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A System Dynamics Model of Water Security in the Gaza Strip

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Abstract: The Gaza Strip may experience regional challenges soon due to the increasing population influences on water security, energy security, and infrastructure. This study presents a novel simulation model to serve as a strategic decision aide for the international community through high-level analysis and forecasting of the future challenges if current trends remain unchanged. The system dynamics model initially focuses on the challenges of water security given the population growth in Gaza. Water supply will become insufficient to sustain minimum thresholds of survivability at around 2038, thus identifying the importance in timely infrastructure and policy investments. It is the sincere hope that this model might influence diplomatic action and donor-nation investment for the people of Gaza to eschew the growing water security challenges.

Keywords: System Dynamics, Water Security, Gaza Strip

1. Introduction and Background

The Gaza Strip (Figure 1) is a coastal enclave of Palestinian territory that sits on the Mediterranean next to Egypt and Israel, disconnected from the Palestinian territories in the West Bank. With a population of over 1.8 million people and a density of 13,000 people per square mile, the Gaza Strip is one of the most densely populated places in the world (Middle East Observer, 2016). The territory is incredibly strained for resources, and without major international investment or diplomatic course correction on the part of the international community, a major water security challenge may be just over the horizon.

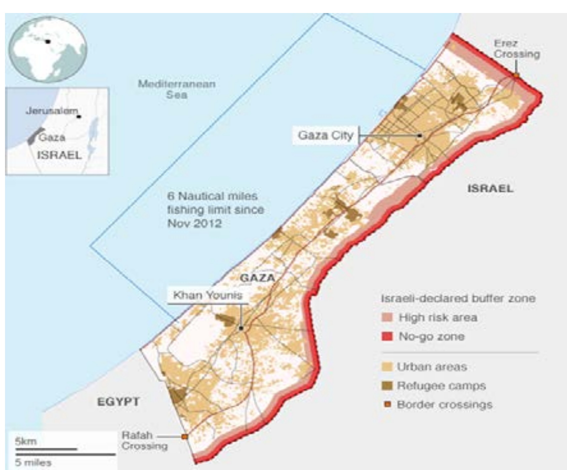

Figure 1. Map of Gaza Strip (UN OCHA, 2018)

The Interim U.S. National Security Strategic Guidance of March 2021 is explicit in highlighting the importance of global investment in infrastructure which enables water security. In particular, the promotion of foreign assistance to develop or improve water systems which 'prevent disease and improve public health' are described as 'ways' toward achieving regional stability 'ends' through partnerships which create global development (Interim NSS, 2021, 12). The U.S. and donor-community would require clarity of population dynamics in Gaza relative to water resource limitations so that investment is timely and of the right magnitude.

The purpose of this system dynamics model application is to gain understanding of the future challenges to water security as part of the socio-technical system for policy decision makers in interested from donor nations and non-governmental organizations. The model provides a general forecast of the future water security challenges facing the Gazan people without significant investment.

2. Problem Articulation

2.1 Understanding the Water Security Challenge

To begin, an overview of the status quo in Gaza, disaggregated into five components: population growth, population density, water insecurity, electricity insecurity and untreated sewage output.

2.1.1 Population Growth

As stated earlier, the territory is home to over 1.8 million people (Middle East Observer, 2016). The CIA estimates that the birth rate of Gaza is about 28.6 births per 1,000 people, or just under four births per woman, with no slowdown of this trend in sight (CIA, 2020). The United Nations forecasts that the population of Gaza could very well double in the next thirty years, which, considering the energy and water problems plaguing the Strip, would be unsustainable (al-Mughrabi, 2016).

2.1.2 Water Insecurity

Water Security was highlighted as a potential problem as early as 1991: "with such a large population living in such a very small arid to semi-arid area, maintaining adequate water supplies to meet domestic, industrial and agricultural needs is a pressing problem" (Y. S. Abu-Maila & Y. F. Abu-Maila, 1991, p. 209). Today, 70% of Gazans only have piped water for six to eight hours every two to four days (UN OCHA, 2015). Many thousands of Gazans have no running water at all (Blumenthal, 2015).

Israel, Gaza and Egypt share the same coastal aquifer basin, where groundwater primarily originates from recharge areas inland which then flow to the sea. The rainfall recharge of the aquifer is much lower in the Gaza Strip than in Israel and Egypt, likely due to the high urbanization, leading to much lower quantities of available drinking water (UN-ESCWA, 2013). This is incredibly concerning, as groundwater is the one of the only sources of drinking water for the majority of the population, and due to largely unregulated water-tapping policies, Gaza is running out (Eljamassi and El Amassi, 2016). This is in addition to the fact that as Gaza's population grows, so too does its water usage. From 1995 to 2011 alone, total annual abstractions increased by more than 30% due to increased municipal demand (UN-ESCWA, 2013).

Additionally, most of the extracted groundwater in Gaza exceeds World Health Organization guidelines for potability due mostly to seawater intrusion and sewage runoff (Eljamassi and El Amassi, 2016). As much as 90% of the water taken from the aquifer is undrinkable for this reason (B'Tselem, 2014). Most Gazans purchase water from unregulated private vendors to supplement their needs, as the amount that is drawn from the aquifer and is imported through aid is insufficient. That said, waterborne disease remains incredibly prevalent in the Strip: a quarter of *all disease in Gaza* is waterborne, and diarrhea is a leading cause of all child- and infant-mortality at 12% of all deaths (OCHA, 2018).

The confluence of these issues leaves Gaza dependent on the outside world for water, as Gaza's large-scale desalination plants were destroyed in prior Israeli incursions (Blumenthal, 2015). New desalination plants could be built for Gaza to draw water from the sea, much like Israel, but this would require a large amount of electricity – a resource that Gaza, as will be discussed in the subsequent section, is severely lacking (Yakubovitch, 2017).

Ultimately, there will likely be a severe water deficit in Gaza's future if these problems remain unaddressed; as the population increases, so too will Gaza's water demand, and if the status quo remains the same, Gaza will be unprepared to meet this demand.

2.1.3 Population Growth

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2.1.4 Power Insecurity

The aforementioned trends, while already concerning in isolation, are further complicated due to the energy issues facing the Strip. Nearly all Gazans suffer from power outages for sixteen to eighteen hours every day, with those in heavily urban areas being the most effected, due to the out-of-commission Gazan power plants (UN OCHA, 2015). According to the UN Office for the Coordination of Humanitarian Affairs, the current electricity demand of the Gaza Strip is estimated to be around 470 megawatts, and less than 45% of this need is currently being met (UN OCHA, 2015). Gazan power plants traditionally have used gasoline, but due to severe fuel shortages, the Gaza power plant operated in 2013 at only half of its capacity: 60 of 120 MW per day or below (TRT World, 2017). The plant requires about 600,000 liters of fuel per day to run at full capacity, but since Gaza is dependent on the outside world for its fuel needs, importing from both Israel and Egypt, it is seldom able to do so (Khoury, 2017). To make matters worse, the plant has been shut down since 2017 due to damage from Israeli incursions, leaving Gaza dependent on the purchase of electricity from Israel at about 120MW per day and Egypt at 28MW per day (UN OCHA, 2015). As with before, as the population increases and the electricity situation remains the same, the electricity deficit will increase.

2.1.5 Untreated Sewage

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3. System Dynamics Model

System Dynamics (SD) is a useful mechanism for conducting high-level analyses of complex systems (Forrester, 1958). The SD model in Figure 2 captures the relationships between the variables explained in the above causal loop diagram: population, population density, water demand, electricity demand, and untreated sewage. This model is an introductory analysis, meant to translate the diagnosed problematic system behavior into a medium that can convey trends over time to forecast the general direction of water security challenge in Gaza and guide investment in essential services. The timeline of this model begins in the year 2020 and ends in the year 2100 to illustrate the near-term future of Gaza without political course correction.

3.1 Population

To begin model construction, the CIA World Factbook for statistics on the population and population trends of Gaza was utilized. The stock, which is the population of Gaza, is represented in equation 1, where the starting population is 1.918 million people, the birth rate is 0.0286, the death rate is 0.003, and the net migration rate is -0.0047 (CIA, 2020). The variable entitled "Water-Related Loss Rate" will be discussed in Section 3.3.

Population of Gaza = Birth Rate – Death Rate – Net Migration Rate – "Water-Related Loss Rate" (1)

3.2 Population Density

Next, the population density is simulated in equation 2, where "Area (in km)" is 360 square kilometers, the total amount of space of the Gaza Strip.

Population Density = Population of Gaza/Area (in km) (2)

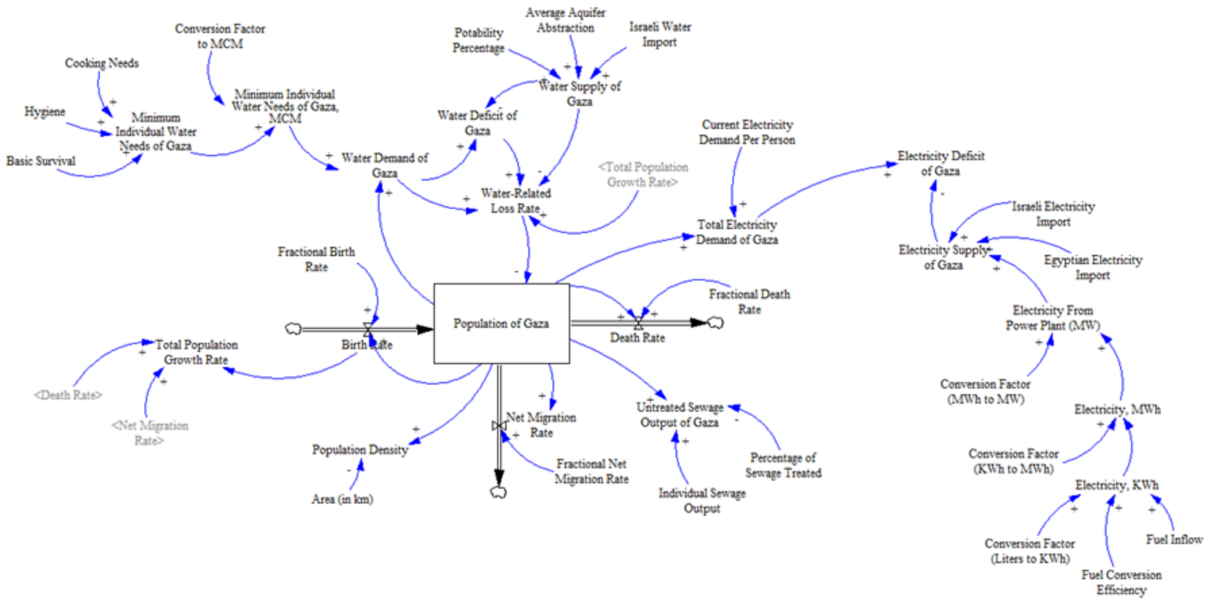

Figure 2. System Dynamics Model

3.3 Water Insecurity

To account for the water insecurity of Gaza, one first needs to calculate the approximate water needs for an individual. This is accomplished in equation 3, which utilizes guidelines from the World Health Organization on water consumption in emergency situations, where basic survival requires 2.5 to 3 liters per day or around 1095 liters per year, hygiene practices require 2 to 6 liters per day or around 2190 liters per year, and cooking needs require 3 to 6 liters per day or 2190 liters per year (Reed, 2011). After converting liters per year to MCM per year, equation 4 multiplies the individual water need by the population of Gaza to get an accurate picture of the total Gazan water demand.

The water supply of Gaza in equation 5 consists of the average annual aquifer abstraction which is between 150 and 180 MCM per year (UN-ESCWA, 2013) and the amount of water Israel imports into Gaza at 5 MCM per year (B'Tselem, 2014). The potability percentage is the percentage of water drawn from the aquifer that is actually drinkable, estimated at 10% (B'Tselem, 2014). The water deficit of Gaza in equation 6, representing the amount of water Gaza is lacking to meet its needs, is merely the total water demand subtracted from the supply.

Finally, equation 7 depicts the "Water-Related Loss Rate", which represents the total amount of people per year the water deficit of Gaza will force into complete water-insecurity. This equation is activated when the water demand exceeds water supply. Then, it runs a proportion function comparing current population growth with "Total Population Growth Rate", to the population growth that the water deficit would allow to be sustained given assumed water needs. Since this proportion is based on current water levels, not *optimal* water levels, the actual loss rate would likely be higher.

Minimum Individual Water Needs = Basic Survival + Cooking Needs + Hygiene (3)

*Water Demand of Gaza = Minimum Individual Needs * Population of Gaza* (4)

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*Water Supply of Gaza = (Average Aquifer Abstraction * Potable Percentage) + Israel Water Import* (5)

Water Deficit of Gaza = Total Water Demand of Gaza – Water Supply of Gaza (6)

*Water – Related Loss Rate = IF THEN ELSE (Water Demand of Gaza > Water Supply of Gaza, (Total Population Growth Rate * Water Deficit of Gaza)/Water Supply of Gaza, 0)* (7)

3.4 Power Insecurity

While section 3.4 and 3.5 begin to examine 'layers' of infrastructure for model expansion, the results of preliminary model results and underlying equations will not be presented in section 4 pending validation of the water security model. However, the following briefly describes the inputs to added power and sewage layer complexity in future model iterations.

For electricity insecurity, it is necessary to begin calculation at Gaza's power plant and its conversion of fuel to electricity, where the fuel inflow is 600,000 liters per day, or 219,000,000 liters per year (Khoury, 2017). Next, the "Conversion Factor" is the constant that is used for the conversion of liters of fuel to KWh of electricity, which is generally, 10 KWh per liter (AWEO.org, n.d.). Finally, the conversion efficiency is the percentage of fuel that is *actually* converted to electricity, rather than lost to heat, approximated at 30%, but it is likely much lower. Next, the total electricity demand of Gaza as seen in equation 9 is equal to the current electricity demand per person multiplied by the population of Gaza.

The electricity supply of Gaza is a function of the current electricity demand per person, which is 0.07 MW per person based on modern data for how much electricity the average Gazan uses, the amount of electricity Egypt imports into Gaza at 25MW per day or 9125MW per year (Avra, n.d.), and the amount of electricity Israel imports into Gaza at 120MW or 43800MW per year (Cohen, 2016). As with before, the electricity deficit of Gaza is represented by the amount of electricity Gaza is lacking to meet its needs, is the total electricity demand subtracted from the supply.

3.5 Untreated Sewage Output

Finally, the untreated sewage output is calculated with an average individual's sewage output. It is approximated with the average wastewater output of a person in the UK, which is 150 liters per person per day (CBRE, n.d.). This is then multiplied by the population of Gaza and the percentage of sewage that is actually treated by Gaza's facilities, which is about 25% (B'Tselem, 2014).

4. Results

4.1 Population

The simulated population trends are depicted in Figure 3, and if trends remain constant, the results are very alarming. Based on this model, Gaza is experiencing exponential population growth, and has the potential to reach over four million people by 2044.. This increase in population is incredibly worrisome; the Gazan administration lacks the infrastructure and funds to tend to this population, let alone a population twice its size. Water levels will be inadequate to ensure survival for this level of population growth. The discrepancy between the projected growth and a population that would be sustainable is pictured by the red line in "Population Comparison" as well as the "Water-Related Loss Rate" in Figure 4. The latter variable projects how many people would *not* be adequately nourished given current trends.

The model relies on the current trends and is based on statistics from the CIA. If the birth, death and net migration rates change from year to year, this model can easily be adjusted to address this. Additionally, this model compares the current population growth with the amount of people that could reasonably be sustained with the templated water supply. The reality is that Figure 3, despite its alarming nature, is a very optimistic projection.

4.2 Population Density

The population density projection of Gaza is depicted in Figure 5. Based on these trends, it will become incredibly challenging for the Gazan administration to adequately provide for its people, as the increase in population density will stretch its urban planning and infrastructure capabilities.

The "area" of the Gaza Strip is represented by the current space available to Gaza at present. This variable would likely stay constant, barring an increase of land contiguous to the Gaza Strip a-la previous historical peace proposals or the implementation of more unconventional plans like the "New State Solution" that seeks to cede territory that currently belongs to Egypt in the Sinai Peninsula to Gaza (Peri et al., 2019).

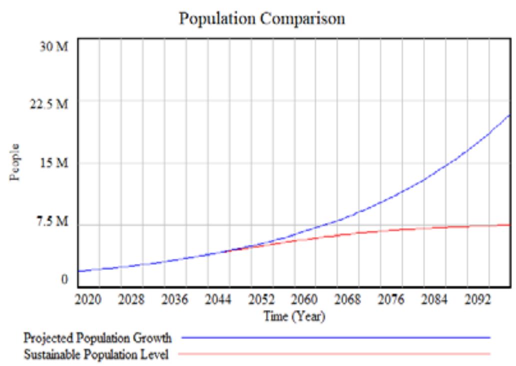

Figure 3. Current Population Trends and Sustainability

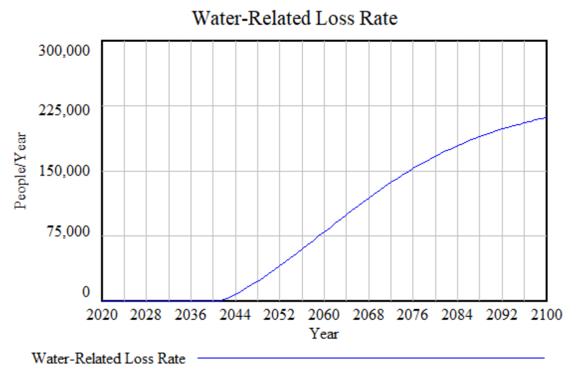

Figure 4. Water-Related Loss Rate

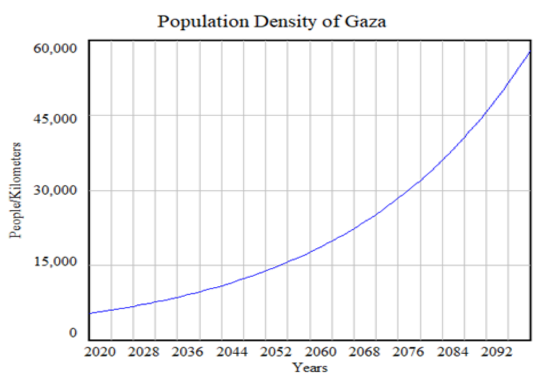

Figure 5. Population Density of Gaza

4.3 Water Insecurity

The simulated trends for water insecurity are below in Figures 7 and 8; the total water demand is pictured in blue, the supply in red, and the water deficit in green. Based on the current trends outlined in Figure 6, Gaza will face a serious water deficit at around 2038, as this is where the demand exceeds the supply. This makes sense, considering the serious lack of potable drinking water that exists in the Gaza Strip today. The projection into the future is also intuitive; without a change to the status quo, both the water demand and the water deficit will only increase, leaving potentially millions of future Gazans without options.

Figure 7 projects what the water insecurity trends would be given that water levels stay relatively sustainable. As addressed earlier, the Water-Related Loss Rate is based on current, not optimal, water levels. This discrepancy is illustrated below; even given relatively sustainable levels, there would still be a large water deficit, starting in 2038.

Several limitations and confounding variables to this portion of the analysis must be addressed. First, the individual water inputs of this model are based on the United Nation's guidelines for *emergency situations*. The actual water need for an individual to stay relatively healthy over a long period of time is likely much higher. With this in mind, it is likely that we may see a divergence in the water supply and demand at a much earlier point in time than is projected here.

Agricultural needs are likely to increase as the population increases, but due to the lack of data that is easily interpreted on the subject, this model does not factor in this relationship. The model is operationalized using the most available data, but this data can be easily changed upon further review. This limitation also applies to the data on the Israeli water import and the aquifer abstraction.

Finally, upon review from policymakers, water could feasibly be imported from elsewhere. Additionally, as stated before a desalination plant could be build for Gaza. Again, the utility of this model is that this would be a small adjustment

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to make, but barring major course correction and investment, the general trend toward major water deficit in Gaza will remain constant.

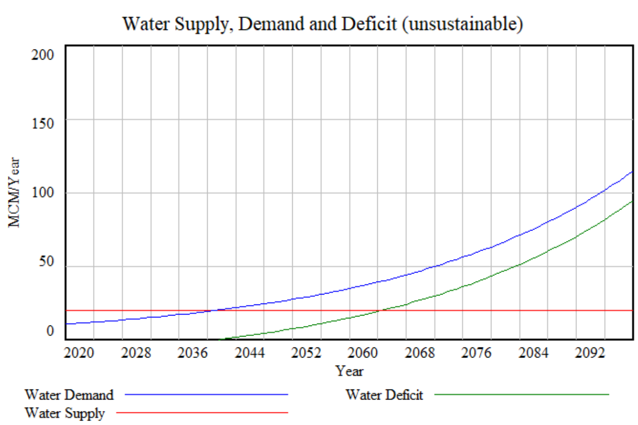

Figure 6. Water Sustainability Given Current Trends

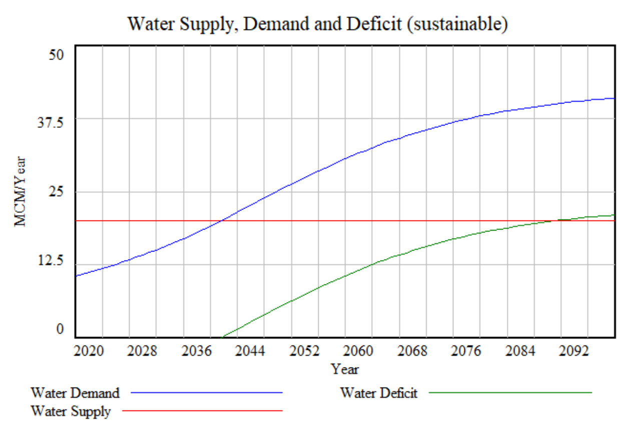

Figure 7. Water Sustainability Given Sustainable Growth

4.4 Model Validity

This system dynamics model is most certainly inexact in that data inputs of population growth rates, water availability, and water usage from section 3 of this paper. The goal of this, and any model should be to help clients make better decisions informed by the best model and data available knowing that every model is innacurate to some degree (Sterman, 2000). The limitation of this paper's model includes layers of complexity and uncertainty in electricity and sewage being deliberately excluded from the current model outputs. The pace of technology advancements in water de-salination could influence investments as well. Statistical approaches such as multiple regression will allow for determination of which variables might most complicate the dependent variable of the population in Gaza and its overall wellbeing. Further development of the model will enable meaning in its validation.

5. Model Validity

It is readily apparent that the model illustrates the unsustainable situation for the people of Gaza; they do not have the infrastructure, funds or capabilities to cope with this multifaceted resource problem alone. One should not look at this model and believe that the problems in Gaza can afford to wait until 2038. As stated before, 2038 is when the *absolute minimum* water needs will not be met and Gazans may begin to die from a lack of water resources. To mitigate this, the international community must consider investment soon. As stated before, the purpose of this model is to guide investment and policy adjustments on the part of nations, international bodies, and NGOs for the Gaza Strip.

Ultimately, most of these problems stem from the fact that Gaza's population is increasing at an alarming rate with no room to grow. Until there is deviation from the status-quo, this trend will continue, leaving millions of future Gazans without hope.

6. Future Work

In summary, the purpose of this model is to serve as an initial, broadly scoped system dynamics analysis of the challenges in Gaza so that international stakeholders can understand the effect of unchecked population growth on the population density, water insecurity, electricity insecurity, and untreated sewage output. Additional work must be completed to understand in greater detail the effects of unchecked sewage output on the water supply, fishing capacity, waterborne disease, and ultimately, the population of Gaza. However, this initial model shows how the current essential services require immediate investment and diplomatic action to eschew increasing water insecurity.

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