Water Vulnerability in Low-lying Coastal Cities

Environmental Studies 600: Water in a Changing World

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1. Abstract

The objective of this study is to assess and compare the effects that climate change will have on coastal cities with similar elevation and topography. The cities in this study are chosen because they each have different climates, climate change readiness, institutional challenges, infrastructure, and socioeconomic problems; but yet all will face the same threat of sea level rise. Other water vulnerabilities such as changes in rainfall and/or changes in river water flow continue to create more pressure on to these cities as each location make the city highly sensitive to any changes. To begin this study, the differences between cities who have “developed” and cities who are “developing” were considered. When looking closer there are three main differences between developed and developing cities. First, in developed cities there are working and present institutions while in developing cities there are inefficient or non-existent institutions. Secondly, in developed cities there is high economic capability while in developing cities have a relatively low economic capability. And third, infrastructure: in developed cities, there are governmental, non-governmental and educational infrastructure in place while in developing cities, many are lacking or have poor infrastructure needed to help mitigate effects of climate change.

The first city our study looks at is Rotterdam, Netherlands. Rotterdam is an example of a developed city in a wet temperate climate with relatively few issues barring it for adapting to a changed climate. Adaption and mitigation policies are already in place and funding is not a huge problem. The second developed city is New Orleans in the United States. New Orleans, Louisiana (NOLA) is a city with a wet subtropical climate. The problems surrounding NOLA, however, are not the access to institutions, but instead, is its many issues implementing the proper adaptations needed to survive. Third, Alexandria is in a hot desert climate and is still developing and the adaptations needed are also difficult to spur because of the lack of institutions, including stable government needed to introduce legislation to mitigate and adapt to rising sea levels. Last, wet and tropical Phnom Penh is still in the very early stages of development, it faces many institutional and economic obstacles in its plans to ready the city for changing climate. With different climates, readiness ability, institutional and socioeconomic challenges, each of the selected cities can detail a different perspective on the issue. Each city’s report also demonstrates the amount of attention that needs to be focused on the future of many cities worldwide concerning both climate change and sea level rise.

2. Rotterdam, Netherlands

Introduction:

Rotterdam lies in the Netherlands' Rhine-Meuse delta region near the Belgian border. The city’s elevation is just at sea level (0 m) and is largely made up of polders (low-lying lands surrounded by dikes). Major bodies of water near the city are the North Sea (about 25 km away from city center) and the

Nieuwe Maas River, a distributary of the Rhine River that the runs right through the city. Rotterdam is the second-largest city in the Netherlands with a population of 616,456 (“Facts and Figures Rotterdam 2012”, 2013). Rotterdam is home to one of the busiest ports in the world and is one of the major economic centers of the Netherlands. The average disposable income per household in Rotterdam is around $33,550. The Netherlands is ranked 17th most prepared country for future climate change by the Notre Dame Global Adaptation Index, with a majority of its vulnerability coming from water.

Water Vulnerabilities:

Extreme dry events are expected to increase from once in every ten years, to once in every two years. Longer dry periods put Rotterdam at greater risk for land subsidence. As groundwater is evaporated from soil, the land will subside, change elevation, and become unstable (Gebaard et al., 2013); possibly damaging buildings. Peat polders and dikes are especially at risk as the process of these peaty areas drying out is irreversible. Losing these areas will remove an important water buffer, increase runoff potential, and increase the risk of flood. Other plant forms life can die off during these periods as well. Having more drought tolerant plants will become much more important in the future. Shrinking surface water pools during drought periods can also lead to an increased concentration of waterborne nutrients, which in turn lead to algal blooms, harming both water quality and ecosystem health.

The increased frequency of prolonged drought periods and sea level rise will increase the likelihood of saltwater intrusion into Rotterdam’s water system. These droughts will reduce the Nieuwe Maas’ water level and volume of flow, allowing for more saltwater to move inland (Gebaard et al., 2013). In order to maintain water levels in the canals and to keep the port operating, more seawater will need to be let in regardless of salt concentration. The decreased water quality will hurt the city's plant life and ecosystem health problems caused by this will only be exacerbated by drought. However, saltwater intrusion will not affect the city's drinking water quality as most of its water is retrieved from sources further upstream and there are already storage facilities and redundancies in place.

Although there has been no observed increase in sea level so far, Dutch experts expect to see a 35 - 85 cm increase in sea level by 2100 and possibly an increase of 1 - 2.15 m by 2300 (Knoop et al., 2013). Some dikes may not be large enough to deal with a half-meter rise in water level and will put the city at a greater risk for flooding. Many inner area dikes with severe height deficits are in urban areas. The building density will make reinforcing them quite costly and difficult. However, the inner dike regions will only be indirectly affected sea level rise as the outer dike regions will act as a buffer and take the brunt of the damage. Vulnerability in the outer dike regions can vary greatly, the elevation in some places can be as high as 6 meters above sea level, and with others being a few meters below sea level. The low-lying outer dike areas are the at most risk part of Rotterdam for flooding. A 60 cm increase in sea level

will change the flood frequency from happening once in every 50 years, to a once per year event. Many of the power stations, water treatment plants, roadways and gas distribution networks etc. that serve Rotterdam exist in these outer dikes regions. Polder areas, however, will not be at risk for flooding as they already have pumping stations to keep them dry in place. Thus regardless of elevation, outer dike buildings and infrastructure will need to be reinforced to properly adapt.

Increased storm frequency and rising water levels mean that Rotterdam's main storm barrier, the Maeslant barrier, will have to be closed more often. In a strong climate change scenario, the Maeslant storm barrier will have to be closed on average of at least once per year; up from the present once in every twelve years (Gebaard et al., 2013). The Maeslant barrier is only designed to accommodate a 50 cm sea level rise, any higher and its protection will become limited. Current estimates predict that the barrier will eventually have to be replaced by 2070.

Institutional Challenges:

In comparison to many other low-lying areas around the world, Rotterdam is quite well prepared for sea level rise and climate change. The Dutch government already has a national action plan, called the Delta Programme, to combat climate change by raising and widening dikes at critical points, increasing protection to important buildings, evacuating people from high-risk areas, and preserving available freshwater resources ("Delta Programme 2015 Brochure", 2014). The Dutch government aims to have an extremely safe and secure system, reducing the risk of death by drowning from floods to no more than 1 in 100,000 per year. Regional governments are also expected to do their own part in managing water resources and waterproofing cities.

The city of Rotterdam is the leading the country (if not the world) in preparation for climate change, with plans already in place to transform and adapt the city to rising sea and river water levels. The Rotterdam Climate Proof program incorporates improved flood management measures, adaptive buildings, a revamped urban water system, and a redesigned urban spatial environment all to achieve the goal of becoming 100% climate proof by 2025 (Molenaar et al., 2010). The program aims to minimize negative effects of climate change and while maximizing its benefits.

However, getting citizens involved, educating them, and keeping up communication continues to be a challenge. While the idea of adapting society to climate change is generally accepted in the populous, the Rotterdam Climate Proof and Rotterdam Adaptation Strategy 2010 were made with little to no public consultation (Miller, 2015). A lack of transparency outside annual summary reports also needs to be addressed. A "climate barometer" was supposedly set up to track the city's readiness, however, information regarding this has never made public. The unwillingness to share the information casts doubt on if the city is actually meeting its targets.

The lack of public knowledge and interest in flood prevention measures also continues to be a problem. Over half of Rotterdam citizens do not know if they live in inner or outer dike regions. This leads to a lack of personal preventable measures taken by citizens and thus exposing them to a greater risk for flooding. The lack of interest in Rotterdam's younger generations stems from not having experienced a major flooding event in their lifetime (Miller, 2015). The last major flooding event in Rotterdam occurred in 1957 when the North Sea breached the storm barriers, killing 1,836 people in the Netherlands and causing over 4 billion dollars worth of damages (Koekoek, 2016). The problems that lead to this event have been addressed, but preventive measures will need to be increased as sea level rises.

Socioeconomic Challenges:

Rotterdam is the 11th busiest port in the world by volume of shipments and is the busiest in Europe. The port's continued operation is crucial to the Netherlands economy thus making funding the city's protection a non-issue, however, this does not mean it will be cheap. Nationwide, adaptive flood prevention measures are expected to cost between $1.36 - 1.81 billion annually from present to 2050, and then between $1.02 - 1.70 billion annually from 2050 to 2100 (Hof et al., 2014).

Rotterdam's older neighborhoods and historic areas along the Nieuwe Maas River will need to be fortified somehow as much of these areas are dense, lack green spaces, and are heavily paved. Surface water runoff will become a big problem and make these districts more prone to flooding. Most of Rotterdam's public housing is located in these older neighborhoods and whose residents are disproportionately made up of immigrants (Entzinger & Engbersen, 2014). It is much more likely for a Dutch native to live in the inland areas North or East of the city. The combination of these factors makes it much more likely for low-income immigrants to become victims of flooding.

As mentioned above, more prolonged and intense droughts may destroy peaty areas causing land subsidence and increasing flood vulnerability. Older buildings with wooden pile foundations are at the most risk for flooding because their foundations may shift, causing the building crack. Surface water runoff will also increase as vegetation may die off during prolonged drought events. Conversely, intense rainfall during the summer will become a problem too. Rotterdam's climate is becoming more polarized, with winter storms becoming more frequent and summer storms becoming more sporadic and intense. The increased rainfall is already becoming a problem and must be managed and diverted through an already stressed stormwater system. Replacing paved areas with greenery in would help to delay runoff and relieve some pressure on the system.

Geographical Challenges:

Rotterdam's elevation makes it extremely susceptible to any change in water level and is already extremely reliant on water management to prevent flooding and seawater intrusion. Almost 55% of the Netherlands lies below sea level or is along a river, and a whole 60% of the country is deemed to be at risk for flooding (Knoop et al., 2013). There is not a whole lot of room in the country to retreat inland, thus, adaptation is a must. More intense climate change scenarios estimate that by 2200, sea levels two meters taller than today's are not unforeseeable. Such an increase would put more pressure on the barriers and dikes; however, there is much uncertainty on to how large this effect would be.

Conclusion

International water management agreements will need to be made with France and Germany to ensure a relatively consistent river water flow in the future. If this issue is not addressed, the Netherlands may experience large river water shortages in the summer and surpluses in the winter. Communication with neighboring France and Germany about water flow in the Rhine and Meuse rivers will become very important in the future. The Rhine river winter discharge is expected to increase between 17%-28% and the Meuse is expected to increase by 6%-18% by 2100 (Knoop et al., 2013). However, summer discharge is expected to have a much greater decrease, with the Rhine having 40% less than present. The Netherlands is very dependent on flood prevention measures are taken upstream, if France and Germany take no actions to improve them, Rotterdam and many other cities along these rivers will be at a greater risk for flooding.

3. New Orleans, United States:

Introduction:

Since its founding in 1718 by the French Mississippi Company, New Orleans was under both French and Spanish control before being sold to America in 1803 as part of the Louisiana Purchase. After becoming under American control, the population grew quickly. By the end of the nineteenth century, the population had risen to over a quarter-million and the white, English population was starting to push back against the free people of color and ex-slaves who found refuge in New Orleans, Louisiana (NOLA) (Infoplease, 2012; Krupa, 2011). This racism followed into the twentieth century with the introduction of Jim Crow. During the early twentieth century, construction of railways and highways decreased river traffic, diverting goods to other transportation corridors and markets (Durham, 2014).

It has been well-recognized that southern Louisiana was founded and developed on land below sea level. As the city expanded, New Orleans' government and business leaders had to drain many outlying areas to provide for the city's expansion. This plan, devised by A. Baldwin Wood, allowed the city to drain huge tracts of swamp and marshland and expand into low-lying areas. Scientists and New

Orleans residents gradually became aware of the city's increased vulnerability (Durham, 2014). In 1965, flooding from Hurricane Betsy killed dozens of residents and although the majority of the city remained dry, it demonstrated the weakness of the city's drainage system. After Betsy, measures were undertaken to dramatically upgrade pumping capacity. But by the 1980s and 1990s, scientists observed that this extensive and rapid pumping and divert of water had led to erosion of the marshlands and swamp surrounding New Orleans, leaving the city more exposed to catastrophic storm surges than before (Architecture Planning Commission, 2010).

New Orleans was catastrophically altered by what Dr. Raymond B. Seed of the University of California-Berkeley called "the worst engineering disaster in the world since Chernobyl," when the levee system failed during Hurricane Katrina in 2005 (Frangoulis, 2014). The failed floodwalls and levees constructed by the US Army Corp of Engineers did not have correct specifications and were out of date. And, these miscalculations allowed 85% of the city of New Orleans to become flooded in only 64 hours (Fialkoff, 2015). Even after a mandatory evacuation was instituted, some persons still could not leave. Since Katrina, Hurricanes Rita, Gustav, and Isaac and countless tropical storms have all hit the city. Each weakening the levees, pummeling the city, and continuing to lower the population, as many have fled the sinking city.

Water Vulnerabilities:

Though New Orleans will not face water deficits because of climate change, NOLA will have fresh water vulnerabilities as seawater encroaches further into the fresh water supply. As seawater rises, the salt water will overtake the freshwater lakes in the area. There are two main lakes that are in this area, namely Lake Pontchartrain and Lake Borgne (Durham, 2014). There is also the Mississippi River that traverses through the city. All these freshwater waterways are in real danger of becoming saltwater, especially as sea levels continue to rise.

As NPR reported "On Jan. 9, 2016, as record floodwaters roared down the mid-Mississippi River valley, hundreds gathered on the shores of Lake Pontchartrain to witness the opening of the Bonnet Carre Spillway (the flood control between the Mississippi River, Lake Pontchartrain and the Gulf)" (Wendland, 2016). Since then, ocean fish such as the speckled trout and the redfish have been continuously spotted and caught in Lake Pontchartrain. This will continue to be a problem as the Bonnet Carre Spillway becomes overtaken by saltwater. Another looming problem is the Mississippi River its freshwater security (Wendland, 2016). Low water flow at the mouth of the Mississippi River has allowed a "wedge" of saltwater from the Gulf of Mexico to start moving upriver. So far it is not considered a threat to New Orleans' parishes of St. Bernard or Jefferson water supplies. The federal drinking water standard for salt is 250 parts per million, but this level could be reached if the wedge's upper level reaches the parish's

intakes (Wendland, 2016). Denser, heavier saltwater flows upriver beneath fresh water flowing downstream when the river's flow drops below normal. This lack of freshwater in the river stems from the large-scale damming of the river upstream. The problem is exacerbated by the river mouth not being only 2 feet above the sea (Wendland, 2016). So, as the Mississippi River is depleted of freshwater flow, sea level is pushing saltwater further up the mouth of the river, soon it will reach NOLA which will affect the city's water supply.

Lastly, the problem of groundwater overdrafting can have implication with salt water as well. As sea levels continue to rise and there is no more freshwater in the groundwater aquifers under the surface, these aquifers could be filled with salt water. If this occurs, there would be problems not only with salt water polluting freshwater storage but it would also poison the soils around it. As salt and minuscule pieces of shale are introduced to the underground water table, soils would not be able to survive, they would suffocate from the salt.

Institutional Challenges:

The governance structure of New Orleans city is complex. There are many levels of government that all deal with the problems facing the city. The New Orleans Municipal Land-Use Authority has planning and regulatory jurisdiction but only over a small fraction of the at-risk area while the Official Regional Planning Commission which encompasses all the at-risk area, is a policy body without authority over regulation (Architecture Planning Commission, 2010). The Planning Commission also do not have jurisdiction over coastal ecosystems. Agencies of the state and federal government such as the US Environmental Protection Agency and Federal Emergency Management Agency, are the ones who are positioned to maintain and protect the larger coastal system and regulate uses that impact these waters and wetlands, but they usually do not have the mandate or political will to intervene in land use matters especially those involving private property (Architecture Planning Commission, 2010).

Recently, the Comprehensive Master Plan (CMP) for New Orleans has been slated for development. This CMP and Comprehensive Zoning Ordinance would focus on bettering: non-transportation related infrastructure included water and waste disposal, characteristics of key community facilities like schools and emergency stations, transit and transportation infrastructure, and environmental quality of the coast (Architecture Planning Commission, 2010). In his study, Lopez (2006) talks that the future safety of New Orleans will depend on "multiple lines of defense" from storm surge and relative sea level rise. This strategy includes coastal wetlands and barriers, levees and pumps, internal drainage improvements, and land use planning and regulation. However, while the CMP/Comprehensive Zoning Ordinance project provides an opportunity for New Orleans, many of the land use necessities needed for the plans lie outside the jurisdictional boundaries of Orleans parish (Architecture Planning Commission,

2010). And so, are subject to a fragmented and uncoordinated land use planning and governance structure for implementation.

To further complicate the problems of institutional governance, there is a lack of public trust in government and developers within the returning NOLA residents. After such structural failure of the levees and floodwalls during Katrina, New Orleans communities are wary of the US Army Corp of Engineers and many of the other institutions who promised security in the past (Carbonell & Meffert, 2011). Another issue is while conversion of residential areas to wetlands or green space to buffer the rising seawater is seen as a good strategy for rebuilding coastal barriers, these additions of green space are also generally seen as a way to decrease market value of surrounding residential property and potential ways to deny residents the ability to return to their former homes on the ocean side (Carbonell & Meffert, 2011).

Socioeconomic Challenges:

New Orleans has had large socioeconomic challenges since its founding. Today, the city ranks 8th in big city poverty nationwide and 7th out of the top 30 murder capitals of America (Bouffard, 2015; Neighborhood Scout, 2015). The poverty rate in New Orleans has declined from 28 percent in 1999 to 21 percent in 2007, but rose again to 28 percent in 2014, which is almost double the US poverty rate during the same years (Nonprofit Knowledge Works, 2016). Recently, NOLA has been in the news because 39% of New Orleans children live in poverty. This is the ninth highest child poverty rate among mid-sized cities in the US (Catalanello, 2015). The New Orleans murder rate has been halved since its peak in 2006, but it continues to be many percentage points higher than many other cities in the United States (NPR, 2015). And, the rise of sea level will only exacerbate the problem. Trying to fit the city population into a smaller area mixed with the competition of limited resources only raises the socioeconomic challenges for NOLA.

With the encroaching water, not surprisingly, persons in the lower income bracket and persons of color will be those most affected as sea levels begin to rise. Discriminatory housing practices have affected many cities around the United States. These discriminatory practices have a history in NOLA with strong connections to Jim Crow laws passed after the Great Flood of Louisiana in 1932. One particularly controversial law stated, “no persons or corporation shall rent an apartment in an apartment house or other like structure to a person who is not of the same race as the other occupants” (Fialkoff, 2015). These laws had two main effects: apparent segregation between Jefferson and Orleans Parish and nearness of the African-American community to the ocean on both sides of the bayou. While Jim Crow was outlawed after the 1960s, discriminatory housing and zoning practices have not stopped. Just thirteen months after Hurricane Katrina hit, St. Bernard Parish passed the infamous “blood relative” ordinance

(Fialkoff, 2015). This discriminatory bill restricted home rentals to those "within the first, second or third direct ascending or descending generations" (Fialkoff, 2015). And regardless of the original intent, the result has been to effectively exclude lower class and minority groups from obtaining sustainable housing options after the Hurricane.

In a post-Katrina migration report by E. Fussell et al. (2011), she notes "blacks tended to live in areas that experienced greater flooding and hence suffered more severe housing damage which, in turn, led to their delayed return to the city". She later notes that when a large-scale disaster occurs and causes destruction and the displacement of persons, the return is "shaped by demographic and socioeconomic characteristics of the individual and is constrained by both the pre-disaster circumstances and the post-disaster context" (Fussell, 2011). Morrow-Jones (2011) states in her disaster mobility study that "individuals who were forced to move after a disaster are less advantaged with respect to recouping their losses in the disaster-affected area: they tend to be older, members of female-headed households, socioeconomically disadvantaged, and are disproportionately black" which also confirms this socioeconomic bias when resettling and migrating to new places. Data has also shown that when disasters occur, advantaged individuals are not only the first to voluntarily leave but also are more likely to perceive the risk, leaving the less advantaged persons to cope with the effects of the disaster (Hunter, 2015).

Geographical Challenges:

Most of the present landmass of southeast Louisiana was formed by deltaic processes of the Mississippi River. Over the past 7,000 years, during a period of relatively small variations in sea level, the river deposited massive volumes of sediment and now lie in various stages of abandonment (Hart, Burkett, & Zilkoski, 2009). A combination of levees and diversion structures along the banks of the Mississippi River has prevented the depositional processes that had been naturally maintaining the altitude of the land surface above sea level (Hart, Burkett, & Zilkoski, 2009).

In addition to the stoppage of natural processes, the loss of large-scale marshes and barrier islands have increased the risks of flood disaster. Since 1940, approximately 1 million acres of coastal wetlands have been converted to open water in southern Louisiana as a result of natural and human-induced environmental change (Hart, Burkett, & Zilkoski, 2009). The extensive loss of coastal marshes and cypress forests that once flanked the hurricane-protection levees of St. Bernard and Plaquemines parishes, has increased the threat of storm-surge flooding. Several barrier island and wetland restoration projects are planned by the State of Louisiana, local governments, and Federal agencies, but will take time and money to implement (Hart, Burkett, & Zilkoski, 2009).

However, the greatest geographical threat is that not only is the sea level rising, but the land is sinking. Most of the land surface of NOLA's seven parishes is sinking or "subsiding". When observing the New Orleans subsidence problem there are four main causes: (1) drainage and oxidation of organic soils, (2) aquifer-system compaction because of groundwater withdrawals, (3) natural compaction and dewatering of surficial sediments, and (4) tectonic activity (Hart, Burkett, & Zilkoski, 2009). The drainage and oxidation problem has caused and further aggravated by flood-protection measures which have disrupted the natural drainage ways of the Mississippi River (Rodgers, 2014). As this drainage, debris, and peaty soils cannot make it to the ocean, they increase stress on underlying clay soils who are not used to the river. Groundwater withdrawals have also caused problems within the delta. Lowering the water table increases the effective stress on underlying sediments and hastens rapid biochemical oxidation of organic materials (Rodgers, 2014). Overdrafting groundwater is dangerous to the land surface for when the groundwater is overdrawn past the point of revival or when the extraction of oil and gas causes pressure depletion, the ground will fold and create tectonic problems (Rodgers, 2014). And while movement along growth faults causes problems in many deltas and basins, it creates greater problems in NOLA because of these faults have formed parallel to the depressed coastline (Rodgers, 2014).

Conclusion:

If there is a bright spot in any of this, it is that the people of NOLA understand what is happening. To them it is not a political issue, it is their reality (Landrieu & Hebert, 2015). These people living in the bayou know that sea level is rising and this has led them to start focusing on efforts to repair riparian buffer areas between the sea and the freshwater outlet and how to rebuild the levees to disallow any new storm from devastating the community of New Orleans like Katrina did only a few years ago. While climate change is knocking on the door, scientists and community members have come together in NOLA to show their resilience and their forward thinking strategic actions to shape the future of their city. ResilientNOLA is a project headed by the Mayor of New Orleans focused on bettering the community (Landrieu & Hebert, 2015). There are three main goal area in this plan: (1) adapting to thrive: embracing the changes ahead, (2) connecting to opportunity: NOLA the equitable city, and (3) transforming city system: becoming the dynamic and prepared city (Landrieu & Hebert, 2015). Each plan lays out objectives and a game plan for the community. This plan illustrates a perfect example of the government and community coming together to help NOLA grow together and become more resilient to their new future which will include climate change and sea level rise (Landrieu & Hebert, 2015).

4. Alexandria, Egypt

Introduction:

Due to its unique combination of political, demographical, and economical challenges, Egypt is one of the most vulnerable countries to the impacts and risks of climate change (Medhat, 2015). The city of Alexandria, in particular, is especially at risk due to its coastal nature and low altitude. With just a 25 cm rise in sea levels, 60 percent of Alexandria's population (of 4 million) would be displaced; a 50 cm rise in sea levels would result in the displacement of millions more from the Nile Delta (Lewis, 2015). Alexandria and the Nile Delta contain fertile soils that produce half of Egypt's annual crops, and are extremely vulnerable to saltwater intrusion due to the rising sea levels, according to IPCC (Lewis, 2015). Alexandria is considered a major economic center, home to approximately 40 percent of the nation's industry and a number of the nation's rich historical and architectural heritages (Medhat, 2015). Due to Alexandria's population density, considerable economic contributions, and uncommon fertile soils, the impacts of water vulnerability (because of climate change, rising sea levels, unequal distribution, etc.) are extremely significant.

Water Vulnerabilities:

A critical cause of water vulnerability in Alexandria—and all of Egypt—is the unequal distribution of the Nile River's resources by countries upstream such as Burundi and Ethiopia. Taking advantage of the political strife that has plagued Egypt in recent years, the countries are gaining more control over the rights for the Nile (Dakkik, 2016). As the Nile supplies 95 percent of Egypt's freshwater, losing any control of the water supply can lead to catastrophic consequences (Dakkik, 2016).

Egyptian farmers on the Nile Delta utilize flood irrigation, a highly wasteful irrigation technique. This enacts further restraints on Egypt's limited annual precipitation, a mere 80 mm of rainfall per year (Dakkik, 2016). In addition, agricultural runoff (containing pesticides and herbicides), industrial discharge (containing toxic chemicals), and municipal sewage are being dumped into the Nile River, gradually making the water unfit for human consumption (Dakkik, 2016). These situations highlight the need for water restriction policies and water treatment plans.

Since 2012, the Mediterranean Sea has been rising by 3.2 mm every year, causing the United Nations to predict an increase in sea levels of 1-1.8m by the end of the century (Schwartzstein, 2016). Additionally, the ground level in Alexandria is declining approximately 2mm per year, which results in the decrease of time until Alexandria and surrounding areas are fully submerged (Schwartzstein, 2016). An estimated 30 percent of the Nile Delta could become submerged within the next 15 years (Donovan, 2015). Proof of rising sea levels can be seen in Abu Qir, an area in eastern Alexandria located on the edge of the bay, where fierce waves (reaching over 7.5 m in height) routinely strike windows located several stories high (Schwartzstein, 2016).

Rising sea levels are impacting other sectors as well. Increased salinity in the coastal waters has resulted in increased salinity in the groundwater, destroying the once fertile soils and forcing farmers to utilize wastewater for irrigation and spend a significant amount of their incomes on expensive fertilizers in order to produce even minimal outputs (Donovan, 2015). A Climate Institute study in 2009 stated that Egypt could lose more than 15 percent of its most fertile land in the Nile Delta by 2020 (Aman, 2015). Because the agricultural sector contributes to 29 percent of the area's jobs and 15 percent of the gross domestic product (GDP), the increased salinity is causing significant negative impacts on the area's residents (Donovan, 2015). Previously, the Nile floods would drown the Nile Delta with fresh water that washed away any salt water, but the floods have not occurred since the construction of Aswan Dam in 1970 (Donovan, 2015).

Institutional Challenges:

Following the Revolution of 2011, when then-President Mubarak resigned, power was assumed by the Supreme Council of the Armed Forces, which dissolved the Parliament and constitution. Since then, Mohamed Morsi has been elected and also deposed by army chief Abdel Fattah el-Sisi who became Egypt's sixth president in 2014 (Online, 2014). With such unrest, it is definite that institutional challenges in Alexandria are the greatest of the challenges which Alexandria will face.

Although Egypt has participated in international negotiations regarding adaptation to climate change, the government has yet to take action. Egypt formed National Council on Climate Change in July 2015 to update its strategy for climate change and sustainable development, but few concrete actions have been officially announced (Lewis, 2015). Mohamed Ateia, a water researcher at the Tokyo Institute of Technology, stated "there are major disparities regarding climate change studies in Egyptian academic and official institutions…the official strategies and plans that the state announces are unrealistic and unfeasible" (Aman, 2015). Mohamed El Raey, a professor at Alexandria University, remarked on the irony that Egypt is among the 10 most vulnerable countries to climate change yet is 104th in terms of adaptation measures (Schwartzstein, 2016).

In 2015, a vicious storm buried Alexandria in high winds and driving rain that left neighborhoods under water without electricity; numerous apartment buildings collapsed due to structural deficits (Schwartzstein, 2016). Few residents were surprised that the street drains had been closed, preventing the waters from flowing back out to the sea or when the security chiefs deflected blame onto a banned Muslim Brotherhood Islamist group that had "supposedly" sealed the manholes with cement (Schwartzstein, 2016). In perhaps the most disturbing picture of the government's negligence, Alexandrians were forced to resort to "surfing their flooded streets behind donkey carts and offering inflatable-raft taxi services when the roughest weather hit" (Schwartzstein, 2016).

Socioeconomic Challenges:

Due to the numerous impacts of water vulnerabilities on agriculture and other major economic sectors, Egypt's economy will continue to suffer if climate change policies and adaptations are not undertaken. With the loss of arable land, unemployment would significantly increase, especially for the youth because many are employed in agriculture (Dakkik, 2016). In Alexandria, where 40 percent of the country's industry is housed, a half-meter rise in sea level would force 1.5 million people to evacuate and nearly 200,000 jobs would be lost; the tourism industry, which accounts for 12.6 percent of employment, would also be severely impacted (Donovan, 2015). Egypt's population has increased by 41 percent since the start of the 20th century and is expected to reach over 98 million by the year 2025 (Dakkik, 2016). An estimated 40 million citizens live in Alexandria and the rest of the low-lying Nile Delta, much of which is currently 5 m below sea level (Schwartzstein, 2016). Submergence of the Nile River Delta would displace approximately half of Egypt's 82 million residents, including those residing in Alexandria (Donovan, 2015). A 2011 study suggests that climate change could cost Egypt up to $20 billion if actions are taken immediately (Schwartzstein, 2016).

Geographic Challenges:

Climate change has resulted in the increased frequency of sandstorms, rainstorms, temperature fluctuations, earthquakes, and changes in the start and end dates of seasons. Climate change also impacts the Nile River Basin due to its sensitivity to small changes in temperature and precipitation (Medhat, 2015). These changes decrease citizens' reliability on previous rainfall and temperature patterns, increasing the difficulty of agricultural production in the Nile River Basin.

Conclusion:

Due to its extreme water vulnerabilities—particularly sea level rising—policies addressing the impacts of climate change are detrimental. Unfortunately, the Egyptian government has yet to construct or enact policies that are adequate considering the challenges Egypt will face. If the government does not enact policies to address climate change immediately, Alexandria could be lost to the sea by the end of the century, along with its fertile agricultural land and priceless historical and architectural heritages.

5. Phnom Penh, Cambodia

Introduction:

Located in Southeast Asia's low-lying Mekong River Delta, Phnom Penh is extremely susceptible to climate change. According to the Notre Dame Global Adaptation Index, Cambodia is the most

vulnerable and least prepared country in Southeast Asia, ranking the 56th least prepared country for future climate change overall. Access to reliable drinking water has steadily declined over the past decade, and furthermore, extreme periods of rainfall patterns and rising sea levels hugely threaten the region's ability to produce vital agricultural production. As such, there is a dire need for investment and innovative solutions to improve readiness and a huge urgency for action.

Water Vulnerabilities:

A warmer global climate will mean a shift in fundamental water cycles, including seasonal monsoons which greatly affect Cambodia's yearly farming practices. This shift toward more severe rainfall patterns will include both more droughts and floods. During periods of drought, water from the rivers does not flow into canals, failing to irrigate crop fields. On the other hand, intense and increased rainfall in the long term threatens to destroy fields with flooding. Flooding in 2009, 2011 and 2013 caused more than $1 billion in damage and 461 fatalities, and this will only exacerbate as the climate continues to warm (Bopha, 2015).

Rising sea levels as a result of climate change will also present severe problems for the nation. Because Phnom Penh is located in the low lying Mekong River Basin, sea levels that rise even a couple meters could severely affect the region. Saltwater intrusion into agricultural fields could wipe out vital food production, and flooding of sea waters into populated areas could leave Phnom Penh and its surrounding areas uninhabitable. Furthermore, because the country lacks the resources to address these potential issues, a failure to more adequately prepare will mean Cambodians will have extremely minimal capacity to adjust as climate warms.

Depreciated fisheries also currently pose a huge threat to overall nutrition and food security of Phnom Penh residents, and these challenges will only exacerbate as a combination of climate change and population increase affects the availability of fish populations. This will mean the loss of livelihoods for potentially millions of individuals, threatening the capacity of Cambodians to sustain their basic needs.

Institutional Challenges:

The Cambodian government is particularly ill-equipped to deal with the effects of climate change currently. Although having established the Cambodia Climate Change Alliance, the program has only identified response goals and has done little to implement reactionary changes. Because the country has so little infrastructure and other mitigation methods, it possesses little means of moderating the impacts of these changes (Bopha, 2015). Periods of severe drought and intense flooding, along with rising sea levels, will stress vital infrastructure for delivering water and sanitation services currently in place as well, likely leading to increased and unsustainable demand for resources.

Cambodia will observe a great deal of difficulty adapting to climate through institutional methods due to the power structures that comprise its government. For instance, the problem of corruption among government officials in the logging sector is a deeply embedded problem; officials accept illegal compensation from loggers who fail to meet environmental standards (Baird, 2010). Although this issue arises among the forestry sector, it does demonstrate the current Cambodian government's overwhelming corruption and large number of self-interested individuals who hold little regard for regulating resources responsibly and mitigating the environmental effects of climate change.

Socioeconomic Challenges:

Phnom Penh is the economic center of Cambodia. It is also the most densely populated area in the country and observes a human development index of 0.936. Among its inhabitants, a large portion of the population already lives in quite compromised conditions. Slum inhabitants in the city number 105,771 (Padilla, 2011). Increased stress on resources within the city will disproportionately affect those who are more marginalized than others. In general, with more severe weather patterns, it will also be increasingly difficult for inhabitants of Phnom Penh to remain in their homes. This is evidenced by the 2009 Typhoon Ketsana, which caused around $140 million in damages and displaced tens of thousands of families in the region (Padilla, 2011).

Climate change will lead to the loss of livelihoods and food security for millions of people in surrounding areas as well, which will increase the stress on Phnom Penh's already dense population. As the surrounding rural areas will observe widespread inundation, this will lead to mass migration into urban areas with potentially more access to resources. In particular, movement of ethnic groups from lowland to upland areas throughout Southeast Asia will likely cause ethnic conflict by severely displaced native ethnic minorities. For this reason, groups in and around Phnom Penh who are socially marginalized will become even more so, and this will increase the potential for violence to occur between various groups who are forced to compete for basic resources.

Geographic Challenges:

Phnom Penh is located in the Kandal Province, in the south-central region of Cambodia. It is situated on the banks of the Tonlé Sap, Mekong, and Bassac rivers. These compose the city's main water sources and utility, the Phnom Penh Water Supply Authority. The city is also located in an area of tropical wet and dry climate. Flooding during the monsoon season, May to October, already presents many problems, and changes will only exacerbate flooding and related issues. Although the country used to face major challenges associated with flooding once per decade, it has since become a huge annual challenge for the nation. In the areas surrounding Phnom Penh, there are an estimated 365 areas of agriculture under

irrigation. Sea level rise from all surrounding seas hugely threatens Phnom Penh's food security. The average levels of surrounding seas are predicted to rise by 28-33 by the year 2050 and by 65-100 cm by the year 2011 (Padilla, 2011). As water will continually spill into the low-lying basin, sea level rise will present huge threats to the agricultural productivity of the region. Studies show that 90% of agricultural land in the Mekong Delta will be affected by flooding in coming years, and 70% of the delta will suffer from saline intrusion as sea levels rise. Furthermore, the rice yield potential of the Mekong Delta will decline by up to 50% by 2100, threatening the food security of not only Phnom Penh residents but those of numerous surrounding countries. A large portion of the Mekong Delta could soon become uninhabitable since 38% of the delta would be inundated with water if the sea level were to rise just one meter (Padilla, 2011).

Conclusion:

Due to its unique combination of political, socioeconomic, and geographic conditions, Phnom Penh is particularly vulnerable and ill-prepared to deal with the effects of climate change. It is possible that better irrigation systems that can buffer against bad weather will help farmers combat changes in the water cycle. The Cambodia Climate Change Alliance is also in the process of identifying and enact reactionary change to these changes. However, Phnom Penh will certainly observe huge stresses in the forms of severe weather patterns and rising sea level. Cambodia will need assistance from industrialized countries, yet studies say these nations are mostly responsible for contributing to global warming (Bopha, 2015). It remains imperative that both developing and developed countries enact policies addressing climate change and work together in generating effective solutions.

6. Discussion

Sea level rise and other water vulnerabilities will have varying levels of effects in different locations. A city/country's level of development is the leading factor contributing to vulnerability. More developed countries generally have the institutional capabilities to deal with threats and adjust to changes, whereas developing countries get bogged down by their own systems. Developed countries also have the socioeconomic capability to invest in fighting climate change, with how to allocate funds usually being the only issue. Developing countries typically do not have the capital to pay for large adaptation programs and what little money they do have is lessened by the means of corruption, embezzlement etc. However, regardless of location, socioeconomic standing is the greatest threat to dealing with climate change and sea level rise.

Even if a country had systems in place to protect itself from climate change, without the needed resources and resources, there are not many feasible ways to combat it. Rotterdam and New Orleans both

lay in topographically similar locations to Alexandria and Phnom Penh, but because they have the resources, they are able to take more significant actions to protect their city and citizens. And yet money does not make every single problem disappear. Rotterdam is generally quite wealthy and already funding major adaptation programs, however, immigrants in older public housing districts may not be as well protected as native Dutch people. New Orleans is also receiving a lot of funds post-Katrina for improving infrastructure and flood prevention measures, but racist housing zoning laws mean that these funds are not getting evenly. Climate change is the least of the government's problems for Phnom Penh and Alexandria. These governments do not have the money to spend costly protection programs or improve infrastructure. Both of these cities may see huge displacements of people from sea level rise and destroy the livelihood of millions. Displaced and jobless people may create conflicts with other people as they move more inland.

One underlining theme seen throughout every city, regardless of the level of development, is that poor and marginalized people will be at most risk from climate change and flooding. In Rotterdam it will be immigrants, in New Orleans it will be black communities, and in Alexandria and Phnom Penh it will be communities living in areas with poor infrastructure. Marginalized people in Rotterdam and New Orleans are split along racial lines; it is much more likely for a black person to be the victim of a flood than a white person. High population densities in Alexandria and Phnom Penh means that many more people will be affected than in Rotterdam or New Orleans. Institutions within these cities have insufficient capacity to deal with the sheer number of people that would be displaced or affected and would make them marginalized even more.

Institutional challenges can arise from either having too little or too many institutions. In many developing nations there are not enough institutions so to allow for the correct governance of the cities, or these institutions may be compromised by corruption. Many developed nations also face similar difficulties when there are too many different government bodies who do not what falls under their particular jurisdiction. In this study, Alexandria, Egypt and New Orleans, USA exemplify either under or over-governance. The political system in Egypt has been in turmoil for many years as different factions have taken over the government or at least the governance structure. Though President Fattah el-Sisi has been the sitting president for three years, the political unrest has not fallen. The largest consequence this unrest has had for climate change has been the complete lack of ecological or water management department. Without any department’s oversight and with the country itself in complete unrest, sea level rise practices and policies have not been on the forefront of policymakers’ minds. In opposition to Egypt’s too little governance, is New Orleans, USA where there is too many governing bodies present. Overall, there are just too many levels of government that all deal with the sea level rise problems facing the city. The New Orleans Municipal Land-Use Authority has planning and regulatory jurisdiction but

only over a small fraction of the at-risk area while the Official Regional Planning Commission which encompasses all the at-risk area, is only a policy body without authority over regulation (Architecture Planning Commission, 2010). The best governing bodies to take on the full-scale issue and whose jurisdiction encompass the whole at-risk areas are the agencies of the state and federal government such as the US Environmental Protection Agency and Federal Emergency Management Agency; however, usually they do not have the political will to intervene in land policy matters especially involving private property (Architecture Planning Commission, 2010). With all the confusion over who has the authority to do what over a which areas, even the best plans and policies enacted will be lost or not enforced properly. So while perhaps unsurprising, both too little and too much government and governance systems attribute to why cities like Alexandria, Phnom Penh, New Orleans, and Rotterdam cannot effectively use their resources to combat water vulnerabilities and sea level rise for their residents.

A city's unique geography is deeply intertwined with its capacity to address the effects of climate change. The cities that comprise our study are all relatively low-lying. As global temperatures cause polar ice caps to melt, resulting in rising sea levels, these elevations will make cities susceptible to the effects of climate change regardless of their level of development. In New Orleans, not only is sea level rising, but the city itself is sinking as the Mississippi basin is being pushed further out to sea. Rotterdam and most of the Netherlands is also at or below sea level, and there are many rivers and bogs in this region. There is not much land in the Netherlands to retreat to if sea level does rise more than a couple meters. These cities all exemplify how a combination of low elevations and rising sea levels place populated areas at risk. Some areas may become uninhabitable, and furthermore, flooding and intrusion of saltwater into surrounding agricultural areas will threaten vital agricultural production. For these reasons, there are little differences in geographic challenges between "developed" and "developing" nations that are vulnerable based on their respective elevations. Differences mainly arise between access to resources and how these nations are prepared to combat these geographic challenges. Rotterdam and many parts of the Netherlands, for example, would be at much greater risk if it weren't for their superb water management and engineering. Geographic challenges also arise as warming climate compromises existing resources, which will more negatively affect already challenged developing nations. Located in the lower latitudes near the equator, Alexandria and Phnom Penh both have already limited water resources that are further diminished with climate change-related droughts.

As mentioned, while developed and developing countries might share similar water vulnerabilities, their ability to address those vulnerabilities is vastly different. New Orleans suffers saltwater intrusion that is eroding the land bridge and contaminating the river's freshwater. Rotterdam is also suffering from saltwater intrusion, as well as additional climate change impacts such as drought and flooding, increased storm frequency and intensity, and insufficient dike and barrier strengths. Similarly,

Egypt, a developing country, is suffering from saltwater intrusion, exacerbated by the rising sea levels. However, Egypt has yet to provide adequate policies for water management and this has led to extreme flooding and casualties. In addition, Egypt lacks adequate policies for wastewater management, resulting in the contamination of its severely limited freshwater supply. Both Cambodia and Egypt have their access to clean water steadily declining over the past decade. The two developing countries lack the resources and/or the governmental strategy to address the impacts of climate change or obtain freshwater from other countries.

In conclusion, the institutional challenges, socioeconomic challenges, and geographic challenges of Rotterdam, New Orleans, Alexandria, and Phnom Penh have resulted in increased water vulnerabilities for each city. The consequences of these impacts are severe and could result in significant loss of lives if these impacts are not immediately addressed. The developed countries have the advantages of resources and organized governmental subcommittees. The developing countries lack such advantages, and the continuation of climate change impacts could devastate these countries. If climate change threats and impacts are not immediately addressed worldwide, millions of people could die.

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