# STUDY OF VULNERABILITY IN THE WATER MANAGEMENT IN THE REPUBLIC OF PANAMA UNDER THE DEVELOPMENT OF FOUR SCENARIOS USING *FUZZY COGNITIVE MAPS* FOR THE INTEGRATION OF SDG6 INDICATORS

By

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**Author's declaration**

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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The management of water resources in Panama, a developing country whose economic growth has been accelerated in recent years, often lacks integrated water resource management in the multiple economic, environmental, social and, of governance as a whole that impact the system. The lack of integrated water resource management amplifies the potential negative and positive impacts on different components of water management in the country's development plans under four future socio-economic priority scenarios for Panama. In this study, the vulnerability of the water system is identified with the use of *Fuzzy Cognitive Maps*, a tool that provides support in the integration of variables within different components that form part of an integral water management, facilitating the identification of the weak points within the system incorporating all the elements, connections, concurrence between the variables and the magnitude of these in an organized way providing information that are represented in a visual way. The identification of the elements within the most vulnerable system allows the integration of the SDG 6, which compiles a set of indicators that propose to achieve water security and sanitation for all, as part of a sustainable social, political, economic and environmental development. Based on this, the most appropriate ones were selected within each of the four pillars for the development of the Panamanian society without compromising the country's water security.

**Keywords:** water management, vulnerability, water resources, socioeconomic growth, development, indictors, integration

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# 1. Introduction

## 1.1 Background

From ancient times water has always played a very important role in humans civilization development and has given multiple uses. For this purpose, water requires knowledge in different disciplines such as physics, geology, biology, mathematics, chemistry (Cech, 2010). Water is important for socio-economic development, to keep healthy ecosystems and for all living forms on earth, therefore, it is the motor for production and preservation of environmental services for humans (Yildiz, 2017). For the big picture, the water security component must be addressed and ensured in the development plans since the strong relationship of water and socio-economic growth.

Health, Sanitation, nutrition and housing are factors that influence the human well-being and in order to achieve this, access to water is necessary. Access to water is important for many other activities that are vital for human development such as food production. In the world 70% of the water is used for agriculture. To achieve food security, reduce poverty, improve health, and provide sanitation, a correct and efficient policy and water management are key, starting with the government's commitment and community involvement (Akhmouch, 2012).

Panama is a country that bases its whole economy on the services provided by its water either directly or indirectly. Covered by the Caribbean (Atlantic) in the North and the Pacific in the South, Panama has made water its most valuable resource. In terms of economy Panama was one of the fastest growing countries in the period of 2005 to 2015, part of this growth is associated to the Panama Canal since, inside the transport and communication sector, it is the third economic contributor of the country (Hausmann, *et al*., 2016).

UN-Water defines Water Security as "the capacity of a population to safeguard sustainable access of quality water for sustaining livelihoods, human well-being, and socio-economic development" all this with the goal of ensuring protection against pollution, disasters and to preserve ecosystems and political stability (UN-Water, 2013). Even though the water availability in the country seems to be less than a problem among the urban population right now, water security, especially under development scenarios, has been questioned recently. In Panama is expected that Water resources are at risk because of human circumstances tied to development, such as urbanization, industry, international trade, economic development, population migration and population growth and in addition to all this and as a side effect of uncontrollable anthropogenic influence combined with weather conditions, climate change represents a high pressure on water resources. In recent years, the country has experienced longer dry seasons and floods have been increasing in intensity mainly because of climate change and a lack of infrastructure. In addition, drinking water and sanitation are missing in several parts of the rural areas which only worsen the situation in those already vulnerable areas (Embassy of the Kingdom of the Netherlands in Panama, 2018).

The environmental problems caused by climate change to the country, coupled with the mismanagement that has been made to water resources presents a serious threat to both the quality and quantity of water available to the population, industry and ecosystems. Frequently, it is in the part of water management and existing policies in the countries where water problem is concentrated, since reaching a sustainable management of water resources requires an integrated resource management in which all the stakeholders are involved in a holistic and coordinated way to tackle these vulnerabilities, although initially identifying these vulnerabilities and integrating all stakeholders is always a complicated issue. For this reason, it is important an assessment of impacts in the water system and how these will affect in future scenarios considering all the factors expected to cause extreme conditions and destabilize socioeconomic aspects in the country, but also in ecosystems. The use of tools, such as *Fuzzy Cognitive Mapping*, help to identify specific gaps in complex systems and the concurrence and linkages of these. It is an innovative way to focalize vulnerabilities and use them as indicators in future scenarios (Kosko, 1986).

In this regard, Panama has a very clear path to grow the country's economy by promoting four economic sectors that have the potential to increase GDP in the country. These strategic plans are embodied in the ***Strategic Government Plan 2015-2019*** that the current government created to inform about the economic investments that the country has carried out to boost the logistics and transportation sectors, agriculture, mining and tourism, which are expected to provide high social and economic growth for Panama.

In this study, vulnerability denotes the exposure of the water system under different development paths, these will be analyzed to estimate the concurrence through the linkages between them in order to prioritize the vulnerabilities that might have impacts in the system under four economic scenarios identified as a priority for the country, building up using the information gathered in the report **Strategic Government Plan 2015-2019: logistics/transportation, agriculture, mining and tourism** and running the FCM to identify critical changes to variables on the water system, and finally connecting these major changes to a prioritized list of SDG indicators for a national water management with prioritized socioeconomic activities. With the use of an integrated cross-sectoral methodology, this identifying process will inherently reflect the complexity of water management in a visual and practical way.

### 1.2 Justification

Water is a valuable resource for Panama either for its population and its economy. Due its gaps in governance, lack of infrastructure, climate change, population growth and more recently, the development of water demanding activities, this resource it is under high pressure and its availability is under threat. This study looks at water sector in Panama with special focus on water management vulnerabilities that the country could face in developing scenarios that the government is attempting to impulse by 2019 (current year) but that the government is planning to keep developing in the future. This study presents important information about the status quo of water management in Panama, gaps in the system and threats, as well as an innovative way to place indicators with the use of systematic tools that help tackling future problems in terms of feasibility, quality and quantity of water resources while, at the same time, the country keeps growing social and economically.

# 2. Research question

## 2.1 Aim

The aim of this research is to identify central vulnerabilities in the water system of Panama in order to interconnect each one of the concepts found in each vulnerability classification (five for this study) making use of the conceptual mapping tool *Fuzzy Cognitive Map (FCM)*. Therefore, design four expected scenarios (Logistics and Transport, Agriculture, Mining and Tourism) based on the ***Strategic Government Plan 2015-2019*** and in which these vulnerabilities will have an impact connecting both vulnerabilities and the scenarios to analyze in depth, and lastly to identify SDGs indicators that can be allocated for each vulnerability on each scenario to identify management pathways that strength resilience in the water system.

*"what are the future vulnerabilities and pressures that the water system of Panama might face with the current boost in four economic sectors: logistics / transport, agriculture, tourism and mining"*

*and*

*"How do the knowledge of these vulnerabilities enable to localize indicators of the SDG6 after the scenario analysis?"*

Through this main question, aspects such as current gaps in social, economic and administrative areas will be analyzed to determine the linkages between specific pressures and the activities that, under future scenarios, represent a risk for the water system whereas, this analysis will provide information that can be utilized to align SDG indicators, providing a more dynamic way to focalize management efforts in complex issues.

## 2.2 Objectives

- Analyze the status quo in the water system from an economic, social, environmental and governmental perspective in Panama.

- Build the scenarios based on the four pillars for socio-economic development in (already carried out in the country) with possible pressure on the water system.

- Interconnect the gaps found on water systems in Panama with the four scenarios using the conceptual mapping tool *Fuzzy Cognitive Map* (FCM).

- Align the results from the FCM scenarios to the SDG6 indicators that can help to enhance water management strategies in Panama and reduce vulnerabilities.

# 3. Literature review

## 3.1 Study Area

Panama has a land area of 75,520 km$^2$ and is located southeast of Central America, at coordinates 7 ° 12'07 " and 9 ° 38'46 " north latitude, and between 77 ° 03'07 " of west longitude It shares borders to the North with the Caribbean Sea, to the South, with the Pacific Ocean, to the East, with the Republic of Colombia, and to the West, with the Republic of Costa Rica (Espinosa, *et al*., 1997) (Figure 1).

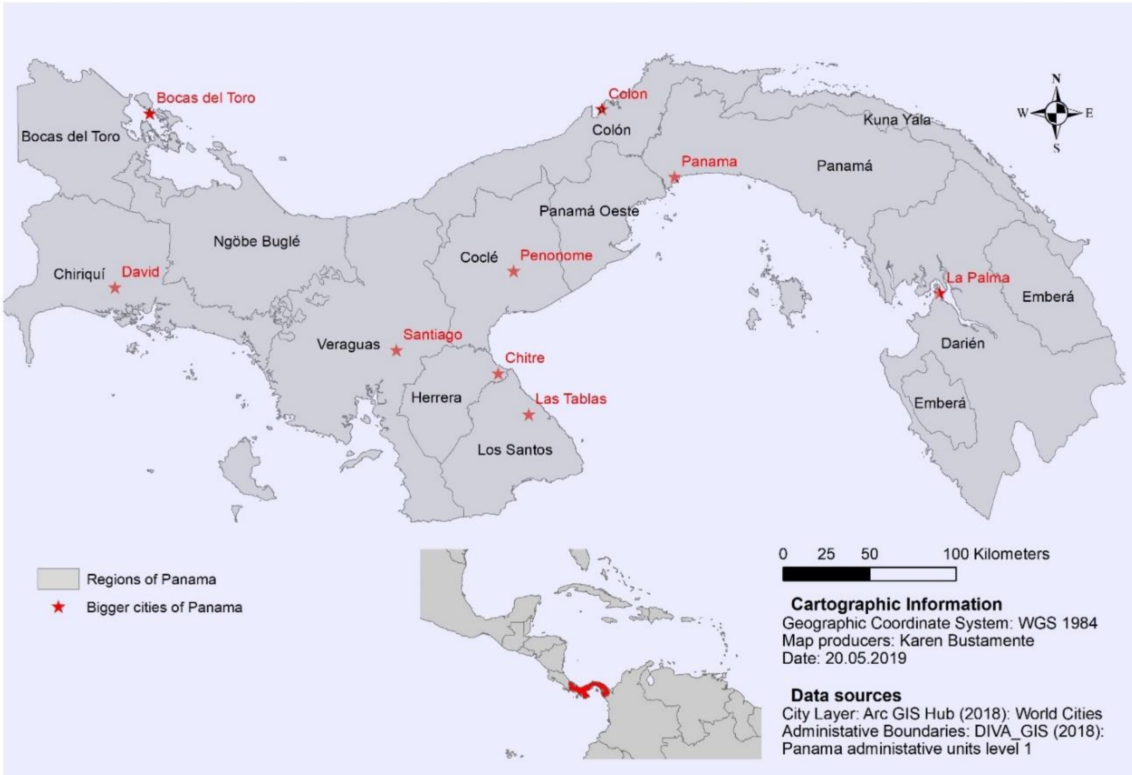


Figure 1. Geographical location of the Republic of Panama.

In this country, two seasons have been identified: dry season and rain season. The variation in the temperature is relatively low and goes from 24°C to 32°C usually (Harmon, 2005). Panama has a tropical climate that branches from its location between 7-10° N latitude. Although in the whole country the high temperatures and precipitation persist year-round, temperatures are slightly higher on the Atlantic and precipitation is more intense with an average of 2,970 mm and about 1,650 mm on the Pacific side (Harmon, 2005; Microsoft, 2001). The hydrographic network of the country consists of 52 hydrographic basins (18 in the Atlantic and 34 in the Pacific). It has a total of 500 rivers (350 in the Pacific and 150 in the Atlantic) (Escalante, *et al*., 2011) (Figure 2).

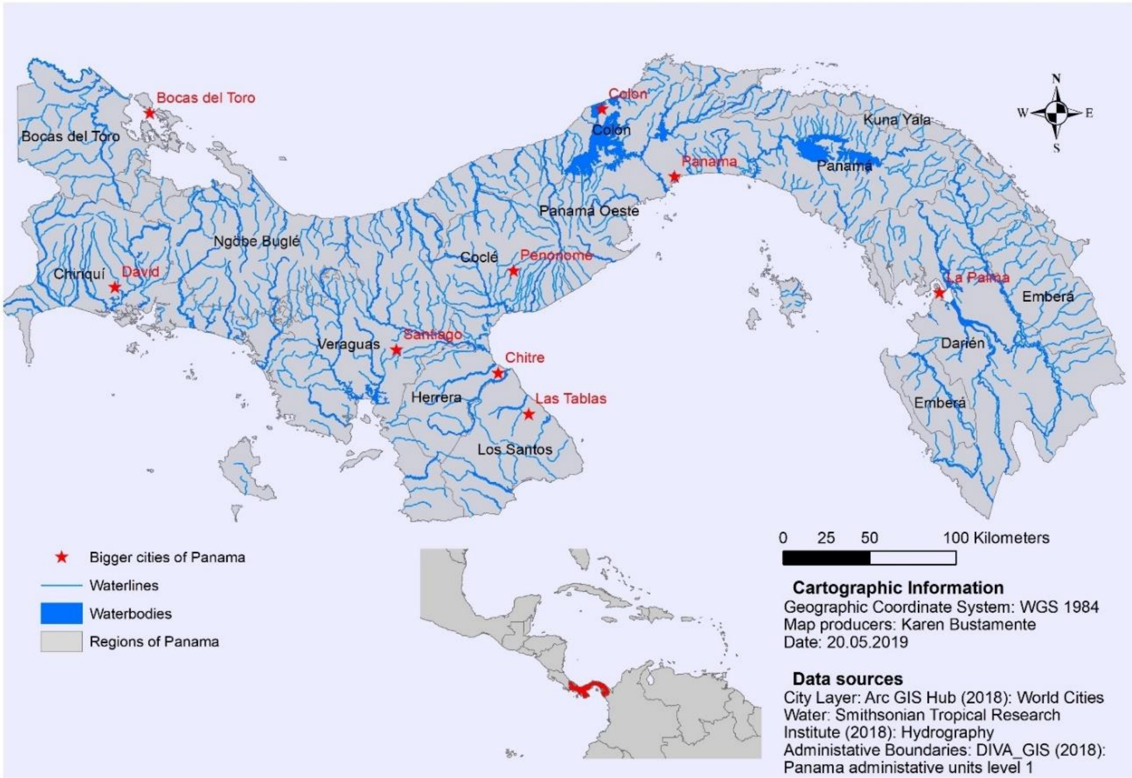


Figure 2. Map of the network of surface water bodies within the Panamanian territory: rivers, lakes, lagoons, streams.

Another important component about the country is that it is part of the Dry Corridor of Central America, a zone of dry tropical forest from Southern Mexico down to Panama and it is characterized by its high temperatures that cause extreme dry seasons (FAO, 2017) (Figure 3). Additionally, Panama is also impacted by the effects of ENSO (*El Niño-Southern Oscillation)* which, according to NOAA, causes fluctuations in the temperature between the ocean and atmosphere in the east-central Equatorial Pacific.


Figure 3. Geographical delimitation of the Dry Corridor of Central America. source: CCAD 2011.

## 3.2 Water availability, supply and management

### *3.2.1 Status of water and supply*

Panama has abundant water resources, of which precipitation plays the most important role for recharging the country's water bodies. It is estimated that the total volume of precipitation is 233.8 billion $m^3$ / year, estimating an annual national average of 2.924 l / $m^2$, with a minimum of 1,000 l / $m^2$ and a maximum of 7,000 l / $m^2$, these numbers place Panama with the highest precipitation in Central America (Comité de Alto Nivel de Seguridad Hídrica, 2016).

The institution in charge of the public aqueduct for water supply in the country is the Institute of Aqueducts and Sewerage Systems (acronym IDAAN in Spanish) which is responsible for supplying water to populations over 1,500 inhabitants and the Ministry of Environment (MINSA), through the Aqueduct Management Boards Rural (JAAR in

Spanish) to populations below 1,500 inhabitants (Observatorio regional de planificación para el desarrollo, 2014).

Much of the country's rainfall is captured by the extensive and complex water network. Panama's water network, just like most networks is the world, is made up of different components in which water is captured, stored, conducted, distributed and treated in its different stages. It is a complex system involving several operational and administrative institutions (Morales-Vergara, 2015). Broadly speaking, this composition is developed as follows:

- Water recharge zone: this is composed of aquifers and springs in which water is filtered from the rains.
- Sources of supply: this is composed of exposed water bodies, such as lakes, rivers and lagoons that capture water from rainfall.
- Water intake and water collection: this consists of the infrastructure works necessary to capture the water for its use.
- Line of conduction: composed of structures and elements that make possible the transfer of the water resource from the intake of water to the reservoirs / storage tanks.
- Storage tanks: an element whose main function is to replace water reserves, which cover needs at different times of community consumption when it is necessary to carry out repairs at the intake site or the driving line. Basically, as a substitute in case of emergencies.
- Distribution network: this basically consists of the pipes that connect the entire water supply system in the country.

- Water treatment (potabilization): in this stage the water that is captured and stored goes through a purification process.
- Water use (private or public): in this stage it refers to the use and amount of water consumed for different activities of daily household or industrial use.
- Water treatment (wastewater): In this stage, sanitation processes are applied to the post-use water.
- Administrative management: In this part all the processes that are required for the administration in the water management processes and components are conglomerated.

According to ETESA data, in Panama the total availability of water for consumption has been estimated at *"119.5 billion cubic meters of which only approximately 25.8% is used"*. It also estimates an *"increase in water demand by 2050, foresee a surplus greater than 50% of that availability"* (Comité de Alto Nivel de Seguridad Hídrica, 2016).

Studies indicate that due to the intensive and uncontrolled exploitation of water resources for agricultural, industrial and domestic activities, it has caused the reduction in the flow of the main rivers of the region and reducing the availability of the resource. At the same time, this has increased the exploitation of underground water resources, which promotes the acceleration of desertification. It is precisely in the region of the Dry Arc characterized by low precipitation and high temperatures led to the exploitation of underground water resources (Morales-Vergara, 2015).

### *3.2.2 Water demand and use*

Panama is known for being among the countries with the highest precipitation in the world, this is a good factor when it is about water availability, on top of this, the country is composed for a large amount of water bodies that help to provide water to the population.

At present, the quantity of existing aquifers in Panama is unknown since they have not been identified and delimited, nor the water resources stored in them and the safe yield of each of them (recharge) (Hausmann *et al*., 2016) But it is estimated that in Panama the total availability of fresh water is 119.5 billion $m^3$ of which only 25.8% is used. Estimates of the increase in water demand by 2050, foresee a surplus greater than 50% of that availability (Comité de Alto Nivel de Seguridad Hídrica, 2016). Of the total amount of freshwater used (underground and not underground), in terms of the classification of consumptive and non-consumptive (Table 1).

Table 1. Uses of water in Panamá per volume and percentage. Source: Geo Panamá 2014, MiAMBIENTE.

| **Consumptive** | **Volume (m3)** | **Percentage (%)** |
|---|---|---|
| Agricultural sector | 518,270,000 | 1.7 |
| Human consumption | 389,883,992 | 1.3 |
| Industrial sector | 8,310,000 | 0.2 |
| Recreational tourism sector | 3,460,000 | 0.1 |
| **Non-consumptive uses** | | |
| Hydroelectric sector | 27,579,390,000 | 89.6 |
| The Panama Canal | 2,274,000,000 | 7.0 |
| Scenic beauty | 2,790,000 | 0.1 |
| **Total** | 30,776,103,992 | 100 |



By classifying the different uses of water in consumptive and non-consumptive, one can verify that non-consumptive uses represent almost the entire percentage of water use with an approximate of almost 97%. Within the percentage of water intended for human consumption, 92.5% of the population has coverage through various sources of supply such as: public aqueduct, community aqueduct, private aqueduct and tank vehicles. (Comité de Alto Nivel de Seguridad Hídrica, 2016); INEC, 2010).

#### *3.2.3 Wastewater management*

The wastewater management of the country is carried out through two institutions: IDAAN and the Ministry of Health. The Institute of Aqueducts and Sewerage Systems (IDAAN) is responsible for managing, operating and maintaining drinking water supply systems, sanitary sewer systems and wastewater treatment. In terms of sanitation and treatment of sewage collected through the sewerage system managed by IDAAN, the Ministry of Health oversees the treatment of this sewage collected by the sewage system. The sanitation is carried out through different physical-chemical processes.

The management of the sewage was carried out in various ways, since the West of the Federico Boyd Avenue to the Casco Viejo of the city of Panama, the system is a combined system. The quality in the Casco Viejo sanitary sewer system has a large number of pipes that have lost their vertical and / or horizontal alignment, and their self-cleaning capacity, and suffer from frequent obstructions as a result of these conditions. In general terms, sanitary sewer networks located east of Federico Boyd Avenue to the Juan Díaz River, and between Transístmica Avenue and the Bay of Panama work properly (Quiroz-Tejeira, 2017).

The efforts made in terms of wastewater management are established under the MINSA-IDAAN agreement in which the Panama Sanitation Program is created. The agreement establishes the responsibilities and specific commitments of the parties involved; the planning and performance of teamwork, which, as a whole, will make successful the concretization of this advantageous Program; The period of execution of this agreement will be ten years ("Convenio MINSA – IDAAN," 2016).

But in the country, the IDAAN and MINSA as representatives of the public sector are not the only ones that carry out wastewater treatment work, since there are also small treatment plants operated and maintained by private groups, within the categories of urban, commercial and urban projects. or industrial. There is no defined criterion in the application of the appropriate values in the parameters of the wastewater treatment plants. Despite this, work is being done for hospitals and industries to build treatment plants with the purpose of reducing the pollution levels of both Panama Bay and natural water currents.

According to data registered in the 2010 Population and Housing Census carried out by the INEC, in Panama City 94.5% of the population has some type of sanitation system (private or communal use), either by sanitary sewer, latrine or septic tank. This information positions Panama in a relatively good place. However, the country still considers defiant that more than 10% of the population in rural areas does not have this service, and among people with sanitation, about 31% still use latrines (INEC, 2010). However, the situation at a country level does not reflect the same level of achievement, only 56% of the population have access to sanitation covered by aqueducts from the IDAAN network (Observatorio Regional de Planificación para el Desarrollo, 2014).

Within this type of treatment systems are Imhoff and septic tanks, and other facilities that provide service to part of Panama City, do not work efficiently due to hydraulic overload, design problems and lack of maintenance or routine cleaning. The precarious infrastructure and inadequate management of most of the sewers in the area mean that the wastewater flows into the sea without any treatment.

The treatment of wastewater, even of those that are captured for sanitation in existing plants, continues to be precarious and inefficient. The removal of solids in suspension is medium, that of organic load is low, and that of total and fecal coliforms is practically nil. Different types of treatment are used indifferently, such as SBR (Batch Reactor System), conventional activated sludge, aerated lagoons and Grana (fluidized bed) (Quiroz-Tejeira, 2017).

In 2017, the Ministry of Health, through the Coordination Unit of the Panama Sanitation Program, reported on the award of the Design, Construction and Assembly Project for the Second Module of the Wastewater Treatment Plant of Panama City and Operation and Maintenance of the First and Second Module of the Plant (Figure 4). The objective of this expansion is to increase the current treatment capacity from 2.7$m^3$ / s to 5.5$m^3$ / s of wastewater from Panama City, taking into account the rapid population growth and accelerated development that the city has had. It is estimated that this second module will be operational by mid-2020 (Canavaggio, 2017).

Figure 4. Wastewater treatment plant in Panama. Source: Programa de Saneamiento de Panama

### *3.2.4 Infrastructure*

Panama is proud to hold an innovate infrastructure when considering technology, port infrastructure, as well as airport infrastructure and transportation. Energy and communications are also all of very high quality, which, together with other 11 indicators, places Panama in the 58th country of 144 in terms of competitiveness in the period of 2014 to 2015 (Observatorio Regional de Planificación para el Desarrollo, 2014; Embassy of the Kingdom of the Netherlands in Panama, 2018). In any case, this report does not mention the quality of the country's infrastructure in terms of aqueducts and sewerage.

Since 2007, all kinds of progress in relation to environmental and territorial planning, and regional hydrographic basins have been stopped. Currently Panama does not have a socio-territorial planning and environmental planning, infrastructure and urban planning. For an efficient economic growth, the country has considered narrowing this gap in its development. The country is aware of the lack of, above all, road infrastructure and recognizes the problem of accessibility and connectivity between the different logistics points mostly the southern part of the country. The conditions in some sections of the Pan-American Highway do not meet design standards for cargo transportation and road safety. (Observatorio Regional de Planificación para el Desarrollo, 2014) (Figure 5).

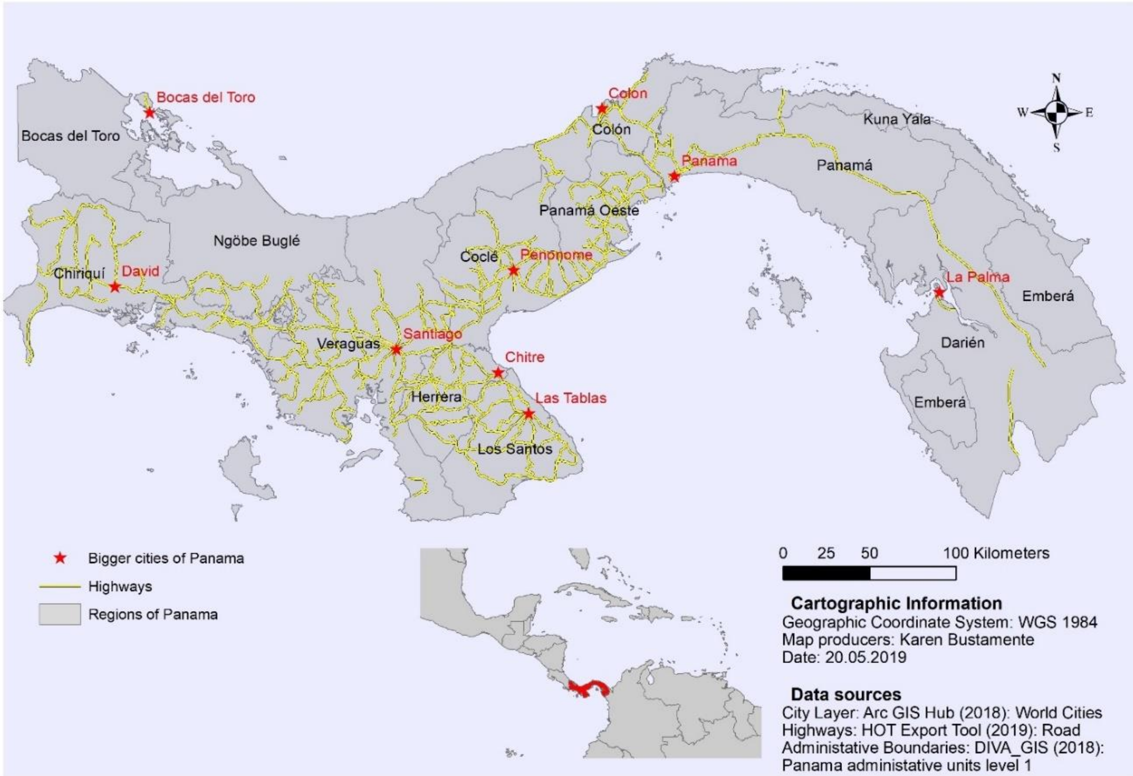


Figure 5. Road infrastructure map that connects the main strategic and populated areas of the country.

In the ***National Water Security Plan 2015-2050***, Panama registered the different types of infrastructure involved in water management. This registry includes 60 water treatment plants; 5,397 rural aqueduct systems; 783 irrigation systems (public and private); 1 wastewater treatment plant; 45 hydroelectric projects; 263 hydrometeorological stations for water resource monitoring (Comité de Alto Nivel de Seguridad Hídrica, 2016).

Although in general terms, Panama's infrastructure is projected as of good quality to the world, the infrastructure in its water system does not have the same scope, since in the metropolitan area of the country and in remote rural regions, it is not yet available with adequate infrastructure coverage for water supply and sanitation, despite the fact that Panama continues to reaffirm the importance of basic infrastructures (water and sanitation, decent, safe and healthy habitat), which are essential to improve the quality of life of any population (Observatorio Regional de Planificación para el Desarrollo, 2014).

In addition to the lack of water infrastructure, there is the lack of adequate maintenance of the existing infrastructure mainly in central areas of the city of Panama, as for example in the tourist area of Casco Viejo, where the sewage system suffers from irregularities in its operation, due to the loss of vertical or horizontal alignment, absence in self-cleaning capacity, so it suffers from frequent obstructions (Quiroz-Tejeira, 2017).

#### *3.2.5 Governance*

Water security along with an efficient management require financial management and functional infrastructure, as well as projects that do not compromise invasive and unsustainable natural resources. The resilience to runoff, floods and droughts is a sign of a country with a strong economy and solid water security (Yildiz, 2017). In order to secure this, good governance is needed from National level with implementation involving all stakeholders in a multilevel approach.

The hydrological information is found primarily in two institutions, in the Hydrometeorology Directorate of ETESA and in the Water Resources Section of the Panama Canal Authority. Regarding natural waters (consumptive and non-consumptive uses). The responsible for the control, inspection and processing of water concessions is the National Environmental Authority (ANAM), this authority provides temporary and permanent concessions as established by Water Law 35 of 1966.

Regarding water supply in the country, this service is managed by two authorities, the first one is the Institute of Aqueducts and Sewers of Panama (IDAAN), which provides drinking water to communities larger than 1,500 inhabitants (Hausmann *et al*., 2016).

The cost of water provision among citizens does not include operation and maintenance costs of the network, it can be said that this service is subsidized, which benefits Panamanians but promotes the culture of waste in the city. The second authority is the Ministry of Health (MINSA), which provides water to rural populations under 1,500 inhabitants. In rural communities, water management is through community participation and under the Article 112 of the National Constitution of 1972 which grants them with the capacity of construction, administration, operation and payment of rural aqueducts (Escalante *et al*., 2011).

The Department of Underground Sources was created in the 1970s, with headquarters in the City of Chitré, located in the heart of the Panamanian Dry Arc, the area of the country with the least amount of rain and where groundwater is exploited extensively for multiple purposes due to the low precipitation per year in the area. Groundwater management in Panama shows a notable lag. Groundwater has been exploited in an isolated, empirical and disorganized manner, without knowledge of the hydrogeological network and its extension and without the application of hydrogeological management tools to guarantee sustainable use of the resource, exploration of the threats such as contamination, (Centroamérica GWP, 2015).

## 3.3 Importance of water in Panama

### *3.3.1 Water and Growth*

Panama is a country which has a strong connection with water resources, and it acknowledges the importance of the ecosystem services that water provides to the country. This importance makes Panama recognized worldwide because of the Panama Canal, which it is one of the main routes of transportation to cross from the Caribbean to the Pacific Ocean and which represents, along with construction and wholesale, retail and repair sectors 57% of the growth (GDP) recorded from 2005 to 2015 (Hausmann et al., 2016). the management of water resources cannot be seen independently and isolated from other sectors, but in an integral way considering important economic sectors of society, such as the ones, relevant for this country: logistics and transportation, agriculture, tourism and mining, which undoubtedly depend on the realization with the management of water resources (Embassy of the Kingdom of the Netherlands in Panama, 2018). For this reason, growth and development in the country depend principally on quality and abundance of natural resources, which are being increasingly degraded by an untidy urban and economic development (Escalante et al., 2011).

This heritage places the country as one of the best examples in the global scale of a country driven by water (Comité de Alto Nivel de Seguridad Hídrica, 2016) reason why sustainable development is essential and urgent in the country. The problem of sustainable development in Panama must be traced to considering the coexistence between forms of sustainable exploitation and the destructive abuse of the country's natural resources. As has been the case of the reorganization of the Chagres river basin, which, with the purpose of creating the freshwater reserves required by the Panama Canal for its operation, underwent invasive and extensive changes in the area of the basin and that It became a river that flows into both the Pacific and the Caribbean (Castro, 2006).

The fact that the prosperity of the transit zone depends on the operation efficiency of the canal enclave has generated a situation in which the most active sector of the economy does not prompt the development of the most backward sectors and the most vulnerable population.  All this contributes to the increase in the distribution of wealth in the country over the years (Castro, 2006; Ailigandi, 2011).

**T**he development of major infrastructure projects (Canal expansion completed in 2015 and the second Metro line still in progress) provide a clear image of what to expect regarding the Panamanian growth. With public and private investments, there is no indication of a decline in more investment in a near future for residential and non-residential construction leading indicators (such as construction permits). The constant stable macroeconomic environment and the measures performed by the Government to guarantee that the banking sector fits the international standards will also continue to make Panama an attractive country for FDI (World Bank, 2015).

### *3.3.2 Panama Canal*

historically, the construction of the canal was initially planned in 1881 by the French entrepreneur Ferdinand de Lesseps, the same person behind the construction of the Suez Canal, when Panama was still part of Colombia. Unfortunately, his attempt was full of many complications that were not considered by de Lesseps, such as the changes of the Chagres river during rainy season, the spread of diseases by mosquitoes, which were responsible to kill hundreds of workers per month and the lack of a previous route. However, this did not stop de Lesseps efforts and it was after de Lesseps went to bankrupt in 1889 when the cessation of the construction of the Canal occurred. The United States sought an opportunity after the French efforts failed and took over the project in 1904 (McCullough, 2001).

Panama is well recognized worldwide because of its canal which has shaped the economy and geography of the country. The construction of the Panama Canal entailed three main problems: engineering, sanitation and organization (Panama Canal Authority, 2013). Despite being a relatively short time process, it suffered from an intense environmental disturbance in a small portion of the country, which provided economic and social stability in a developing country. As part of the construction of the Panama Canal, the Chagres River was dammed in Gatun, which therefore led to the creation of Gatun Lake, responsible for providing water for the proper functioning of the locks that move ships between oceans through the Canal. Lake Gatun has an area of 423 square kilometers formerly comprised of forests, grazing lands and peasant communities (Castro, 2006).

Worldwide, the Canal represent a very important trade route between the east coast of the United states to Asia being the one with the highest traffic followed by the trading route between Europe to the west coast of the United States and Canada. The other important traffic routes in the canal are the East coast of the United States to west South America and coast to coast of South America (Figure 6) (Panama Canal Authority, n.d)

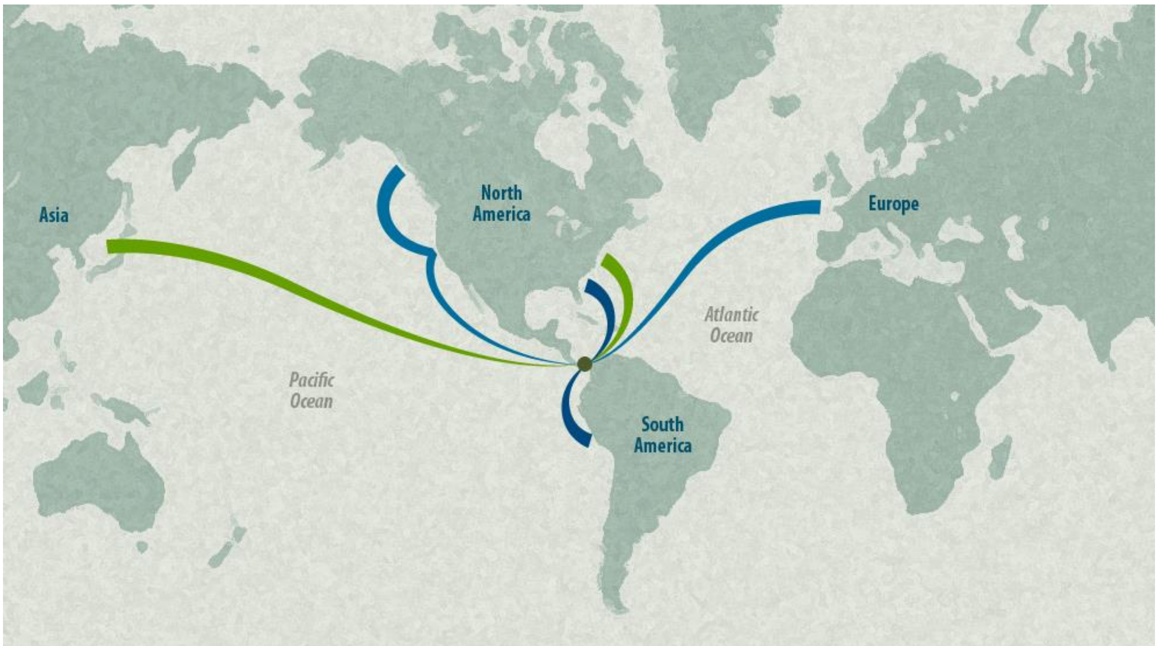


Figure 6. Interoceanic traffic routes of the Panama Canal. Source: The Panama Canal Authority.

For operational purposes and by design to rise and Iower ships moving through the Canal, it requires enormous amount of freshwater. A total of 197,000 m3 of water stored in artificial reservoirs ends up in the ocean during each transit, using approximately half of that volume to raise vessels to the highest point of the canal (Gatun Lake) at 26 m above sea level and the other half to descent vessels to sea level (Carse, 2017).

The Panama Canal plays a very important role in the economy of the country, it is for this reason that the Panamanian government in order to increase the economic potential and the operational capacity of the Canal that officially started the project on September 3, 2007. Canal expansion. The third set of Canal locks was officially inaugurated on June 26, 2016. This new set of locks allows the transit of larger capacity ships called Neopanamax.

By 2018, this represented a total of 13.692 of ships transiting through the Panama Canal and which in terms of economic income contributed with 2.513,2 million dollars, 8.5% more than the 2,316.3 million of the previous year (2017) (INEC, 2018).

Figure 7. Panama Canal locks in Miraflores port. Source: The Panama Canal Authority.

### 3.4 Climate Change

The vulnerability to climate change in the Central American region is among the highest according to the DARA's Climate Vulnerability Monitor carried out in 2012. This report placed Panama in the severe category of the five that it uses (acute (most vulnerable), severe, high, moderate and low (least vulnerable)). This vulnerability has its effects on the ecosystems that provide ecosystem services to the country including pollination, pest control and regulation of humidity, local climate and water cycle (CEPAL, 2018).

The climate factors might have natural or anthropogenic origins, nevertheless, both the increasing anthropogenic driven origins and natural events are hitting with increased strength and frequency. Panama is in a very vulnerable area to the effects of climate change. The global climate risk index created by the organization German Watch rates Panama in ninetieth position of the most vulnerable countries to climate risks in the world (CEPAL, 2018).

Another study carried out by the World Bank about countries with the greatest exposure to natural disasters positions Panama at number 14, since the country is located in an area that is very exposed to a great variety of natural disasters both on its Pacific side, as on its side of the Caribbean, including hydrometeorological and geophysical hazards. (Dilley *et al*., 2005)

Due to the relevance of this topic for the Central American country, the government had to assume the commitment to face climate change by including the subject and make it part of the knowledge of all the stakeholders. Thanks to this, the bases for the management of climate change in the country have been institutionalized. Regarding environmental policies, these are established in Law 41 of July 1998, the General Environmental Law and the Participatory Strategic Plan (PEP) 2002-2006 agreed with the entities that are part of the Inter-Institutional Environment System (SIA) that defined the lines of joint action, to combat the national environmental problem. With the National Climate Change Policy as a guiding framework for activities that contribute to the reduction of greenhouse gases, to the promotion of adaptation measures and ensure sustainable development in the country by the public and private sectors and civil society , based on the principles of the UNFCCC, the Kyoto Protocol and the General Environmental Law of the Republic of Panama (ANAM, 2011).

It is impossible to ignore the fact that the need and demand for water is finite and more frequently, in a situation of venerability that continues to increase, as well as competition for access to the resource. An example of this is the uncontrolled exploitation of groundwater for irrigation and human consumption, coupled with the effects of climate change impacting surface water bodies (Cosgrove & Loucks, 2015).

Some of the effects of climate change expected for the country are shared regionally[1] and some of them are already evident, such as the increase in extreme weather events, floods in urban and rural areas and droughts worsen with the presence of an El Niño event (ENSO) in the Pacific slope and affecting mainly the agricultural sector, but which in extreme cases would affect other socioeconomic sectors important for the development of the country.

### *3.4.1 Socioeconomic impacts of Climate Change*

The influence in water quality and availability caused by current population growth and infrastructure development and land-cover change to satisfy population needs particularly in Panama City already represents a high pressure for water system. In addition to the anthropogenic pressure, climate change inevitably adds a pressure on the system, having great impact in the most vulnerable people and agriculture and land-cover.

In Central America, climate change has direct effects on rainfall levels in the region, and although Panama is not among the most affected countries in the region, it ranks 90 out of 183 countries (CEPAL, 2011). The impact that this would have on the socioeconomic aspects of the country is undoubtedly considerable. In terms of water resources, the climatic events that currently impact its availability and quality are the high precipitation levels (Figure 8) caused by rains that occur with greater force but each in a shorter period, this because climate change in turn has severe effects on droughts that affect the country annually and that appear every time in longer periods. As a result of the prolonged period of droughts during the dry season, the communities



[1] Central American countries (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama).

that inhabit the well-known Panamanian Dry Arc suffer more from the effects of climate change (CEPAL, 2011).

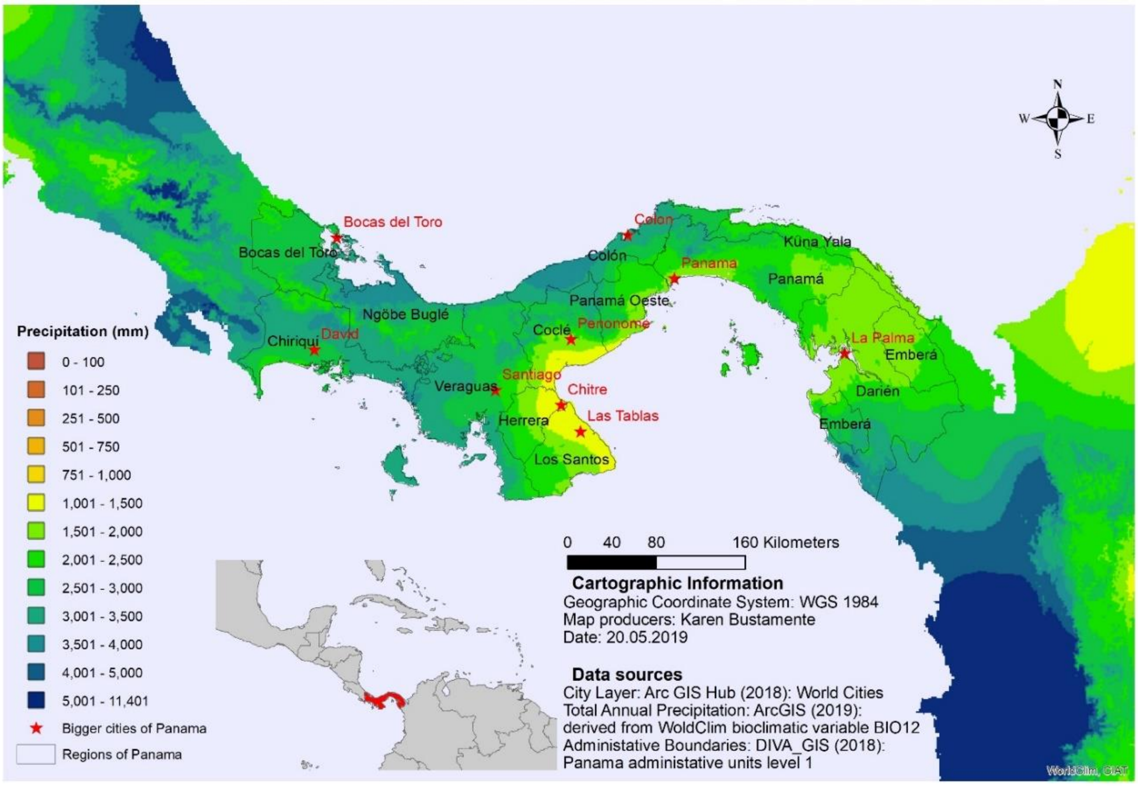

Figure 8. Map of annual average precipitation within the Panamanian territory.

The IPCC report states that natural variability will continue to be a factor that alters climatic events, but in addition to this, the great influence of anthropogenic activities must also be considered (IPCC, 2011).

In the most recent IPCC special report, it is mentioned that the increase of 1.5 ° C caused by the high greenhouse gas emissions generated by anthropogenic activities, would have a very serious socioeconomic impact in the Central American region, reducing food security due to droughts in water bodies, thus contributing to the increase of poverty in the most vulnerable regions (IPCC, 2018).

According to the FAO during the 2015-2016 agricultural period, the impacts of heavy droughts reduced the cultivation of rice and corn and caused the loss of weight of 72,500 head of cattle in 2014 (Calvo-Solano *et al*., 2018). While MIDA reports from previous years recorded that the combined effects of ENSO and climate change caused losses of up to 50% in rice crops, a 14% reduction in maize production in 2010 and losses of up to 30% in orange production due to changes in temperature in 2009 (Calvo-Solano *et al*., 2018). Currently, the areas where agricultural activities are carried out in the country is very reduced and keeps decreasing throughout the years (Figure 9) (Observatorio Regional de Planificación para el Desarrollo, 2014).

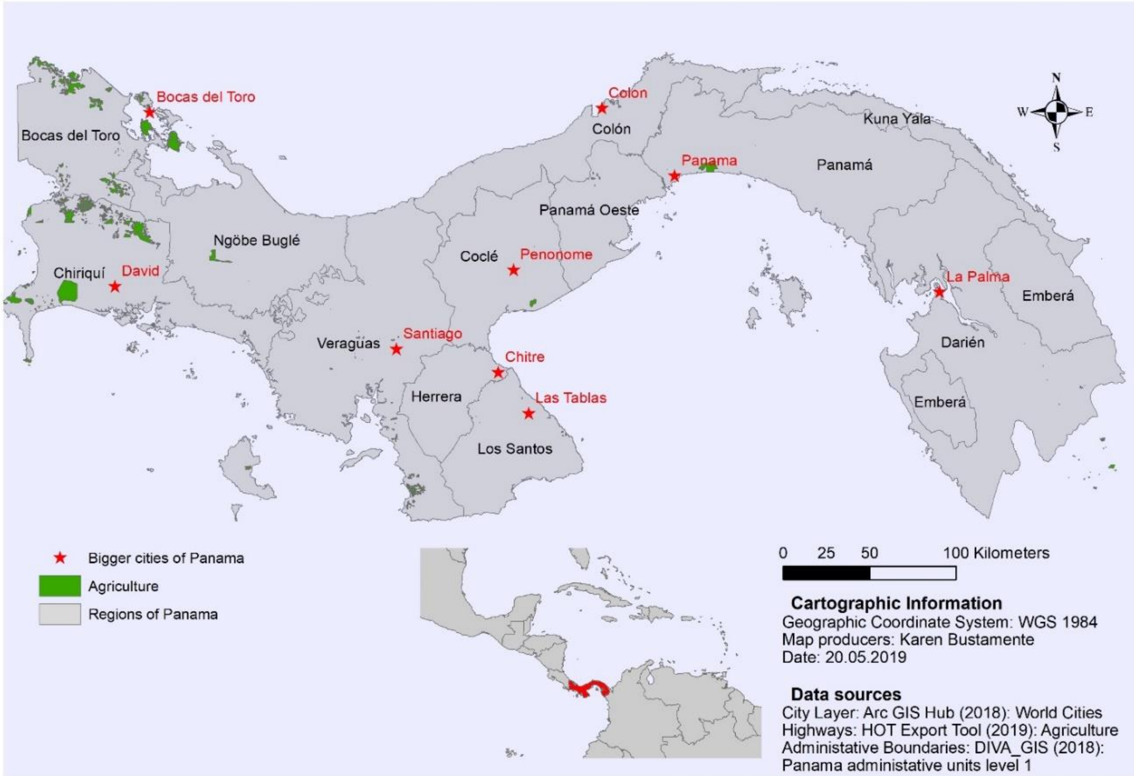


Figure 9. Map of areas where agricultural activities are carried out in Panama.

The climate change also has its impacts in the Panama Canal watershed, altering the rainfall and together with the ENSO phenomenon in the period of 2015-2016 affected the levels of the Gatun and Alajuela reservoirs, registering in mid-May 2016, the lowest levels in 103 years (Comité de Alto Nivel de Seguridad Hídrica, 2016).

### 3.5 Socioeconomic Scenarios for Panama

In 2018, Panama's gross domestic product obtained its largest contribution from the category of non-market production, transport, storage, communications wholesale and retail market and, construction which represented a total of 72% of the total annual contribution to the country's GDP in 2018. According to the INEC, the country's GDP in 2018 in dollars (USD) was equivalent to 41,693.4 million, which represented 1,478.7 million or 3.7% more than the same period of the previous year (Ministry of Economy and Finance, 2019).

The high contribution of these sectors in the Panamanian GDP, does not represent any surprise for the Panamanian government since much of the contribution depends mainly on the services carried out by transportation, storage and communications offered by the Panama Canal, contributing with a quarter of the GDP (25.7%). Unfortunately, the same cannot be said for the tourism sector, agriculture, and manufacturing industries, which compared to other activities that the Panamanian government plans to target, did not represent a significant contribution to GDP and that, contrarily, are decreasing year by year (INEC, 2018).

During the period from 2015 to 2019, Panama has planned to increase its economy by giving a boost to the driving sectors of the Panamanian economy, such as logistics and transport, agriculture, tourism and mining; while at the same time, it aims to provide drinking water 24 hours a day to the entire population of the country, as well as access to improved sanitation by eliminating the latrines of more than 300 thousand households and installing bathrooms, which will improve quality of life of more than 1 million Panamanians (Observatorio Regional de Planificación para el Desarrollo, 2014).

With the objective of achieving the competitive integration of the marginal socio-economic tissues in the modern economic system of Panama, the government selected "potential sectors" with an important role in boosting the country's future. Taking into account the criteria obtained in the *Strategic Government Plan 2010-2014*, this new strategic plan obtained the necessary information to contribute to the objectives of this new stratified plan in terms of competitiveness and inclusion. The criteria considered to strengthen the Panamanian economy are:

- Productivity and international insertion capacity (generation of exports).
- Capacity to generate employment (new or better quality).
- Potential impact on low-income population.
- Chaining capacity with other sectors of the economy.

Only the Panama Canal itself offers a wide variety of growth possibilities for the government as well as an attractive way to keep adding important investors to contribute in different sectors. This was well reflected when the expansion project for the Canal was signed in 2006 and in which public but also investment from multilateral agencies financed this project. The project was financed by The Panama Canal Authority (ACP) along with five multilateral agencies: Japan Bank for International Cooperation (JBIC), European Investment Bank (EIB), Inter-American Development Bank (IDB), Corporación Andina de Fomento (CAF) and the International Finance Corporation (IFC) (Panama Canal Authority, 2008). But the outlook for sustained high growth for the future of Panama is supported by more important and emerging opportunities in other key sectors such as mining, financial services and tourism (World Bank, 2015).

### 3.6 Sustainable Development Goal 6

The SDGs (Sustainable Development Goals) are a very important tool created with the purpose to tackle issues that represent the main root of several environmental, social, political and cultural problems worldwide. Each SDG comes with a set of targets and indicators that help to localize and measure the effectiveness under the action taken for the SDG. the SDG agenda is marking an unprecedented scope and significance. It is accepted by all countries and has the flexibility to be adopted by all, without discrimination between a developed and developing country and always considering different national issues, contexts, capacities as well as levels of development and respecting national policies and priorities (UN, 2015).

Particularly in the SDG 6 (clean water and sanitation), as the name implies, it is mainly to ensure quality water for consumption, treatment of sewage, access to sanitation, while all this is accessible for all. SDG 6 aims to safeguard water resources through comprehensive strategies of management, conservation, education and international cooperation in order to guarantee quality water resources for future generations.

In the 2015-2050 Water Security Plan, Panama has already contemplated the SDG 6 indicators to take them as a basis for its government plans in relation to water management throughout the country. This integration is made considering the needs of the country, as well as the gaps in different social, economic, political and environmental areas with the aim of safeguarding the country's water resources and expanding the reach of these to all the neighboring regions of Panama. At the same time considers the sustainable use of water resources so that the integration of sustainability in each of the economic development plans that are intended to be executed in the country, either for supply or sanitation.

# 4. Methodology

## 4.1 Overall methodology

The methodology applied to this study will be incorporated in three sections that aim to analyze the current management in the water system in Panama at country level and connect it to the projected development scenarios focused in the progress of four socioeconomic sectors in the country according to the government goals reported in the ***Strategic Government Plan 2015-2019***: logistics and transport, agriculture, tourism and mining and the Sustainable Development Goals (SDGs), focusing in the SDG 6: clean water and sanitation. This study suggests a way to focalize the SDG6 indicators in the whole water management system to identify gaps and issues in order to suggest possible strategies to tackle these issues under the different developing scenarios.

## 4.2 Fuzzy Cognitive Mapping of the Water System

Fuzzy Cognitive Maps (FCM) is a tool that is used to show in a visual and representative way and, to a certain extent, a little more simplified, systems that have a certain level of complexity. To make such representations through FCM, it is necessary to identify those concepts or variables that are part of the system, as well as the cause and effect interaction of these concepts in a diagram structure (Kosko, 1986).

The use of FCM to represent a system does not pretend to give a degree of absolute certainty and much less precision (Kosko, 1986), it is more a tool that helps to understand, from a visual and more ordered environment, how elements within the system interact and as well as the impact that has between them and, at the same time, the impact as a whole in the system.

Although the FCM concept may be confused with that of a mental map, there is an important difference between them. The representation of a system in an FCM is more complex and is not static, has connections that represent a greater or lesser impact between them weighted from 0 to 1, while these impacts can be negative or positive (+/-) (Taber 1991).

After identifying the system, for the identification of concepts that make up this system it is usually necessary the participation of groups of experts, or participatory panels of stakeholders that understand the interaction of the elements and their effects to later assemble them. For the case particles of this study, were taken as a basis the concepts collected by the "water group project" applied in Lesbos, made up of students of the MESPOM 2017 program and supervised by the professor and expert in hydrogeological systems of the University of the Aegean, Petros Gaganis.

The insertion of the variables adjusted to the situation that applies to Panama in the matrix of the baseline of the FCM, was carried out with the help of literature review, opinions of experts in the subject and of the personal analysis after consulting the statistical and qualitative data of the country. . With this information you can then locate the connection points of the variables. "The FCM model" is then used to model predesigned scenarios for Panama, in which the degree "impact force" of certain variables that represent problems in the scenarios generates a system response that is simulated each time the model finds a new equilibrium around the predetermined variables of the baseline.

## 4.3 Scenario building with the Logical Framework Approach

The process for building scenarios for Panama was made under consideration of development priorities for the country and as explained in depth in its ***Strategic Government Plan 2015-2019***. In this, the Panamanian government focuses on four sectors: logistics and transport, agriculture and tourism. These represent important targets for socio-economic growth in the country and in which important advances have been carried out.

Based on the methodology of the Logical Framework Approach (LFA) in its analysis phase, it was possible to locate the problems that could represent a threat to the country's water system caused by the development of these scenarios. The LFA is a set of tools and approaches frequently used for the design and management of projects. This methodology presents four phases: Activities, Outputs, Purpose and Goal, which are developed using the reasoning of "activities that lead to assumptions that, if carried out, carry out purposes, purposes that, if carried out, lead to objectives that will be achieved.

Following this sequence in this study, we have as final objectives a set of variables generated by the FCM that would have a greater impact on the water system, and that being connected with the four proposed scenarios (logistics and transportation, agriculture, tourism and mining) ) would show to a great extent the vulnerability of the system under each of the scenarios that the Panamanian government plans to reinforce.



## 4.4 Integration of SDG 6 in the scenarios

The Sustainable Development Goals (SDGs) are a set of objectives that aim to generate the strengthening of social, cultural, economic and environmental policies and practices that contemplate human well-being, eradicating poverty, safeguarding natural resources, promoting international cooperation, inclusion of the most vulnerable actors, among other goals.

The SDG 6 has its own set of indicators which allow identifying the targets that are necessary to achieve this objective. As Le Blanc mentions in its paper published in 2015, the achievement of SDG 6 would not only ensure water quality and sanitation for all, but would also improve the performance of others of the objectives, since SDG 6 is connected in turn with other objectives that have an impact in areas such as well-being and health, gender equality, poverty reduction, conservation of terrestrial ecosystems, reducing inequality, contributing to sustainable consumption and production, as well as contributing to development of sustainable cities.

Once designed the scenarios with the help of the LFA in which the FCM will run to know the elements in which the development of these scenarios would have a greater impact. With support from the SDG 6 Policy Support System developed by UNU-INWEH, which includes a set of indicators which allow the integration of this objective at a national level and its achievement in seven important categories: national capacity, policy and institutions, transparency , finance, disaster risk and reduction, status of water resources and gender mainstreaming. As a result of this integration, a list of indicators is obtained that allow the measurement of the positive and negative elements with the greatest impact in the FCM model scenarios in which quantitative data can be obtained.

# 5. Results

## 5.2 FCM of the Water System in Panama

Fuzzy Cognitive Mapping of water system used to analyze the status quo of the water system in the Republic of Panama includes concepts that were previously used in the FCM analysis of the local water management system in Lesbos, Greece, by Wang *et al*. 2017, and adapted to the situation of the Central American country at national level. This analysis through the modeling of the current situation of water management in Panama, reflects the need for an integrated water resources management (IWRM), which, as experts from the World Water Council explain, reconciles competent uses of water with legitimacy through of the participation of different public and private stakeholders and in coordination with a technical base in several levels (Smith & Jønch-Clausen, 2015).

It is important to mention that for this study assumptions are taken into account around the information obtained through the literature consulted and mainly from the official government reports, such as the aforementioned Strategic Government Plan 205-209 and that compiled by other sources. These assumptions were chosen considering long-term impact and large magnitudes for the social and economic development of Panama.

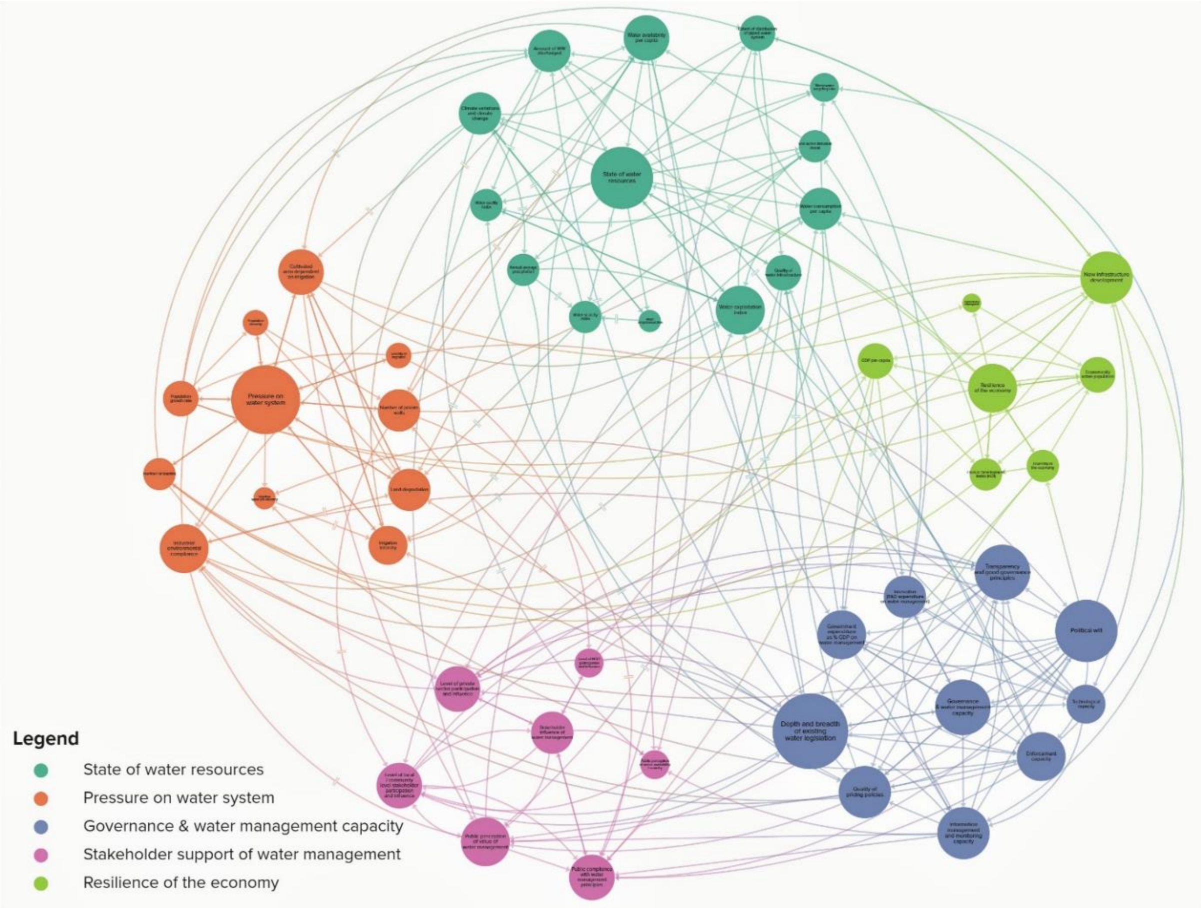


Figure 10. Fuzzy Cognitive Map of the water management system of the Republic of Panama displaying linkages between components and elements inside the components. Each color represents a group of components, the size of the elements is given by the amount of interactions (linkages) the element has with other elements.

### *5.2.1 State of water resources and water system*

Water availability seems to be relatively stable in Panama. Water scarcity does not represent a big issue especially when the country's weather is rainy half of the year. However, a portion of water is lost in evapotranspiration during the dry season and hot days (CEPAL, 2018) and another portion is lost because of the bad or insufficient infrastructure in the city (Morales-Vergara, 2015). Panamanians perception of the value of water resources is not positive or negative about this. For many years lack of water has never been an issue, which is one reason why in the country there is a culture of wasting water (Comité de Alto Nivel de Seguridad Hídrica, 2016). There are many ways to satisfy the need of water in the country, even when the extent of distribution in the country does not reach all the areas of the metropolitan areas, the government has installed wells that pump water to those areas which represents a high risk in two ways: an increased salt water intrusion threat, decrease in water quality index.

Table 2. Elements introduced in the matrix FCM model for the component of the *state of water resources and water system* that have positive and negative impacts.

| Element | Positive | Negative |
|---|---|---|
| Water availability per capita | **State of water resources and water system (0.75)**, Cultivated area dependent on irrigation (0.50), Government expenditure as % GDP on water management (0.25), Public perception of high water availability and quality (0.75) | Depth and breadth of existing water legislations (-0.50), Quality of pricing policies (-0.50) |
| Amount of WW discharged | N/A | **State of water resources and water system (-0.75)**, Water quality index (-0.75), |
| Climate variations & climate change | Water evapotranspiration (0.50), Land degradation (as decrease in vegetation cover) (0.25) | Water availability per capita (-0.50), Annual average precipitation (-0.50), Cultivated area dependent on irrigation (-0.25), Public perception of high water availability (-0.25) |
| Water quality index | **State of water resources (0.75**), Water availability per capita (0.75), Water exploitation index (0.50) | N/A |
| Annual average precipitation | Water exploitation index (0.75) | Climate variations and climate change (-0.50), Water scarcity index (-0.50), Sea water intrusion (-0.25), Irrigation intensity (-0.50), Land degradation (-0.75) |
| Water scarcity index | N/A | Climate variations and climate change (-0.50), Sea water intrusion (-0.25), Irrigation intensity (-0.50), Land degradation (-0.75) |
| Water evapotranspiration | Water scarcity index (0.75) | Climate variations and climate change (-0.50) |
| Water exploitation index | Sea water intrusion threat (0.75) | **State of water resources and water system (-0.75)**, Water quality index (-0.50), |
| Water consumption per capita | Amount of WW discharged (0.75), Water exploitation index (0.75), Extent of distribution of piped water system (0.50) | N/A |
| Sea water intrusion threat | N/A | Water availability per capita (-0.25), Water quality index (-0.75) |
| Quality of water infrastructure | **State of water resources and water system (0.25)**, Public perception of high water availability and quality (0.75), Public perception of value of water management (0.25) | N/A |

| | | |
|---|---|---|
| Extent of distribution of piped water system (area / population covered) | Quality of water infrastructure (0.25), New infrastructure development (0.25), Public perception of high water availability (0.75) | Number of private wells (-0.50) |
| Wastewater recycling rate | N/A | Amount of WW discharged (-0.75) |

Among the important elements of this component it is imminent the positive correlation between the increase in water consumption per capita and amount of wastewater discharged, this last one represents a high risk in other elements of this component such as decrease in the water quality index which at the same time affects negatively the whole state of water resources and water system. In simple words, increase in wastewater discharge has no positive effects in the water system of Panama but it does affect negatively and consequently more than one element.

For the state of water resources and system in Panama the element that has more impacts in several elements of the component is certainly climate variation and climate change. This element has inevitable and unpredictable impacts which have fluctuations all year-round. with the current climate events their average annual precipitation, water availability will decrease significantly and water evapotranspiration, especially during dry season, increases enormously adding extra pressure in the water scarcity index and consequently to the overall state of water resources and system.

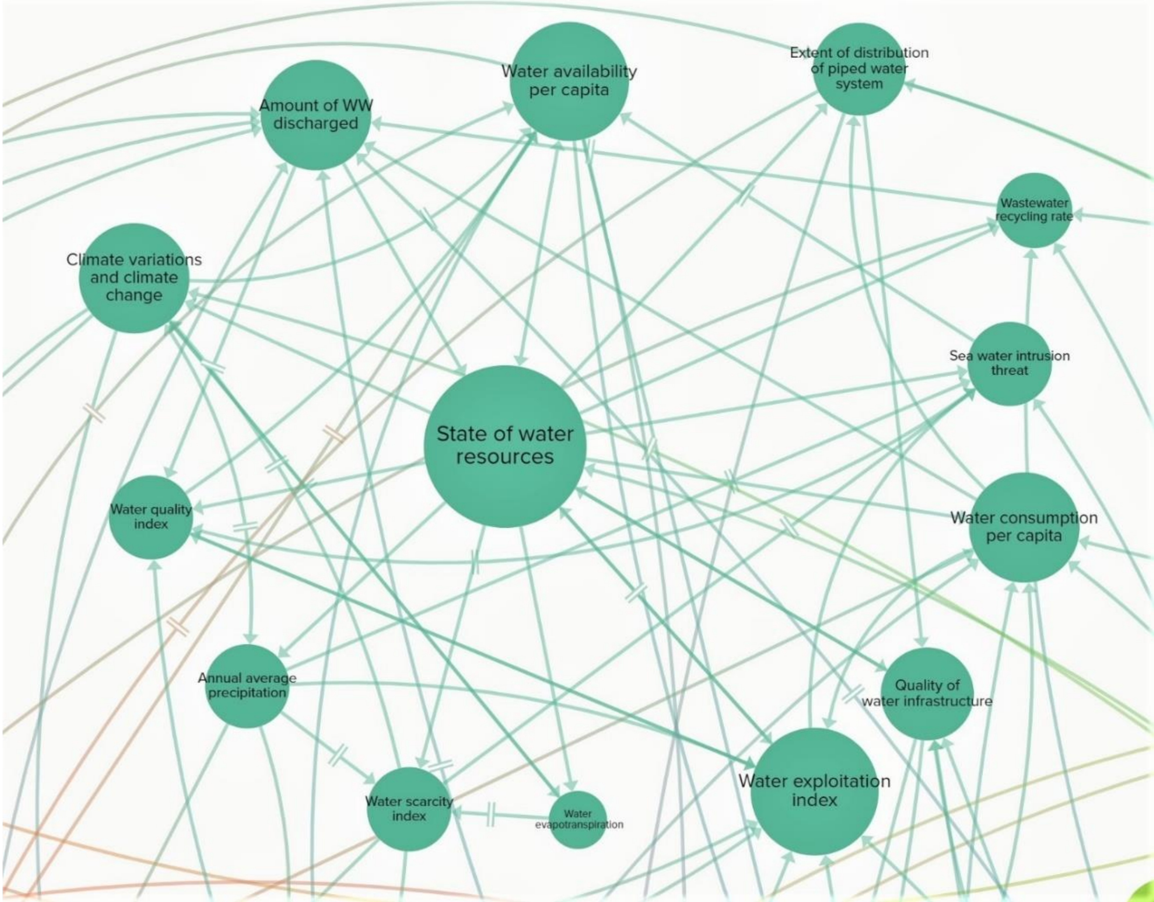


Figure 11. Conceptual map displaying the FCM results of the positive and negative linkages in the baseline of the component *state of water resources and water system*. Negative impacts are shown with a straight line and negative impacts are shown with a disruption.

### *5.2.2 Pressure on water system*

In Pamana there this is one of the most important components due the importance of the current government priorities and the all the social and economic aspects around the pressure on water system. For Panama the variables either positive or negative are very strong because of the high level of vulnerability of the whole water system to different elements.

There is no doubt of the important influence of the population growth in the pressure on the water system. Panama already suffers from that pressure, especially in dry season when water levels in the lake Alajuela, which supplies water to the main areas of the city, are very low. Water availability in the city is being threatened by increasing population, this situation many times leads to an uncontrolled building of wells to extract water which adds an immeasurable pressure to the system since it is not visible it is difficult to calculate its extent.

Table 3. Elements introduced in the matrix of the FCM model that have positive and negative impacts in the component *pressure on water system*.

| Element | Positive Variable and Impact | Negative Variable and Impact |
|---|---|---|
| Population density | Pressure on water system (0.75), Land degradation (as decrease in vegetation cover) (0.25), Number of private wells (0.75) | N/A |
| Population growth rate | Amount of WW discharged (0.75), Extent of distribution of piped water system (0.50), **Pressure on water system (0.75)**, Population density (0.75), New infrastructure development (0.75), Economically active population (0.50) | N/A |
| Number of tourists | Amount of WW discharged (0.50), Water consumption per capita (0.50), Pressure on water system (0.75), New infrastructure development (0.75), GDP per capita (0.50) | N/A |
| Industrial environmental compliance | Wastewater recycling rate (0.75), Level of private sector participation (0.75) | Amount of WW discharged (-0.50), Water exploitation index (-0.50), Land degradation (as decrease in vegetation coverage) (-0.50), Public perception of value of water management (-0.25) |
| Irrigation water use efficiency | N/A | Irrigation intensity (-0.75) |
| Irrigation intensity | Pressure on water system (0.75), Cultivated area dependant on irrigation (0.50) | Water availability per capita (-0.75) |
| Land degradation (as decrease in vegetation coverage) | Pressure on water system (0.75), Cultivated area dependant on irrigation (0.50) | N/A |
| Cultivated area dependent on irrigation | Water exploitation index (0.75), Pressure on water system (0.75), Irrigation intensity (0.75), Land degradation (as decrease in vegetation cover) (0.50), Agri-industry employment (0.50), Public perception of value of water management (0.50) | N/A |

| | | |
|---|---|---|
| Severity of migration and refugee crisis | Pressure on water system (0.50), Population growth rate (0.25), Political will (0.50), Level of NGO participation and influence (0.50) | N/A |
| Number of private wells | Water exploitation index (0.75), Water consumption per capita (0.50), Pressure on water system (0.75), | Water availability per capita (-0.50), Level of local / community level stakeholder participation and influence (-0.50), Public compliance with water management principles (-0.50) |

In addition, subjects like migration which is in high trend in Latin America because of the political crisis in Venezuela and Nicaragua, are also affecting Panama although at the moment this does not represent greater impact. However, for people seeking refuge, Panama is still seen as a country for transit since most of the migrants that come from South America aim to get into the United States. Another important flux of migrants in Panama comes from tourism which at the same time, although temporary, represents a high pressure. In the city of Panama and coastal areas where hostels and hotels concentrate it is necessary large amounts of water to satisfy all the needs of tourists such as drinking, swimming pools, washing, water sports and other recreational activities (Klytchnikova & Dorosh, 2012). This kind of activities are more difficult to accomplish especially in dry season when water availability is not constant.

Another important element in this component is the perception of the public about the value of water resources through the increase of cultivated area dependent on irrigation, because of the linkage of this with the increase in employment in the agri-industry sector, the more the agri-industry increases the more the positive public perception increases as well, particularly in the areas where agriculture generates the main income.


Figure 12. Conceptual map displaying the FCM results of the positive and negative linkages in the baseline of the component *pressure on water system*. Negative impacts are shown with a straight line and negative impacts are shown with a disruption.



### *5.2.3 Resilience of the economy*

In order to create a resilient economy, it is necessary that Panama has a comprehensive vision of all the components and actors that make up the economy of the country and of which it is necessary to maintain assets, and productive in order to keep growing. It is from this knowledge that the country takes its foundations for the *Strategic Plan of the Government 2015-2019*. This whole plan is based on the resilience of the economy and which includes components of diversification in the economy, increase in the index of human development, increase of the GDP and improvements and development in infrastructure and water infrastructure. As the results from the FCM baseline displays (Table 4), the Panamanian government in its current development pathways has developed several infrastructures works and as mentioned in the *Strategic Government Plan*, in terms of infrastructure and construction, the country is among the best of the world. With this information, the baseline results have several positive impacts of high strength in the element new infrastructure development and GDP per capita.

Table 4. Elements introduced in the matrix of the FCM model that have positive and negative impacts in the component *resilience of the economy*.

| Element | Positive | Negative |
|---|---|---|
| Resilience of the economy | State of water resources and water system (0.25) | Climate variations & climate change (-0.25) |
| New infrastructure development | Water consumption per capita (0.50), Extent of distribution of piped water system (0.50), Resilience of the economy (0.75), Government expenditure as % GDP on water management (0.75), Information management and monitoring capacity (0.25), Technological capacity (0.25), Level of private sector participation and influence (0.75), Level of local / community level stakeholder participation and influence (0.50) | N/A |
| Agri-industry employment | Economically active population (0.75) | N/A |
| GDP per capita | HDI (0.75), Innovation (R&D expenditure on water management) (0.75), Government expenditure as % GDP on water management (0.75), Level of private sector participation and influence (0.50), Public compliance with water management principles (0.50) | N/A |
| HDI | Water consumption per capita (0.50), Number of tourists (0.50), **Resilience of the economy (0.50)** | N/A |

| | | |
|---|---|---|
| Diversity in local economy | **Resilience of the economy (0.75),** HDI (0.75)**,** Economically active population (0.75)**,** Depth and breadth of existing water legislations (0.50)**,** Quality of pricing policies (0.25) | N/A |
| Economically active population | **Resilience of the economy (0.75)**, GDP (0.75), HDI (0.75) | N/A |

To achieve a resilience in the system, there is a more inclined approach to the economic which in turn improves social capacities, although at the same time it increases the vulnerability of water resources and reflects poor water management.

The results presented by the FCM baseline demonstrate the importance of the infrastructure to reduce the vulnerability of water in both. The linkages of the new infrastructure element (roads, roads, warehouses) with other elements within the resilience component in the economy is very representative, although it is also of great importance for other elements.


Figure 13. Conceptual map displaying the FCM results of the positive and negative linkages in the baseline of the component *resilience of the economy*. Negative impacts are shown with a straight line and negative impacts are shown with a disruption.

### 5.2.4 Governance and water management capacity

It is in this component where most of the impacts and interactions influence all the components. It is also in this component where most of the efforts must be concentrated due to the relevance that it has in improving or, failing that, increasing the capacities within the water management system.

The most repeated element is the Governance & water management capacity which is affected in a positive way thanks to the already considered economic growth plans established by the Strategic Government Plan.

It is in this component that the responsibility in decision making for planning is concentrated to ensure the availability of quality water for each inhabitant of the population at the same time that policies are created to safeguard the integrity of resources.

Table 5. Elements introduced in the matrix of the FCM model that have positive and negative impacts in the component *Governance & water management capacity.*

| Element | Positive | Negative |
|---|---|---|
| Transparency and good governance principles | Industrial environmental compliance (0.50), Governance & water management capacity (0.75), Government expenditure as % GDP on water management (0.50), Depth and breadth of existing water legislations (0.75), Quality of pricing policies (0.75), Public perception of value of water management (0.75), Public compliance with water management principles (0.75) | N/A |
| Innovation (R&D expenditure on water management) | Sea water intrusion threat (0.25), Quality of water infrastructure (0.50), Wastewater recycling rate (0.75), **Governance & water management capacity (0.75)**, Information management and monitoring capacity (0.75), Technological capacity (0.75), Level of private sector participation and influence (0.75) | N/A |

| | | |
|---|---|---|
| Government expenditure as % GDP on water management | Quality of water infrastructure (0.75), **Governance & water management capacity (0.75)**, Depth and breadth of existing water legislations (0.50), Information management and monitoring capacity (0.75), Enforcement capacity (0.50), Technological capacity (0.75) | N/A |
| Depth and breadth of existing water legislations | Water quality index (0.50), Irrigation water use efficiency (0.75), Land degradation (as decrease in vegetation cover) (0.50), **Governance & water management capacity (1.00)**, Quality of pricing policies (0.50), Enforcement capacity (0.50), Level of private sector participation and influence (0.50), Level of local / community level stakeholder participation and influence (0.75) | Amount of WW discharged (-0.75), Water exploitation index (-0.50) |
| Quality of pricing policies | Industrial environmental compliance (0.50), **Governance & water management capacity (0.50)**, Enforcement capacity (0.50), Public perception of value of water management (0.50) | Water consumption per capita (-0.50), Number of private wells (-0.25) |
| Information management and monitoring capacity | Transparency and good governance principles (0.75), Depth and breadth of existing water legislations (1.00), Quality of pricing policies (0.50), Political will (0.75), Level of private sector participation and influence (0.50), Public perception of high water availability and quality (0.25), Public perception of value of water management (0.75), Public compliance with water management principles (0.75) | N/A |
| Enforcement capacity | Wastewater recycling rate (0.25), Industrial environmental compliance (0.75), Irrigation water use efficiency (0.50), Transparency and good governance principles (0.75), Public compliance with water management principles (0.75) | Amount of WW discharged (-0.50), Water exploitation index (-0.50) |
| Technological capacity | Quality of water infrastructure (0.75), Wastewater recycling rate (0.50), Irrigation water use efficiency (0.50), Transparency and good governance principles (0.50), Information management and monitoring capacity (0.75) | N/A |

| | | |
|---|---|---|
| Political will | Industrial environmental compliance (0.50), New infrastructure development (0.50), Diversity in local economy (0.75), Governance & water management capacity (1.00), Transparency and good governance principles (1.00), Innovation (R&D expenditure on water management) (0.75), Government expenditure as % GDP on water management (0.75), Depth and breadth of existing water legislations (1.00), Quality of pricing policies (0.50), Enforcement capacity (0.75), Public perception of value of water management (0.75), Public compliance with water management principles (0.75) | N/A |

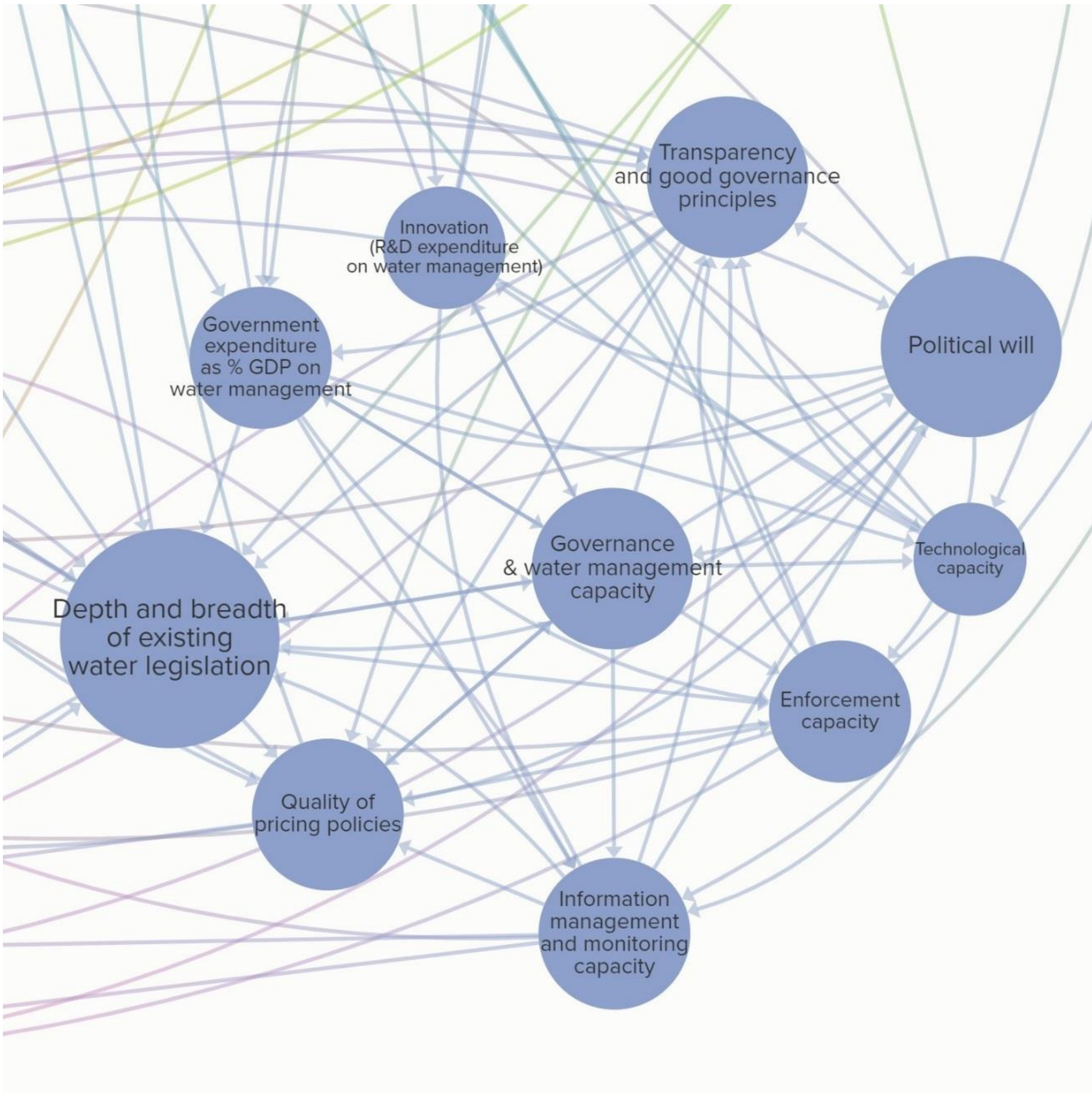


Figure 14. Conceptual map displaying the FCM results of the positive and negative linkages in the baseline of the component *governance & water management capacity*. Negative impacts are shown with a straight line and negative impacts are shown with a disruption.

### 5.2.5 Stakeholder influence on water management capacity

This component considers all the actors involved within the system, as well as their level of participation, and is already active (participation of the private sector in the strengthening of capacities in water management) Level of local / community level stakeholder participation and influence and Public compliance with water management principles. Elements that include the interaction of other elements of the system with a very high impact, since these are the elements that receive the greatest impact due to poor or poor management of the system.

This component also includes the population in vulnerable areas, the population in urban areas, governments, companies and organizations and institutions.

Table 6. Elements introduced in the matrix of the FCM model that have positive and negative impacts in the component resilience of the economy.

| Element | Positive | Negative |
|---|---|---|
| Level of NGO participation and influence | Economically active population (0.50), Transparency and good governance principles (0.75), Depth and breadth of existing water legislations (0.50), **Stakeholder influence of water management (0.75)** | N/A |
| Level of private sector participation and influence | Industrial environmental compliance (0.50), Transparency and good governance principles (0.50), Depth and breadth of existing water legislations (0.25), **Stakeholder influence of water management (0.50)** | N/A |
| Level of local / community level stakeholder participation and influence | Transparency and good governance principles (0.75), Depth and breadth of existing water legislations (1.00), Political will (0.75), **Stakeholder influence of water management (1.00)**, Public compliance with water management principles (0.50) | N/A |

| | | |
|---|---|---|
| Public perception of water availability / scarcity | Amount of WW discharged (0.50), Water consumption per capita (0.50), Level of local / community level stakeholder participation and influence (0.75), Public compliance with water management principles (0.75) | N/A |
| Public perception of value of water management | Level of local / community level stakeholder participation and influence (0.75) | N/A |
| Public compliance with water management principles | Water consumption per capita (0.50), **Stakeholder influence of water management (1.00)** | N/A |


Figure 15. Conceptual map displaying the FCM results of the positive and negative linkages in the baseline of the component *stakeholder influence of water management*. Negative impacts are shown with a straight line and negative impacts are shown with a disruption.

### 5.3 Socioeconomic scenarios for the country

In order to grow the country's economy, Panama has developed a strategic plan that focuses on four sectors that are expected to continue strengthening in the future. the government of Panama hopes that the growth of these sectors will improve the current social conditions of the Panamanian people. These four sectors were identified thanks to studies and censuses made to the population and are included in the Strategic Plan for the Government of the period 2015-2019, mentioned above. For the optimal development of each scenario, a series of actions would have to be carried out that would have direct and indirect impacts on the country's water system under each of the pillars identified as priorities for the economic and social development of Panama. The scenario that was constructed using the Logical Framework Analysis was defined for each sector in order to identify the variables collected from the FCM model.

As a result, the following scenarios were left:

- **Scenario 1**: Enhancing logistics and transportation capacity and services
- **Scenario 2**: Promoting agriculture (agriculture, fishery and forestry) and rural development
- **Scenario 3**: Improvement of the services in the tourism sector
- **Scenario 4**: Promotion of the mining sector



#### *5.3.1 Logistics and Transportation*

The logistic and transportation sector in panama is one of the strongest in the country and in Latin America mostly because of the Panama. In this sector, it is obviously considered the Panama Canal that, since its construction and start-up, has been the country's largest economic contributor. For this reason, the government plans to give it more scope and expand the potential operating capacity that the channel can provide, in order to project the country as the leader in logistics services. To carry out this expansion, the government knows that it is necessary to improve the infrastructure within the whole country and the infrastructure already existing in its ports of greatest affluence.

The development of this sector in its maximum potential, would enable other important areas for social and economic growth, while reinforcing other very significant. Among the variables within the water management system that would have an important positive impact thanks to the development of this sector are the growth of the economically active population, that the impulse of an economic activity of such magnitude and, particularly for Panama, of so much socio-economic importance will require human efforts for a greater start-up. As an example of this, since the start of the Panama Canal expansion project in 2007, it generated more than 40 thousand direct jobs (Panama Canal Authority, 2016).

Another benefit that driving this type of services brings is compliance with environmental regulations to provide the security to prolong the activities carried out through the channel for many more years.

Table 7. Proposed scenario for enhancing logistics and transportation capacity services in Panama.

| **Proposed Scenario** | **Assumptions** | **implications on the FCM variables** | |
|---|---|---|---|
| Scenario 1:<br>Enhancing logistics and transportation capacity and services:<br>Improving and extending the connectivity and infrastructure to improve transportation and communication for local and international services | Promote and increase competitiveness in logistics and transportation sector at international level.<br>Expansion of the current capacity in ports and customs to increase the number of ships received and reduce time in custom process<br>Building and re-building highways to connect different remote areas of the country. | Operation of ports at a bigger capacity will require human efforts.<br>Reforms in the highways and railway infrastructure of the current transportation system.<br>Expansion of infrastructure will require reorganization in urban planning for a proper development and improving of the current networks. | V1: Increase in overall population that is economically active.<br>V2: increase in new infrastructure.<br>V3: Increase industrial environmental compliance |

### *5.3.2 Agriculture*

Agricultural activities and, in general, activities of the primary production are decreasing its percentage of contribution to the GDP. In the seventies it used to contribute with and approximate of 25%, by the end of the nineties this percentage dropped to 7% and in recent years it only represents around 3% of the country's GDP (Observatorio Regional de Planificación para el Desarrollo, 2014). It is evident that agricultural activities in Panama are dropping, consequently and as part of the strategic government plan 2015-2019 to increase impulse and promote diversification of the economy, the government will re-struct the current economic model and prioritize areas that were left behind for decades. In this plan the government has already identified key issues that have been causing the decline of this sector, the lack of access to technology as well as the lack of funding.

25% of the country's soils have natural aptitude for agricultural use; however, national statistics reflect that current use does not necessarily coincide with this potential use. In 2000, the area on which agricultural production and subsistence agriculture production is based to 36.6% of the national territory (ANAM, 2004; ANAM, 2011).

According to the ***Strategic Government Plan 2015 – 2019***, in Panama, agricultural activities such as the harvest of rice, beans, yucca and corn are already carried out in marginalized areas, this kind of agriculture is mainly for subsistence of vulnerable population and it is developed under low quality conditions in soils with low productivity and inappropriate irrigation. Access to proper technology and resources will significantly improve the execution of these activities in these areas. Another important factor that represents an obstacle for this sector is the lack of infrastructure in rural areas, this is a consequence of the lack of infrastructure in the internal connectivity of the country. Since it is difficult to have access to rural areas, it is also difficult to provide adequate conditions for this specific sector of the population.

In the country, the current conditions are not even sufficient to satisfy its own population. Almost a 20% of the products of basic consumption are imported and the cost of these is increasing year by year, reaching a 7% annually. According to the strategic plan of the government, the demand of those basic products can be satisfying by producing them in the same country, enabling with this, food security in the country. In order to make agriculture an important economic sector, it is also important to improve connectivity in the country, this is a constant issue in most of the development plans since without connectivity, farmers cannot have access to bigger important markets in the city.

In any case, the development of the agricultural sector in optimal conditions and on a larger scale, would require the use of irrigation systems that supply all the areas where this type of activity is carried out. Commonly, agricultural activities are highly demanding in water resources that, in themselves, tend to be scarce in areas such as Dry Arc, which would require a better technological capacity able to provide water to these areas efficiently and sustainably and of the improvements in the infrastructure for water supply in this type of problem areas but with high agricultural potential.

Table 8. Proposed scenario for promoting agriculture and rural development in Panama.

| **Proposed Scenario** | **Assumptions** | **implications on the FCM variables** | |
|---|---|---|---|
| Scenario 2:<br>Promoting agriculture (agriculture, fishery and forestry) and rural development:<br>diversify the economy, achieve food security and impulse development in rural areas through agricultural activities. | Impulse the economy through primary sector in rural areas.<br>promotion of sustainable practices in agricultural activities. | diversification of the economy and increase in production of the primary sector will allow to enable food security. Enhancing agriculture with target in vulnerable people. Promotion of sustainable practices in agricultural activities enabling technology access and financing. improving infrastructure for connectivity of farmers and markets, as well as improvement in quality of water infrastructure. | V1: Increase in technological capacity.<br>V2: Increase industrial environmental compliance<br>V3: Increase irrigation intensity.<br>V4: increase quality of water infrastructure. |



### 5.3.3 *Tourism*

Tourism in Panama is an already consolidated sector, in the period of 2008 to 2014 the tourism reached a 43% in the growth of the room offer, which it is significantly high if it is compared with the last period from 2004 to 2008 with a 13%. Almost 64% of the infrastructure for tourism in Panama is concentrated in Panama City, which centralizes the demand of resources, business and employment by far in this area, while in second position is Cocle with only a 12% and Chiriqui and Bocas del Toro together only make a 16%. Among the plans of the government to improve the tourism sector, it is expected to diversify the kind of services provided to tourists. In Panama, 54% of visitors arrive with leisure purposes which in comparison to its neighbor, Costa Rica, is very low. However, visitors arriving with to the country for attending congresses and business affairs represents a 38% of the demand which is a percentage that is increasing quickly in recent years (Observatorio Regional de Planificación para el Desarrollo, 2014).

The lack of offer in touristic services greatly affects the promotion of Panama as a country for leisure compared to its neighboring countries and it is more seen as a country to do business and transit. Even when it is intended to promote other areas of the country for leisure, adventure and cultural tourism in Panama, the difficult access to the interior of the country would need to be improved in order to make it feasible to move from one area to another. along with this it would be necessary to train the population regarding the offer of tourist services and install adequate infrastructure to sustain a high capacity of visitors. This would have a very great impact on the water resources of the country, even before being able to receive visitors since works of such magnitude require a lot of energy and water from its development to its completion.

The decentralization of tourism services, which is mostly concentrated in the city of Panama, will require the expansion of tourism to other remote and difficult areas of the country. This would imply the construction of roads and bridges that connect these areas with the city, as well as infrastructure expansion works. The consequences of this would be reflected in an increase in water consumption, as well as a decrease in the quality of water available due to high consumption, but also because of the increase in wastewater discharges produced caused in turn by the high-water consumption.

Table 9. Proposed scenario for improvement of the services in the tourism sector in Panama.

| **Proposed Scenario** | **Assumptions** | **implications on the FCM variables** | |
|---|---|---|---|
| Scenario 3:<br>Improvement of the services in the tourism sector:<br>Expansion of touristic activities to the interior of the country and diversify the demand of services along with new opportunities in recreational activities (eco-tourism and cultural tourism). | Enhance other kinds of tourism services (recreational, adventure, cultural, nature) in the country and decentralize it to promote other areas of the country.<br>Improve infrastructure to make accessible remote areas of the country. | Panama wants to exploit every single area of the country to promote tourism and increase the demand as well as increase the period of time of visitors inside the country. Promoting other kinds of tourism in other areas of the country that are not adequate to receive tourists will require new infrastructure and will decrease water availability and as a consequence will increase wastewater discharge.<br>Decentralization of the tourism and extension of the visitors' number of days will add extra pressure on the water system. | V1: Increase water consumption per capita.<br>V2: Decrease water availability per capita.<br>V3: Increase new infrastructure development.<br>V4: Increase amount of wastewater discharge. |

### 5.3.4 *Mining*

Mining is a relatively new industry in the country, although it is already being carried out, its potential has not been fully exploited. This activity leads to various environmental risks with social implications, thus hindering the full implementation of these.

This industry has had an important growth annually, registering a percentage of 18%. This growth does not reflect the same success when compared with its contribution to GDP, which is less than 2% per year. The economic activity related to this sector has multiplied since the second half of the 90s, particularly in the extraction of gold and non-metallic minerals, from 0.3% to 1.8% (US $ 459.7 million in 2012) (Observatorio Regional de Planificación para el Desarrollo, 2014).

In this scenario, the government plans to strengthen mining activities in areas such as Colon, where roads and related infrastructure would be built. With the aim of integrating a greater part of the population into the productivity of the country, mining would offer a very important source of employment in rural sectors where employment sources are scarce. With such development, the government intends to give a boost to environmental conservation so that as part of the planning in the execution of these activities would strengthen compliance with environmental regulations in order to safeguard the natural resources of the area. In any case, although this is taken literally, it is inevitable to consider the pressure that mining activities exert on water resources, especially due to the use of chemicals and the massive quantities needed for the extraction of minerals. This would negatively impact the quality of the water, as well as the availability of the resource for human consumption. In the possible scenario where mining is developed in a productive way in Colon, the availability and quality of water in this area would be very impacted and seriously compromised for the population of Colon.

Table 10. Proposed scenario for promotion the mining sector in Panama.

| Proposed Scenario | Assumptions | implications on the FCM variables | |
|---|---|---|---|
| Scenario 4:<br>Promotion of the mining sector:<br>Enforcement and promotion of the mining sector to attract foreign investment and increase export of minerals (gold, copper and non-metallic minerals). | The Panamanian government will promote sustainable mining activities and increase exports of minerals mainly gold and copper, as well as non-mineral exports with foreign capital investment. | The economic boost that would be given to mining would impact the quality of the country's water in areas such as Colon, where a mining area would be built, where port and highway infrastructure projects would be developed. Mining projects would strengthen compliance with environmental regulations. The growth of this sector would favor the creation of jobs in vulnerable areas. | V1: decrease in water quality per capita.<br>V2: increase industrial environmental compliance.<br>V3: increase new infrastructure development.<br>V4: increase in economically active population. |

### 5.4 Results of the FCM model in the scenarios

Once the "vulnerable points" were identified in terms of water management in each scenario individually and they were selected to be run in the FCM model, when our "base scenario" was compared with what was obtained for each sector, they were achieved the elements within the 5 categories within the water management system that by order of impact, whether positive or negative, and within that if by means of a numerical scale of 4 to 1 from very weak to strong, where 4 = very weak, 3 = weak, 2 = medium, 1 = strong.

For this particular case we consider only the scale of the medium and strong for the elements within the system with positive and negative impacts, which, as indicated, are those that have a greater impact on the dynamics of the scenario (Figure 15, 16, 17 and 18).

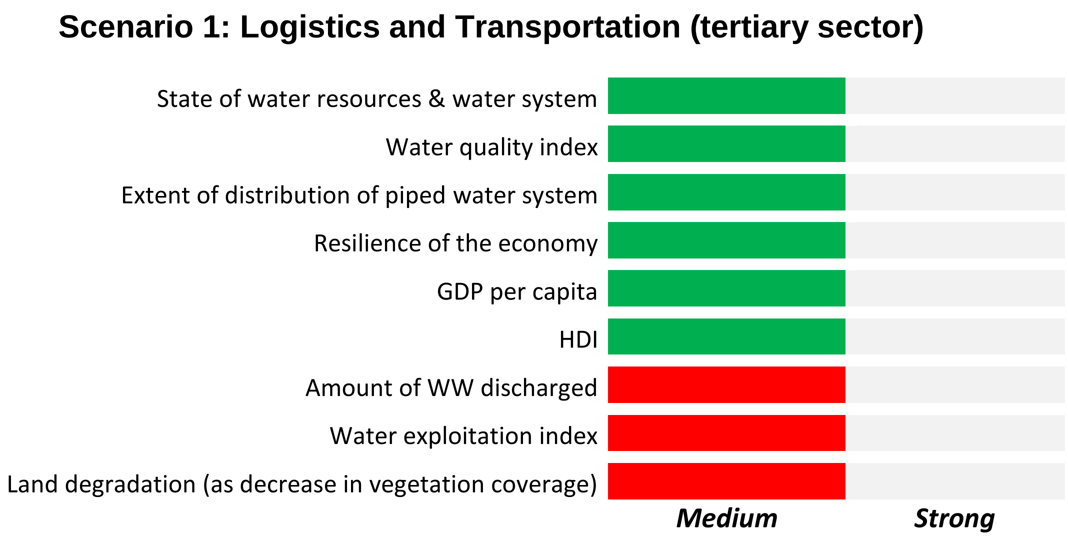


Figure 16. FCM model results of the most impacted elements under the logistics and transportation scenario (green= positive, red= negative).

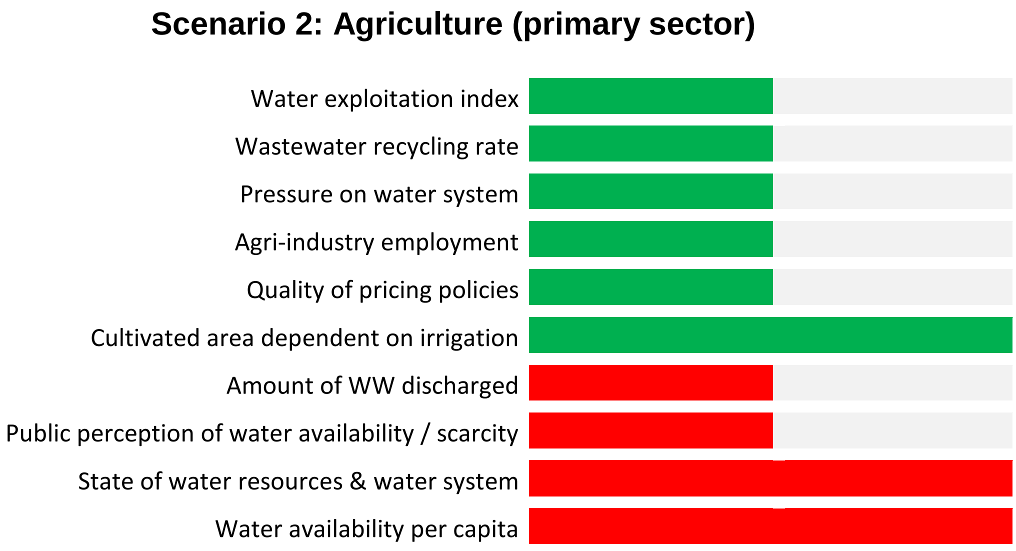

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Figure 17. FCM model results of the most significant elements impacted under the agriculture scenario (green= positive, red= negative).

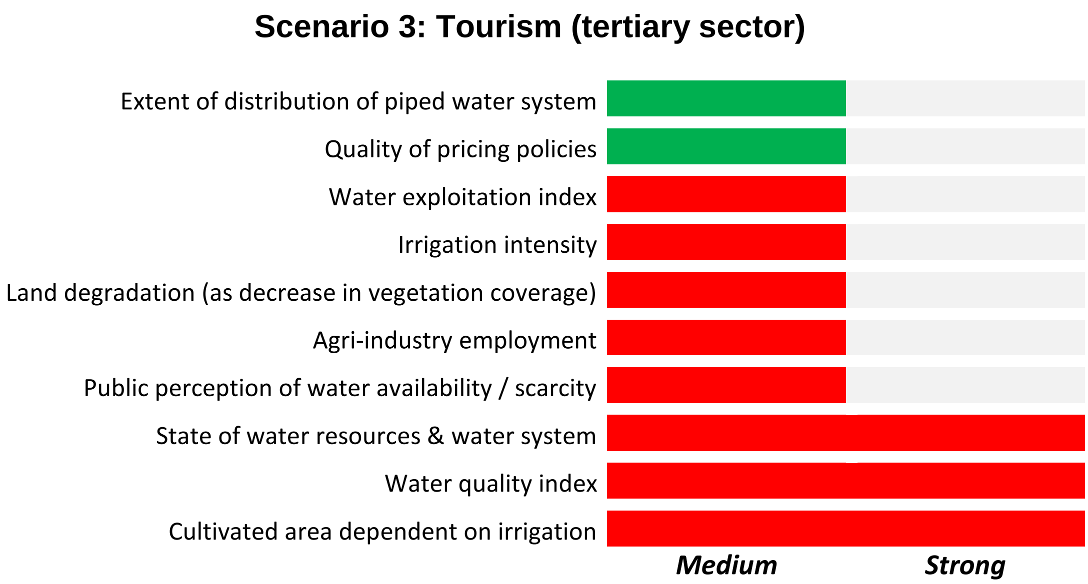


Figure 18. FCM model results of the most significant changes of elements in the tourism scenario (green= positive, red= negative).

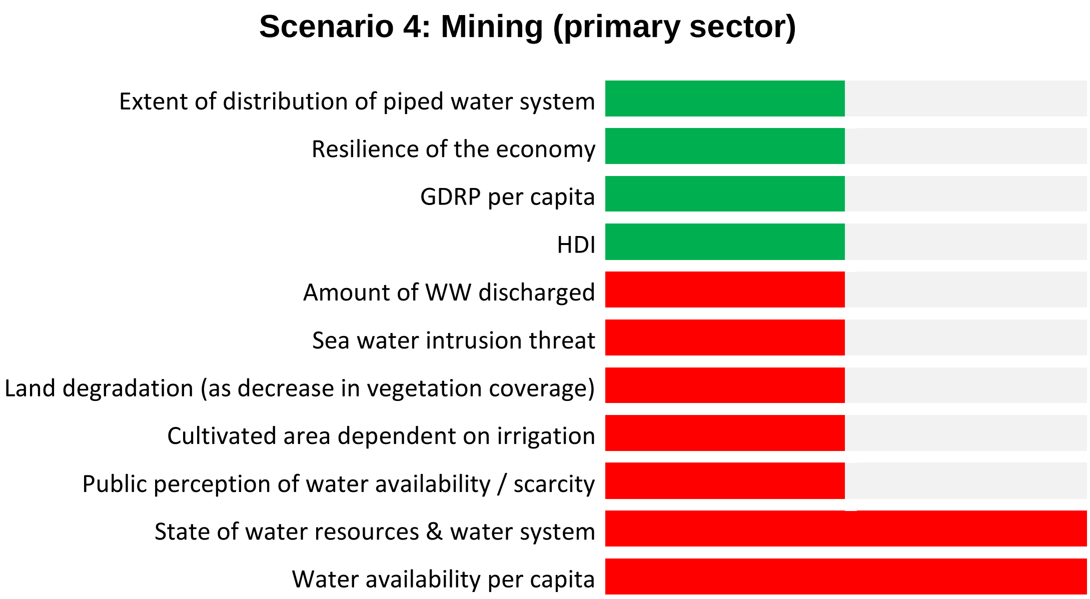


Figure 19. FCM model results of the most significant changes of elements in the mining scenario (green= positive, red= negative).

When visualizing the results obtained by the FCM model in each scenario, it can be noted that the scenarios with the greatest impact and the greatest number of elements involved are tourism and mining, both of which present some elements that coincide like water exploitation index, cultivated area dependent on irrigation, public perception of water availability / scarcity, land degradation and state of water resources, which have a negative impact on the system. It is also in these two scenarios where the negative impacts on the elements within the system are significantly greater than the positive ones.

Elements within the logistics and transportation sector are those that show average impacts to the water management system in Panama and most of them are positive. The agricultural sector also presents, in its majority, positive impacts to the system although the few negatives impact in a strong level the state of water resources & water system and water availability per capita.

### 5.4 Localized indicators for water management from SDG6

With the analysis obtained by the FCM model, it was possible to allocate SDG 6 indicators that would need more attention in order to face the challenges presented by the development of these four economic activities that would jeopardize the country's water security.

The integration of SDG 6 into the scenarios obtained from the FCM model was carried out in support of the online tool created by the UN University SDG 6 - Policy Support System, which aims to facilitate the adoption of the SDG in the political agenda at the National and international. This tool takes shape through six basic components to assist policymakers in making decisions in order to make the adoption of SDG 6 more effective. These components are the following:

- Capacity assessment
- Finance assessment
- Policy and institutional assessment
- Gender mainstreaming
- Disaster Risk Reduction (DRR)/Resilience Mainstreaming
- Integrity

After introducing the necessary information in the indicator identification tool, those that could quantify the elements of higher impact (medium and strong) previously selected in each of the scenarios for the development of Panama were selected. The designation of indicators is organized by positive changes and negative changes regardless of whether the same indicator applies to both types of changes. At the same time, an indicator can serve to provide information on more than one element impacting the scenarios. This is the case of indicator 6.6.1: percentage change in the extent of water-related ecosystems coverage and sub-indicators that are recurrent in all scenarios. Following this, indicator 6.1.1: percentage of population and industries using safely managed water services, is the second most recurrent indicator.

Other indicators that have a great relevance within the scenarios are the D1: Number of Financial Plan or Budget within the institutions that clearly assess the available sources of finance and strategies for financing future water needs and indicator D.2: Percentage of national and municipal government budget specific to water which are required for positive changes within the system in the logistics and transportation and mining scenario. both activities where intensive use of water resources is required.

Table 11. List of proposed indicators to measure the elements of greatest impact within the water management system in Panama under the scenario of strengthening the logistics and transportation sector.

| Scenario | Indicators for Positive Changes | Indicators for Negative Changes |
|---|---|---|
| Scenario 1:<br>Enhancing logistics and transportation capacity and services: Improving and extending the connectivity and infrastructure to improve transportation and communication for local and international services | 6.4.1 Percentage change in water use efficiency over time | 6.6.1.6 Percentage change in depth (volume) of major water bodies and discharge |
| | 6.3.2 Percentage of water bodies with good ambient water quality | 6.6.1.4 Percentage change in area of surface water (lakes, rivers and dams) |
| | 6.1.1 Percentage of population and industries using safely managed water services | 6.6.1.7 Percentage of change in the extent of water related ecosystems |
| | D.1 Number of Financial Plan or Budget within the Panama Canal Authority that clearly assess the available sources of finance and strategies for financing future water needs | |
| | D.2 Percentage of national and municipal government budget specific to water | |



Table 12. List of proposed indicators to measure the elements of greatest impact within the water management system in Panama under the scenario of promoting agriculture (agriculture, fishery and forestry) and rural development.

| Scenario | Indicators for Positive Changes | Indicators for Negative Changes |
|---|---|---|

| | | |
|---|---|---|
| Scenario 2:<br>Promoting agriculture (agriculture, fishery and forestry) and rural development:<br>diversify the economy, achieve food security and impulse development in rural areas through agricultural activities. | 6.4.1 .1 Percentage change in water use efficiency over time | 6.3.1.1 Improvement in percentage of wastewater from hazardous industries that is safely treated (from food processing plants including oils, fats, fruits and vegetable). |
| | 6.6.1 Percentage change in the extent of water-related ecosystems coverage | 3.d Number of male/female perceptions of/knowledge of current total household use of water by category of use and primary user. |
| | 6.4.2 Percentage of total available water resources used taking environmental water into account (level of water stress) | 6.4.1.2 Percentage change in water use efficiency of irrigated agriculture land |
| | 1. Number of pricing policies that enable effective implementation of the pricing policies in each sector promoting transparency, efficiency, equality and sound market. | 6.3.2 Proportion of bodies of water with good ambient water quality |
| | 6.4.1.2 Percentage change in water use efficiency of irrigated agriculture land | 6.6.1 Percentage change in the extent of water-related ecosystems over time (land use change). |

Table 13. List of proposed indicators to measure the elements of greatest impact within the water management system in Panama under the scenario of expanding and diversifying touristic activities.

| Scenario | Indicators for Positive Changes | Indicators for Negative Changes |
|---|---|---|
| Scenario 3:<br>Improvement of the services in the tourism sector:<br>Expansion of touristic activities to the interior of the country and diversify the demand of services along with new opportunities in recreational activities (eco-tourism and cultural tourism). | 6.1.1 Percentage of population and industries using safely managed water services | 6.6.1.6 Percentage change in depth (volume) of major water bodies and discharge |
| | 1. Number of pricing policies that enable effective implementation of the pricing policies in each sector promoting transparency, efficiency, equality and sound market. | 6.6.1.4 Percentage change in area of surface water (lakes, rivers and dams) |
| | | 6.6.1.8 Percentage change in surface water quality over time |

| | | |
|---|---|---|
| | | 3.d Number of male/female perceptions of/knowledge of current total household use of water by category of use and primary user. |
| | | 6.6.1 Percentage change in the extent of water-related ecosystems coverage |

Table 14. List of proposed indicators to measure the elements of greatest impact within the water management system in Panama under the scenario of promoting mining activities.

| **Scenario** | **Indicators for Positive Changes** | **Indicators for Negative Changes** |
|---|---|---|
| Scenario 4:<br>Promotion of mining sector: Enforcement and promotion of the mining sector to attract foreign investment and increase export of minerals (gold, copper and non-metallic minerals). | 6.1.1 Percentage of population and industries using safely managed water services | 6.3.1.1 Improvement in percentage of wastewater from hazardous industries that is safely treated (heavy metals, acid water) |
| | D.1 Number of Financial Plan or Budget within the Panama Canal Authority that clearly assess the available sources of finance and strategies for financing future water needs | 6.6.1 Percentage change in the extent of water-related ecosystems coverage |
| | D.2 Percentage of national and municipal government budget specific to water | 6.3.2 Percentage of water bodies with good ambient water quality |
| | | 6.4.1 Percentage change in water use efficiency over time |
| | | 6.4.2.1 Reduction in percentage of freshwater withdrawal to available freshwater resources |
| | | 6.1.1 Percentage of population and industries using safely managed water services |

# 6. Discussion

The objective of this study is to analyze the possible gaps in the management of water resources with the help of the Fuzzy Cognitive Map in Panama to facilitate the adoption of SDG 6 indicators: clean water and sanitation under four pillars for socioeconomic development from the country. Through four defined objectives XXXXXXXXXx. To meet the objectives, we consulted literature about the current situation or the most recent possible, as well as the consultation of information in mass media about social, economic, environmental and political issues related to the management of the country's water resources to analyze the baseline with which you would work.

Very relevant information was obtained about the importance that water resources have in a country like Panama, which is practically maintained thanks to it. Many of the socio-economic development plans of the country consider the need to use water resources, unfortunately, and although there are institutional bodies such as CONAGUA that brings together all ministries and institutions for integrated water management, no specific laws or regulations have been deepened. for an adequate management of the resource. This unfortunately facilitates the exploitation of the resource in an inadequate and inordinate manner, especially in remote areas where, in addition to this, they do not have the adequate infrastructure to satisfy basic needs, supplies and sanitation.

In the FCM model such of linkages were considered, displaying results in which, for instance, there is vicious cycle between climate change and agriculture which is very difficult to break when the conditions to develop agriculture in the country are not sustainable and, on top of that, the water infrastructure for carrying out these activities is not adequate and outdated. These issues enable the intense exploitation of the aquifers due to the low levels of annual precipitation, which constrain the availability of surface water bodies to meet the needs of the population.

There is a very interesting contrast in terms of the water management of the country and the importance that this resource has. Panama is a country that, thanks to its Canal, has achieved a rapid economic growth from its creation to today. In any case, there is still no responsible culture in the management of the resource in other sectors by the responsible authorities, which affects the view that the population has about the availability of water. In 2015, after one of the worst droughts experienced in the country, associated with the effects of the ENSO phenomenon (Carse, 2017) and with the government's concern that it could not supply water to the population due to the low levels of the bodies of water that provide water to major areas of the city, the government developed a campaign to promote savings in water consumption "drop by drop water runs out". However, it is difficult to quantify the true impact or effectiveness of this campaign, since in Panama, there is a perception that water is a resource that is not at risk.

The problem in poor water management, mainly in rural areas of the country, also comes from the lack of economic resources aimed at improving service to all regions of the country. Much of what was obtained from the collection for sewerage services of IDAAN is used to repair pipes for the provision of water in urban areas (Vega-Cervera, 2012), that is, what was collected by IDAAN is still concentrated in the provision of water in Panama City. Because sewerage and pipeline services are very poor and wastewater treatment plants do not have sufficient capacity, much of the contamination of water bodies near populated areas is caused by the discharge of sewage (Quiroz). Tejeira, 2017).

Although in general terms, Panama's infrastructure is projected to the world as of good quality, the infrastructure in its water system does not have the same scope. Among the findings got from the FCM results that represent a risk, is the lack of proper infrastructure and access to it, usually represent most of the water problems related to agricultural activities, logistics and transportation, tourism (because of the lack of proper wastewater treatment) and mining (because of the lack of hazardous wastewater from industry). To tackle this issue the SDG6 indictor of improvement in percentage of wastewater from hazardous industries that is safely treated (heavy metals, acid water) is one of the important one even though this one is only mentioned in two scenarios (mining and tourism).

In addition to this, in the modeling with the FCM tool, it was considered that the pressure of water resources in Panama is worsened due to the global climatic problem. In conjunction with poor sewage infrastructure, the prolongation of the drought season and the increasing intensity of rainfall. Panama experiences many difficulties in the management and supply of water while the quality and quantity of water are threatened and the best that can be done now is to prevent the population from the days in which the service will be suspended due to the inclement weather.

The hydrometeorological department of ETESA reported, at the end of November 2018, an 80% probability that the ENSO phenomenon would occur next year, causing intense and prolonged droughts. According to reports, this extension in the dry season already has its impacts on the usual functions of the Canal, which has minimized water consumption for operational functions such as electrical generation at the Gatún hydroelectric plant, the elimination of hydraulic assistance in the operation of the locks, filled in cross chambers and joint lockage that include the transit of more than one ship through the Panamax locks[2]. Although the authorities reported that these droughts would not affect human consumption, by the end of April 2019 the effects of this could be seen in Panama City where IDAAN had to cut off the water supply due to low levels in the water reserves of Lake Alajuela which supplies water to Panama City (see appendices, figure xx).

With the integration of indicators such as 6.6.1.6 Percentage change in depth (volume) of major water bodies and discharge and 6.6.1.4 Percentage change in area of water surface (lakes, rivers and dams). Enabling a constant monitoring and recording of the state of the bodies of water that supply water to the population would help strengthen the system's resilience capabilities.

In the case of the logistics and transportation scenario, the government seems to be well prepared. The key indicators for measuring positive and negative changes in the variables obtained by the FCM and that are properly integrated are D.1 Number of Financial Plan or Budget within the Panama Canal Authority that clearly assess the available sources of finance and strategies for financing future water needs, and D.2 Percentage of national and municipal government budget specific to water, on investment for assessment the available sources of finance and strategies for financing future water needs. This would facilitate the improvement and execution of programs that promote conservation, which in turn improve other variables within this scenario that also fall within the sub indicators within indicator 6.6.1 regarding the change in extent of water related ecosystems.

The complexity of this system makes efficient management of water resources difficult. The estimation of future vulnerability when the current gaps in the system are known,

[2] https://elcapitalfinanciero.com/extension-de-la-temporada-seca-podria-afectar-la-operacion-del-canal/

provide a different and very useful approach, from a perspective in which any type of tools that facilitate the integration of components with complex elements in the management of a system that involves several stakeholders, while considering constant changes in the interaction of the elements that make up the system, offer an opportunity to scope possible pathways in the development of the country. Once these gaps are known, it is a bit simpler to identify SDG 6 indicators that enable the conditions for sustainable and integrated management.

# 7. Conclusion and recommendations

Panama is a country highly dependent on water resources and the management that is given to them. A high percentage of GDP depends on the availability of water. In the country, there are no constant monitoring programs of any kind, which allow to know the efforts in conservation, investment, development, policies and integration of water management. It is often difficult to achieve this integration, mainly in a system in which different components are related. The use of innovative tools such as the FCM help to know the status quo of the management of water resources in the country.

With the modeling of a future where socio-economic scenarios of logistics and transportation, agriculture, tourism and mining are developed; Panama would generate an economic boost, which in turn would benefit the population's quality of life, but under a high degree of vulnerability in water resources due to the high risks in which water security is compromised, mainly due to climatic variability, lack of policies and infrastructure, the lack of awareness of the importance of water within the population, among others.

The reality to be faced by the government is the need to redouble efforts in terms of investment and integrated water resources management policies due to the importance of water resources in the country, provided that sustainability is integrated into the management of the water.

Many of the problems surrounding the supply and sanitation that Panama currently faces are already considerable and often difficult to manage. In a scenario where scenarios are developed in which the majority would have negative impacts on the quantity and quality of water bodies that provide water for human consumption and water for the restoration of ecosystem services; the improvement in wastewater treatment as well as the volume and quality monitoring of water bodies must be considered, which would allow a better management of the resource, as well as prevention and adequate intervention if an extreme weather event occurs that affects the water quality and availability parameters.

For a scenario of promotion of agricultural activities, with a sustainable approach that Panama would like to develop. The integration of the indicators proposed for the constant monitoring of the use of soil change and the percentage of efficient irrigation would help to know the gaps in the development of these activities and would allow to improve the way in which they are carried out, achieving a very sustainable beneficial for economic development in rural areas of the country.

In the case of the logistics and transportation scenario, the government seems to be well prepared, and even, a scenario in which the expansion of the capacity of the Canal and of the operations, would encourage the improvement of current environmental policies, as well as the training of specialized personnel, which will create jobs and port infrastructure.

Nevertheless, it is the government's responsibility to continue developing economic activities in the country without compromising water security along the way. It should be considered an integrated management in each of the socio-economic development plans that in turn integrate sustainability that tools such as the modeling of complex systems and SDGs offer, particularly for this case the SDG6 that through indicators, provide information beneficial about the state of the water system, mainly in a country where water management policies are still very weak and in which there is not enough information to know in a measurable way the true state of the resource, but they depend highly on the effectiveness of the same for an effective growth.

However, even if the use of these tools does not offer a solution or a definitive panorama, they are definitely very useful to establish a starting point in the generation of information, policies and methodologies in countries such as Panama, where they do not yet exist. a way to integrate complex components in an integrated management or that do not have enough information, that can provide an overview of vulnerability in the future that in turn does not consider water pressure in their economic development plans and the effects of these in society and the economy itself.

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## Appendix 1: Results of the FCM linkages analysis obtained by the online mapping tool Kumu.

| Label | Type | degree | betweenness | closeness | eigenvector | indegree | metrics::last | micmac exposure | micmac influence | outdegree | reach | reach-efficiency | size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water consumption per capita | State of water resources | 10 | 0.018634786952606102 | 0.35729166666666666673 | 0.028161652644279275 | 7 | 0.7846047595438465 | 0.7846047595438465 | 0 | 3 | 0.22448979591836735 | 0.02040816326530612 | 11 |
| Irrigation water use efficiency | Pressure on water system | 4 | 0.006637363818214882 | 0.3010416666666666667 | 0.013676125406305 94 | 3 | 0.4583847556832 83 | 0.4583847556832 83 | 0.336556358284815 67 | 1 | 0.102040816326530 61 | 0.020408163265306124 | 5 |
| Number of private wells | Pressure on water system | 10 | 0.041684431723770225 | 0.48263888888888889 | 0.016250863534856757 | 4 | 0 | 0 | 0.11726608889697 37 | 6 | 0.5510204081632653 | 0.0551020408163265 25 | 10 |
| Quality of pricing policies | Governance & water management capacity | 13 | 0.037229546704657 56 | 0.4618055555555555 | 0.033816911514056296 | 7 | 0.51289532609140 94 | 0.51289532609140 94 | 0.741644843855917 9 | 6 | 0.5102040816326531 | 0.039246467817896 39 | 13 |
| Enforcement capacity | Governance & water management capacity | 12 | 0.017193342013484 71 | 0.44201388888888889 3 | 0.028655607027307187 | 5 | 0.4920252670949586 | 0.4920252670949586 | 0.412236023491635 | 7 | 0.3877551020408163 | 0.029827315541601254 | 13 |
| Water quality index | State of water resources | 7 | 0.015561851145006064 | 0.353472222222222224 | 0.038002986792244176 | 5 | 0.6517868076026 87 | 0.6517868076026 87 | 0.4667501171614296 | 2 | 0.20408163265306123 | 0.02915451895043732 | 7 |
| Public perception of water availability / scarcity | Stakeholder support of water management | 6 | 0.012399147057161613 | 0.30902777777777778 | 0.017175168958123307 | 5 | 0.967368106243448 8 | 0.967368106243448 8 | 0.705133695687593 3 | 1 | 0.142857142857142 85 | 0.020408163265306 12 | 7 |
| Level of NGO participation and influence | Stakeholder support of water management | 6 | 0.018992738939547 45 | 0.4392361111111111 1 | 0.005625053158518772 | 2 | 0.434008441347973 | 0.434008441347973 | 0.508210504845749 9 | 4 | 0.4693877551020408 4 | 0.0782312925170068 | 6 |
| Human Development Index (HDI) | Resilience of the economy | 7 | 0.020112098303587664 | 0.4010416666666666 67 | 0.003502196107240 15 | 4 | 0.8599514488800316 | 0.8599514488800316 | 0.448628295534598 04 | 3 | 0.3061224489795918 4 | 0.043731778425655975 | 7 |
| Transparency and good governance principles | Governance & water management capacity | 14 | 0.022542883879320047 | 0.443055555555555554 | 0.033171043852465 76 | 8 | 0.5055381402054286 | 0.5055381402054286 | 0.259744361536930 15 | 6 | 0.4693877551020408 4 | 0.031292517006802724 | 15 |
| Public perception of value of water management | Stakeholder support of water management | 12 | 0.029428040091579358 | 0.386111111111111107 | 0.04034667036757775 | 8 | 0.294069889054704 77 | 0.294069889054704 77 | 0.659952099878221 9 | 4 | 0.265306122448979 6 | 0.020408163265306124 | 13 |
| Agri-industry employment | Resilience of the economy | 3 | 0.013072019587977032 | 0.289236111111111144 | 0.006069876197574658 | 2 | 0.43871822880030986 | 0.43871822880030986 | 0.73250028155257 22 | 1 | 0.102040816326530 61 | 0.025510204081632654 | 4 |
| Amount of WW discharged | State of water resources | 10 | 0.056210206509408 64 | 0.34409722222222222 2 | 0.042301504779529146 | 8 | 1 | 1 | 0.422045631895818 2 | 2 | 0.285714285714285 7 | 0.025974025974025972 | 11 |
| Water exploitation index | State of water resources | 12 | 0.042068222852797314 | 0.35104166666666666 7 | 0.050849194145816116 | 9 | 0.427003194980063 7 | 0.427003194980063 7 | 0.569828314398801 7 | 3 | 0.265306122448979 6 | 0.024118738404452 69 | 11 |
| Cultivated area dependent on irrigation | Pressure on water system | 11 | 0.058243847610311116 | 0.4600694444444444 | 0.025325751775816 97 | 5 | 0.70517465854474 13 | 0.70517465854474 13 | 0.383728561198325 6 | 6 | 0.4693877551020408 4 | 0.052154195011337 87 | 9 |
| Industrial environmental compliance | Pressure on water system | 12 | 0.027053103515869474 | 0.43715277777777777 8 | 0.033318304833458 67 | 6 | 0.6813575155590 68 | 0.6813575155590 68 | 0.610998067963699 8 | 6 | 0.367346938775510 2 | 0.030612244897959186 | 12 |
| Political will | Governance & water management capacity | 16 | 0.0698126271557905 | 0.55902777777777777 8 | 0.015646475541516484 | 4 | 0.004453805120785088 4 | 0.004453805120785088 4 | 0.6311111643352981 | 12 | 0.673469387755102 | 0.042091836734693876 | 16 |
| Level of local / community level stakeholder participation and influence | Stakeholder support of water management | 11 | 0.075866282385423 37 | 0.4444444444444444 4 | 0.030200212248022423 | 6 | 0.9207948507576368 | 0.9207948507576368 | 0.512729381399103 1 | 5 | 0.4693877551020408 4 | 0.046938775510204 08 | 10 |
| Pressure on water system | Pressure on water system | 18 | 0.155019594320843 86 | 0.5208333333333333 3 | 0.025031029332473 09 | 8 | 0.307735833202128 5 | 0.307735833202128 5 | 0.416308787302111 7 | 10 | 0.5510204081632653 | 0.0500927643784786 56 | 11 |
| Annual average precipitation | State of water resources | 7 | 0.006939395004979703 | 0.407291666666666666 | 0.008471697740998 02 | 2 | 0.217305517771743 | 0.217305517771743 | 0.149749118820935 97 | 6 | 0.285714285714285 7 | 0.035714285714285 71 | 8 |
| Level of private sector participation and influence | Stakeholder support of water management | 11 | 0.031867530215251 48 | 0.4149305555555555 6 | 0.027797735189525483 | 7 | 0.643460532531853 9 | 0.643460532531853 9 | 0.490315977506510 1 | 4 | 0.408163265306122 46 | 0.045351473922902494 | 9 |
| Depth and breadth of existing water legislation | Governance & water management capacity | 20 | 0.119649306526573 63 | 0.5312499999999999 9 | 0.042818614239221654 | 10 | 0.666090171701350 4 | 0.666090171701350 4 | 0.599613523595528 4 | 10 | 0.612244897959183 7 | 0.034013605442176874 | 18 |
| Population growth rate | Pressure on water system | 8 | 0.019970778581150917 | 0.48958333333333332 | 0.006113271827285283 | 2 | 0.625549680262479 5 | 0.625549680262479 5 | 0.540718103688302 1 | 6 | 0.571428571428571 4 | 0.071428571428571 42 | 8 |
| Climate variations and climate change | State of water resources | 10 | 0.046479981516208 11 | 0.4496527777777777 7 | 0.012263047187083488 | 5 | 0.595413401791171 6 | 0.595413401791171 6 | 0.153493023058339 45 | 6 | 0.408163265306122 46 | 0.040816326530612 25 | 10 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GDP per capita | Resilience of the economy | 8 | 0.02564484126984127 | 0.437499999999999994 | 0.003196004594601951 | 3 | 0.4838576201012744 | 0.4838576201012744 | 0.16426635314001853 | 5 | 0.40816326530612246 | 0.045351473922902494 | 9 |
| Extent of distribution of piped water system | State of water resources | 8 | 0.04979993349373441 | 0.4305555555555554 | 0.014877608844895664 | 4 | 0.5410276805538408 | 0.5410276805538408 | 0.22447757561562345 | 4 | 0.3673469387755102 | 0.04591836734693878 | 8 |
| Water evapotranspiration | State of water resources | 4 | 0.00022163120567375886 | 0.329513888888888883 | 0.00847169774099802 | 2 | 0.217305517771743 | 0.217305517771743 | 0.45214296902232826 | 2 | 0.20408163265306123 | 0.05102040816326531 | 4 |
| Sea water intrusion threat | State of water resources | 7 | 0.011278848872801232 | 0.35347222222222222 | 0.021758511367525577 | 5 | 0.7797152602813263 | 0.7797152602813263 | 0.8135620607205919 | 2 | 0.20408163265306123 | 0.025510204081632654 | 8 |
| New infrastructure development | Resilience of the economy | 13 | 0.0677188146021032 | 0.5225694444444444 | 0.009542262827837208 | 5 | 0.36146632652612853 | 0.36146632652612853 | 0.7755549490306359 | 8 | 0.673469387755102 | 0.05612244897959184 | 12 |
| Economically active population | Resilience of the economy | 8 | 0.0477789546938483 | 0.39756944444444436 | 0.005377053310240473 | 5 | 0.5881505131644235 | 0.5881505131644235 | 0.4974091039984967 | 3 | 0.30612244897959184 | 0.03826530612244898 | 8 |
| Quality of water infrastructure | State of water resources | 8 | 0.02244699504519374 | 0.3805555555555555 | 0.018378324480909255 | 5 | 0.6634152162536144 | 0.6634152162536144 | 1 | 3 | 0.3673469387755102 | 0.04591836734693878 | 8 |
| Innovation (R&D expenditure on water management) | Governance & water management capacity | 10 | 0.013875674414238242 | 0.4635416666666665 | 0.008968270236944477 | 3 | 0.1152884327785948 | 0.1152884327785948 | 0.2192162818185224 | 7 | 0.4897959183673469 | 0.04897959183673469 | 10 |
| Diversity in the economy | Resilience of the economy | 7 | 0.021660626115413348 | 0.4618055555555554 | 0.00410485408363683 | 2 | 0.04045822502228273 | 0.04045822502228273 | 0.8286922405921139 | 5 | 0.5102040816326531 | 0.0728862973760933 | 7 |
| Governance & water management capacity | Governance & water management capacity | 14 | 0.03312144685844214 | 0.5052083333333333 | 0.02533328987253784 | 5 | 0.643474085628423 | 0.643474085628423 | 0.14001363597666963 | 9 | 0.5918367346938775 | 0.05918367346938776 | 10 |
| Public compliance with water management principles | Stakeholder support of water management | 11 | 0.0216108015310143 | 0.28298611111111111 | 0.04782864169140177 | 10 | 0.34942994425585744 | 0.34942994425585744 | 0.48380773009681594 | 1 | 0.14285714285714285 | 0.012987012987012986 | 11 |
| Water availability per capita | State of water resources | 11 | 0.1287444910801518 | 0.49999999999999994 | 0.029044516114566352 | 6 | 0.7310551700607993 | 0.7310551700607993 | 0.41654848902051517 | 6 | 0.673469387755102 | 0.05612244897959184 | 12 |
| Technological capacity | Governance & water management capacity | 9 | 0.007547024084347156 | 0.4260416666666667 | 0.01367901549911703 | 4 | 0.20853620186954666 | 0.20853620186954666 | 0.5110094754548663 | 5 | 0.3673469387755102 | 0.036734693877551024 | 10 |
| Number of tourists | Pressure on water system | 7 | 0.031939673063343284 | 0.4791666666666666 | 0.005792625152314599 | 2 | 0.6098873347392884 | 0.6098873347392884 | 0.08563542832375186 | 5 | 0.5714285714285714 | 0.08163265306122448 | 7 |
| Severity of migration | Pressure on water system | 5 | 0.016107311719013848 | 0.4618055555555555 | 0.0050816326533417435 | 1 | 0.735597791628024 | 0.735597791628024 | 0.45122169239941284 | 4 | 0.5714285714285714 | 0.11428571428571428 | 5 |
| Government expenditure as % GDP on water management | Governance & water management capacity | 12 | 0.05052643377186827 | 0.4607638888888889 | 0.023536064897072856 | 6 | 0.41880252277716296 | 0.41880252277716296 | 0.689735013855212 | 6 | 0.5102040816326531 | 0.04251700680272109 | 12 |
| Population desnsity | Pressure on water system | 5 | 0.000572547281323877 | 0.3923611111111111 | 0.006322708332797941 | 2 | 0.6552036729386503 | 0.6552036729386503 | 0.3357716825094454 | 3 | 0.32653061224489793 | 0.06530612244897958 | 5 |
| Land degradation | Pressure on water system | 10 | 0.04501018758063908 | 0.3663194444444445 | 0.03308569658909817 | 8 | 0.1826629822709648 | 0.1826629822709648 | 0.19369815738044352 | 2 | 0.2857142857142857 | 0.031746031746031744 | 9 |
| Resilience of the economy | Resilience of the economy | 12 | 0.06565602935283787 | 0.5208333333333333 | 0.004573152672944599 | 4 | 0.43562857321243714 | 0.43562857321243714 | 0.7396231173962734 | 8 | 0.673469387755102 | 0.07482993197278912 | 9 |
| Wastewater recycling rate | State of water resources | 6 | 0.0016094647078689632 | 0.2593749999999999 | 0.02316136691015794 | 5 | 0.40370300965662365 | 0.40370300965662365 | 0.7746327739475416 | 1 | 0.08163265306122448 | 0.011661807580174927 | 7 |
| Stakeholder influence of water management | Stakeholder support of water management | 10 | 0.049691827085444104 | 0.40659722222222205 | 0.022626169191604973 | 4 | 0.576474080885066 | 0.576474080885066 | 0.3833868908717288 | 6 | 0.2857142857142857 | 0.04081632653061224 | 7 |
| Water scarcity index | State of water resources | 7 | 0.00888236190805299 | 0.37256944444444434 | 0.009421870840495167 | 3 | 0.2811879619626774 | 0.2811879619626774 | 0.3433671555973112 | 4 | 0.24489795918367346 | 0.030612244897959183 | 8 |
| Information management and monitoring capacity | Governance & water management capacity | 13 | 0.025428165652451366 | 0.48263888888888884 | 0.016456038005966254 | 5 | 0.39344770572027593 | 0.39344770572027593 | 0.5177733648534601 | 8 | 0.5102040816326531 | 0.03644314868804665 | 14 |
| Irrigation intensity | Pressure on water system | 9 | 0.06476880948333033 | 0.4201388888888889 | 0.025324916162675345 | 6 | 0.5277565374926727 | 0.5277565374926727 | 0.22205528246779202 | 3 | 0.40816326530612246 | 0.05102040816326531 | 8 |
| State of water resources | State of water resources | 16 | 0.1605284042474171 | 0.5190972222222221 | 0.029466713525020977 | 5 | 0.5698651487590596 | 0.5698651487590596 | 0.5122239468087137 | 12 | 0.5102040816326531 | 0.034013605442176874 | 15 |

Appendix 2: Table of definitions of positive and negative changes of the water management system.

1. State of water resources

| ***Element*** | ***Positive change of given variable means…*** | ***Negative change of given variable means…*** |
|---|---|---|
| Water availability per capita | Increased water availability | Decrease of water availability |
| Amount of wastewater discharged | Increased amount of wastewater discharge | Decreased amount of wastewater discharge |
| Climate variations & climate change | N/A – is unaffected by other variables | N/A – is unaffected by other variables |
| Water quality index | Increased overall water quality | Decreased overall water quality |
| Annual average precipitation | Increased average annual precipitation | Decreased average annual precipitation |
| Water scarcity index | Increased overall water scarcity | Decreased overall water scarcity |
| Water evapotranspiration | Increased rates of evapotranspiration | Decreased rates of evapotranspiration |
| Water exploitation index | Increased overall exploitation of water | Decreased overall exploitation of water |
| Water consumption per capita | Increased water consumption per capita | Decreased overall water consumption per capita |
| Sea water intrusion threat | Increased threat of sea water intrusion | Decreased threat of sea water intrusion |
| Quality of water infrastructure | Improvement of water infrastructure | Decline of quality of water infrastructure |
| Extent of distribution of piped water system | Increase in area or number of households served by distribution network | Decrease in area or number of households served by distribution network |
| Wastewater recycling rate | Increased rate of wastewater recycling | Decreased rate of wastewater recycling |

2. Pressure on the water system

| ***Element*** | ***Positive change of given variable means…*** | ***Negative change of given variable means…*** |
|---|---|---|
| Population density | Increased density of population | Decreased density of population |
| Population growth rate | Increased growth rate | Decreased growth rate |
| Number of tourists | Increased number of tourists (representing growth in tourism) | Decreased number of tourists (representing decline in tourism) |
| Industrial environmental compliance | Increase in industry compliance to environmental regulations (resulting in decreased dumping of untreated waste, etc.) | Decrease in industry compliance to environmental regulations (resulting in more dumping of untreated waste, etc.) |
| Irrigation water use efficiency | Increase in efficiency of irrigation practices (same crop area, reduced water use) | Reduction in efficiency of irrigation practices (same crop area, increased water use) |
| Irrigation intensity | Increase in amount of overall water use for agriculture | Decrease in amount of overall water use for agriculture |
| Land degradation | Increase in land degradation (considered reduction of vegetation cover and increased soil degradation) | Decrease in land degradation (considered increase in vegetation cover and reduced soil degradation) |
| Cultivated area dependent on irrigation | Increased agricultural area dependent on irrigation | Decreased agricultural area dependent on irrigation |
| Severity of migration and refugee crisis | Increased number of migrants supported in Lesbos | Decreased number of migrants supported in Lesbos |
| Number of private wells | Increased number of water wells operating on private property (out of control of government water system) | Decreased number of water wells operating on private property |

## 3. Resilience of the economy

| ***Element*** | ***Positive change of given variable means...*** | ***Negative change of given variable means...*** |
|---|---|---|
| New infrastructure development | Increased infrastructure development in all public sectors (transport, etc.) | Decreased infrastructure development in all public sectors (transport, etc.) |
| Agri-industry employment | Increased employment rates in the agri-industry sectors | Decreased employment rates in the agri-industry sectors |
| GDRP per capita | Increased GDRP/capita | Decreased GDRP/capita |
| Human Development Index | Increased HDI score | Decreased HDI score |
| Diversity in the local economy | Increased diversity in the economy (qualitative measure of economic options) | Decreased diversity in the economy |
| Economically active population | Increase in overall population that is economically active | Decrease in overall population that is economically active |

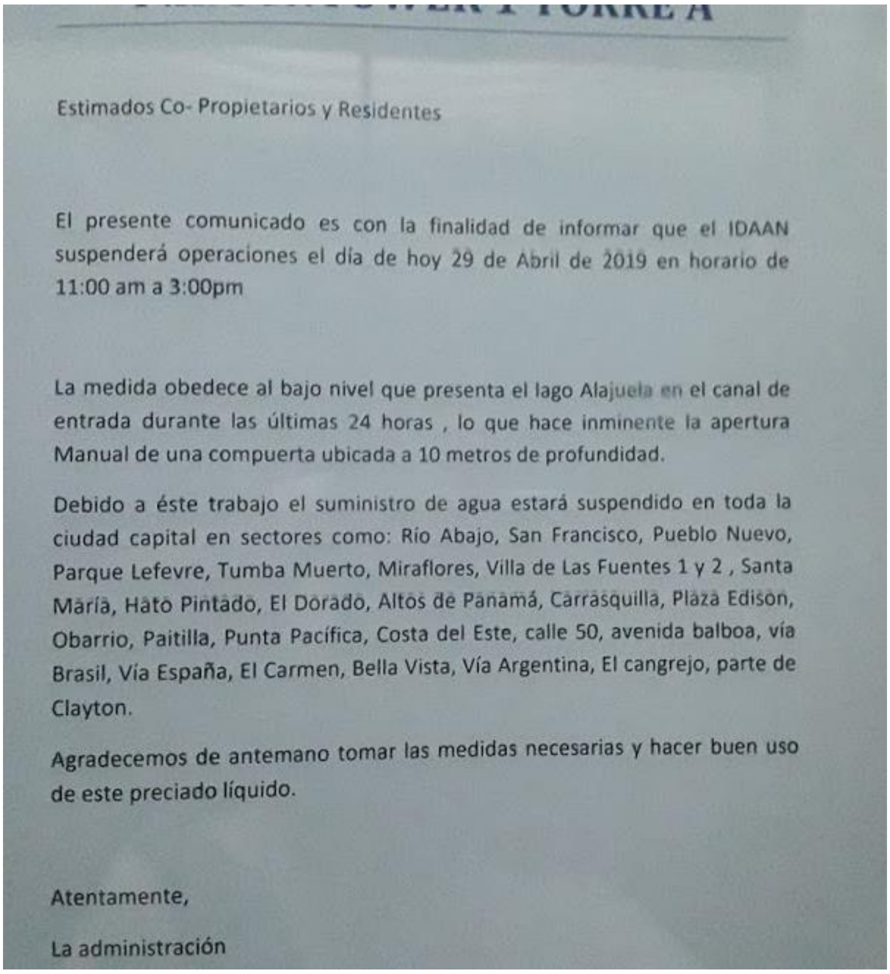
## 4. Governance & water management capacity

| ***Element*** | ***Positive change of given variable means...*** | ***Negative change of given variable means...*** |
|---|---|---|
| Transparency and good governance principles | More transparency and increase in use of good governance principles | Less transparency and decrease in use of good governance principles |
| Innovation (R&D expenditure on water management) | Increase in expenditure on research and development for water management | Decrease in expenditure on research and development for water management |
| Government expenditure as % GDP on water management | Increase in government expenditure as a proportion of total budget on water management | Decrease in government expenditure as a proportion of total budget on water management |
| Depth and breadth of existing water legislations | Increase in qualitative assessment of overall depth and breadth of existing regulations for water management | Decrease in qualitative assessment of overall depth and breadth of existing regulations for water management |
| Quality of pricing policies | Increase in the qualitative assessment of overall quality and effectiveness of pricing policies | Decrease in the qualitative assessment of overall quality and effectiveness of pricing policies |
| Information management and monitoring capacity | Increase in ability of government to gather and manage data related to water management | Decrease in ability of government to gather and manage data related to water management |
| Enforcement capacity | Increase in ability of government to enforce legislation relevant to water management | Decrease in ability of government to enforce legislation relevant to water management |
| Technological capacity | Increase in ability of government to invest in technology that ensures sustainable water management | Decrease ability of government to invest in technology that ensures sustainable water management |
| Political will | Increase in political will prioritising water management as essence of development and economic recovery | Decrease in political will prioritising water management as essence of development and economic recover |

5. Stakeholder influence of water management

| ***Element*** | **Positive change of given variable means...** | **Negative change of given variable means...** |
|---|---|---|
| Level of NGO participation and influence | NGO participation and influence in water management efforts increases | NGO participation and influence in water management efforts decreases |
| Level of private sector environmental buy-in | Private sector is more involved in environmental initiatives, reflecting buy-in | Private sector is less involved in environmental initiatives, reflecting buy-in |
| Level of local / community level stakeholder participation and influence | Community level stakeholder participation and influence increases, in the amount mechanisms for participation and the quantity of citizens taking advantage of them | Community level stakeholder participation and influence decreases, in the amount mechanisms for participation and the quantity of citizens taking advantage of them |
| Public concern for water resources | Public concern over the state of water resources, either availability or quality of supply, increases (more concerned) | Public concern over the state of water resources, either availability or quality of supply, decreases (less concerned) |
| Public perception of value of water management | Public perceive that water management is more valuable than previous perceptions | Public perceive that water management is less valuable than previous perceptions |
| Public compliance with water management principles | The public is more compliant with water management principles, such as water conservation and avoiding pollution | The public is less compliant with water management principles, such as wasting or polluting water |

Appendix 3: Notice about water shortage in Panama City



Estimados Co- Propietarios y Residentes

El presente comunicado es con la finalidad de informar que el IDAAN suspenderá operaciones el día de hoy 29 de Abril de 2019 en horario de 11:00 am a 3:00pm

La medida obedece al bajo nivel que presenta el lago Alajuela en el canal de entrada durante las últimas 24 horas , lo que hace inminente la apertura Manual de una compuerta ubicada a 10 metros de profundidad.

Debido a éste trabajo el suministro de agua estará suspendido en toda la ciudad capital en sectores como: Río Abajo, San Francisco, Pueblo Nuevo, Parque Lefevre, Tumba Muerto, Miraflores, Villa de Las Fuentes 1 y 2 , Santa María, Hato Pintado, El Dorado, Altos de Panamá, Carrasquilla, Plaza Edison, Obarrio, Paitilla, Punta Pacífica, Costa del Este, calle 50, avenida balboa, vía Brasil, Vía España, El Carmen, Bella Vista, Vía Argentina, El cangrejo, parte de Clayton.

Agradecemos de antemano tomar las medidas necesarias y hacer buen uso de este preciado líquido.

Atentamente,

La administración

Appendix 4: Flood occurred in the City Center