 1 highlights this development pattern.

The 1983 sea level exposed 79 buildings, 5%, of buildings digitized from the 1983 USGS map. By 2018, the same sea level exposed 207 buildings, 6.4%, more than doubling the exposure in 35 years. This is due to Koror's method for incorporating growth.

However, as the tide gauge data showed average local sea level rose 8.2 cm over the same time period. After accounting for the rise in sea level, three more buildings were

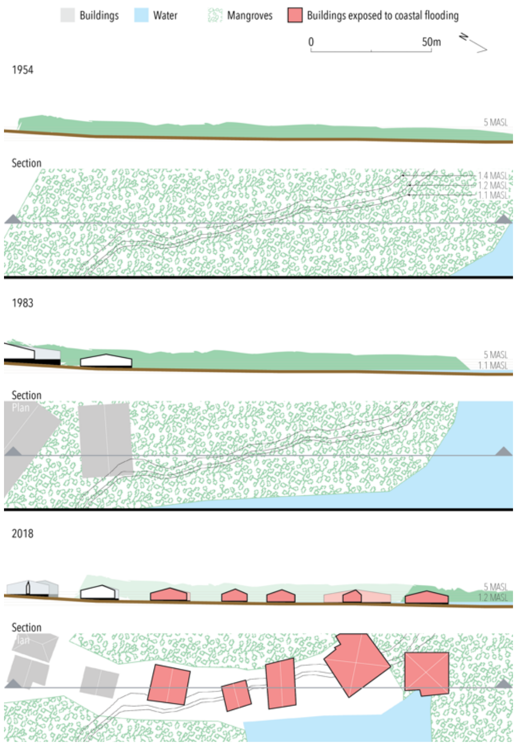

Figure 1 - Section and plan of coastal flooding in Sechemus, Koror

did not significantly increase hazards and thus risk of coastal flooding. Accounting for future sea level rise, with the 2018 building footprint, found a further eight buildings exposed.

Government reports and newspapers revealed seven water shortages in Palau from 1980 to 2018. Three major droughts occurred in 1983, 1998 and 2016 forced severe water hours on Koror and some other states while also affecting agriculture and coastal waters. Four minor water shortages occurred in 2002, 2005, 2010 and 2018. Water hours from these events only appeared happen in Koror already suggesting that urbanization played a key role in increasing exposure in the urban center to water shortages.

The WSI successfully predicted six out of seven of these water shortages, though it counts two water shortages for the major 2016 water shortage, which was only one event, (see figure 9). This may be explained by the fact implementation of water hours is how we define water shortages and this decision is made by local officials and not necessarily always triggered in the same circumstances. It is possible that in 2016 decisionmakers waited longer than before to enact water hours. The model also recorded 18 months above the WST.

To determine how urbanization possibly contributed to these water shortages, we removed population growth after 1980 from the population, while maintaining the same annual tourist visitors and ran the WSI again. The reduced urbanization resulted in three fewer water shortages. In 2005, 2010 and 2018 Koror likely would not have been forced to implement water hours. While the major water shortages remained, the lack of population growth reduced the number of months above the WST by two-thirds to only 6, less than the total number of water shortages experienced, suggesting that these events may not have been as severe if not for the increased population drawing water.

In total, the actual WSI recorded 18 months above the WST. Maintaining the 1980 population through study period lowered that to 6 months and using the maximum population, 2005, raised it to 24 months above the WST. Showing that population change within this small water system can have major consequences regardless of rainfall.

Future rainfall with today's population and tourists shows even more water shortages occurring. All three rainfall models predict a significant increase in water shortages (see figure 10). Hg2e projects the fewest number of water shortages, 16, which is still more than double the number that occurred over past analysis period. Mc3 not only projects the most, 21, but also projects the highest severity with four times as many months over the WST, 78.

The three models all point to higher risk in the future the only vary in severity of this increase. Additionally, these are most likely underestimates as Palau's tourism industry is expected grow and with it water demand in the urban area, which will only compound water shortage risk.

Conclusion

This research attempted to unwind the complicated relationship between climate change and urbanization to determine to what extent population growth in Palau's urban area affected coastal flooding and water shortage risk using a wide variety of data and methods as required by a research area with limited data availability. It illustrated how urbanization has increased exposure to climate risks and further how future Climate Change will only add to the same risks. PICs, with their miniscule emissions, have little control over global climate. However, this research showed that internal urbanization patterns can have significant effects on the same climate risks, meaning that PICs can to a certain extent still exert some control over future climate risks. Thus, while advocating for strong emission reduction targets at the international level, PICs should begin urban management programs to make maximum use of land and water resources to lower their risk to coastal flooding and water shortages.

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