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Evaluating the Uncertainty of a UN indicator for Sustainable Development Goal 6.1: A Case Study on Water Access in Morocco

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Evaluating the Uncertainty of a UN indicator for Sustainable Development Goal 6.1: Case Study on Water Access in Morocco

by

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Dedication

Dedicated to the memory of my father, to my dear mother, brother, and sister.

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My proclivity for organized but chaotic communication needs no reminder, and for that alone, I appreciate the tenacity of my interlocutors, with a special emphasis on Laila, for helping me understand what I was trying to accomplish as I was desperately “fishing” for ideas.

And lastly, to my fellow students and faculty at the LBJ School, I was blessed with your company for the past two years. I only hope that my impact on your lives will rise to match the influence you’ve had on mine.

Abstract

Evaluating the Uncertainty of a UN indicator for Sustainable Development Goal 6.1: Case Study on Water Access in Morocco

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This report examines the reliability of an indicator used by the UN to monitor the progress of member nations on Sustainable Development Goal 6.1 related to improved universal water access. The report examines the international and national framework for development indicators with a case study on Morocco. This study discusses limitations posed by household surveys and post-census investigations on providers of water services. It proposes a methodology to harmonize conflicting indicator definitions that is leading to contested statistics. The new methodology combines user-based stratified sampling techniques and provider-based definitions of the population's strata with satellite image processing to select households. Two experiments demonstrate improvements in the indicator's precision and accuracy. A first experiment simulates the uncertainty of water access estimates resulting from a typical household survey. A second experiment provides the reasoning and implementation of the new sampling methodology, showing a clear reduction of bias and variance in water access estimates.

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Introduction

In August 2015 the UN General Assembly (UNGA) drafted the resolution for Sustainable Development Goals (SDGs) and set 2030 as the target date for their achievement.[1] The UNGA's agenda recognizes key focal points for the success of the global initiative, imagining a cohesive world committed to safeguard its people and the planet from possible harms and dangers. The SDGs outline 17 distinct goals that address a wide range of economic, social and environmental objectives.[2]

The UN's statistical division has formulated a list of 230 indicators to monitor progress in relation to all SDGs. Of the 17 proposed Goals, this thesis focuses on the implementation of Goal 6, which aims to ensure access to water and sanitation for all.[1] More specifically, I will scrutinize the methodology for measuring national progress in Morocco as the government works towards achieving compliance with desired outcomes for sustainable management, and the provision of water and sanitation.

This research would be unimpressive if it were restricted to a simple critique of the SDGs on the premise that they lack realistic objectives, for doing so would shift us away from the important and admirable reasons for which these goals were unanimously adopted by the international community. Every goal is tailored to a specific issue and arises from the international community's historic efforts to end poverty, protect the environment, and ensure prosperity for all. Yet in order to take this work seriously, we must endeavor to ensure that the indicators and methodologies employed to capture progress in the fulfillment of these goals are both rigorous and precise. As Heisenberg famously stated in his work, *Physics and Philosopy*: "what we observe is not nature itself, but nature exposed

[1] Table A.1 of Appendix 1 p.106 lists the 8 targets of SDG 6 and its corresponding indicators.

to our method of questioning."[3] This quote borrowed from the father of the uncertainty principle, relates to our pursuit of SDGs in that the methods we deploy to capture national progress have a baring upon whether their objectives will be met. It is therefore up to us to discover the limitations of what we capture and abstract from that the reality of our progress in achieving these goals.

This report analyzes sustainable management of water and sanitation through a SDG case study. The performance criterion to be evaluated is the proportion of the population using safe drinking water as an indicator for Goal 6.1. This case concentrates on Morocco, whose water policy and development strategy were shaped in parallel with the history of the Kingdom's public institutions.

Chapter 1 examines the role of international agencies participating in the indicator framework for SDGs. Chapter 2 provides a background on Morocco's legal system for water resources, followed by a historic evolution of the government's water institutions, and the birth of local stakeholder groups that fit in the network of agencies. Chapter 3 describes Morocco's national process of formulating its water indicators and the elected organizations that carry out their measurement. Chapter 4 presents results that arise from my simulation of household surveys used to generate outcomes for the country's water access indicator. This report concludes with proposed improvements to the current sampling methodology, which may reduce uncertainty and bias arising from typical household surveys.

Introduction references

[1] General Assembly resolution 69/244, Organization of the United Nations summit for the adoption of the post-2015 development agenda, A/RES/69/244 (29 December 2014), available from undocs.org/A/RES/69/244.

[2] General Assembly resolution 70/1, Transforming our world: the 2030 Agenda for Sustainable Development, A/RES/70/1 (29 December 2014), available from undocs.org/A/RES/70/1

[3] Werner Heisenberg, *Physics and Philosophy: The Revolution in Modern Science* (Prometheus Books, 1958).

Chapter 1: Development Progress, the International Tracking System

FROM MILLENNIUM DEVELOPMENT GOALS TO SUSTAINABLE DEVELOPMENT GOALS

The 2015 UNGA Sustainable Development Goals represent an evolution from the Millennium Development Goals (MDGs) of September 2000. The new international covenant is a continuation of earlier commitments. The revisions reflect wars, social unrest, financial uncertainty and security crises that have amplified damages on the least resilient.[4] There had been substantial progress along some performance measures during the MDG era, see Table 1.1 below showing a 100 percent improvement in water access and child mortality, and a threefold reduction in extreme poverty:[5]

Table 1.1 – Development progress during the MDG era

Indicator	1990	2015
Extreme Poverty	47%	14%
Number of global out-of-school Children	100 Million	57 Million
Child Mortality	12.7 Million	6 Million
Access to piped drinking water	2.3 Billion	4.2 Billion

Source: "The Millennium Development Goals Report 2015" (New York: The United Nations, 2015), http://www.un.org/millenniumgoals/reports.shtml

This progress reflects the efforts of multiple international groups that tackle environmental degradation, including access to clean water. For instance, the World Health Organization (WHO) and UNICEF work together to help nations plan and manage drinking water and sanitation by enhancing their monitoring systems.[6] In addition to the adoption of SDG's, two actions initiated in Rio's 1992 Earth Summit took place in 2015, the Addis Ababa Action Agenda on Financing for Development (AAAA), and the Paris Agreement on Climate Change.[7] The Budapest Water Summit of November 2016 promulgated a series of policy recommendations including some that uphold the importance of data accuracy in the context of SDG's.[8] Table 1.2 below lists these policy items relating to indicators and monitoring for informed decision making.

Table 1.2 – Policy recommendations for indicators from the Budapest Water Summit

Policy recommendations for indicators from the Budapest Water Summit [9]
Build a more exhaustive evidence base, through normative work and monitoring, carried out by national governments. National governments and international organisations need to reinforce their financing to initiatives that are designed to allow better monitoring in countries where access to water and sanitation remains a critical barrier to progress and economic growth to help them to build political commitment and capacity.
Carry out an intensive assessment of undertaken actions and the progress towards goals and targets for the management of water resources under an SDG scenario. Since SDG 6 and other water-related targets cover aspects not previously monitored, for which data sources and monitoring capacities still need to be developed, an effort must be made to establish them and their indicators with clear procedures, so data cannot only be known but compared and interpreted. To support this requires strong global monitoring coordination between UN agencies.
Coordinate inputs to be sent to High Level Political Forum (HLPF) and establish a legitimized process to discuss the monitoring results and challenges before the HLPF.
Develop appropriate indicators (including governance indicators) to identify solutions that address the root cause of the water system problem, governance issues, guide investment in infrastructure building and enable the achievement of multiple objectives that are inherent in SDG 6.
Develop new sources of data, monitoring of high quality and increased capacities to report accurately on the water–related SDG targets in a coherent manner, considering the interlinkages with other SDGs.
Place monitoring as a central, coordinated focus in efforts of development partners and UN organisations.

Source: "The Budapest Water Summit Messages and Policy Recommendations" (The Budapest Water Summit, November 28, 2016), http://www.budapestwatersummit.hu/budapest-water-summit/budapest-messages-policy-recommendations/

Table 1.2 – Policy recommendations for indicators from the Budapest Water Summit (Continued)

Encourage the production, collection, use and sharing of data and information, and scientific evidence needed to support water use monitoring and efficiency, using techniques such as water accounting, water auditing or crowdsourcing at the field level.
Develop for new methods facilitating data gathering, and knowledge sharing between countries.
Expand existing and create new global water-environmental services observatory to assess progress or backsliding in sustainable management of water assets, combining state-of-the-art Earth observations, survey data, and simulation models depicting conditions from worldwide to local scales and with near realtime, operational coverage.
Devise and establish new indicators to assess the economic impacts of actions (jobs, economic growth, environmental sustainability) and of inactions and to link SDG 6 to other goals and targets.
Avoid any regression with regard to the level of ambition – both in terms of quality (for example, on drinking water), as well as on the encompassing nature of SDG 6.
Cover issues connected with conditions and changes within the indicators, providing a sense and measurement of actions and covering availability, uses, vulnerability, risk assessment and level of governance of water resources. As water connects, indicators must cover not only the immediate needs of management of water resources and SDG targets but help describe accurately many of the dynamic trends that are occurring among them.
Carry out primary data collection, monitoring, indicators and modelling to form a cyclic process to map the situation, determine trends and the need to introduce corrective measures.
Employ in situ and remote sensing technologies to support the assessment of water targets and identify emerging risks.
Encourage use of citizen/schools/youth water in quality monitoring and environmental management.

Source: "The Budapest Water Summit Messages and Policy Recommendations" (The Budapest Water Summit, November 28, 2016), http://www.budapestwatersummit.hu/budapest-water-summit/budapest-messages-policy-recommendations/

WHO CARES ABOUT STATISTICS? DEFINING THE TARGET AUDIENCE

The UN statistical apparatus and recent activity

A number of bodies affiliated with the United Nations Statistics Commission, a functional branch of the United Nations Economic and Social Council (ECOSOC) oversee the work of the UN Statistics division (UNSD) in monitoring progress by collecting national statistics: the Inter-Agency and Expert Group on SDG Indicators (IAE-SDGs), the UNSD, and the Statistical Commission Friends of the Chair Group on Broader Measures of Progress (FOC). Table 1.2 lists information on UN agencies involved in the indicator framework.

For example, in January 2017, a UN World Data Forum held in South Africa explored innovative methods and applications in development statistics. This was an opportunity for the UNSD and the High-Level Group for Partnership, Coordination and Capacity Building for Statistics (HLG) to advance the Global Action Plan for Sustainable Development Data.[10] The UNSD reported on plans for building statistical capacity, by granting the nations the exclusive duty of producing and communicating statistics. The UNSD Action Plan builds on a foundation of the World Bank's Action Plan for Statistics[11], first introduced in Morocco in 2004 to aid governments in producing timely data and tracking development outcomes.

The transition from MDGs to SDGs is not easy because SDGs are not a simple continuation of MDGs with more intended outcomes. The SDGs are more ambitious and extensive in their definition of targets, with additional stages in measurement to create or modify indicators that need to be reused or updated.

The IAE-SDG proposed three tiers of indicators based on their level of quality assurance, reliability, and testing. A fifth IAE-SDG meeting took place on March 31st 2017 in Ottawa, and considered including in the global database third tier indicators that did not possess a custodian agency.

The percentage of people accessing clean drinking water is considered among the most mature as a Tier 1 indicator due to its use over time.[12] The WHO-UNICEF Joint Monitoring Programme (JMP) previously accepted the percentage of people with access to clean drinking water as a criterion for monitoring progress towards MDGs. As it appears in the latest classifications, the JMP is still appointed as a custodian for the indicator of SDG 6.1.[13]

This case study contributes knowledge on the reliability of sample surveyed development indicators to members of the integrated management system for national and international data. Its results relate the possible uncertainty associated with the indicator for SDG 6.1 to diverse target statistical agencies, including the Kingdom of Morocco's National Statistical Division (Haut Commissariat au Plan), the WHO-UNICEF JMP, the National Office for Electricity and Drinking Water (ONEE Branche Eau), the Ministry of Water Resources in Morocco, and the IAE-SDG.

Refer to table 1.3 below for more information on UN agencies involved in the Indicator Framework.

Table 1.3 – UN agencies participating in the indicator framework

<table>
<tr><th>Agency</th><th colspan="3">Role</th></tr>
<tr><td rowspan="2">IAE-SDGs[14]</td><td colspan="3">Created in March 2015 by the UN Statistical Commission, formed of 27 member states with regional and international agency observers. In charge of developing an indicator framework for the goals and targets of the post 2015 development agenda and to support its implementation. Three working groups were created on its third meeting to address different knowledge areas of statistical improvements. They are extending their invitation to non-IAEG-member States, international organizations, civil society, academia and the private sector to participate in future work</td></tr>
<tr><td>Working Group on geospatial information

Promotes taking advantage of spatial attributes and big data to unveil the geographic aspect of measurements. The group builds functionalities introduced by the UN Committee of Experts on Global Geospatial Information Management (GGIG). [15]</td><td>Working Group on Inter-linkages of SDG Statistics to allow for Integrated Analyses in the Monitoring

Identifies linkages between different goals and targets by exploring relations between common indicators. [16] Looks for correlation and causality between indicators, to understand challenges for development targets.</td><td>Working Group on Statistical Data and Metadata Exchange (SDMX)

The working group is in charge of providing the logistic infrastructure for automated and manual aggregation, dissemination, and communication of data and Metadata. It is called upon to develop standards for managing and storing national statistics. [17]</td></tr>
</table>

Source: Haytham Oueidat, "UN Agencies participating in the SDG indicator framework", 2017

Table 1.3 – UN agencies participating in the indicator framework (Continued)

UNSD	The division's initial mandate is quite diverse. Since its inception in 1946 it delivered technical work for the Statistical Commission, standardized statistical methods, compiled and disseminated data, and strengthened national capacity to produce reliable statistics. Its working programme to this day embodies the objectives it was initially conceived for. [18] Before the SDGs the UNSD was reporting on progress and publishing data for MDGs.
FOC	This group was formed by the Statistical Commission to "build a work programme to develop broader measures of progress". [19] It is mainly a taskforce that provided advice and support to a once growing dialogue on the objectives of sustainable development policy towards the end of the MDG period, and prepared the UNSD for the post-2015 development agenda.

Source: Haytham Oueidat, "UN Agencies participating in the SDG indicator framework", 2017

Chapter 1 references

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[4] Felix Dodds, Amb. David Donoghue, and Jimena Leiva Roesch, *Negotiating the Sustainable Development Goals, A Transformational Agenda for an Insecure World* (Routeledge, 2016).
[5] "The Millennium Development Goals Report 2015" (New York: The United Nations, 2015), http://www.un.org/millenniumgoals/reports.shtml.
[6] "WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) Archives," *UN-Water*, accessed June 21, 2017, http://www.unwater.org/publication_categories/whounicef-joint-monitoring-programme-for-water-supply-and-sanitation-jmp/.
[7] Felix Dodds, Amb. David Donoghue, and Jimena Leiva Roesch, *Negotiating the Sustainable Development Goals, A Transformational Agenda for an Insecure World (Routeledge, 2016)*.
[8] "The Budapest Water Summit Messages and Policy Recommendations" (The Budapest Water Summit, November 28, 2016), accessed August 13, 2017, http://www.budapestwatersummit.hu/budapest-water-summit/budapest-messages-policy-recommendations/.
[9] Ibid.
[10] "Cape Town Global Action Plan for Sustainable Development Data — SDG Indicators," accessed March 18, 2017, https://unstats.un.org/sdgs/hlg/Cape-Town-Global-Action-Plan/.
[11] "Marrakech Action Plan for Statistics," accessed March 18, 2017, http://www.worldbank.org/en/data/statistical-capacity-building/marrakech-action-plan-for-statistics.
[12] "Tier Classification for Global SDG Indicators," December 21, 2016, https://unstats.un.org/sdgs/iaeg-sdgs/.
[13] Ibid.
[14] "IAEG-SDGs — SDG Indicators," accessed August 13, 2017, https://unstats.un.org/sdgs/iaeg-sdgs/.
[15] "Inter-Agency and Expert Group on the Sustainable Development Goal Indicators - Working Group on Geospatial Information - Draft Terms or Reference," April 15, 2016, https://unstats.un.org/sdgs/files/Working-Group-ToR--GeoSpatial.pdf.
[16] "Inter-Agency and Expert Group on the Sustainable Development Goal Indicators - Working Group on Inter-Linkages of SDG Statistics to Allow for Integrated Analyses in the Monitoring - Terms of Reference," n.d., https://unstats.un.org/sdgs/files/Working-Group-ToR--Interlinkages.pdf.
[17] "Inter-Agency and Expert Group on the Sustainable Development Goal Indicators - Working Group on SDMX - Draft Terms of Reference," n.d., https://unstats.un.org/sdgs/files/Working-Group-ToR--SDMX.pdf.
[18] "2016 Statistic Division Brief" (United Nations Statistics Division - Department of Economic and Social Affairs, n.d.), http://unstats.un.org/unsd/statcom/brochures/2016%20UNSD%20Brochure_7%20March.REV.pdf.
[19] "Archive of the Friends of the Chair Group, Statistical Commission | United Nations," accessed March 18, 2017, https://unstats.un.org/unsd/broaderprogress/about.html.

Chapter 2: Evolution of Morocco's Water Policy

This chapter describes the historic context of Morocco's governance and water policy during the 20th and 21st century. In that regard, the first part of the chapter emphasizes the kingdom's transformative episodes from the experience of its water administration. The second part lists contemporary resolutions, and large scale projects to outline the current challenges of the water sector. That perspective allows us to fathom the extent to which in the Arab world, people's relationship with water is ubiquitous. Water is not just a scarce commodity, as evidenced by over 20 synonyms in the Arabic language conveying various expressions of thirst,[20] it is a cultural medium that permeates all aspects of civilization.

Morocco gained its independence from France in 1956 after having been a protectorate of both France and Spain. Water services, electricity and gas under colonial rule were provided by private distribution companies in the cities of Casablanca, Rabat, Sale, Tangier and Meknes.[21] Although the country has undergone significant institutional changes since 1956, urban retail utilities continue to provide water, electricity and gas services. The public and private sectors work conjunctively to provide utilities to the rest of Morocco's population.

Saleth and Dinar have evaluated water institutions of several countries.[22] In this chapter, I use their road map in my account of Morocco's institutional reforms.

Doukkali describes three stages of institutional evolution with the changing laws of land and water. The first stage occurred prior to the French protectorate, where Muslim law influenced the distribution of resources. In that stage, religious theorists elected a flexible interpretation of water ownership and favored its deregulation.[23] As a result, this allowed for diverse practices suited for customs and traditions of Moroccan society.

During the French protectorate, water was put under public domain. The state took full control of the resources, and suppressed private development of irrigation. Private associations awaited permission to develop infrastructure until laws were issued by the protectorate administration enabling their activity and recognizing them as "Associations syndicates agricoles privilégiées" (ASAP).[24]

Later, the French colonial administration created a trilateral rights system: the state owned the majority of rivers and pond waters; ASAP and local agencies were tasked with managing some utilities; and holders of recognized customary rights possessed privileges to facilitate development and delivery of services.[25] There also existed unrecognized rights holders, such as tribal members, whose rights in some regions are still binding.

Morocco's post-colonial era could be described as the nation's green affirmation. The Kingdom was committed to an ambitious development strategy to fulfill a Million Hectare potential of irrigated surface area. The government provided financing and set goals for the country's agricultural potential according to a 1969 legislation, the Agriculture Investment Code.[26] Even today, the National Water Plan upholds the Green Morocco Plan (Plan Maroc Vert) to safeguard irrigation as a pillar of policy towards 2020.[27]

ONTO THE MODERN INSTITUTION

Doukkali has described post-independence reforms in Morocco's water sector that validate Saleth and Dinar's patterns of institutional reform[28] through some anecdotal evidence from the 80s and 90s.[29] Saleth and Dinar's theory of transaction and opportunity costs[30] gives a theoretical explanation for the influence of droughts, economic transformation, and modern resolutions on the shape of the post-colonial water institution.

Environmental factors

Droughts occurred in Morocco repetitively during the first half of the 1980s. As a result, Morocco enacted waivers for well digging and private irrigation investments.[31]

These arrangements allowed regions that would otherwise have been severely affected by droughts to mitigate the damages and sustain through critical seasons. Consequently, aquifers lost a significant volume of their water between 1980 and 1985.[32] For example, the Berrchid aquifer lost 700 million cubic meters (Mcm) of water from its 1500 Mcm storage capacity.[33] These experiences have led to reliance on groundwater (GW) as a common source for irrigation and domestic use in areas with limited surface water sources.[34] Water tables fell forming brackish aquifers, prompting Morocco to develop policy for GW regulation.[35] Salt water intrusion was encountered in some coastal areas such as the Chaouia aquifer system which had been overused even before the precipitous drought incidence.[36]

Economic crisis

Half-way through the drought, Morocco suffered a macro-economic collapse that led to revised economic policies that propelled the country into the free-market,[37] which had significant consequences for water management. Morocco decentralized, empowering regional communities with the role of managing local water resources and economic activity.[38] This policy is known to reduce transaction costs.[39]

One of the revised policies was to relax crop regulations.[40] Previously, agricultural production had been dependent on state authorized grain and water. By allowing farmers to choose their own crops, the policy catalyzed market activity and granted the agricultural sector the autonomy to fulfill its potential. A second policy allowed farmers to allocate and manage their supplied water. A third policy revised water pricing. Farmer organizations were brought together in arrangements of varying scales, depending on pre-existing farmland partitions, as part of Water User Associations (WUAs) that either belonged to Small and Medium Scale Irrigation districts (SMSIs) or Large Scale Irrigation Districts (LSIs). The Ministry of Agriculture participated in provincial administrative organizations (ORMVAs) where there were large irrigation activities.[41]

The challenges encountered by the agricultural sector during the crisis reflected the "rent seeking" theory, as mentioned in Saleth and Dinar's stage-based perspective on institutional reform.[42] A sustained drought reduces water for agricultural purposes, leading to changes in perceived land value disadvantaging some farmers over others. Some areas would become more attractive; lands with access to the proper water quantities and factors of production would be more "fertile" than others. Saleth and Dinar mention welfare theory to explain how on the one hand, these disparities provoke unnecessary tensions, but how on the other, they present opportunities for institutional reform.[43] In fact, farmer groups could not economically exploit the land of which they were suddenly made wardens.[44] The delegation of autonomy in water management to farmer associations could have also served as a political compromise by the government to exonerate itself from encumbering the livelihood of farmer unions whose only means of subsistence was contingent on their access to state authorized agricultural input of grain and water.

Contemporary resolutions

In 1995 the Moroccan government introduced a new ground and surface water law, championing a more integrated strategy for the management and allocation of water resources and creating River Basin Agencies (RBA).[45] RBAs can act as a wholesaler of water to regional authorities: ORMVAs, WUAs, and the National Office for the Supply of Potable Water (ONEP)[46]. The movement was backed by an environmental policing system that sought to contain the over-exploitation of resources under RBA Authority through well monitoring, registry, etc.

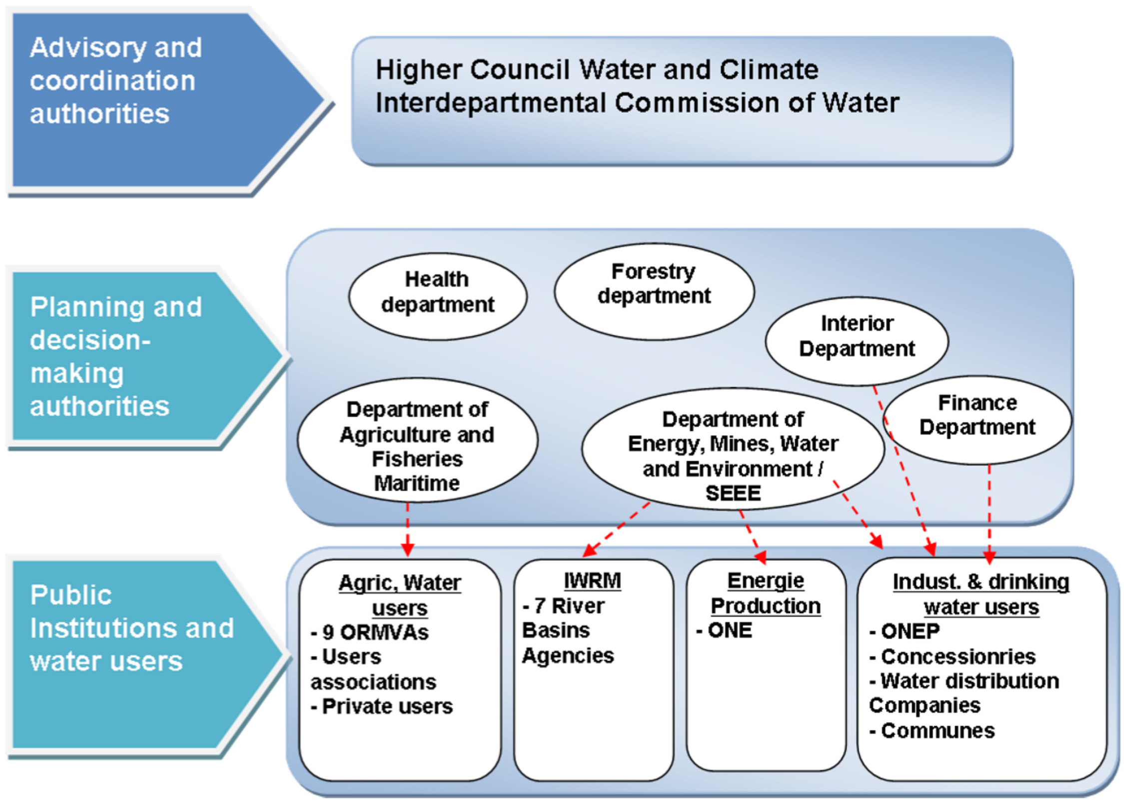
The 1995 law also produced the Water Mater Plan (Plan Directeur). Morocco's first formal managerial element that tied resource distribution and allocation across sectors to water availability and demand.[47] This law shifted the focus towards controlling the supply of surface water to preserve the safety of activities dependent on regional aquifers.

Despite the 1995 law, in the final years of the 20th century, Morocco exhausted river development options. It became challenging to mobilize surface water to make up for the deficit caused by reduced GW resources. King Hassan 2 himself advocated for the construction of a dam every year until 2000.[48] He passed away in 1999, leaving behind a legacy of 126 major hydraulic structures.[49]

The new water regime offered farmers incentives to switch from flood to drip irrigation in an attempt to extend GW sources. Procedural hurdles hindered the adoption of drip irrigation by local farming associations,[50] given the limited impact it could have on resuscitating regional aquifers.[51]

Recent changes to the law of 1995 are featured in law n° 36-15.[52] It strengthened RBAs, and developed a more participatory framework among water users. The changes authorized IWRM to implement the Water Master Plan and proposed non-conventional uses of water. The new law provided supporting regulation to encourage water desalination and formulated conditions on contracts and concessions for Morocco's upcoming large scale water supply projects.[53] Figure 2.1 illustrates Morocco's water institutions falling under the authority of planning authorities and ultimately the advisory and coordination authorities.

Figure 2.1 – Major stakeholders of the Moroccan water sector[54]



Source: Ouassou et. al,2005, Cited in Choukr-Allah R., "Comparative Study Between Moroccan Water Strategies and WFD," CIHEAM, Serie A . Seminaires Mediterranneens, 2011, 181–88.

Current Priorities

Domestic Water Supply

ONEP was later merged with a sister organization, the National Office for the Supply of Electricity (ONE). In 2012 the National Utility Company changed its name to ONEE, and began delivering electricity and water utility services in rural and urban settings. ONEE is also in charge of sanitation for domestic wastewater.[55]

Access to water in Morocco as indicated in Muslim law is considered a human right, and water itself is a public property. In terms of bulk quantities, domestic water use claims a minimal share of available resources.[56] The national utility company (ONEE) is not the only entity responsible for domestic water supply. As described earlier, in the major cities, private multinational companies manage urban service delivery. Water demand and availability vary across the Moroccan territory, so urban and rural infrastructure are not similar. The challenge for Morocco was to expand water supply to rural areas without compromising service quality.

In 1995, Morocco launched a drinking water procurement program, the "Programme d'Approvisionnement Groupé en Eau Potable des populations Rurales" (PAGER), with an objective to increase the fraction of rural residents with access to water to 80 percent by 2010, up from the level of 14 percent access as recorded in 1994.[57] As a former organization with the name of ONEP, ONEE functioned under the General Directorate for Hydraulic Works, and intervened in nearby "douars" (rural communes) by installing connections to their existing networks.

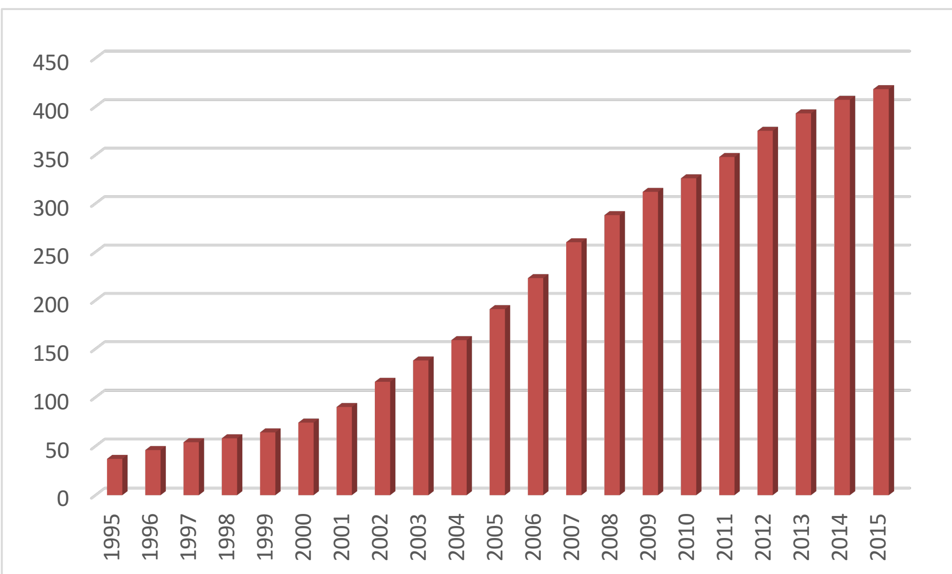
In November 2002, the High Council for Water and Climate (CSEC) declared its objective to aim for a 90 percent rural water access by 2007. The CSEC designated ONEP as the responsible agency to achieve three goals: [58]

- Construct new drinking water projects to provide fresh water for populations without access, and prioritize services to the most deprived.
- Enhance the sustainability of existing or projected systems with innovative management and design solutions.
- Rehabilitate and upgrade dysfunctional systems identified during an investigation in 2004 assisted by the Food and Agricultural Organization (FAO).

According to a conversation I've had with an agency official in Rabat in December of 2016, ONEE's strategy consists of building new infrastructure and wells; improving existing systems; and "taking over" control of inefficient systems by providing technical assistance to medium and smaller operators.[59]

Figure 2.2 below illustrates ONEE's program activities called interventions between 1995 and 2015. The dominant trend in PAGER projects is the capitalization on existing infrastructure: ONEE takes advantage of its own existing supply networks spanning from the source to the urban areas by loading its main lines with connections to intermediary rural centers.[60] These interventions are part of a generalization strategy for drinking water through which ONEE was able to provide clean potable water for an estimated population of 97,000 inhabitants.[61]

Figure 2.2 – Progressive interventions in rural centers



Source : ONEE direction de l'Alimentation en Eau potable en milieu rural AEPR, "Généralisation de l'accès à l'eau potable" (Note Générale, Rabat Morocco, June 10, 2016)

Table 2.1 below lists the current percentage of the rural population accessing drinking water as estimated by ONEE in 2015. On average, the agency assessments indicate that rural water access increased from 94.5 percent in 2014 to 95 percent in 2015.[62]

Table 2.1 – Percentage of rural population accessing drinking water (ONEE estimates)

REGION	Percentage of population accessing drinking water in 2015
Béni Mellal-Khénifra	94%
Drâa-Tafilalet	96%
Eddakhla-Oued Eddahab	99%
Fès-Meknès	92%
Grand Casablanca-Settat	91%
Guelmim-Oued Noun	97%
Laayoune-Sakia El Hamra	99%
Marrakech-Safi	90%
Oriental	89%
Rabat-Salé-Kénitra	98%
Souss-Massa-Draa	94%
Tanger-Tetouan-Al Hoceima	82%

Source : ONEE direction de l'Alimentation en Eau potable en milieu rural AEPR, "Généralisation de l'accès à l'eau potable" (Note Générale, Rabat Morocco, June 10, 2016)

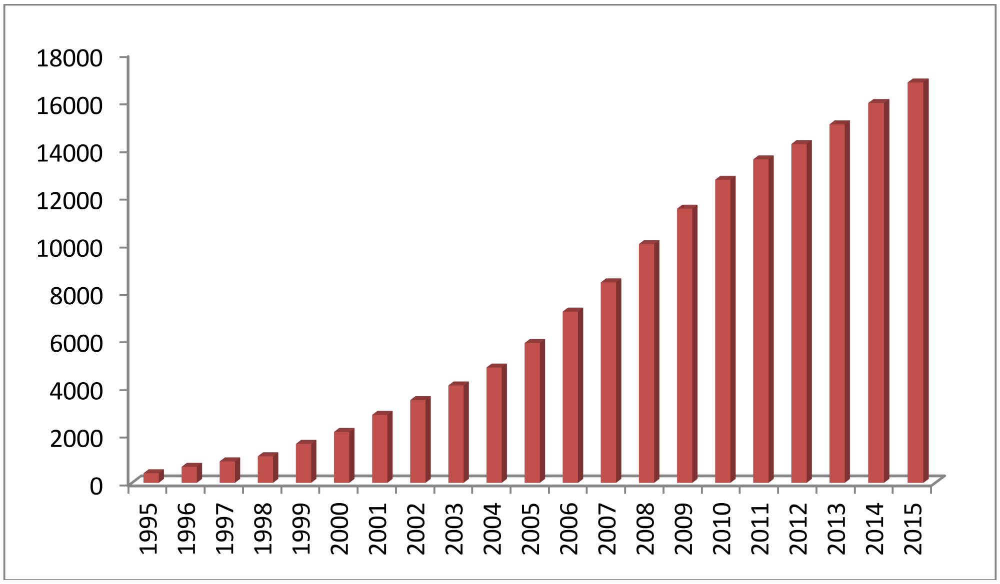
Rural School Water Supply Improvement

Since 2008, ONEE has focused on supplying water to rural schools as part of a larger Ministry of National Education (MEN) project. Of the schools serviced between 2009 and 2015 in need of infrastructure improvements, 1,691 are located within a distance inferior of 100m, while 500 others lie between 100, and 2000 meters from the nearest main water line.[63]

Financing Development

ONEE owes its operational success to its ability to mobilize important investments from international lenders and donors such as the European Investment Bank (EIB), the Inter-American Development Bank (BID), the World Bank (BIRD), the European Bank for Reconstruction and Development (BERD), the African Development Bank (BAD), in addition to local lending instruments from its national banking institutions. Figure 2.3 below illustrates how these investments increased from an average yearly amount of nearly 200 Million Moroccan Dirhams (MAD[ii]) to more than 1 billion MAD (unadjusted), with a cumulative of 16.8 billion MAD spent in the last 20 year period.

Figure 2.3 – Annual Cumulative investments on water infrastructure (MAD)

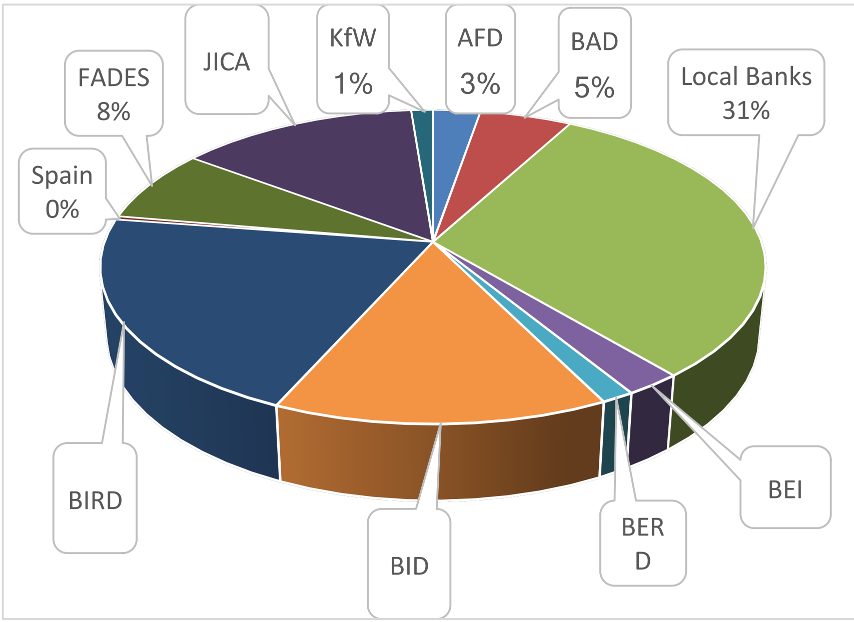


Source: ONEE direction de l'Alimentation en Eau potable en milieu rural AEPR, "Généralisation de l'accès à l'eau potable" (Note Générale, Rabat Morocco, June 10, 2016)

Figures 2.4 and 2.5 below show that nearly two thirds of loans ONEE receives for water supply projects are issued by international lenders, while donations are in majority endowed by European nations, the European Union, and German owned development bank KFW.

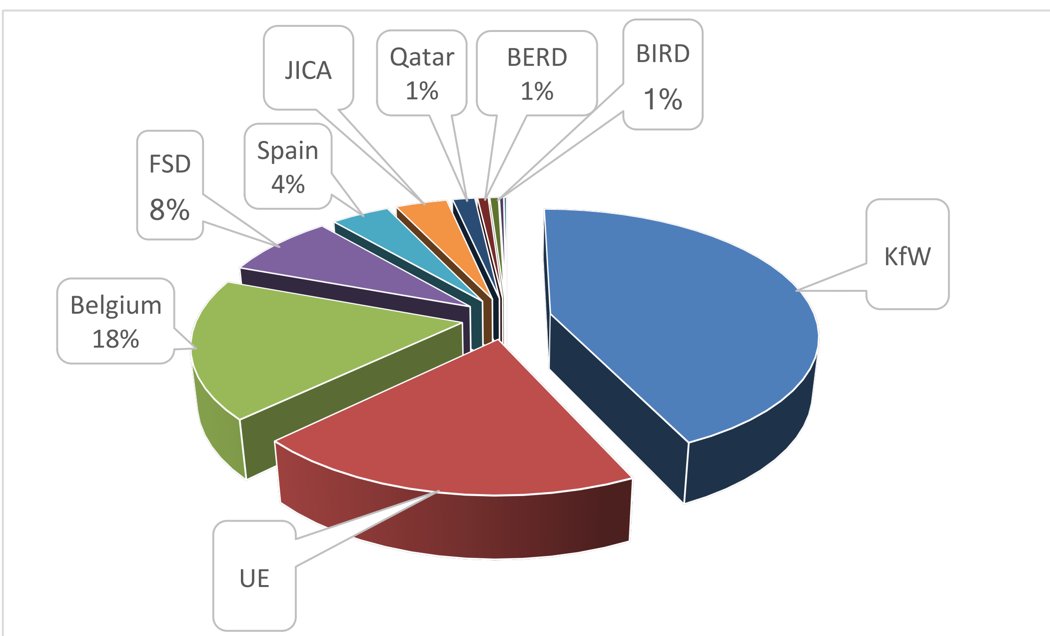
[ii] 1 MAD = 0.1 USD (3/24/2017)

Figure 2.4 – Loan breakdown by lending agency for ONEE's water supply projects



Source: ONEE direction de l'Alimentation en Eau potable en milieu rural AEPR, "Généralisation de l'accès à l'eau potable" (Note Générale, Rabat Morocco, June 10, 2016)

Figure 2.5 – Donations breakdown by agency for ONEE's water supply projects



Source: ONEE direction de l'Alimentation en Eau potable en milieu rural AEPR, "Généralisation de l'accès à l'eau potable" (Note Générale, Rabat Morocco, June 10, 2016)

WASH PROJECTS AND INTERNATIONAL ASSISTANCE

ONEE plans to invest 835 million MAD in 2016 to continue its ongoing efforts in the hope of achieving a level of rural water access of up to 96%, with a targeted population of almost 110,000 inhabitants. [64] These include World Bank projects awaiting bids for construction by national conglomerates. [65]

World Bank

The WB has been avid supporter of ONEE's mission since 2004 despite problems encountered in Morocco's water sector. Table 2.2 below provides an account of these challenges as presented in a WB report from 2014.[66]

Table 2.2 – Challenges reported by the WB in Morocco's water sector

Problems of uneven development: some areas such as the Rif and Pre-Rif Mountainous ranges are lagging behind national average percentages.
Flowrates in some pipes' standing uptakes are sometimes incongruous with initial design rates which could damage water quality.
Problems arising from poor choices of WUAs and standpipe guardians. (Standpipes or SP's are the infrastructure model of choice for rural areas; they are public water fountains secured and maintained by one or more rural operators or guardians, they are additionally in charge of collecting monthly usage fees).
The population has demonstrated a strong preference for house connections in growing rural areas as opposed to SPs.
There is still a need for additional sanitation and wastewater management.

Source: The World Bank, "Morocco - Rural Water Supply Project" (The World Bank, April 3, 2014), http://documents.worldbank.org/curated/en/558531468109460721/Morocco-Rural-Water-Supply-Project

The future intended stage of PAGER's water supply strategy is to extend these SPs to rural households on demand. The approval of these upgrades will depend on cost justification and a needs assessment for household requests. In a stepwise manner, ONEE is able to service communities that otherwise would have endured labor intensive methods to supply their own water.

USAID

Morocco celebrated in 2016 its 60th partnership year with USAID. See table 2.3 and the map in figure 2.6 for more information on USAID projects concentrated mainly on irrigation, water supply and sanitation.

Table 2.3 – USAID Projects in Morocco between 1992 and 2014

Project Name	**Description**
Potable Water Supply to Outerbate	Initiated in 2011 and completed in 2014, the project consisted of replacing aging infrastructure and connecting pipelines to households with a cost of US$ 204,984.67
Water Supply and Sanitation for Aghbalou Village	The project was conducted in parallel with the Outerbate project, it improved water quality and potable water supply, and provided sanitation systems (network connections and latrines, safeguarding the water system from contamination).The project cost was US$ 296,482.68
Sewage and Wastewater reuse in the Tidili area	The construction of a wastewater treatment plant began in 2011 and finished in 2014 for a total cost of US$ 1,554,399. Treated water for irrigation.69

Source: Haytham Oueidat, unpublished, accessed July 13, 2017, https://usaid-gov.secure.force.com/PublicProjectDetail?id=a0cd00000011q7rAAA&cid=Morocco.

Figure 2.6 – Map of USAID WASH projects in Morocco from 1992

Disclaimer: The geographic names and boundaries may not reflect the views of the United States Government on the sovereignty over geographic features. **A subset of USAID's field offices participated in the initial rollout of the map. Over time the intent is to display a comprehensive portfolio of USAID projects from all international locations.**

Source: "Interactive Map | U.S. Agency for International Development," accessed March 13, 2017, https://usaid-gov.secure.force.com/

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Chapter 3: Measuring Water Access in Morocco

This chapter introduce Morocco's national statistical framework with a report of demographic data and estimates of water access published by the UN as an indicator for SDG 6.1. A further inquiry into the methodology behind these statistics unveils a key discovery regarding the indicator on the population's access to water: the UN data deviates from that of the national utility company (ONEE) due to an inherent contradiction in the indicator's definition affecting its method of calculation. The indicator estimated from household surveys is qualified as user-based and yields results that conflict with provider-based data. In the attempt of denouncing user-based indicators for their limited serviceability in water planning, the chapter explores this divide by documenting global testimonies from England, Wales and the US on the reliability of census and post-census investigations.

CONFLICTING STATISTICS

The first measurement of water access was obtained in 1982 through Morocco's general census for population and habitat "Recensement Général de la Population et de l'Habitat" (RGPH). Tables 3.1 and 3.2 below display Morocco's post-independence demographic trends as determined by successive census surveys between 1960 and 2014. Household numbers reflect a positive population growth in urban areas and migration from rural areas in the latest negative rate of 0.01 percent.

Table 3.1 – Urban households and population data

Census		1960	1971	1982	1994	2004	2014
Population		3,389,613	5,409,725	8,730,339	13,407,835	16,463,634	20,432,439
Households		--	1,023,020	1,593,718	2,524,974	3,439,755	4,807,743
Pers/ Household		--	5.29	5.48	5.31	4.79	4.25
Evolution	Population (yearly)	--	4.34%	4.45%	3.64%	2.07%	2.18%
	Housholds (yearly)	--	--	4.11%	3.91%	3.14%	3.40%
	Pers/ Household (yearly)	--	--	0.32%	-0.26%	-1.03%	-1.18%

Source : Document aquired from ONEE branche eau direction de la planification DPL, Rabat Morocco, unpublished, December 2016

Table 3.2 – Rural households and population data

Census		1960	1971	1982	1994	2004	2014
Population		8,236,857	9,969,534	11,689,156	12,665,882	13,428,074	13,415,803
Households		--	1,727,451	1,839,140	1,919,297	2,225,509	2,506,063
Pers/ Household		--	5.77	6.36	6.60	6.03	5.35
Evolution	Population (yearly)	--	1.75%	1.46%	0.67%	0.59%	-0.01%
	Housholds (yearly)	--	--	0.57%	0.36%	1.49%	1.19%
	Pers/ Household (yearly)	--	--	0.88%	0.31%	-0.89%	-1.19%

Source : Document aquired from ONEE branche eau direction de la planification DPL, Rabat Morocco, unpublished, December 2016

UNSD recognizes the national statistical division (HCP) as the official entity for Morocco in the SDG indicator framework[70]. Table 3.3 below lists the surveys used by the JMP to produce water access statistics for Morocco.[71] Almost all of them were supervised by HCP in collaboration with international agencies. This diversity of carriers and high cadence of surveys suggests that the statistical framework is capable of producing timely and verified data.

Table 3.3 – Household surveys in Morocco between 1982 and 2011

Household Survey	Agency	Code	Year
Recensement Général de la Population et de l'Habitat	Direction de la statistique (Former HCP)	CEN82	1982
Demographic and Health Survey	USAID	DHS87	1987
Enquête Nationale des Conditions de Vie	Direction de la statistique	ECV91	1991
Demographic and Health Survey	USAID	DHS92	1992
Recensement Général de la Population et de l'Habitat	Direction de la statistique	CEN94	1994
Demographic and Health Survey	USAID	DHS95	1995
Enquête Nationale sur la Santé de la Mère et de l ’Enfant (ENSME) 1997	Direction de la planification des ressources financières - DPE	ENSME97	1997
Enquête nationale sur les niveaux de vie des ménages	Direction de la statistique	ENV98	1998
Enquête nationale sur les niveaux de vie des ménages	Direction de la statistique	ENV99	1999
Enquête nationale sur l’emploi	Direction de la statistique	ENE00	2000
Enquête Nationale sur la Consomation et les Dépense des Ménages	Direction de la statistique	ECM01	2001
Enquête nationale sur l’emploi	Direction de la statistique	ENE01	2001
Enquête nationale sur l’emploi	Direction de la statistique	ENE03	2003
World Health Survey	WHO	WHS03	2003
EPSF,(PAPFAM)	Ministère de la Santé DPRF/DPE/SEIS – USAID - PAPFAM	EPSF04	2004

Source: https://www.wssinfo.org/documents/?tx_displaycontroller%5Bregion%5D=&tx_displaycontroller%5Bsearch_word%5D=morocco&tx_displaycontroller%5Btype%5D=country_files

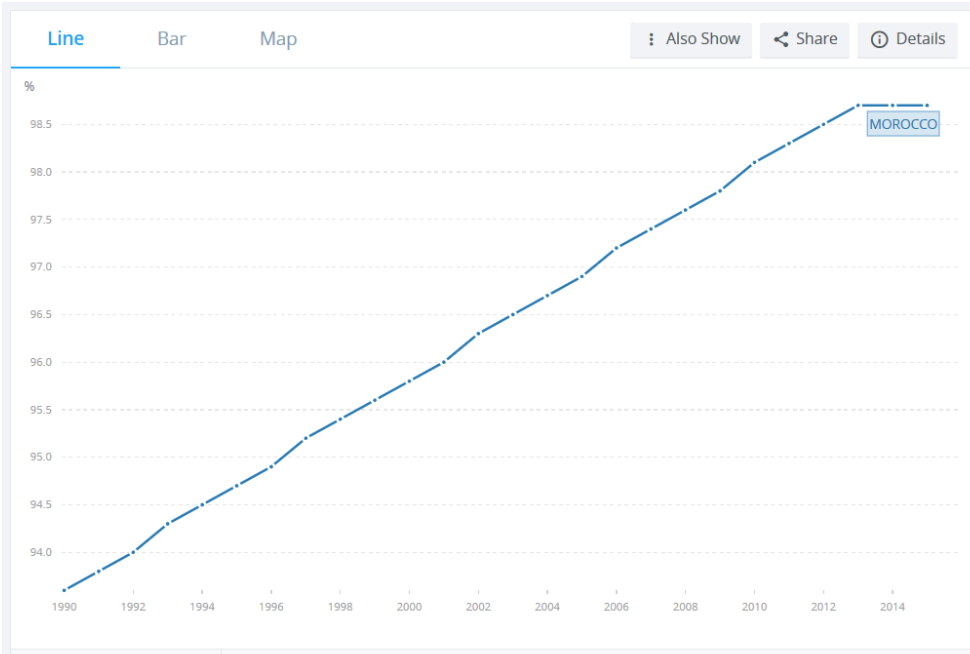
Table 3.3 – Household surveys in Morocco between 1982 and 2011 (Continued)

Enquête nationale sur l'emploi	Direction de la statistique	ENE04	2004
Recensement Général de la Population et de l'Habitat	Direction de la statistique	CEN04	2004
Enquête nationale sur l'emploi	Direction de la statistique	ENE05	2005
Enquête Nationale à Indicateurs Multiples et Santé des Jeunes, Ministère de la Santé	Ministère de la Santé	ENIMSJ06	2006
Enquête nationale sur l'emploi	Ministère de la Santé	ENE06	2006
Enquête nationale sur l'emploi	Direction de la statistique	ENE07	2007
Enquête Nationale sur la Population et la santé	Ministère de la Santé	ENPS11	2011

Source: https://www.wssinfo.org/documents/?tx_displaycontroller%5Bregion%5D=&tx_displaycontroller%5Bsearch_word%5D=morocco&tx_displaycontroller%5Btype%5D=country_files

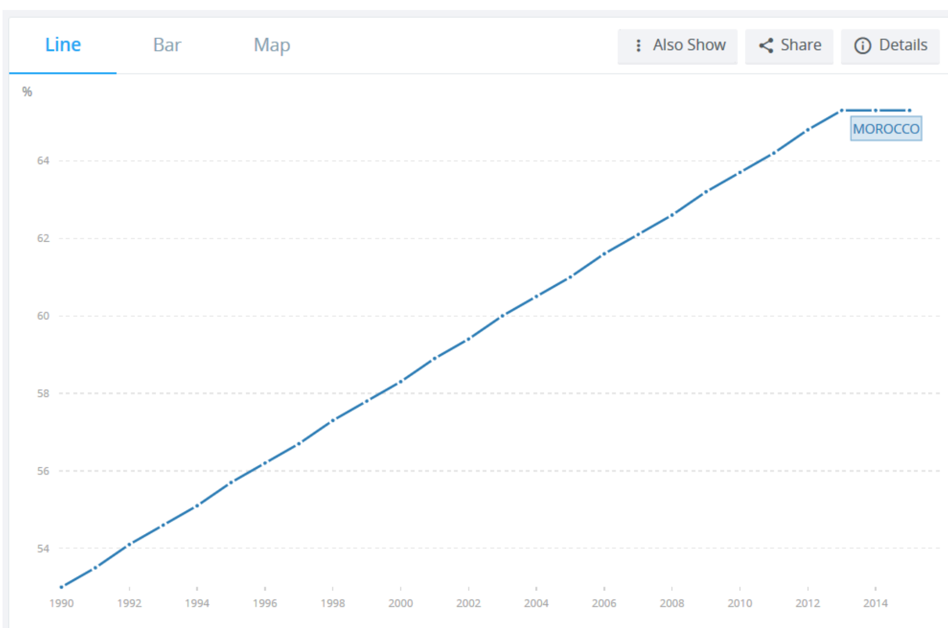
The World Bank's data platform displays water access measurements sourced from the JMP records.[72] Their latest figures indicate that most Moroccan citizens have water access, 98.7 percent to improved water sources in urban areas and a stable level of 65.3 percent in rural areas.[73] These values are not consistent with the 95 percent rural access reported by ONEE (See chapter 2). These inconsistencies are a first sign of competing interests among agencies that provide water services (ONEE in that case), and agencies monitoring national development. Figures 3.1 and 3.2 display the trend of water access in Morocco, showing a near linear pattern in urban and rural areas, which raises suspicion on the soundness of these statistics, and their ability to capture effects of capital water projects and investments on the population, which is naturally cumulative and irregular.

Figure 3.1 – Percentage of urban population with access to improved water sources



Source: Improved water source, urban (Percent of urban population with access), *http://data.worldbank.org/indicator/SH.H2O.SAFE.UR.ZS?locations=MA*

Figure 3.2 – Percentage of rural population with access to improved water sources

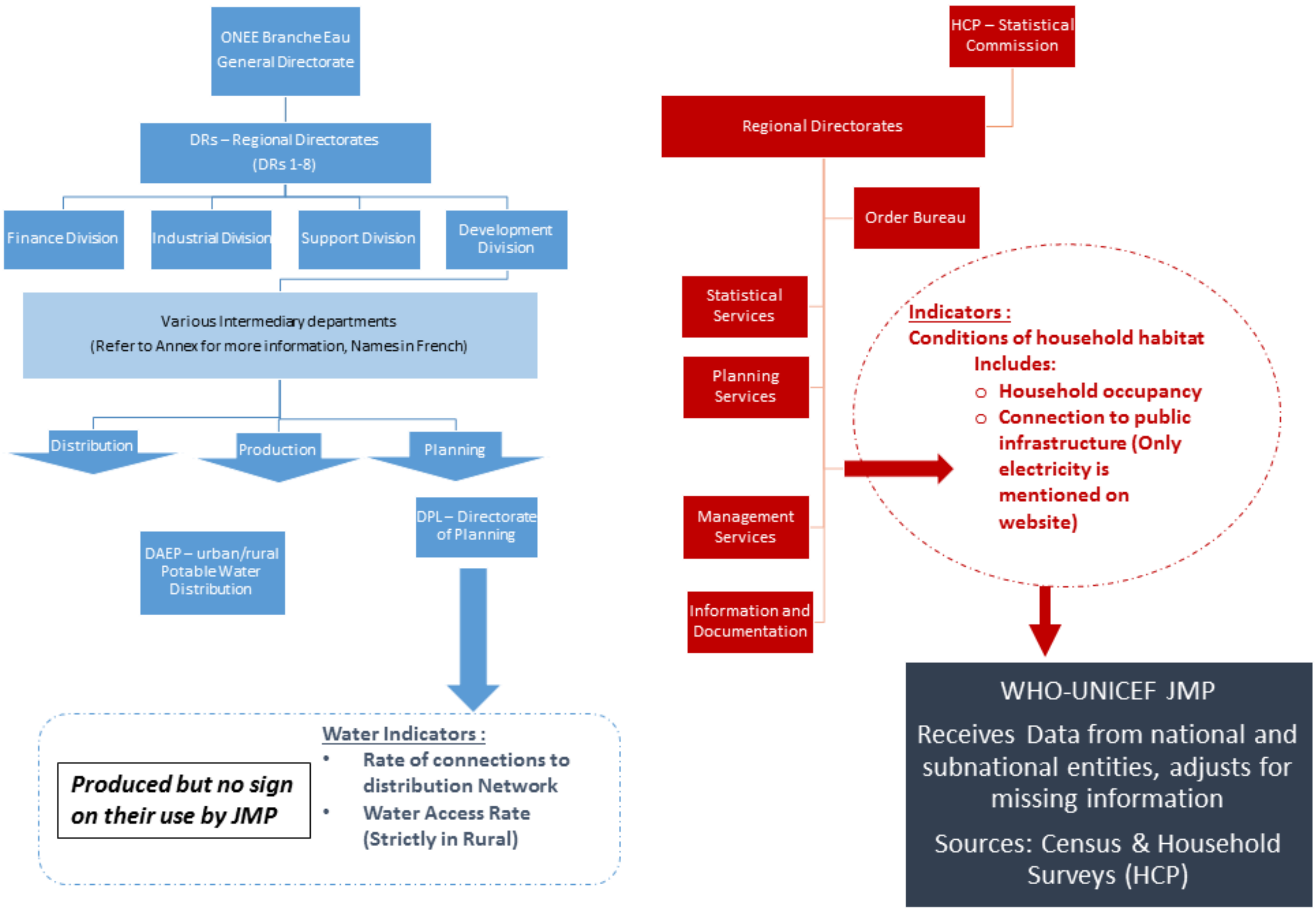


Source: Improved water source, rural (Percent of rural population with access), *http://data.worldbank.org/indicator/SH.H2O.SAFE.RU.ZS?locations=MA*

I've discovered during field work in Rabat that these conflicting numbers have previously caused friction among national entities responsible for measuring water access. According to information from official sources in ONEE, there is still a disagreement among national entities on the correct fraction of the population accessing water.[74] The fact that HCP is UNSD's designated partner agency in Morocco suggests that JMP deliberately chooses household survey data over information from ONEE to produce the indicator on the population's access to water.[75]

Figure 3.3 below illustrates Morocco's complex national indicator workflow for measuring water access, as administered by the water utility company (in blue), and the statistical division HCP that coordinates with national and international carriers on household surveys.

Figure 3.3 – Organizational chart of the national indicator framework [76] - [77]



Source: Haytham Oueidat, "Organizational Chart of the national indicator framework", Unpublished, 6/6/2017

HCP's website does not include a water access indicator. [78] However, the 2004 RGPH (Census) web page lists the fraction of households connected to running water by their respective sources of access (wells, surface water, public fountains and other sources).[79] In 2004 roughly 57.5 percent of the total population had a house connection with running water, while the rest relied on other means to access water. In 2014 the percentage of connections to the water network is recorded without further details on the alternative sources, with 91.3 percent observed in urban areas, and 37.8 percent in rural areas.[80]

It appears that HCP became less involved in capturing conditions of water access in recent surveys, although the JMP reported numbers anyway. JMP values are closer to HCP's than to ONEE's as discussed below.

In 2009 the UNSD organized a workshop in Bangkok for the purpose of monitoring MDG progress, and 28 participant countries were invited to share insights and lessons from their experience with MDG indicators. At that time, MDGs for water and sanitation were goals Nº 7.8 and 7.9. The workshop report recognizes the existence of national/international statistical discrepancies for three reasons: diversity of data sources; heterogeneous methodologies; and conflicting definitions of what is to be measured.[81]

The water access indicator was used as an example, because it suffers from all the problems listed above. There is an added ambiguity: water availability can be defined from two contradictory viewpoints: provider-based or user-based. ONEE is a service provider and their indicators are considered to be provider-based. All other sampled indicators are user-based (HCP, DHS, WHS…). User-based estimates have become more popular because they allegedly capture a still snapshot of the situation, but they are harder to interpret.[82] Furthermore, the user-based approach cannot be valid without the following condition: sampled households must be probabilistically representative of the Moroccan population. In chapter 4, I describe in greater detail how this assumption can be violated.

SHORTCOMINGS OF SURVEYS

Census studies in Morocco are indispensable and represent a foundation for economic planning and policymaking.[83] Census surveys reveal features of the population, its ethnicity, religious composition and the economic status of its diverse communities. The problem with these surveys is that they are inherently costly and rare.

National census surveys are commonly carried decennially in an effort to capture visible change in measurements: Information from every census ought to be interpretable in relation to those from prior censuses. I describe below the sources of unreliability in census measurements and provide some examples to explain how they risk losing consistency.

The most important criterion to preserve in census studies is the "comparability" of insights across time. For a census to generate information for adequate governance and decision making, its metrics ought to be dependable. One principle is that a measurement can be accepted if it can be placed with others in a same time series.

Sabater and Simpson discuss the negative effect of introducing new categories to classify the population's ethnic structure.[84] For example they report problems of under-enumeration of survey subjects in some areas and artificial accounts in others in England and Wales 1991 and 2001 censuses. As a solution to this first problem, they recommend imprecise categories to avoid misrepresentative tabulations.[85]

Another source of inconsistency is due to the geographic boundaries that change with every census. Sabater et. al expose the effect of evolving geographic boundaries on the statistical comparability of findings. [86] Their solution to this challenge consists of harmonizing geographical units.[87] For example, if a subject lived in zone A during census 1 and migrated to zone B at census 2, the boundary that preserves the whole count would engulf zones A and B. To capture the migration effect, these geographies would have to be split to show a positive growth in area A and a negative growth in area B.

Surveys can essentially assume one of two forms: they can be full-scale or sample based investigations (smaller scale). Table 3.3 above regroups both decennial and intermediate surveys performed in Morocco. They differ mainly in the number of subjects sampled.[iii] For example, the full scale census studies of 1960, 1971, 1982, 1994, 2004, and 2014 were based on an exhaustive register of the population.[88] All households filled out questionnaires, and received visits from census officers. The success of this operation depends on the coverage rate (responsiveness of the surveyed population), and the prior knowledge of available households in every census district.

Intermediate household surveys are more recurrent and methodically more diverse than their decennial counterparts. Their sampling procedure is based on a smaller record of households considered as fully representative of the population.[89] When agencies such as the WHO or USAID perform their investigations, they refer to available plans from other surveys, and include data on geographic districts and master samples.[iv] The inquiry volume (sample size) can then be determined by assuming an adequate number of households under predefined budget constraints.[90]

[iii] For detailed descriptions of surveys in table 3.3 refer to Appendix 2.

[iv] A master sample is a collection of units considered to be representative of the entire population

BENEFITS OF SURVEYS FOR WATER PLANNING

According to the targets of SDG 6.1 listed in Appendix 1, everyone in Morocco must be able to access clean water by 2030.[91] If water supply and services are poor, then SDG 6.1 will be hardly attained. The first step towards meeting this target is knowing where everyone is, and identifying water deprived communities. Therefore, demand and supply management are two objectives of the same water planning function. ONEE produces 46 indicators to manage safe drinking water in both urban and rural areas. These values depend on HCP's demographic estimations from census surveys.

Full-scale investigations are not feasible as a yearly task. Intermediate surveys build on the national census using smaller samples, their size varies depending on the purpose of the inquiry: health, economic, or habitat conditions, etc. For example, the DHS survey only covered 0.2 percent of Moroccan households in 2003 and 2004.[92]. Intermediate surveys determine population growth and household occupancy during the years that follow major census events.

Of all the insights offered by intermediate surveys on the population, ONEE only uses their updated demographic data to estimate the percentage of water access.[93]

ONEE's method for calculating water access (Provider-based approach)

In urban areas, ONEE gathers water service subscriptions from its customers and private retailers. Using data on household occupancy from HCP, ONEE determines the number of individuals receiving water to their homes as a fraction of the total population residing in a geographic area.

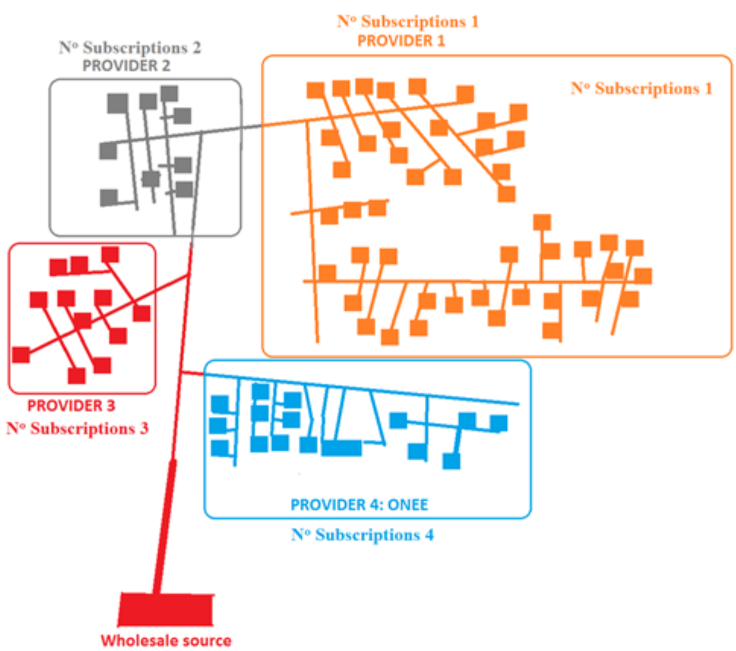
In rural areas, the standard water supply infrastructure is no longer the direct household connection. ONEE evaluates water access by examining the household's distance from the nearest public water source (standpipe or SP). Water sources are more diverse in rural areas than in urban areas. Households often resort to wells or surface water for domestic uses. To remain conservative, ONEE considers individuals located in a distance inferior to 500 meters from the nearest standpipe as having access to water.[94] This maximum allowable distance is also internationally approved as a best practice.[95]

The formulas and figures below illustrate ONEE's method for calculating water access percentages in urban and rural areas. There are clearly discordant definitions for what ideally has to be the same assessment, which is strongly dictated by the categorization of land (urban or rural), and therefore the predominant infrastructure systems in the region.

$$urban\ access = \frac{Population\ connected\ to\ water\ network\ in\ geographic\ unit}{Total\ population\ in\ geographic\ unit}$$

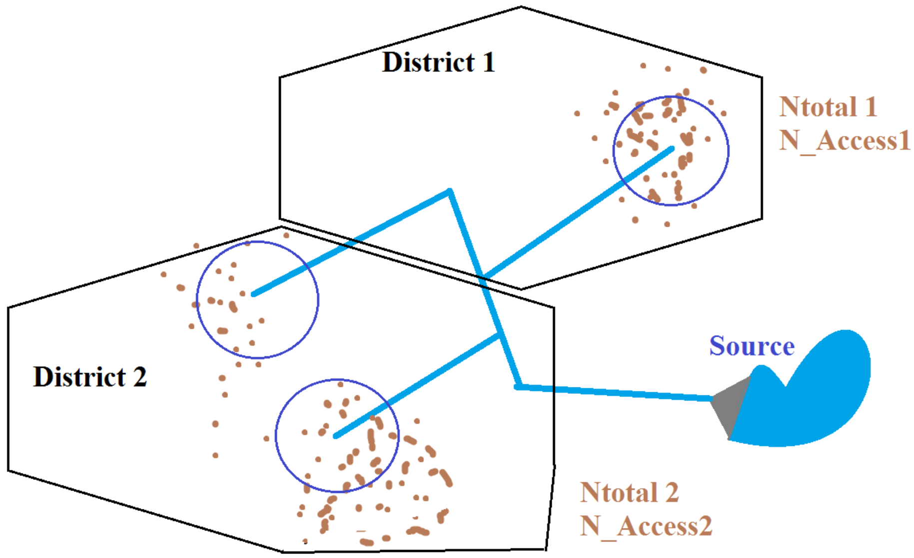
$$rural\ access = \frac{Population\ in\ geographic\ unit\ within\ 500\ m\ from\ nearest\ SP}{Total\ population\ in\ geographic\ unit}$$

Figure 3.4 – Diagram of urban population accessing safe drinking water



Source: Haytham Oueidat, "Diagram of urban population accessing safe drinking water", unpublished, 2017

Figure 3.5 – Diagram of urban population accessing safe drinking water



Source: Haytham Oueidat, "Diagram of rural population accessing safe drinking water", unpublished, 2017

HCP's method for calculating water access (User-based approach)

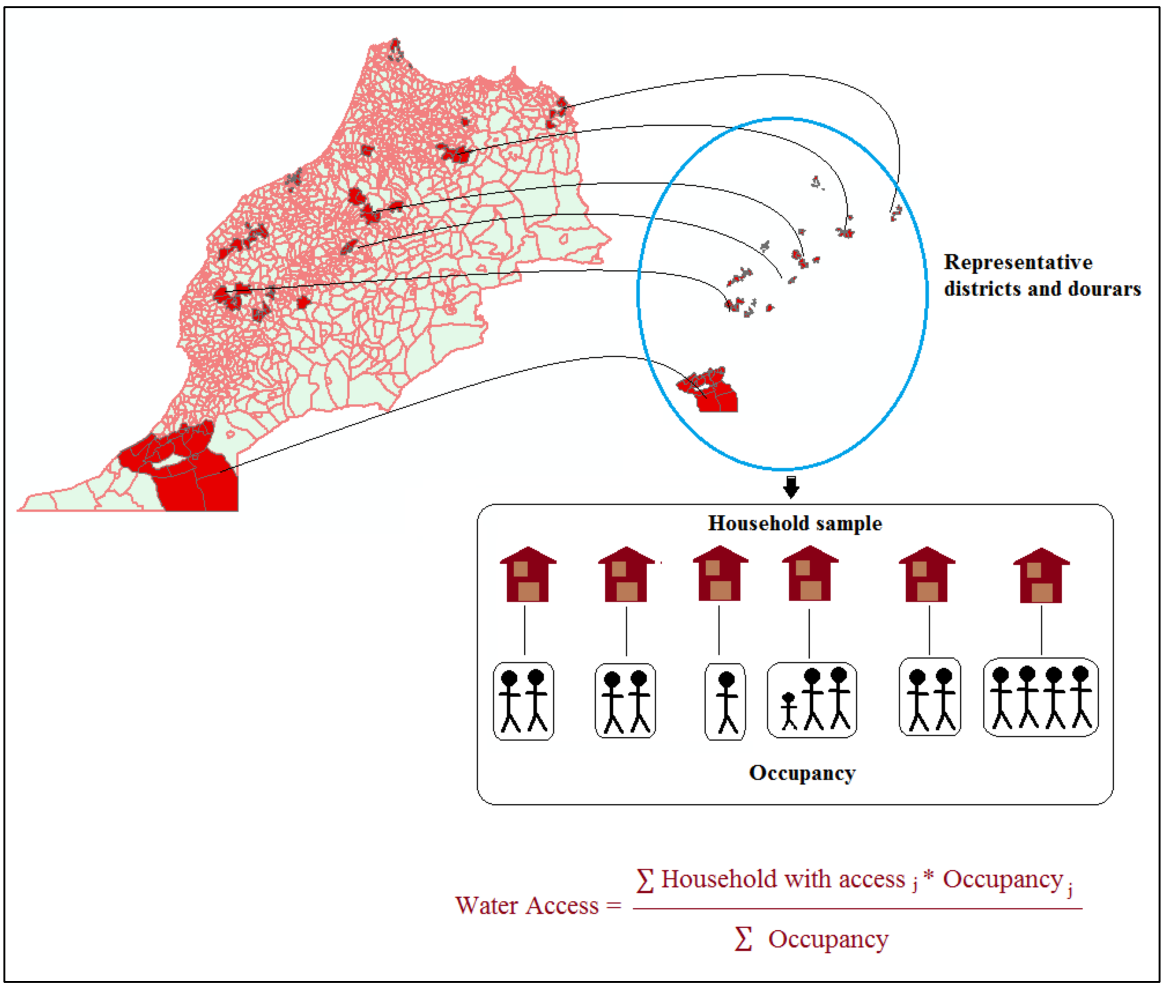
During census and post-census investigations, HCP sends standardized questionnaires to a representative sample of the Moroccan population. The questionnaires include a section on household characteristics, asking the subjects to select their source of water from a list of options. ONEE has pressured HCP to modify the survey by incorporating the following question.

"Is your household within 500 m from the nearest standpipe?" [96]

Prior to this modification, subjects would list the standpipe even when they traveled a distance longer than 500 meters to reach it; these answers would over-estimate water access in rural areas. On the other hand, if the subject was dissatisfied with the 500 meter commute (or less) nothing in the old questionnaire would prevent them from marking themselves without water, thus under-estimating water access in rural areas.

The RGPH FAQs section suggests that HCP modified the latest census questionnaires of 2014 to include the new question.[97] Figure 3.6 below illustrates the user-based method for calculating the water access indicator. Interestingly, their formulas are mathematecally identical to those in ONEE, however they are not probabilistically comparable. Intermediate surveys sample their subjects from an already abstracted record of households, and therefore with a higher tendency for being imprecise.

Figure 3.6 – Method of calculation of water access from intermediate surveys



Source: Haytham Oueidat, "Method of calculation of water access from intermediate surveys", unpublished, 7/17/17

COMPARISON WITH THE AMERICAN COMMUNITY SURVEY

Since 2010, the United States gathered information on household data through an American Community Survey (ACS) which surveyed 1 in 6 American households. [98] It replaced the low-frequency decennial census.[99] The JMP record shows measurements from the National census and the American Housing Survey performed by the US Census Bureau (USCB) in 1990 and 2011.[100] These results suggest that the indicator for SDG 6.1 is rarely computed from census-like surveys in the United States. From a water planning prespective, state and local governments do not wait 10 years for new information to plan their services, especially in cities such as Austin, where the population can double in a 20 year interval.[101] US housing surveys are not paramount for Austin's water planning because utility development strategies follow business models and demand forecasts.[102]

According to the City of Austin, assessing water needs begins by counting the number of household connections from the utility database, and sorting them by customer class (residential, multifamily, commercial, industrial, and wholesale).[103] The city then uses ACS data on household occupancy to project the number of individuals utilizing each connection.[104] This approach resembles ONEE's urban planning strategy. In both the US and Morocco, household surveys are only useful to water utilities for their demographic data.

The ACS was criticized by geographers for tolerating excessive variances. On some accounts the uncertainty exceeded 33 percent, which provoked Macdonald's jovial remark describing the survey as a "[…]"warm" (current) but fuzzy (imprecise) source of data".[105] USCB always reports ACS estimates with their expected margin of error.[106] In contrast, the majority of Morocco's reports do not. While the domain of survey sampling is vast and remains to be explored, numerous methods tested in the ACS succeeded in reducing estimator variances.[107]

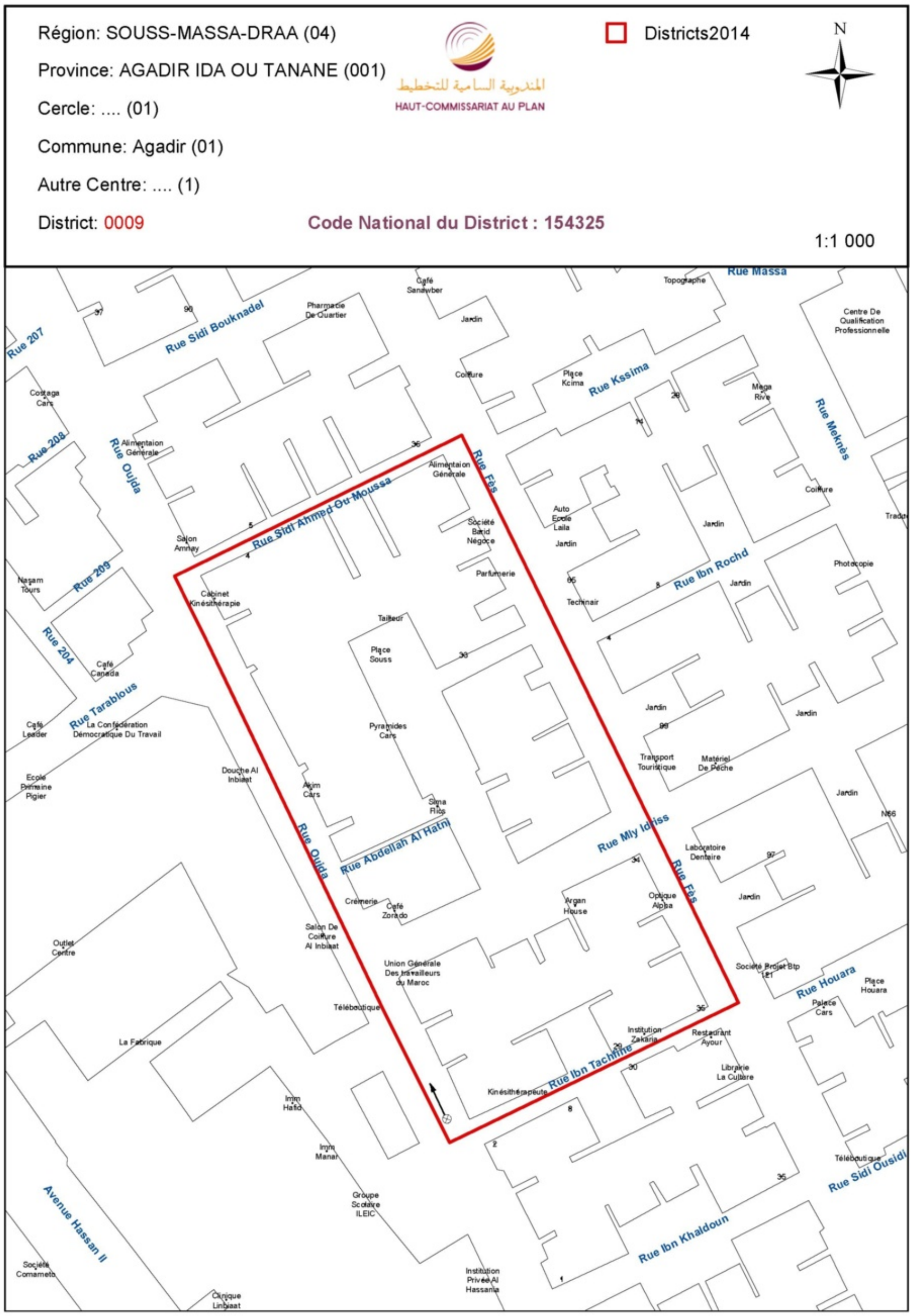
IMPROVEMENTS IN CAPABILITIES OF HCP

The HCP website was upgraded after the 2014 RGPH (census) to facilitate the dissemination of results and achieve a higher level of transparency[108]. Results from the 2014 RGPH can be visualized on a map with corresponding charts and tables. Some sections include public releases from HCP representatives and comments on the innovative techniques employed in the latest surveys. Morocco introduced in the survey of 2004 an automatic system for entering questionnaire responses (Lecture automatique des documents LAD) to preserve the timeliness of observations, to avoid the problems of discontinuity mentioned earlier. This innovation accelerated data entry and allowed HCP to process responses in a duration of two months after completing the survey.[109]

Morocco has taken advantage of technological innovation in satellite imagery to modernize its surveying capabilities. HCP acquired high-resolution imagery and manually carried spatial partitions. Cartography was also important in previous censuses, and map cutouts facilitated the spatial coverage. However, with geographic information systems and the digitization of spatial data, HCP was able to analyze and reveal previously ignored regional aspects of the population. As field operating staff accessed maps with ease, and the quality of the sampling operation improved.[110] Before 2004, hard copy maps of scale 1:2000 and 1:5000 (in meters) delimited the boundaries of urban census districts, but rural maps of the same resolution were not available. The new High –Resolution (Hi-Res) maps allowed HCP to delineate census boundaries in rural areas at much smaller scales using visible infrastructure (asphalt lined roads) and enhanced elevation contours.

HCP refers to the smallest geographic census units as “districts” in urban areas, and “douars” in rural areas (douars can be a single or a combination of units).[111] Figures 3.7 and 3.8 below display their shape and scale differences, and show the increased level of detail that can be obtained from spatial reconnaissance with sharp imagery.

Figure 3.7 – Boundary map of urban census district (scale 1:1000)



Source : Sobha Sobhaz, "Cartographie Du Recensement," Rgph2014, accessed April 19, 2017, http://rgph2014.hcp.ma/Cartographie-du-recensement_a32.html

Figure 3.8 – Boundary map of rural "douar" (scale 1:9000)

Source : Sobha Sobhaz, "Cartographie Du Recensement," Rgph2014, accessed April 19, 2017, http://rgph2014.hcp.ma/Cartographie-du-recensement_a32.html

SURVEY RELIABILITY: LIMITATIONS OF USER-BASED INDICATORS

Azar et. al prove in a paper that using high-res imagery has improved accuracy of population estimations. [112] They demonstrate that scarcely builtup areas (with low density of impervious surfaces) were the first to benefit from higher order image recognition. [113] As is the case with rural areas of Morocco, they would be the first to disappear from sight when images are blurry. Past surveys did not benefit from the same technologies; as a result, their findings are likely to be less accurate. Further research is needed to retrace the magnitude of error in previous surveys by experimenting with older administrative boundaries.

If a survey is able to locate a very small number of households from all corners of Morocco that do not have "improved access" to water, then the result reported as a percentage would lead to the loss of information for the functional entity in charge of "generalizing water access" (ONEE in that case). There are three common weaknesses in user-based indicators:

- The population coverage of intermediate household surveys is small.[v]
- Results are not geographically informative for a national development strategy.
- Samples can rarely be probabilistically representative of the population.[vi]

Household residents access water via direct government services or private providers. If water users are not satisfied with services, they would have many options to petition for improvements. For example, they can request from ONEE a household connection, or a well permit, or they can summon their community to ask for the construction of a public standpipe.

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[v] For example: 0.2 percent coverage from the DHS survey of 2003 cited in previous section
[vi] More on that in Chapter 4.

As a result, the database of a service-provider is equivalent to a continuously updated platform with georeferenced subscriptions for households accessing water, and others petitioning for infrastructure upgrades. If the service-provider has a strong client base and a large regional presence, then they would be a valuable source of data for the computation of water access.

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Chapter 4: Reducing Uncertainty in the water access indicator

In this chapter I evaluate the uncertainty of household surveys with an experiment on two regions of Morocco. I've selected the first location arbitrarily, Rabat-Sale, as a typical urban area of Morocco. In another experiment, I propose a solution that reduces uncertainty using prior knowledge of the water infrastructure network. ONEE has provided data for this experiment on a water generalization project in the rural and urban areas of Safi-Youssoufia. There are distinct indicators of water access for rural and urban areas, but this binary land categorization is subjective and fails to recognize rural districts experiencing urbanization. The new methodology introduces a preliminary sampling phase to scan for early impressions of the geographic area. It uses known geographic features such as maps of infrastructure networks to reassemble the final sample. The proposed solution improves on the design of typical surveys because it allows the preliminary phase to guide household selections, and creates a more representative sample of households.

The experiments indicate how the uncertainty of the water access indicator (error in estimates of the population with access to improved water) can be severe. However, bias and variance can be reduced using a new sampling methodology.

SAMPLING METHODOLOGY OF PREVIOUS HOUSEHOLD SURVEYS (USER-BASED)

Detailed information from Morocco's surveys (see table 3.3) is scarce. To better understand their sampling methodology, the reader is referred to individual descriptions of their sample designs in Appendix 2 at the end of this report. Most surveys list sample sizes but do not disclose information on their geographic components. Some attest to have utilized shared data from other surveys. Nearly all adopt a stratified sampling approach consisting of multiple stages.

In the first stage, the surveying agency decomposes maps of Morocco into primary units (UP's) of certain distinct features not necessarily following administrative boundaries.[114] In the second stage, they draw smaller units (i.e households called secondary units or "US") systematically by an index following an arithmetic sequence. Systematic sampling of housing records is considered a random procedure if the households are randomly distributed in the database.[115]

All surveys use an algorithm to reduce the error of a specific object of measurement and determine the sample sizes.[116] This creates uncertainty in estimates of water access because this maneuver does not minimize errors for the water access indicator. Each survey was meant to investigate a specific aspect of the Moroccan population. None of their samples were designed to preserve the accuracy and precision of the water access indicator. Some survey reports mention that the sample sizes were determined with an added constraint to ensure the reduction of error for other indicators, specifically the one for child mortality. Table 4.1 below displays the error reduction objectives and sample sizes of surveys listed in table 3.3.

Table 4.1 – Sample size and optimization objectives of household surveys from table 3.3

Survey (Agency)	Dates	Sample sizes	Error reduction objective
Recensement General de la Population et de l'Habitat «RGPH» (HCP)	1982 1994 2004 2014	Exhaustive[vii]	NA[viii]
Demographic and Health Survey (US Aid DHS)	1987 1992 1995 2004	- *1987*: 7000 households, 40-120 households per UP[117] - *1992*: 7000 households, 50 average households in urban UPs, 70 average in rural UPs[118] - *1995: 2751* households, subsamples from 1992 baseline survey[119] - *2003-2004*: 12000 households, 40 households per UP on average[120]	Achieving significant estimates for birth and mortality rates[121]
Enquête Nationale sur le Niveau de Vie des Ménages (HCP)	1991 1998 1999 2006	- 1998-1999: 5184 total households, 12 single units per urban UP or compact rural UP[ix], single groups of 12 units in each dispersed rural UPs - 2006-2007: 7200 total households,12 units per "US" with equal probability [122]	Minimizing travel costs[123]

Source: Haytham Oueidat, "Details of household surveys listed in JMP record on Morocco", unpublished, 2017

[vii] Exhaustive signifies that all the population was investigated (The survey is not sample based)
[viii] No information available to declare
[ix] Compact signifies that households are not very dispersed in the rural UP

Table 4.1 – Sample size and optimization objectives of household surveys from table 3.3 (Continued)

Enquête Nationale sur l'Emploi (HCP)	2000 2001 2003 2004 2005 2006 2007	- 2000: 48000 households, of which 16000 are rural[124]. - 2001: 48000 households, of which 16000 are rural[125]. - *2003*: 48000 households, of which 16000 are rural[126]. - *2004*: 48000 households, of which 16000 are rural[127]. - *2005*: 48000 households, of which 16000 are rural[128]. - *2006*: 60000 households, of which 20000 are rural[129]. - *2007*: 60000 households, of which 20000 are rural[130].	NA
Enquête Nationale sur la Consommation et les Dépense des Ménages (HCP)	2001	- *2001*: 15000 households, 12 households per UP[131]	NA
Enquête Nationale sur la Sante de la Mère et de l'Enfant (KoM Ministry of Health)	1997	- *1997*: 44932 households for first level inquiry (63318 female individuals age 15-49). 5686 households for second level inquiry (used for water access)[132].	NA
World Health Survey (WHO)	2003	- *2003*: 4713 total surveyed households (2820 urban, 1893 rural.[133]	NA
Enquête Nationale à Indicateurs Multiples et Santé des Jeunes, (KoM Ministry of Health)	2006	- *2006*: 8094 total households, 1 group of 25 individual households per UP.[134]	Achieving significant estimates for birth and mortality rates[135]

Source: Haytham Oueidat, "Details of household surveys listed in JMP record on Morocco", unpublished, 2017

These parameters display an irregularity in inquiry volumes and versatile purposes in surveys which raises questions on the consistency of findings. Furthermore, the lack of information on the error reduction objectives complicates any attempt to re-evaluate these surveys' reliability.

ESTIMATING UNCERTAINTY OF TYPICAL HOUSEHOLD SURVEYS

Famous statistical procedures

There are many ways to estimate a survey's sampling error, but only a handful are informative for the implementation of experiments 1 and 2. These methods belong to the family of resampling techniques that use iterative computations to solve problems for which analytical solutions are ambiguous and sometimes non-existent. Two well-known resampling methods, the jackknife and the non-parametric bootstrap, are famous for estimating the bias and variance iteratively. The section below provides an annotated reasoning of the jackknife and Bootstrap from a lecture by Hughes.[136] Other renditions of these techniques exist. For example Rust and Rao[137] explain in more detail the application of similar replication methods in survey variance estimation.

Jackknife

The jackknife is a non-parametric method that determines an estimator's bias.

Suppose that n samples are drawn from a population N. The i.i.d. (independent and identically distributed) variables are $X_1, X_2, \ldots, X_n$, and give an estimate $\hat{\theta}$ of θ (i.e the mean of $X_1, \ldots, X_n$). The bias of $\hat{\theta}$ is the difference between the expected value of $\hat{\theta}$ and the actual value of θ that remains unknown. For that reason, a statistic θ_i is needed for each variable of subscript i from 1 to n leaving out variable X_i in every i^{th} iteration (See equation 4.1 for an equation of the jackknife estimator of bias.

$$\widehat{\text{bias\_Jack}} = (n-1)(\bar{\theta} - \hat{\theta}) \tag{4.1}$$

With $\bar{\theta}$ being the mean of leave-out statistics $\theta_{i.}$

And the final bias corrected estimator would be :

$$\widehat{\theta\_\text{Jack}} = \hat{\theta} - \widehat{\text{bias\_Jack}} \tag{4.2}$$

θ_Jack gives statistically sound results up to the second order decimal.[138]

Table 4.2 – List of variables and equations for the jackknife replication method

Method	Variable	Equation	Description	Equation number
	i	-	Replication index	-
Jackknife	$X_1, X_2, \ldots, X_n$	-	Samples drawn in jackknife operation	-
	n	-	Sample size of X statistics	-
	θ	-	True value of the population (mean, median …)	-
	$\hat{\theta}$	-	Estimate of θ after every replication	
	θ_i	-	$\hat{\theta}$ value obtained in i^{th} replication to leave out for the calculation of $\bar{\theta}$	-
	$\bar{\theta}$	-	Average value of all $\hat{\theta}$ estimates while leaving out θ_i	-
	$\widehat{\text{bias\_Jack}}$	$\widehat{\text{bias\_Jack}} = (n-1)(\bar{\theta} - \hat{\theta})$	Jackknife estimator of bias	4.1
	$\widehat{\theta\_\text{Jack}}$	$\widehat{\theta\_\text{Jack}} = \hat{\theta} - \widehat{\text{bias\_Jack}}$	Jackknife bias corrected estimator of bias	4.2

Source: Haytham Oueidat, "List of variables and equations for jackknife replication method", 8/13/2017

Bootstrap

The bootstrap is more general, and produces distribution estimates that expose the variance and the bias of a sample. Instead of leaving out the i^{th} variate with every replication to get i.i.d. statistics, the procedure draws samples of size n, with replacement, from the same population. Similarly to the jacknife, the bootstrapped variance results from statistics obtained from replications as they are themselves i.i.d.

To perform a bootstrap operation, repeat the following steps b times:

- Begin by drawing n $X_1 \ldots X_n$ i.i.d. samples from a given population
- Calculate the estimator of X, $\hat{\theta} = T(X_1, X_2 \ldots X_n)$

The b values of $\hat{\theta}$ would be normally distributed.

The final step is to determine the mean value and variance of $\hat{\theta}$.

The bootstrap variance of the sample (of $\hat{\theta}$s) would be:

$$\hat{v}_{boot} = \frac{1}{b}\sum_{k=1}^{b}(\hat{\theta}_k - \frac{1}{b}\sum_{k=1}^{b}\hat{\theta}_k)^2 \quad (4.3)$$

Table 4.3 – List of variables and equations for the bootstrap replication method

Method	Variable	Equation	Description	Equation number
Bootstrap	k	-	Replication index	-
	b	-	Number of replications	-
	$X_1 \ldots X_n$	-	i.i.d samples drawn from a given population	-
	n	-	Sample size of X statistics	-
	θ		True value of the population (mean, median …)	-

Source: Haytham Oueidat, "List of variables and equations for the bootstrap replication method", Unpublished, 8/13/2017

Table 4.3 – List of variables and equations for the bootstrap replication method (Continued)

Method	Variable	Equation	Description	Equation number
Bootstrap	T	-	Function used to obtain $\hat{\theta}$ based on the estimator's type (mean, median …)	-
	$\hat{\theta}_k$	$\hat{\theta}_k = T(X_1, X_2 \dots X_n)$	Estimator of θ from every k[th] replication	-
	$\hat{v}_{boot}$	$\hat{v}_{boot} = \frac{1}{b}\sum_{k=1}^{b}(\hat{\theta}_k - \frac{1}{b}\sum_{k=1}^{b}\hat{\theta}_k)^2$	Bootstrap estimator of variance	4.3

Source: Haytham Oueidat, "List of variables and equations for the bootstrap replication method", Unpublished, 8/13/2017

A survey on living conditions in Cameroun (ECAM) uses both the jackknife and Bootstrap methods in the sample design.[139] ECAM is very similar to surveys performed in Morocco in its use of a two-level stratified sampling approach to optimize the selection of primary units.[140] The US Census Bureau adopts a method developed by Faye and Train called "successive difference replications" to determine errors of the Current Population Survey (CPS), the Survey of Income and Program Participation (SIPP), and the American Community Survey (ACS).[141]

Description of replication method used in experiment 1

The technique used in the first experiment most closely resembles the bootstrap in that it requires an invariant population to iteratively sample from with replacement. The purpose is to test the efficacy of a typical household survey in capturing the real proportion of the population's with access to improved water after many iterations. The numerical procedure detects bias and variance in the water indicator resulting from the survey's sampling procedure.

Two difficulties arise: there are no real data to sample from, and most surveys only disclose sample sizes. Information on primary units only appears in a handful of surveys.

Suppose that a true record of the population exists. It would be a household spreadsheet with values of 1 for households with access and 0 for those without. Even if some means of access (tap, well, standpipe…) are more "improved" than others, the final judgement results in two unique categories: households with access, and households without. A score-based assignment of water access to the household record risks inflating the uncertainty of estimates because it adds more variability to the values of water access that ought to be compensated with an increase of sample sizes which could often be in multiple orders of magnitude.

In a given location, and with given maps of primary units (UP) and the households they contain, the stratified sampling procedure draws n households randomly from *N* UPs. Each UP yields n values (X_{i1}…..X_{in}) which could be 1s or 0s depending on the household's access to water.

The total access percentage estimate $\hat{\theta}$ from each replication would be

$$\hat{\theta}_r = \frac{1}{N \times n} \sum_{i=1}^{N} \sum_{j=1}^{n} X_{ij} \tag{4.4}$$

And it can be easily demonstrated that the estimator below is unbiased.[142]

$$\hat{\theta}_r = \frac{1}{N} \sum_{i=1}^{N} \frac{1}{n} \sum_{j=1}^{n} X_{ij} \tag{4.5}$$

Every replication yields a different value of $\hat{\theta}_r$. After B replications, the B values of $\hat{\theta}_r$ are in fact possible values of water access from conducting the survey on the same population a B number of times. Once plotted as histograms, they would show the "spread" of B possible estimates around a mean value of $\hat{\theta}$. This spread is the survey's performance metric that defines its precision, and is computed from the stream of B resulting values of $\hat{\theta}$.

The estimated mean $\hat{A}$ of all replications is the indicator's expected value of water access from the survey.

$$\hat{A} = \frac{1}{B}\sum_{r=1}^{B}\hat{\theta}_r \tag{4.6}$$

And the bias is the deviation of $\hat{A}$ from the true mean of the population data A.

$$bias = \left|\hat{A} - A\right| \tag{4.7}$$

The variance takes the same form as the bootstrap variance estimator above:

$$\widehat{var} = \frac{1}{B}\sum_{r=1}^{B}\left(\hat{\theta}_r - \bar{\hat{\theta}}\right)^2 \tag{4.8}$$

With $\bar{\hat{\theta}}$ being the average of B values of $\hat{\theta}$ from the simulation.

The standard deviation is the square root of this estimated variance.

$$\hat{s} = \sqrt{\widehat{var}} \tag{4.9}$$

Table 4.4 - Variables and equations for the replication method in experiments 1 and 2.

Method	Variable	Equation	Description	Equation number
Exp. 1 and 2 replication method	i	-	Index of primary unit (UP)	
	j	-	Index of household or secondary unit	
	r	-	Replication index	
	n	-	Number of households drawn from each UP	
	N	-	Number of primary units in the region	

Source: Haytham Oueidat, "Variables and equations for the replication method in experiments 1 and 2", Unpublished, 8/13/2017

Table 4.4 - Variables and equations for the replication method in experiments 1 and 2. (Continued)

Method	Variable	Equation	Description	Equation number
Exp. 1 and 2 replication method	X_{ij}	-	Household of index j drawn from UP of index i, water access value (1 or 0)	
	$\hat{\theta}_r$	$\hat{\theta}_r = \frac{1}{N}\sum_{i=1}^{N}\frac{1}{n}\sum_{j=1}^{n}X_{ij}$	Estimated water access from every replication of the survey	4.5
	$\hat{A}$	$\hat{A} = \frac{1}{B}\sum_{r=1}^{B}\hat{\theta}_r$	Average water access estimate from all replications at the end of the simulation	4.6
	$\bar{\hat{\theta}}$	-	Average water access estimate at every step of the simulation	-
	$bias$	$bias = \lvert\hat{A} - A\rvert$	Bias of the replicated survey	4.7
	$\widehat{var}$	$\widehat{var} = \frac{1}{B}\sum_{r=1}^{B}\left(\hat{\theta}_r - \bar{\hat{\theta}}\right)^2$	Variance of replicated survey	4.8
	$\hat{s}$	$\hat{s} = \sqrt{\widehat{var}}$	Standard deviation of replicated survey	4.9

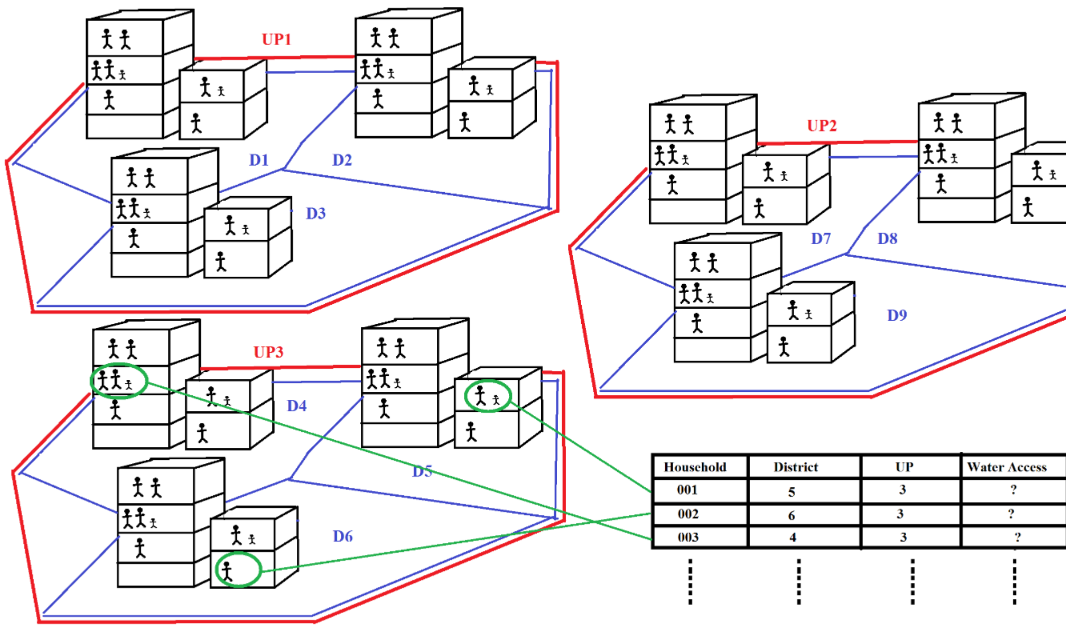
Source: Haytham Oueidat, "Variables and equations for the replication method in experiments 1 and 2", Unpublished, 8/13/2017

Household data architecture

To tackle the first difficulty of limited data, I created my own household data with various proportions of water access to see how different data inputs affect the survey's measurement error. The survey should be tested with various percentages of plausible water access. These different permutations of "real water access" are known as "training data" in statistical nomenclature. The experiment tests the survey on different eventualities of training data to respect the assumption that various "levels of service" or different values of LOS (percentage of the population with access to water) are plausible.

Firgure 4.1 below illustrates the structure of the data frame used in experiments 1 and 2. Households (individuals of a single or group of families) are located in housing units (buildings or houses). These housing units belong to a census district (urban district or rural douar), which in turn belongs to a primary unit, and so forth.

Figure 4.1 – Architecture of water access database



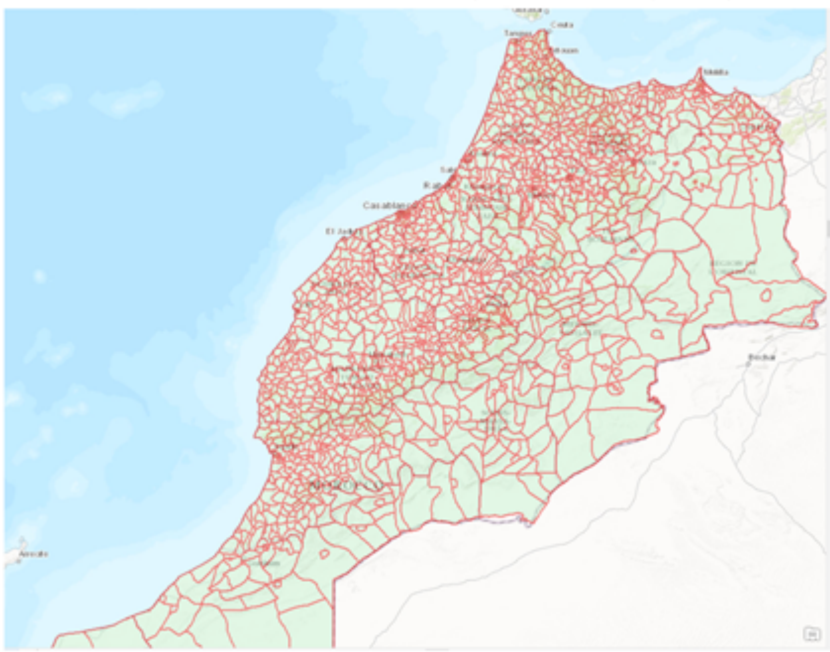
Source: Haytham Oueidat, "Architecture of Water Access Database", Unpublished, 6/1/2017

The data frame assigns values of 0s and 1s to individual households according to predetermined percentages of total water access in a chosen location. This residential database needs to mimic the real spatial distribution of households for the experiment to guarantee valid results.

Creation of Primary Units

Primary units are geographic elements that contain a variable number of census districts. Information on census districts is strictly classified and their maps are not published due to their confidentiality for the electoral process. Consequently I've constructed UPs in this experiment using publically available maps of fourth level administrative boundaries. Figure 4.2 displays the administrative map used in experiments 1 and 2. It holds a total of 1515 UPs spread out across the entire Moroccan territory.

Figure 4.2 – Map of level 4 administrative boundaries used as primary units (UPs)



Source: GADM Database of Global Administrative Areas, [Morocco Level 4 administrative boundaries], http://www.gadm.org/download, 6/1/2017

Creation of Household Units

In order to include a realistic household record per UP to the best possible extent, I processed a Pan-sharpened Landsat GLS image using a Support Vector Machine classification to recognize the land cover of housing and residential units. The pixel resolution has a predefined width and length to emulate the desired dimension of housing units. Figure 4.3 below demonstrates the SVM classification on a satellite imagery of an area in Rabat-Sale. Each pixel represents a household unit that will be filled with values of 1 or 0 to populate the residential record with water access data for further experimentation.

Figure 4.3 – SVM Classification of LandSat8 Image Service in Rabat-Sale

Source: "Pan-Sharpened Landsat GLS Image Service," accessed June 6, 2017, https://www.arcgis.com/home/item.html?id=8ddddc8a5bc412180d84ddf6fdbaeb2

The pixel size determines the fate of the classification. Housing units have varied sizes. The choice of smaller pixels leads to over-counting of residential units per UP. Conversely, choosing larger pixels leads to under-counting.

In Rabat-Sale and Safi-Youssoufia, pixels sizes are 15x15 meters and 30x30 meters respectively. The satellite image service provides panchromatic scenes at 15m resolution, pan-sharpened with natural color bands at 30m resolution from various satellites (Landsat 8, 7 ETM, 5TM, 4, in addition to GLS from years 2000, 2005 and 2010)[143]. Morocco's HCP possesses hi-res satellite imagery that could be exploited for building a similar and more accurate housing record. If it already exists, I was not able to acquire it for the study.

The processed image is actually a matrix with 3 distinct cell values: -1 for no data (the sea), 0 to designate an absence of residential unit, and 1 where a unit is found.I've considered housing units to be equivalent to single households because if a household in a building has access to water, then it necessarily follows that all residents in that building have access.The projected average population per census district adjusts the values of $\hat{\theta}_r$

with equation 4.10. This modified expression of $\hat{\theta}_r$ is a weighted average of water access by population density for a region composed of N primary units.

$$\hat{\theta}_r = \frac{1}{P} \times \frac{1}{N \times n} \sum_{i=1}^{N} p_i \sum_{j=1}^{n} X_{ij} \tag{4.10}$$

Where p_i is the population per UP, and P is the total population in all UPs.

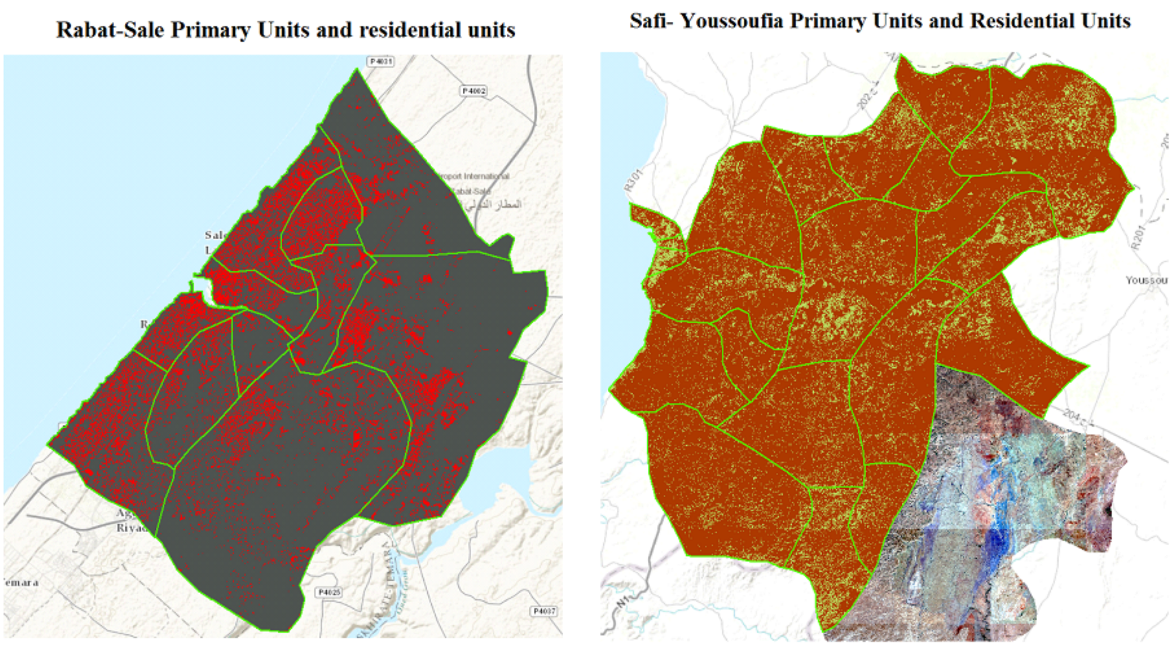
Table 4.5 – Variables and equations for weighting water access estimates at each replication with population density per primary unit

Variable	Equation	Description	Eq. number
i	-	Index of UP	-
j	-	Index of household	-
X_{ij}	-	Household of index j drawn from UP of index i, water access value (1 or 0)	-
p_i	-	Population in UP i	-
P	-	Total population	-
n	-	Number of households selected per UP	-
N	-	Number of UPs	-
$\hat{\theta}_r$	$\hat{\theta}_r = \frac{1}{P} \times \frac{1}{N \times n} \sum_{i=1}^{N} p_i \sum_{j=1}^{n} X_{ij}$	Population density weighted water access estimate of survey at each replication	4.10

Source: Haytham Oueidat, Variables and equations for adjusting replication estimates, Unpublished, 8/13/2017

Figure 4.4 shows the two SVM classified maps from which residential records were created for experiment 1 on Rabat-Sale and experiment 2 on Safi-Youssoufia.

Figure 4.4 – Primary Sampling Units (UPs) and residential units in Rabat-Sale and Safi-Youssoufia

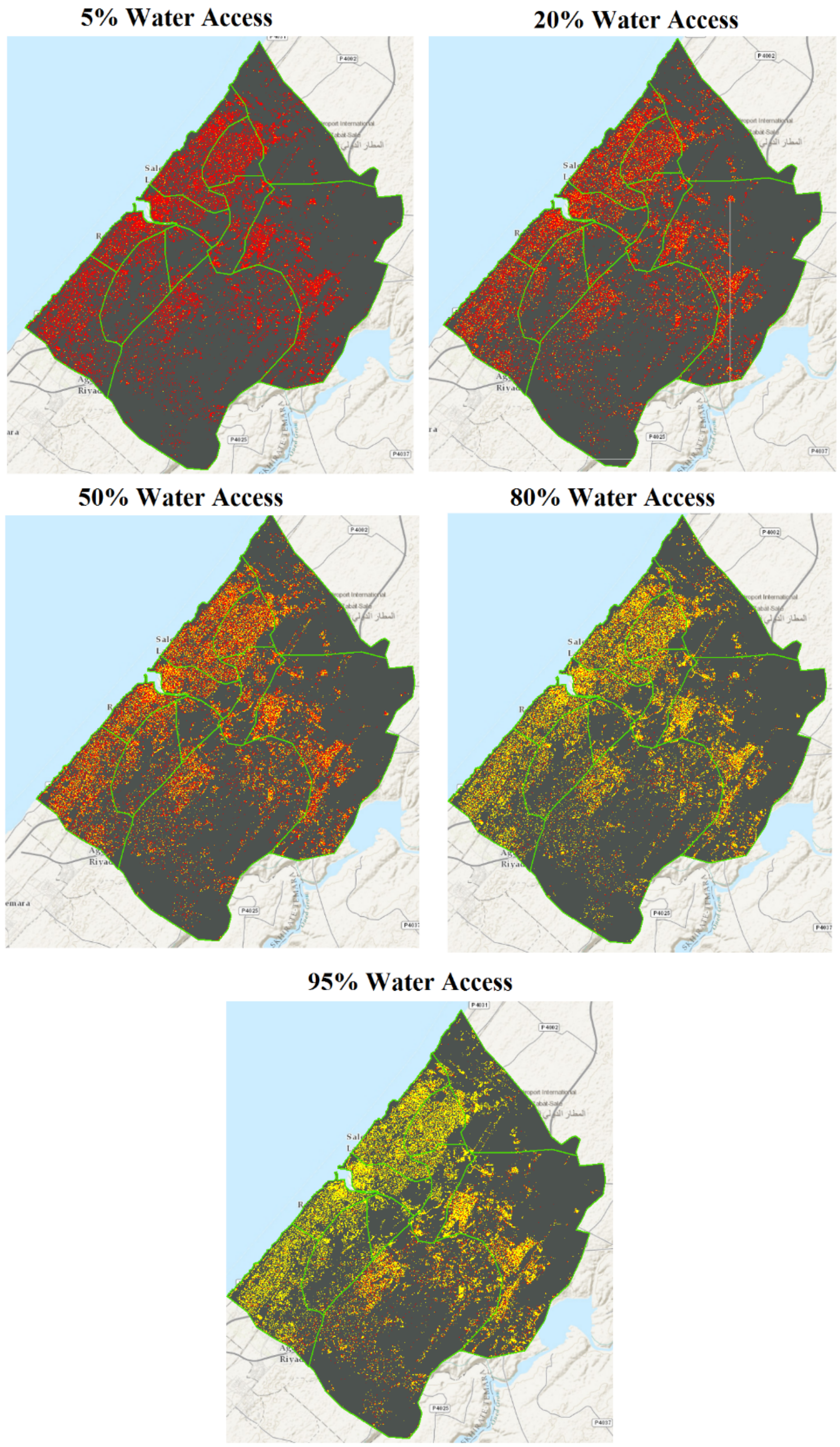


Source: Haytham Oueidat, "Primary sampling units and residential units denoting households in Rabat-Sale and Safi-Youssoufia (Figures not drawn to scale)", Unpublished,, 6/1/2017

Creation of household water access matrices

The first matrices assign binary water access data to the household record in pre-specified proportions. The process uses a pseudo-random number generator to choose households that eventually receive values of 1 or 0 while maintaining the chosen hypothetical proportion of water access for the whole region. For example, for a level of 5%, only 5% of random households in the created records would have a value of 1, and the rest would have a default value of 0. Figure 4.5 below displays matrices generated with a diverse proportions of water access.

Figure 4.5 – Rabat Sale Water Access Matrices

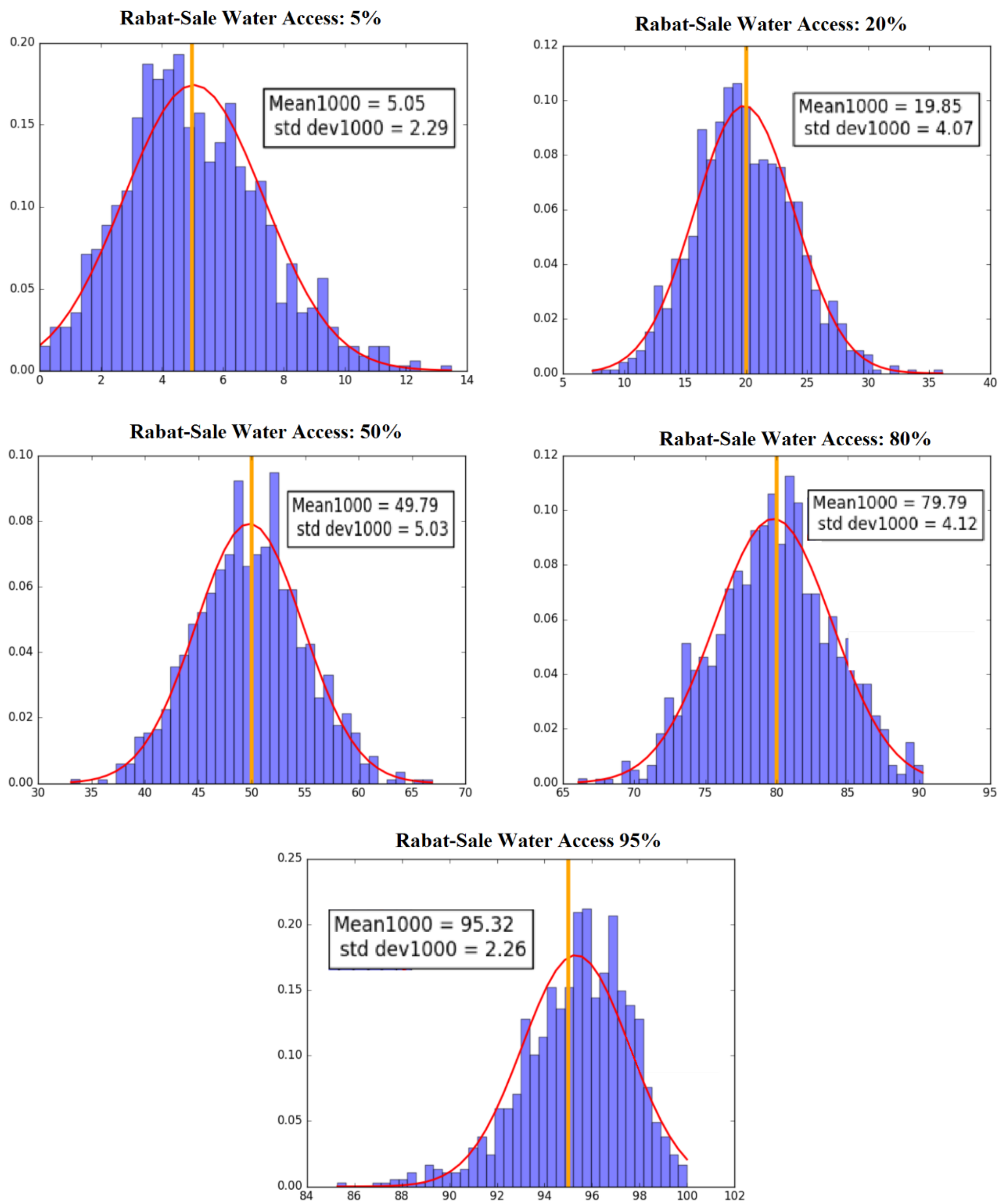


Source: Haytham Oueidat, Rabat- Sale Water Access Matrices, Unpublished, 6/1/2017

EXPERIMENT 1: MONTE CARLO RESULTS OF BOOTSTRAP OPERATIONS ON RABAT-SALE

The survey replicated in experiment 1 is HCP's ECV-ENV-ECM (see the codes in Table 3.3). It uses a more exhaustive sample of UPs than others. Its errors are likely a consequence of either secondary unit selections or the overall sampling strategy. ECV-ENV reports mention that the UP sample had 1848 UPs in 2006[144] and 1500 UPs in 1998[145], and that 12 households (n) are drawn from every primary unit of N total units. As a result, every replication consisted of drawing 12 households with replacement from all 10 primary units of Rabat-Sale. The Python codes for the whole procedure are listed in Appendix 3.

Figure 4.6 – Mean and Standard deviation of ECV-ENV-ECM survey after 1000 replications for various levels of service (5, 20, 50, 80, and 95 percent access to water)



Source: Haytham Oueidat, "Experiment 1Monte Carlo results: Mean and Standard Deviation of ECV-ENV-ECM after 1000 replications on Rabat-Sale household data", Unpublished, 6/2/2017

Convergence theorems prove that bootstrap results will assume the shape of a normal distribution as B tends to infinity: $A \sim N(\mu\,, \sigma)$.

The histograms above show the means and standard deviations of water access percentages. The orange vertical lines represent the true population data from the generated matrices. These results show that the variance is highest when the level of water access is 50 percent with a standard deviation of 5.03% percent. This should not be surprising since it follows from the laws of probability that the standard error of sample estimates for binary data is:

$$s.e = \sqrt{\frac{p \times (1-p)}{n}}$$

With p being the probability of success of the binomial trial. When all n's are the same in every experiment (since we are replicating the same survey with the same number of samples drawn from every UP), this function maximizes at the level where p = 50 percent.

These results show that the variance is largest when the primary units are heterogeneous in water access (when there are as many households with access to water as households without) and smallest when primary units are homogeneous (when the vast majority of households are either deprived of water, or fully access water).

None of these replications gives biased mean estimates of water access (the averages in the small boxes of figure 4.6 coincide well with the true mean shown by the vertical orange line).

To test the effect of added spatial correlation, the last matrix for Rabat-Sale contained water access data allocated according to specific spatial patterns. Hand-drawn polygon shapes represented zones with no access to water. The table below shows the resulting allocation of water access data to the 10 UPs of Rabat-Sale with added spatial correlation.

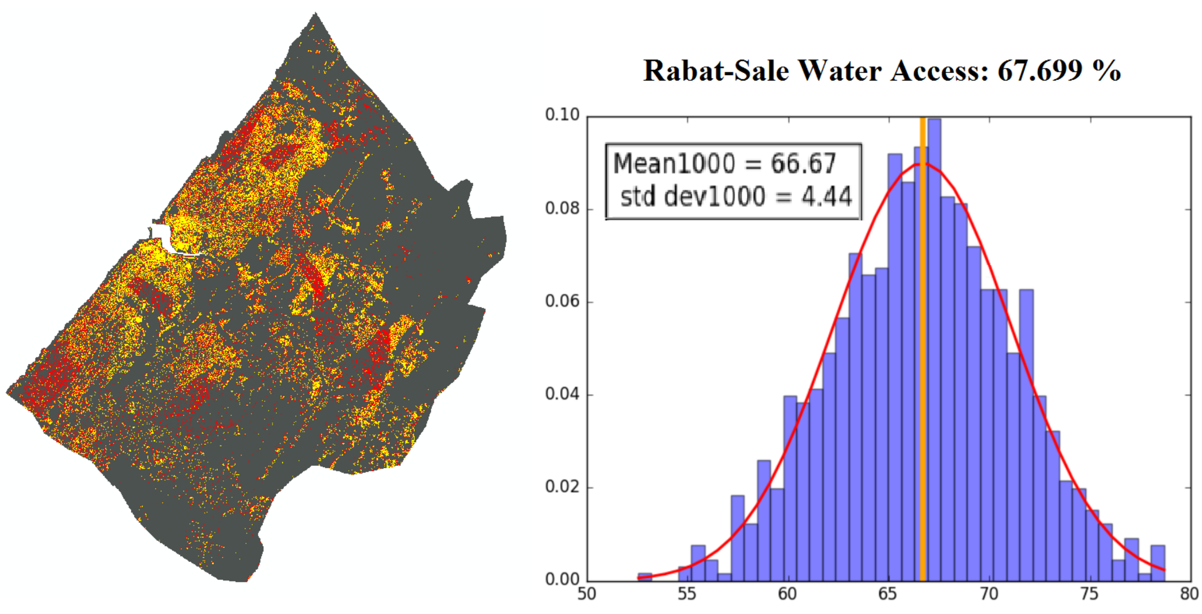
Table 4.6 – Water access of primary units in Rabat-Sale with added spatial correlation

UP	1	2	3	4	5	6	7	8	9	10
Water access proportion	100%	70%	100%	60%	85%	70%	50%	85%	90%	10%

Source: Haytham Oueidat, Water access in primary units of Rabat-Sale with added spatial correlation created for second part of experiment 1, Unpublished, 2017

This distribution of water access amounts to a total of 67.699 percent.

Figure 4.7 – Water access matrix with added spatial correlation and Monte Carlo results of 1000 bootstrap replications using ECV-ENV-ECM



Source: Haytham Oueidat, "Water access matrix with added spatial correlation and Monte Carlo results of 1000 bootstrap replications using ECV-ENV-ECM", Unpublished, 6/2/2017

The histograms are probability density functions, with the Y axis showing the probability of estimates placed on the X axis. Tighter distributions around the true mean (with smaller variance) signify that the surveys are more precise. The best variance resulted from replications on Rabat-Sale having homogeneous water access (5 percent and 95 percent access), and the worst was for a heterogeneous water access of 50 percent.

Let ε denote the accepted margin of error, and let A be the true water access.

And assume that the acceptable measurement error is 5 percent: ε = 0.05.

This survey would be safe to use if its estimates fall in the interval $[A - 5\% \, ; A + 5\%]$ for an accepted "K" percent of the time. The index of reliability K points to the percentage of time for which estimates are within the absolute precision of ε from the true mean A.

Table 4.7 below lists these K values for access levels of 5, 50 and 95 percent.

Table 4.7 – Worst and best reliability scores of survey with respect to true water access

Water access	5%	50%	95%
K	97.5%	67.5%	97.1%

Source: Haytham Oueidat, "Reliability of household surveys with respect to true water access", Unpublished, 2017

The survey is less reliable when water access is heterogeneous. ONEE tracks progress in water access with increments as slight as 0.5 percent. And if that is the accepted benchmark for monitoring national development, then the indicator cannot reliably capture this improvement.

EXPERIMENT 2: REDUCING BIAS AND VARIANCE IN WATER ACCESS ESTIMATES USING A MODIFIED HOUSEHOLD STRATIFICATION TECHNIQUE

Logical reasoning of proposed revisions

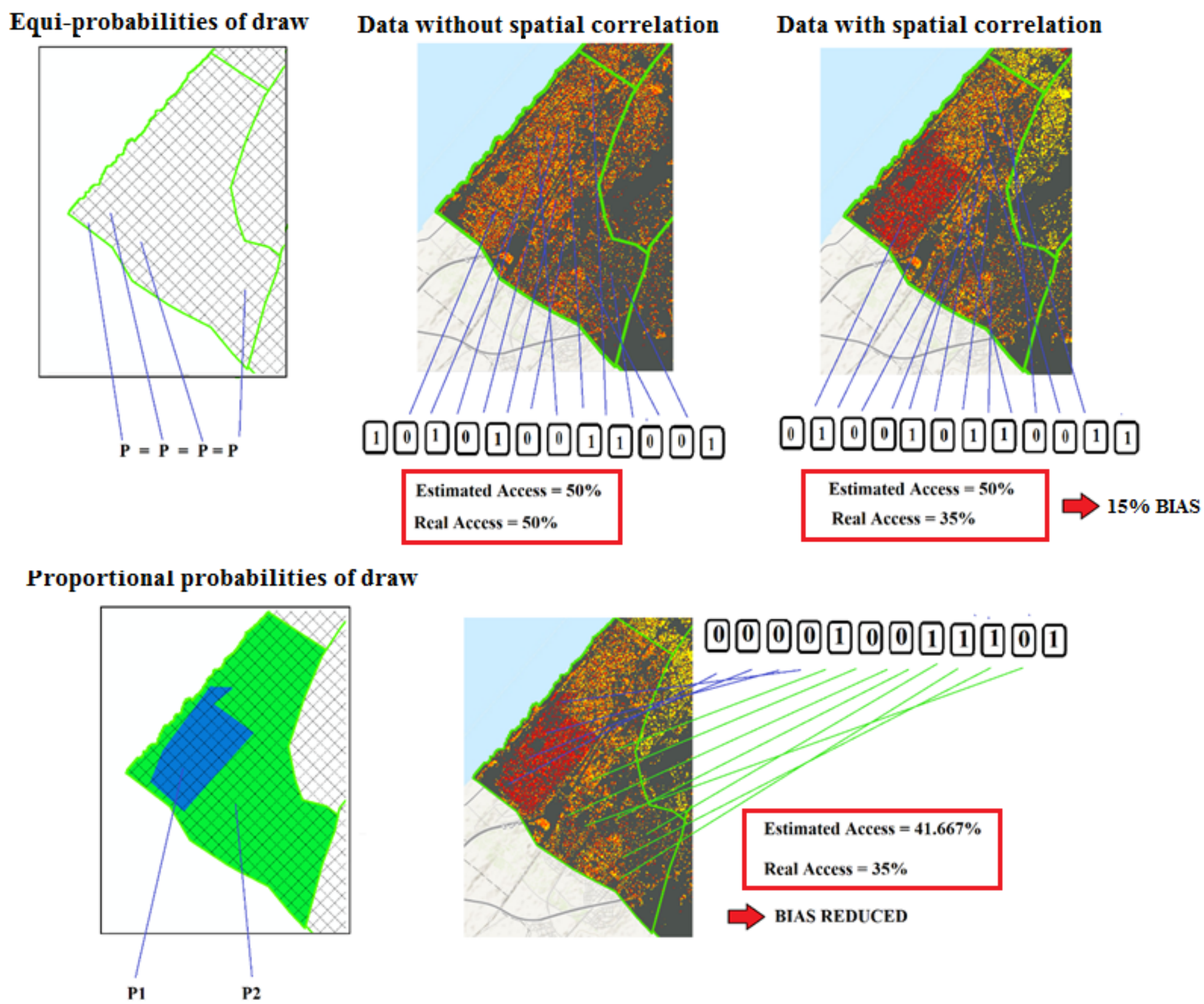
Detecting spatial correlation and heterogeneity in water access

The simulation results have shown that the survey's weakness is in its inability to discriminate between homogeneous and heterogeneous geographic units. The survey relies on pointers such as population density and strata (residential attributes) to select UPs from the Master sample. But experiment 1 shows that the true proportion of water access can also be a decisive criterion for the survey's reliability and the indicator's uncertainty, specifically when the population is heterogeneous.

Drawing more samples is the easy way to resolve this issue. However this becomes wasteful when the primary units are homogeneous. For example, if a UP has a true water access of 95%, drawing additional households from it would only affirm what can be found from only a handful of samples (high/low access level). This is not the case for heterogeneous UPs, and so it is important to differentiate between them in a preliminary surveying phase which tests for heterogeneity in the population's access to water.

Figure 4.8 below explain how spatial correlation can cause bias in the estimates of water access.

Figure 4.8 – Effect of spatial correlation and bias reduction technique



Source: Haytham Oueidat, "Effect of spatial correlation on survey results and technique of proportional probabilities for bias reduction", Unpublished, 6/3/2017

In reality, the green and blue map in the bottom left corner of figure 4.8 is unknown. The new sampling methodology locates in the preliminary phase all the primary units where these spatial patterns are suspected.

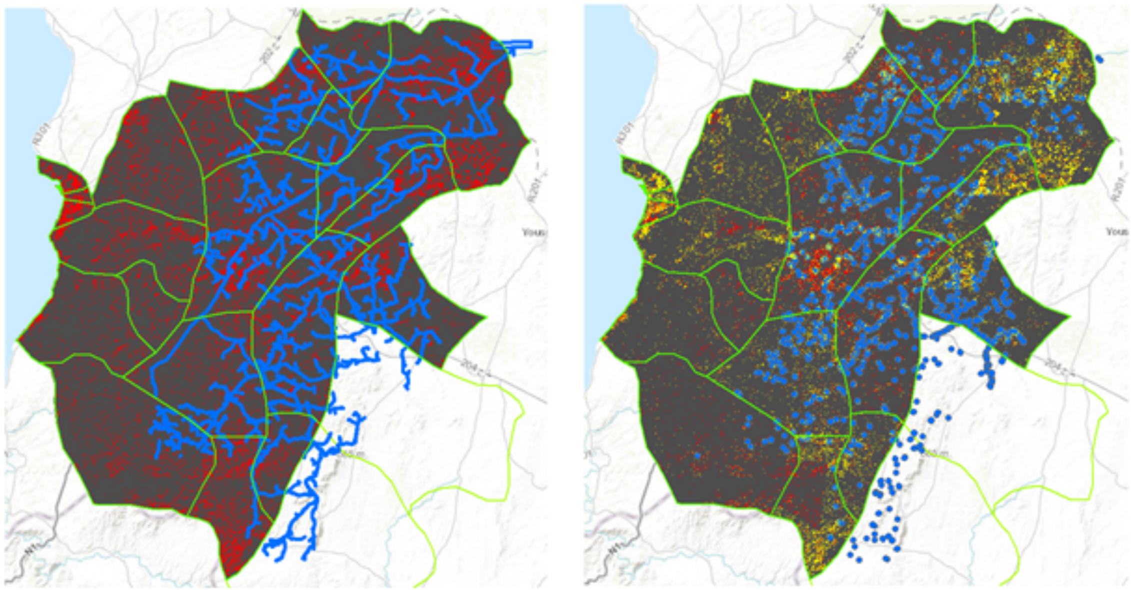
Reconciling user-based and provider-based definitions of water access

ONEE considers households located within a radius of 500 meters from the nearest public standpipe as having access to water. This new information decomposes the geography into two spaces:

- Areas inside the radii around standpipes where households are known to have access to water (A = 1).
- Areas outside of these radii where the household water access is unknown (A = ?).

The new methodology augments the survey's sampling budget because it leaves more samples to spare on the exploration of uncharted primary units. The figure below displays the process of generating water access data in Safi-Youssoufia to test the new procedure. Safi-Youssoufia is a large area composed of 23 primary units greater in size than those in Rabat-Sale, but the primary units ensure that the number of households in each UP is comparable to that of Rabat-Sale. Figure 4.9 below displays the procedure for creating training data following the definitions above. The infrastructure network overlies the household map extracted by SVM and allows the allocation of water access values according to their location inside or outside the standpipe radii. Inside the radii, households would receive a value of A equal to 1. Outside these radii, the household record is populated in a similar fashion to that in experiment 1. The blue dots on the right hand side of figure 4.9 are circular areas of radius 500 meters delimited around public standpipes. They will be referred to as "alveoli" for the rest of this chapter for their resemblance to extremities of a pulmonary system. The alveoli are areas where water access is known to be 1.

Figure 4.9 – Creating spatially correlated water access data for Safi-Youssoufia using map of water infrastructure network



Source: Haytham Oueidat, Creating water access data for Safi-Youssoufia with added spatial correlation using map of water infrastructure network, Unpublished, 6/3/2017

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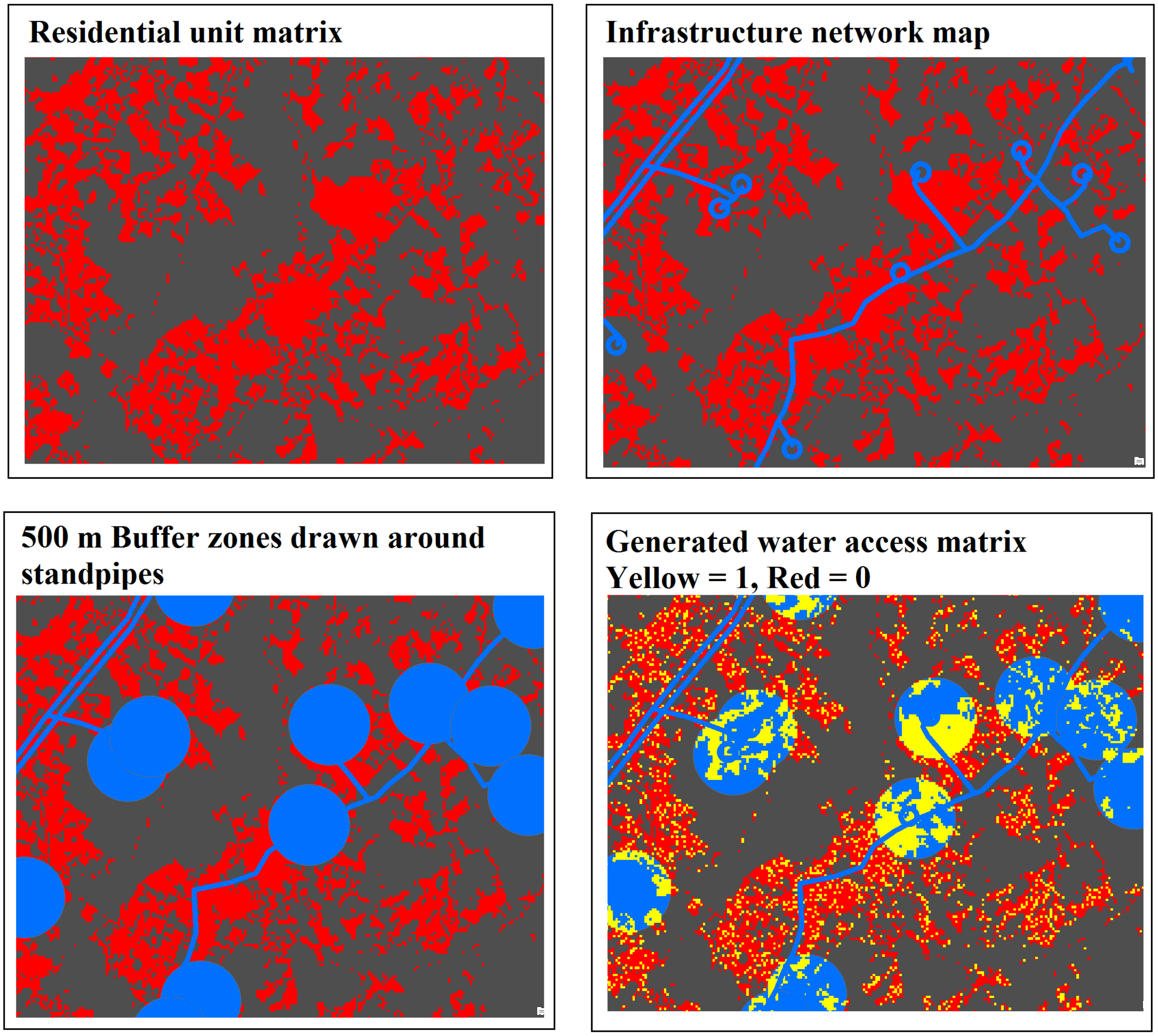
Figure 4-10 provides a magnified view of households accessing water inside and outside of these alveoli.

Figure 4.10 – Generating water access data around standpipes in Safi-Youssoufia



Source: Haytham Oueidat, "Generating water access data around standpipes in Safi-Youssoufia", Unpublished, 6/4/2017

The infrastructure map depicts ONEE's ongoing project in the rural area of Safi-Youssoufia. Table 4.8 below shows the proportions used to construct the matrix of water access for experiment 2.

Table 4.8 – Construction of water access data in Safi-Youssoufia for experiment 2

<table>
<tr><td rowspan="2">Water access in UPs not covered by water infrastructure</td><td colspan="5">Random assignment from options below</td></tr>
<tr><td>20%</td><td>60%</td><td>70%</td><td>95%</td><td>99%</td></tr>
<tr><td>Water access in UP areas covered by water infrastructure outside of alveoli</td><td colspan="5">5%</td></tr>
<tr><td>Water access in UPs covered by water infrastructure inside of alveoli</td><td colspan="5">100%</td></tr>
</table>

Source: Haytham Oueidat, "Construction of water access data in Safi-Youssoufia for experiment 2", Unpublished, 7/21/17

This allocation of data produces a water access level of 69.9% for the population of Safi-Youssoufia.

Background on stratified sampling

The purpose of stratified sampling is to get a representative sample of the whole population. In simulation theory it counts as a variance reduction technique.[146]

Strata are classes of attributes that categorize the population. The stratification of households in household surveys is done on the basis of residential zoning (luxury/modern, industrial, medina, slums, small urban centers…).[147] For some purposes this results in a representative sample of human subjects where all social classes are included in their relative proportion to the whole population. But an individual's access to water may or may not depend on their social status. If it does, then the survey's sample is representative. However, if it doesn't, then the sample risks becoming an assortment of households accessing water in distorted proportions.

From Hasenbein's lecture notes, I explain the mathematical reasoning of stratified sampling with an example of variance reduction for estimates of water access:[148]

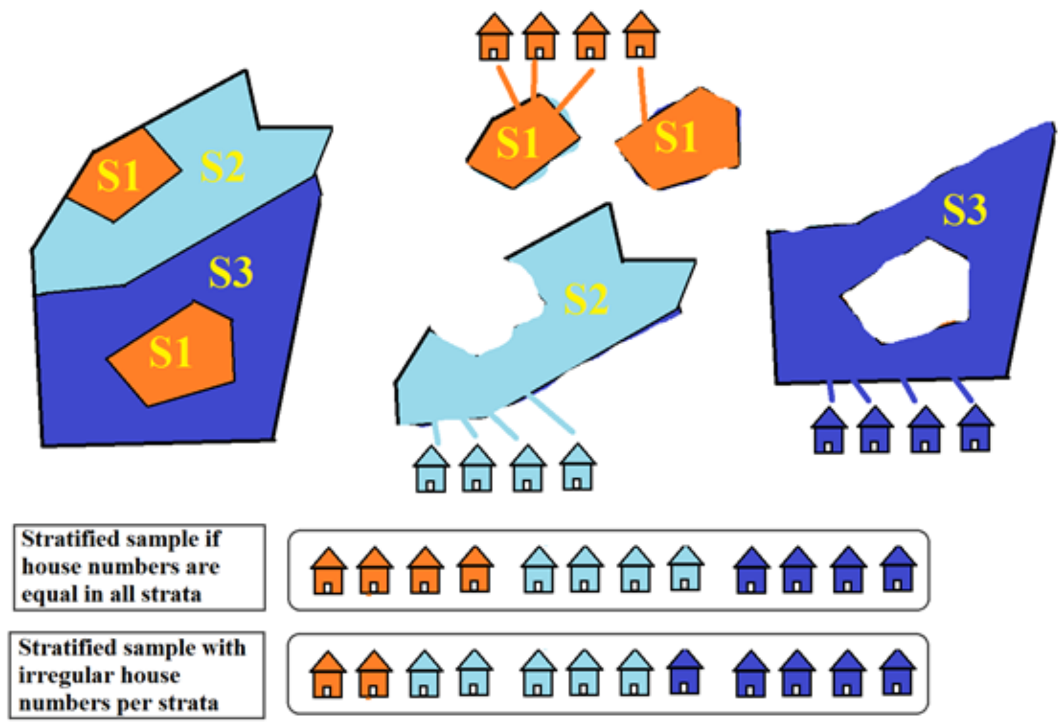
Let X denote the household, and S_1, S_2, S_3, …, S_n be partitions of the "support" of X (the strata used to decompose an initial population with known probabilities).

$$S = \bigcup_{k=1}^{K} S_k \tag{4.11}$$

S is the union of all strata that constitutes the universe for the population's categories.

In the new methodology there will only be two main strata and they are geographic in nature: Known regions of water access (inside of alveoli), and unknown regions of water access (outside of alveoli).

Figure 4.11 – Stratified sampling by geographic stratification



Source: Haytham Oueidat, "An example of stratified sampling", Unpublished, 6/4/2017

If f is the function that should be estimated, then $f(X)$ is defined by the value of a single household's water access, which is either a 1 or a 0.

By expanding the expected value of $f(X)$ using a "tower structure" from the law of total expectations, we get the following formula:

$$E[f(x)] = E[f(X) \mid X \in S_1] \times P(X \in S_1) + E[f(X) \mid X \in S_2] \times P(X \in S_2) + \cdots + E[f(X) \mid X \in S_k] \times P(X \in S_k) \tag{4.12}$$

The expected value of f, $E[f(x)]$ represents the mean value of a household's access to water, which is also the fraction of all households accessing water to the total.

From samples $X_1, X_2, \ldots, X_n$ with n denoting the total number of i.i.d households, the estimate of f becomes:

$$\widehat{f_n} = \sum_{k=1}^{K} P_k \times \frac{1}{n_k} \sum_{i=1}^{n_k} f(X_i^k) \tag{4.13}$$

And its Variance:

$$Var(\widehat{f_n}) = \sum_{k=1}^{K} \frac{{P_k}^2 \times \sigma^2}{n_k} \tag{4.14}$$

With P_k being the prior probability of the k[th] stratum, which represents the relative proportion of households in stratum k to the whole population of households. It could also be thought of as the population density of each primary unit.

The variance reduction of $\widehat{f_n}$ is attained by Langrangian minimization that results in an optimal sample size of:

$$n_k^* = n \cdot P_k \tag{4.15}$$

This sample size is proportional to the household density in each primary unit.

Algorithm used in the new sampling methodology

Table 4.9 – Algorithm used in the new sampling methodology

Phase	Step	Operation
Preliminary phase	1	Define new k primary units (UP*) as the non-intersecting areas of alveoli, and previous UPs from the right side of figure 4-5.
	2	Count the number of households h per UP*
	3	Compute P_k for each UP* as $P_k = \frac{h_k}{\sum h}$
	4	The preliminary phase should cover the widest possible geography with a sample smaller than the old survey's sample, with N being the total number of UPs in previous survey: $$n_{old} = 12 \times N$$
	5	Preliminary sample for each UP* would be: $$n_{prelim}^{*} = n_{old} \times P_k$$
	6	Decompose UP* regions into grids (called G) of n_{prelim}^{*} non-overlapping rectangles (or any other number close to n_{prelim}^{*} that could achieve the largest spatial coverage). Draw one household from each Grid element. The preliminary sample size becomes: $$N_{prelim} = \sum n_{prelim}^{*}$$
	7	Compute the preliminary sample's total and mean water access A_{prelim} and $\overline{X_{prelim}}$ $$A_{prelim} = \sum_{j=1}^{N_{prelim}} X_{prelim\,j}$$ $$\overline{X_{prelim}} = \frac{1}{N_{prelim}} \times A_{prelim}$$

Source: Haytham Oueidat, "Algorithm used in new sampling methodology", Unpublished, 2017

Table 4.9 – Algorithm used in the new sampling methodology (Continued 1)

Phase	Step	Operation
	8	Detect spatial correlation and heterogeneity inside each UP*: - Get x and y coordinates for n_{prelim}^{*} households - Determine centroid for the h_1 households with values of 1: $\overline{x_1} = \frac{1}{h_1} \times \sum x_1$ $\overline{y_1} = \frac{1}{h_1} \times \sum y_1$ Determine centroid for the h_0 households with values of 0: $\overline{x_0} = \frac{1}{h_0} \times \sum x_0$ $\overline{y_0} = \frac{1}{h_0} \times \sum y_0$ - If the UP is heterogeneous and displays spatial correlation then the centroids of access zones and no-access zones should be farther from each other. - Calculate the Euclidian distance between the two centroids: $r_{dist} = \sqrt{(\overline{x_1} - \overline{x_0})^2 + (\overline{y_1} - \overline{y_0})^2}$ Set a threshold on r_{dist} and detect UP**s that appear to be heterogeneous and/or display spatial correlation.

Source: Haytham Oueidat, "Algorithm used in new sampling methodology", Unpublished, 2017

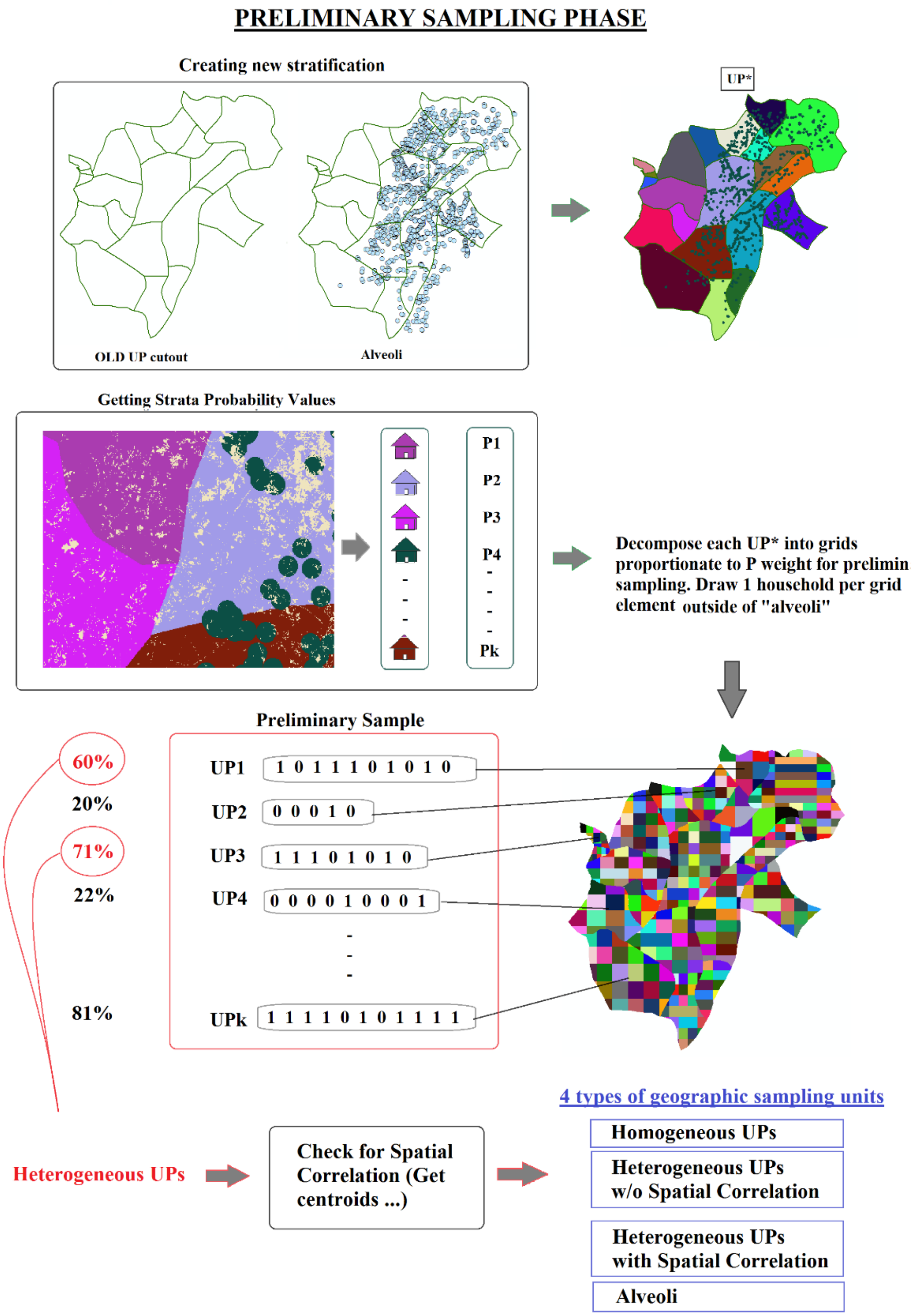
Table 4.9 – Algorithm used in the new sampling methodology (Continued 2)

<table>
<tr><td rowspan="2">Iterative sampling procedure</td><td>9</td><td>Once UP**s have been surveyed for preliminary water access and the nature of their heterogeneity, draw more households for them iteratively. Keep iterating until interrupting condition is met.
For every iteration i:
- Increase the preliminary sample by drawing additional households from each selected UP**: 1 household if heterogeneous only, 2 households if heterogeneous with spatial correlation. We call this increment inc.
- X_{n_i} is the household's water access (0 or 1) in the new sample of total size N_i in iteration i. Compute the new sample's total water access A_i:
$$A_i = \sum_{n=1}^{N_i} X_{n_i}$$
- Compute the i[th] sample's water access percentage:
$$\overline{X_\iota} = \frac{A_i}{N_i}$$
- Compensate the i[th] sample by topping off with a value of 1 to A_i from the households in the alveoli. Their values are deterministic and known to be 1. This will be considered as the bias correcting step of the algorithm because it aids in the convergence towards the true $\overline{X_\iota}$. As more known values are added without being sampled, they would have more influence over the final estimate and therefore the power to reduce uncertainty.
- The bias corrected estimate from the first iteration would yield a water access percentage:
$$\overline{X_{\iota\_b}} = \frac{A_i + inc}{N_i + inc}$$
- *Interrupting condition*: If the bias reduction is less than 1% between iterations, interrupt sampling.
$$i.e: \quad if\ \frac{\left(\overline{X_{\iota\_b}} - \overline{X_\iota}\right)}{\overline{X_\iota}} < 0.01$$</td></tr>
<tr><td>10</td><td>Produce an estimate for water access and give the confidence intervals.
$$\widehat{Water\ access} = \overline{X_{\iota_b}}$$</td></tr>
</table>

Source: Haytham Oueidat, "Algorithm used in new sampling methodology", Unpublished, 2017

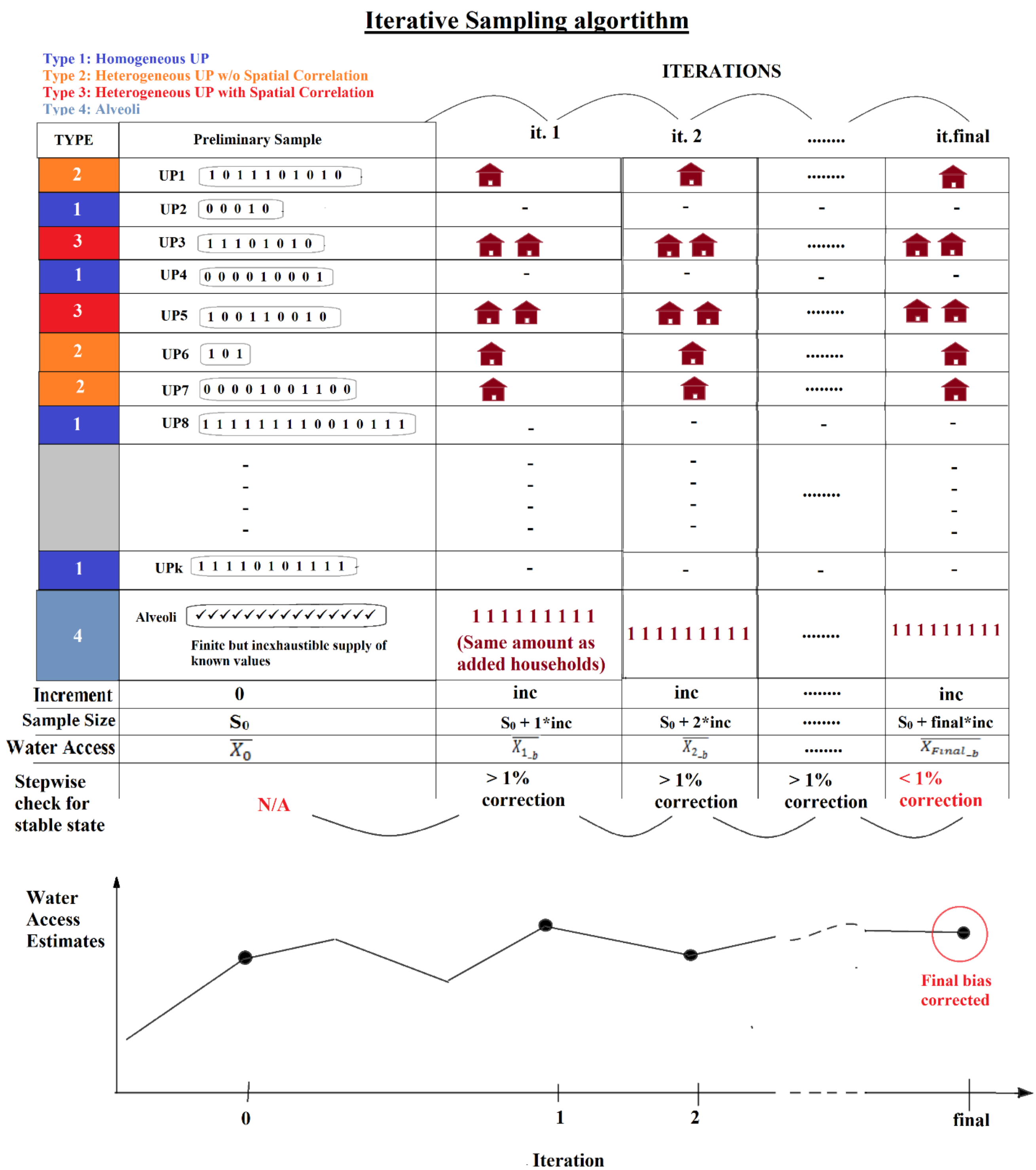
Figures 4.12 and 4.13 below illustrates the step-by-step implementation of this algorithm. This is a specific example of the new survey methodology beginning with a preliminary phase and an iterative sampling phase. The replication of this survey took place after the algorithm was developed. The number of replications was reduced for computational efficiency, and yet experiment 2 results still indicate improvements in reliability.

Figure 4.12 – Preliminary sampling phase in experiment 2 on Safi-Youssoufia



Source: Haytham Oueidat, "Preliminary sampling phase in experiment 2 on Safi-Youssoufia", Unpublished, 6/5/2017

Figure 4.13 – Iterative Sampling Algorithm in experiment 2 on Safi-Youssoufia

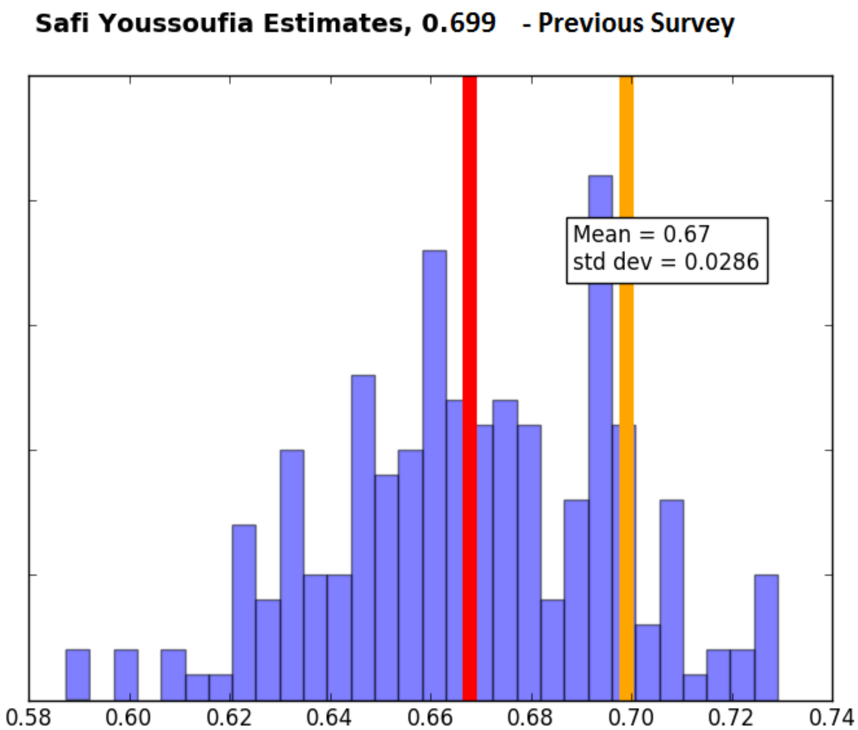


Source: Haytham Oueidat, "Iterative sampling algorithm in experiment 2 on Safi-Youssoufia", Unpublished, 6/5/2017

Monte Carlo results

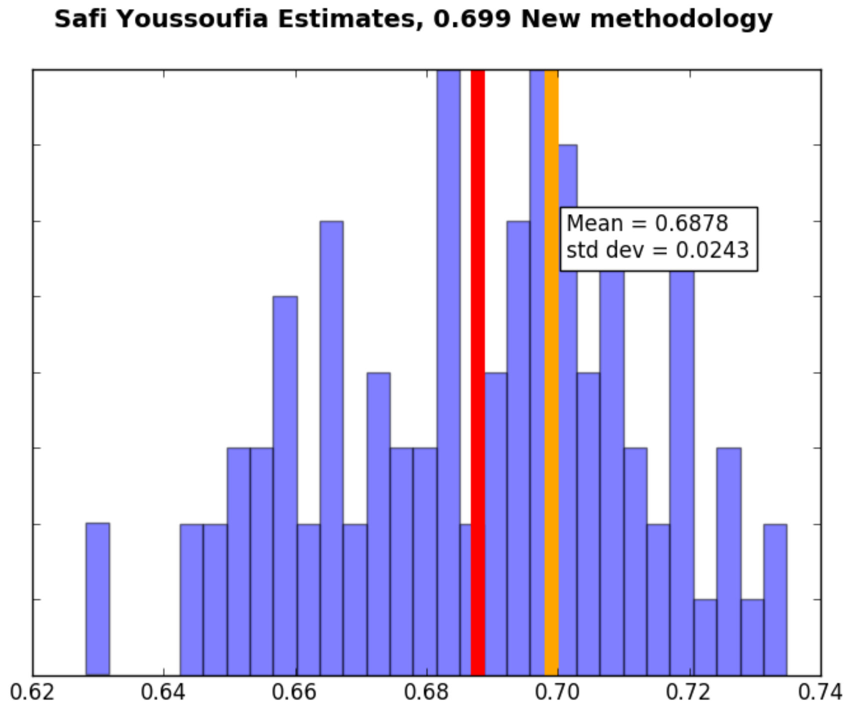
Results from the new survey's replication show a clear reduction in both bias and variance (squared standard deviation).

Figure 4.14 – Distribution of water access estimates using previous survey methodology after 200 replications



Source: Haytham Oueidat, "Distribution of water access estimates using previous survey methodology after 200 replications", Unpublished, 6/5/2017

Figure 4.15 – Distribution of water access estimates using new survey methodology after 100 replications



Source: Haytham Oueidat, Distribution of water access estimates using new survey methodology after 100 replications, Unpublished, 6/5/2017

To compare the two surveys even further, I introduce the concept of coverage. The coverage is the fraction of confidence intervals that successfully contain the true mean μ during a simulation run. The previous survey performed slightly better in that respect.

Figure 4.16: Simulation coverage using previous sampling methodology

```
  Creating samples from old methodology: 12 in all UP's
  1 - [0.5949480289680193 , 0.6967186376986474], mu = 0.699
  2 - [0.6425321182976859 , 0.7408012150356474], mu = 0.699
  3 - [0.58635273609469 , 0.68864726390531], mu = 0.699
  4 - [0.6035602092071204 , 0.70477312412621 3], mu = 0.699
  5 - [0.6251664446011411 , 0.72483355539885 9], mu = 0.699
  6 - [0.6035602092071204 , 0.70477312412621 3], mu = 0.699
  7 - [0.5777740723504501 , 0.6805592609828832], mu = 0.699
  8 - [0.6599728597338295 , 0.7566938069328373], mu = 0.699
  9 - [0.6035602092071204 , 0.704773124126213], mu = 0.699


190 - [0.6165107641707552 , 0.716822569162578], mu = 0.699
191 - [0.6208363791078769 , 0.7208302875587896], mu = 0.699
192 - [0.6208363791078769 , 0.7208302875587896], mu = 0.699
193 - [0.6078727189140596 , 0.7087939477526071], mu = 0.699
194 - [0.5649367431883543 , 0.6683965901449791], mu = 0.699
195 - [0.6251664446011411 , 0.724833555398859], mu = 0.699
196 - [0.6208363791078769 , 0.7208302875587896], mu = 0.699
197 - [0.6035602092071204 , 0.704773124126213], mu = 0.699
198 - [0.5992519911635453 , 0.7007480088364547], mu = 0.699
199 - [0.6208363791078769 , 0.7208302875587896], mu = 0.699
200 - [0.6468851328411678 , 0.7447815338254988], mu = 0.699
Percentage coverage: 0.785 %

Simulation over, {} replications
Total runtime:  13.265469483534496  minutes
```

Source: Haytham Oueidat, "Simulation coverage results from previous sampling methodology", Unpublished, 6/5/2017

Table 4.10 – Comparison of simulation results from previous and new sampling methodologies

	Previous Methodology	**New Methodology**
Simulation replications	200	100
Simulation runtime	0 hours,13 mins, 16 seconds	3 hours, 42 mins, 43 seconds
Mean	0.67	0.6878
Standard Deviation	0.0286	0.0243
Average Sample Size	276	483.2
Coverage	78.5%	78%

Source: Haytham Oueidat, "Comparison of simulation results from previous and new sampling methodologies", Unpublished, 7/21/2017

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Policy recommendations for national and international agencies

In this report I explained the role of the international community in collecting and publishing global statistics to monitor the progress of SDGs and previously MDGs. Many indicators have been ranked according to their years of undergoing amelioration, and many of them are still liable to rank changes.

Development is an item of national pursuit that nations need to be properly equipped for. Progress begins with an introspection on present conditions, and the willingness to learn from trends of the past. Indicators can either benefit or harm the image of developing nations, so they need to be produced with much care and honesty. The UNSD has gone great lengths to institute a functional framework with its national partners, championing universal conventions that have improved national reporting. There is a push towards a standardization of techniques among member parties that seems to defeat at times the purpose of preserving statistical accuracy and precision. Cutting edge technology, and the diversity of data sources will not be able to rescue the imperfections of national development if they are not fully exploited to render useful and valid indicators.

PROBLEMS ENCOUNTERED IN THE RESEARCH:

- Superficial reporting of error estimates by the national statistical agency. Error estimates are an important component of any measurement, and despite the breadth of content in survey reports, only one seemed to mention them. Chapter 4 has shown that there are many ways to calculate survey errors, and therefore the numerical approach or statistical package that was used to compute them should be disclosed.
- International agencies share little information on the procedure that develops country indicators from national statistics. Survey results officially released by the

national agencies go through an intermediate approval phase. Once beyond this barrier, they circulate into the system. More clarity is needed on the empirical methods used to adjust national statistics for their country profiles. This became clear when I've made the observation in Appendix 2 that the most recurrent survey used for the water access indicator in Morocco was the one on employment and labor, which did not survey households for their water access.

- Discords over the definition of indicators causes conflicting estimates. When nations release their statistics they speak for themselves with numbers that represent them. But some interests from within do not often align. More sensibility towards these national tendencies could unveil the hidden story behind the numbers. There is much to gain from harmonizing indicator definitions as it leads to national consensus, and synergy in joint statistical efforts.
- Nation scale indicators are not effectively designed to achieve actual development progress. The indicator for goal 6.1 is not helping water resource institutions plan better or respond to the need of the population.

PROPOSITIONS FOR SUSTAINABLE DEVELOPMENT GOAL 6.1 "ENSURING AVAILABILITY AND SUSTAINABLE MANAGEMENT OF WATER AND SANITATION FOR ALL"

- Reconciling service-based and user-based indicator definitions: I've shown in this report one way of configuring user-based surveys to provider-based preferences. Using spatial data for water infrastructure allows for better selections of primary sampling units, and more representative specimens of the population. I've shown with an application of this methodology that the surveys would result in lower uncertainty.
- Promoting the idea of a sustainable census for water, a distinct national survey, strictly purposed to investigate water access household conditions. The priority was

previously given to the most pressing concerns. Water access investigations have always taken part of surveys meant primarily for other purposes, and as a result they have never been able to unlock the full potential of all of their measurements. On that account, even a "tier 1" indicator can still be improved. Prioritizing water access in a survey of its own is now a necessity, it would produce a more accurate, precise, and instrumental indicator for water planning and national development.

Appendices

APPENDIX 1. LIST OF GOAL 6 CATEGORIES AND THEIR CORRESPONDING INDICATORS

Table A.1 – Objectives for SDG 6

Goal 6. Ensure availability and sustainable management of water and sanitation for all	
6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all	6.1.1 Proportion of population using safely managed drinking water services
6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	6.2.1 Proportion of population using safely managed sanitation services, including a hand-washing facility with soap and water
6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	6.3.1 Proportion of wastewater safely treated
	6.3.2 Proportion of bodies of water with good ambient water quality
6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	6.4.1 Change in water-use efficiency over time
	6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources
6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	6.5.1 Degree of integrated water resources management implementation (0-100)
	6.5.2 Proportion of transboundary basin area with an operational arrangement for water cooperation
6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	6.6.1 Change in the extent of water-related ecosystems over time
6.a By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies	6.a.1 Amount of water- and sanitation-related official development assistance that is part of a government-coordinated spending plan
6.b Support and strengthen the participation of local communities in improving water and sanitation management	6.b.1 Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management

Source:
http://unstats.un.org/sdgs/indicators/Official%20List%20of%20Proposed%20SDG%20Indicators.pdf

APPENDIX 2. HOUSEHOLD SURVEYS IN MOROCCO

Recensement General de la Population et de l'Habitat «RGPH» (HCP)

Dates: 1982, 1994, 2004, 2014

Description:
The RGPH is a decennial census in which the population is surveyed exhaustively[149], there is no abstraction of the full population. Households are visited to determine primarily the demographic attributes of census districts. A record of representative primary units is defined from the full investigation to aid subsequent post-census surveys in their sample selections[150].

Demographic and Health Survey (US Aid DHS)

Dates: 1987 – 1992 – 1995 – 2004 (Code: EPSF)

Description:
Official reports are available for all the dates mentioned above. The surveys relied on updated "master samples" of primary units derived from the periodic RGPH[151] (i.e. the 1987 survey was based off of the 1982 RGPH database and etc.).

Sample Design:
The procedure begins by systematically sampling primary units (UPs) with probabilities proportional to household occupancy and number of households in each UP[152]. Secondary units (US) are then drawn in the form of household groups "grappes" of variable sizes with weights relative to the final sample size. To explain this technique in simpler terms, UP's that manifest a higher population density and household numbers are more likely to be selected in the first stage to form the master sample. As a result, some households would belong in a higher frequency to some of the UP's than to others in that master sample. This fact would increase their likelihood of being drawn in the second sampling stage. However, the secondary sample needs to be probabilistically representative of the full initial household population present in all UPs. It is distorted in its current form since some households are more favored in the selection than others in the second stage, simply for being more numerous in some UPs than in others. In order to correct for that "inflation" of prior probabilities, household group sizes are modified to reduce/increase their final proportion if they were more advantaged/disadvantaged by the first UP draws.

Sample Size:
- 1987: 7000 households, 40-120 households per UP[153].

- 1992: 7000 households, 50 average households in urban UPs, 70 average in rural UPs[154].
- 1995: 2751 households, subsamples from 1992 baseline survey[155].
- 2003-2004: 12000 households, 40 households per UP on average[156].

Sampling optimization objective:

- Achieving significant estimates for birth and mortality rates[157].

Enquête Nationale sur le Niveau de Vie des Ménages (HCP)

(Previously known as « Enquête Nationale des Conditions de Vie »)

Dates: 1991 – 1998 – 1999 - 2006 (Code: ECV – ENV)

Description:
The survey was one of HCP's post-census investigations to facilitate the execution and monitoring of human development programs responding to essential needs of the population. The findings described household characteristics, including their means of access to water.

Sample Design:
The sample frame of this survey is similar to that of the DHS, it is issued from a stratified sampling maneuver of two levels. The only obvious difference between the two surveys is in the first stage selection of UPs, and the second stage draws of households (units or groups). The 1998 report does not mention the logic used to extract primary units from the existing master sample, but explains how the households are chosen in the second stage[158].

Sample Size:

- 1998-1999: 5184 total households, 12 single units per urban UP or compact rural UP (Compact here means that households are not very dispersed in the rural UP), single groups of 12 units in each dispersed rural UPs. In the latter case, group sampling was chosen to minimize the survey's travel costs[159].
- 2006-2007: 7200 total households, three level sample (households are drawn from the secondary units (US)), 12 units per US with equal probability of draw[160].

Sampling Optimization Objective:

- No information available.

Enquête Nationale sur l'Emploi (HCP)

Dates: 2000 – 2001 – 2003 – 2004 – 2005 – 2006 – 2007 (Code: ENE)

Description:
HCP realizes these surveys continuously to provide timely updates on the labor market, and to derive indicators on economic/financial activity, as well as work opportunity[161]. It may be difficult to imagine the use of these findings in the estimation of water access, but they did feature in the JMP list. Their reports only expose the survey results and provide little detail on the sampling methodology. There is no direct inquiry on household water conditions, and therefore we can assume that results are only used by the JMP as control statistics for regressions on missing data.

Sample Design: No information available.

Sample Size:
- 2000: 48000 households, of which 16000 are rural[162].
- 2001: 48000 households, of which 16000 are rural[163].
- 2003: 48000 households, of which 16000 are rural[164].
- 2004: 48000 households, of which 16000 are rural[165].
- 2005: 48000 households, of which 16000 are rural[166].
- 2006: 60000 households, of which 20000 are rural[167].
- 2007: 60000 households, of which 20000 are rural[168].

Sampling Optimization Objective:
- No information available.

Enquête Nationale sur la Consommation et les Dépense des Ménages (HCP)

Dates: 2001 (Code: ECM)

Description:
This survey featured as HCP's fourth investigation on the spending, consumption habits, and living conditions of the Moroccan population since the Kingdom's independence[169]. The unit of measure is again the household and the survey design was partially similar to other surveys of HCP.

Sample Design:
The seasonality of household spending (depending on the availability of certain consumption items such as vegetables and grains) meant that the survey had to be spread

over the course of a year to fully capture the fluctuations[170]. The master sample constructed from RGPH 1994 was used to obtain a two-level stratified sample covering 1/294th of the total Moroccan population[171]. The ECM report mentions new information on the definition of primary units: UPs of this master sample consisted of geographic areas comprising 2-3 census districts[172].

Sample Size:

- 2001: 15000 households, 12 households per UP[173].

Sampling Optimization Objective:

- No information available

Enquête Nationale sur la Sante de la Mère et de l'Enfant (KoM Ministry of Health)

Dates: 1997 (Code: ENSME)

Description:
The survey on maternal and child health was carried in a duration of 7 months by a taskforce of the Ministry of Health and the planning directorate on a multilevel nationally representative sample[174]. The findings produced indications on household and respondent characteristics, the population's fertility, family planning, reproductive health, STDs/AIDS, Infant and Child health, and mortality rates.

Sample Design:
The first level survey identified individuals that would be receiving the questionnaires the next day. Some basic elements were addressed in first level questionnaire for households (i.e occupancy), and first level questionnaires for individuals (relationship to household head, age, sex…)[175].
A smaller subset of households from the first level were chosen to form the second level sample. They received three types of questionnaires, one of which explored with greater detail the additional characteristics of the household (source of water, type of toilet…)[176].
The report does not list any geographic component for the survey and will therefore not be used as a baseline in the numerical procedure.

Sample Size:

- 1997: 44932 total households for first level inquiry (63318 individuals, females age 15-49).
- 5686 households for second level inquiry (used for water access)[177].

Sampling Optimization Objective:

- No information available

World Health Survey (WHO)

Dates: 2003 (Code: WHS)

Description:
The survey targeted Morocco's *de facto* population (a representative portion of all people living in the country). WHS was launched to gather data on all WHO member states related to their population health and existing health systems. WHO stresses the need for comparability, relevance, and reliability of results, and therefore grounds its survey on a standard design methodology applicable to all participating nations. There is additionally an emphasis on the geographic assignment of data to enable the capacity for the analysis and visualization of results using thematic maps[178].

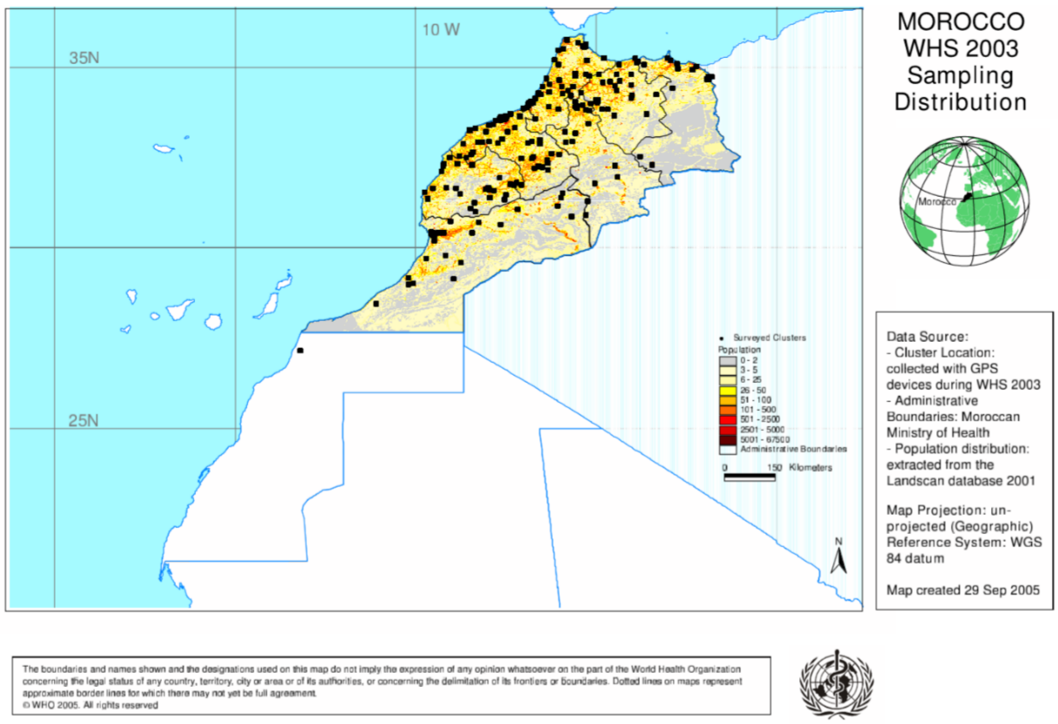
Sample Design:
The adult members of the general population are first identified along with their respective households using a stratified sampling approach[179]. A single individual per household is later selected randomly to serve as the survey subject[180]. The report introduction states that each country report would describe the detailed sampling procedure, but it only provides a sample allocation table[181].

Sample Size:
- 4713 total surveyed households (2820 urban, 1893 rural), also listed in the order of income quantiles[182].

Sampling Optimization Objective:
- No information available.

Geographic distribution of sample clusters: (Black dots)

Figure A.1 – Geographic distribution of sampling clusters during the WHS



Source: http://apps.who.int/healthinfo/systems/surveydata/index.php/catalog/91

Enquête Nationale à Indicateurs Multiples et Santé des Jeunes, (KoM Ministry of Health)

Dates: 2006 (Code: ENIMSJ)

Description:
The survey was initiated to support international organizations for the development of health programs (AFESD, AGFUND, UNFPA, WHO, UNICEF, and IPPF)[183]. As a prolonged effort of the EPSF survey, it targeted the child and young population of age below 5, and ages from 15 to 24. It was conceived to highlight among other parameters their household attributes, labor and work situation, leisure conditions, and family lives.

Sample Design:
Using the sample frame from EPSF 2003 – 2004, a stratified sample of three levels was obtained of which some households were selected. Individuals (grappes) were then

selected from these households for the interview with an age group response rate of 80-98%[184]. The unit of measure for resulting statistics remained the household.

Sample Size:

- 2006: 8094 total households surveyed, 1 group of 25 individual households per UP[185].

Sampling Optimization Objective:

- Refer to section on DHS.

Enquête Nationale sur la Population et la santé (KoM Ministry of Health)

Dates: 2011 (Code: ENPS)

Description:
The survey had been part of the ministry of health activities for almost three decades. It intended to consolidate the national system for information on sanitation (SNIS), to evaluate the population's health status, and the effectiveness of resources/programs in the health sector[186]. The report for this survey was the most elaborate on uncertainty measures for all indicators.

Sample Design:
The sample from HCP's demographic survey of 2009 – 2010 of 100000 households was used as a preliminary sample frame. The final sample for the ENPS was obtained from a three-level stratified approach in which UPs (3-4 census districts) are chosen from the preliminary (master) sample[187]. From these UPs, single USs are then selected to draw household groups from, and form the final representative sample of households[188].

Sample Size:

- 2011: 15343 total households surveyed (9458 urban, 5885 rural), 25 households on average per US[189]. (1 US per UP, so 25 households per UP).

Sampling Optimization Objective:

- Achieving highly significant results for child mortality rates (age < 5), the report mentions that other indicators need only have acceptable precision at the regional level.

Table A.2 - Reported uncertainty values of water access percentages:

Region	National	Urban	Rural	Southern (Western Sahara)
Standard error	0.013	0.005	0.595	0.620
Confidence Interval Half-Width (+ or -)	0.026	0.0095	0.0555	0.099

Source: Uncertainty values of water access percentages, ENPS 2011, http://www.sante.gov.ma/Documents/Enqu%C3%AAte%20.pdf

Note:
These standard error figures represent the sample standard deviation estimates calculated from a single survey, they merely display the degree of variation among sampled households in their access (1) or lack thereof (0) to improved sources of water (not to be confused with the sample variance that results from squaring these values). There is no information on the theoretical basis for these numbers or the numerical operation used to obtain them.

APPENDIX 3: PYTHON CODE EXAMPLES FOR EXPERIMENTS 1 AND 2

Disclaimer: The author apologizes for any violations of scripting conventions. The codes are not intended for replication and they are not presented in a complete form.

Code Script 1: Creating water access matrix in Rabat-Sale for experiment 1

```
########################################################################
############ SPATIAL ARRAY GENERATION OF EXACT PERCENTAGE, NON - UNIFORM
DISTRIBUTION
############ To use this routine, modify perc value to get any desired
matrix with perc LOS

import numpy as np
from matplotlib import pyplot as plt
from scipy import misc
from PIL import Image
from os import listdir
import time


# PRE-Processing first images: Residential & Primary Unit rasters
# Image 1: Residential Units
resid = misc.imread("PATH DIRECTORY\\Rabat_Sale_Pyreident.png",
                    mode= 'I')
img1max = resid.max()
resid[resid == img1max] = -1
resid = resid[:,:-1]
print("Image 1 SHAPE: {}".format(resid.shape))
print("Image 1 UNIQUE VALS: {}".format(np.unique(resid)))


# Image 2: Primary Units
UP = misc.imread("PATH DIRECTORY \\Rabat_Sale_UP_disserv.png",
                    mode= 'I')
img2max = UP.max()
UP[UP == img2max] = -1
print("Image 2 SHAPE: {}".format(UP.shape))
print("Image 2 UNIQUE VALS: {}".format(np.unique(UP)))


#Distribution 1: 10 UP's {High access / Low access, ratio 8:2)

dist = [1.00,0.70,1.00,0.60,0.60,0.85,0.70,0.50,0.85,0.90,0.1]
#Real Distribution of every UP (Simulated)


#Get Profile matrix for every UP

UP_num = len(np.unique(UP))-1
print("There are {} Primary Units to choose from".format(UP_num))
print(" ")
```

```
UPcopy = UP.copy()

for u in range(UP_num):

    prof_u = np.zeros_like(UPcopy)
    residcopy_u = resid.copy()

    mask1_u = np.zeros_like(residcopy_u)

    it = np.nditer([UPcopy,prof_u], flags = ['f_index'], op_flags =
[['readonly'],['readwrite']])
    for a1, a2 in it:
        if a1 == u+1:
            a2[...] = 1

    it = np.nditer([prof_u, residcopy_u], flags = ['f_index'], op_flags =
[['readonly'],['readwrite']])
    for a1, a2 in it:
        if a1 == 0:
            a2[...] = 0

    print("Residential Units in UP {}: {}".format(u+1,
np.sum(residcopy_u)))


    waccess = 0
    realwaccess = 20
    correction = -1

    mask2_u = np.zeros_like(residcopy_u)

    while not abs(waccess - realwaccess) <= 5:

        if correction < 0:
            it = np.nditer([residcopy_u, mask2_u], flags = ['f_index'],
op_flags = [['readonly'],['readwrite']])
            for a1, a2 in it:
                if a1 == 1:
                    a2[...] = np.random.binomial(1, dist[u])
            realwaccess = np.sum(residcopy_u)*dist[u]
            waccess = np.sum(mask2_u)
            correction = (waccess - realwaccess)
            print("xxxxxxx")

        if correction == 0:
            print("Water Access in UP{}: {}; Real Water Access in UP{}:
{}".format(u+1,waccess,u+1,realwaccess))

        if correction > 0:
            it = np.nditer(mask2_u, flags = ['f_index'], op_flags =
['readwrite'])
            for a in it:
                if a == 1:
                    a[...] = np.random.binomial(1, 0.9994)
            realwaccess = np.sum(residcopy_u)*dist[u]
```

```
            waccess = np.sum(mask2_u)
            correction = (waccess - realwaccess)
            print(waccess, " ", realwaccess)
            #print("Water Access in UP{}: {}; Real Water Access in UP{}:
{}".format(u+1,waccess,u+1,realwaccess))

    np.save("PATH DIRECTORY \\UP{}_Waccess".format(u),mask2_u)


print("Using created arrays to generate final matrix")
print("-------------------......-------------------")
print("                   ......                  ")

arrayloc = listdir("PATH DIRECTORY\\"
            "Dist_Disserv")

upWarray = dict()

for i in range(len(arrayloc)):
    upWarray[i] = np.load("PATH DIRECTORY\\"
            "Dist_Disserv\\{}".format(arrayloc[i]))


mask3 = np.zeros_like(upWarray[i])

for i in range(len(arrayloc)):
    it = np.nditer([upWarray[i],mask3], flags = ['f_index'], op_flags =
[['readonly'],['readwrite']])
    for a1, a2 in it:
        if a1 == 1:
            a2[...] = 1

img = Image.fromarray(mask3)
img.save("PATH DIRECTORY\\"
            "Dist1\\service_NonUniform_Disserv.png")

print(" ")
print("The sum of residential units with water access:
{}".format(np.sum(mask3)))
print(" ")
print("PROCESS FINISHED SUCCESSFULLY")
```

Code script 2: Replication of household survey to calculate uncertainty

```
import numpy as np
from matplotlib import pyplot as plt
from matplotlib import mlab
import matplotlib.figure as figure
from scipy import misc
from scipy import stats
from scipy.stats import norm
import time
from PIL import Image

start_time = time.time()


# Image 1: All Residential units
resid = misc.imread("PATH DIRECTORY\\Rabat_Sale_Pyreident.png",
                    mode= 'I')
img1max = resid.max()
resid[resid == img1max] = -1
resid = resid[:,:-1]
print("Image 1(resid) SHAPE: {}".format(resid.shape))
print("Image 1(resid) UNIQUE VALS: {}".format(np.unique(resid)))
print(" ")

# Image 2: Actual Serv
serv = misc.imread("PATH DIRECTORY \\service_NonUniform_Disserv.png", mode=
'I')

it = np.nditer([serv,resid], flags = ['f_index'], op_flags =
[['readwrite'],['readonly']])
for a1, a2 in it:
    if a2 == -1:
        a1[...] = a2
print("Image 2(Service) SHAPE: {}".format(resid.shape))
print("Image 2(Service) UNIQUE VALS: {}".format(np.unique(resid)))
print(" ")

# Image 3
UP = misc.imread("PATH DIRECTORY\\Rabat_Sale_UP.png",
                    mode= 'I')
img2max = UP.max()
UP[UP == img2max] = -1
print("Image 3(UP) SHAPE: {}".format(UP.shape))
print("Image 3(UP) UNIQUE VALS: {}".format(np.unique(UP)))
print(" ")

#CREATING MASTER LIST TO SAMPLE FROM
#We need to start drawing samples
#Loop for 100 total sampling routines
#From every UP we take 12 random, report count

resid = np.ravel(resid)
serv = np.ravel(serv)
UP = np.ravel(UP)
```

```
combo = []
combolist = []
UPunits = np.unique(UP)[1:]

it = np.nditer([UP,resid,serv], flags = ['f_index'], op_flags =
[['readonly'],['readonly'],['readonly']])

for i,j,k in it:
    if (i != -1 and j != -1 and k != -1 and j != 0):
        combo = np.array((int(i),int(j),int(k)))
        combolist.append(combo)


print("We now have a list of points from different: UP, Residential,
Service indices")
print("The number of different residential points from every unit (with  &
w/o serv is: {}".format(np.shape(combolist)))

#Sampling, random choice (12 from each primary unit)---   REPLICATION
METHOD

combolistsize = int(np.size(combolist)/np.size(combo))

sampleHIST = []
semHIST = []
sdHIST = []

sampleHIST2 = []



for N in range(1000):
    bigsample2 = []
    for a in UPunits:
        UPsample2 = []
        for b in range(combolistsize):
            if combolist[b][0] == a:
                UPsample2.append(combolist[b][2])
        sample2 = np.random.choice(UPsample2, size = 12, replace = False)
        weight2 = np.size(UPsample2)/(combolistsize)
        bigsample2.append(sum(sample2)*weight2*100/np.size(sample2))
        prop2 = sum(bigsample2)
    sampleHIST2.append(prop2)

mean2 = np.round(np.mean(sampleHIST2), decimals= 2)
std2 = np.round(np.std(sampleHIST2),decimals= 2)
stderror2 = np.round(stats.sem(sampleHIST2, ddof= 1000-1),decimals= 2)


np.around(sampleHIST2, decimals = 2)

np.save(PATH DIRECTORY \\'Disserv_samplehist1000', sampleHIST2)
```

Code script 3: Creating water access data for Safi-Youssoufia households

```
import numpy as np
from matplotlib import pyplot as plt
from scipy import misc
from PIL import Image
from os import listdir
import time

np.random.seed(4824)

# PRE-Processing first images: Residential & Primary Unit rasters
# Image 1

print("Reading and modifying residential array")
resid = misc.imread("PATH DIRECTORY\\PNG_maps\\residential.png",
                    mode= 'I')

image1_max = resid.max()
resid[resid == image1_max] = -1
resid[resid == 1] = 2
resid[resid == 3] = 2
resid[resid == 0] = 1
resid[resid == 2] = 0
print("Residential matrix size: ", np.shape(resid))
print("Unique Values: ", np.unique(resid))

# Image 2
print("Reading and modifying UP array")
UP = misc.imread("PATH DIRECTORY \\SY_disserv_UP3.png",
                    mode= 'I')

image2_max = UP.max()
resid[resid == image2_max] = -1
print("UP matri size: ", np.shape(UP))
replace = [13,14,15,16,17,18,19,20,21,22]
keep = np.arange(3,13, 1)
keep = keep/10

UP[UP == 0] = -10
UP[UP == 1] = 00
UP[UP == 2] = 10
UP[UP == 23] = 1000
for i in replace:
    UP[UP == i] = (i+1)*10
UP = UP/10
for i in keep:
    UP[UP == i] = i*10
UP = UP.astype(int)

unique = np.unique(UP)
print("Unique Values: ", unique)


#Generate in each UP, the right proportion
```

```python
rows = np.shape(UP)[0]
cols = np.shape(UP)[1]

resid_coord = []
for r in range(rows):
    for c in range(cols):
        #Get r,c coords of house if present
        if resid[r][c] == 1:
            resid_coord.append([UP[r][c],r,c])

#Get house numbers in UP to get series of UP proportions
print("\n Initializing UP proportions")
UP_houses = []
for u in unique[1:]:
    num_house = 0
    for x in resid_coord:
        if x[0] == u:
            num_house += 1
    UP_houses.append([u, num_house])

distpop = []
dist = [0.2,0.6,0.7,0.95,0.99]
prop_disserv = 0.05
BF_disserv = 1

for h in UP_houses:
    if h[0] != 0 and h[0] != 100:
        distpop.append([h[0],int(h[1]*np.random.choice(dist))])
    elif h[0] == 0:
        distpop.append([h[0],int(h[1]*prop_disserv)])
    else:
        distpop.append([h[0],int(h[1]*BF_disserv)])

print(distpop)
total_access_num = 0
for k in distpop:
    total_access_num += k[1]

print("Total houses waccess: ", total_access_num)


#for each segment of UP choose distpop uniform samples to assign access to

print("Generating access segments for each UP")

seg_coord = []

for d in distpop:
    for u in unique[1:]:
        seg = []
        if d[0] == u:
            for x in resid_coord:
                if x[0] == u:
                    seg.append([x[1],x[2]])
            seg_len = len(seg)
```

```
            seg_vec = range(seg_len)
            seg_sample_ind = np.random.choice(seg_vec,
size=d[1],replace=False)

            for i in seg_sample_ind:
                seg_coord.append(seg[i][:])
    print("processing")

print("Total houses waccess generated in segments: ",len(seg_coord))

waccess = np.zeros_like(UP)

for r in range(rows):
    for c in range(cols):
        if resid[r][c] == -1:
            waccess[r][c] = -1
        if resid[r][c] == 0:
            waccess[r][c] = -1


for x in seg_coord:
    waccess[x[0]][x[1]] = 1


print("Process completed, Non Uniform distribution array generated")
print("Total houses waccess generated in array: ", len(waccess[waccess ==
1]))


supercent = len(seg_coord)/len(resid_coord)
supercent = np.around(supercent,decimals=3)

print(supercent)


#Save matrix and image

img = Image.fromarray(waccess)
img.save("PATH DIRECTORY \\SY_Non_Uniform{}.png".format(supercent))


np.save("PATH DIRECTORY \\SY_Non_Uniform{}_mat".format(supercent), waccess)
```

Code script 4: Modified sampling methodology of survey replicated in experiment 2 on the water access data of Safi-Youssoufia

```
import numpy as np
import os
from math import sqrt
from scipy import misc
from scipy import stats as st
from scipy.stats import norm
import math
import statistics
import time
from PIL import Image
from matplotlib import pyplot as plt
from matplotlib import mlab
import matplotlib.figure as figure

print("...Beginning procedure...\n")
start_time = time.time()



#PREPROCESSING
#------------------------------------------------------------------------
#Import water access (-1 = No data, 0 = No Access, 1 = Access)
waccess = np.load("PATH DIRECTORY \\SY_Non_Uniform0.699_mat.npy')
print("Unique water access values: ", np.unique(waccess))
print("Water access matrix size: ", np.shape(waccess))


#Import residential units
print("\nReading and modifying residential array")
resid = misc.imread("PATH DIRECTORY \\residential.png",
                    mode= 'I')

image1_max = resid.max()
resid[resid == image1_max] = -1
resid[resid == 1] = 2
resid[resid == 3] = 2
resid[resid == 0] = 1
resid[resid == 2] = 0
print("Unique resid Values: ", np.unique(resid))
print("Residential matrix size: ", np.shape(resid))


#Import UP's of new array
print("\nReading New UP array")
UP = misc.imread("PATH DIRECTORY \\SY_disserv_UP3.png",
                    mode= 'I')

image2_max = UP.max()
resid[resid == image2_max] = -1

replace = [13,14,15,16,17,18,19,20,21,22]
```

```
keep = np.arange(3,13, 1)
keep = keep/10

UP[UP == 0] = -10
UP[UP == 1] = 00
UP[UP == 2] = 10
UP[UP == 23] = 1000
for i in replace:
    UP[UP == i] = (i+1)*10
UP = UP/10
for i in keep:
    UP[UP == i] = i*10
UP = UP.astype(int)

unique = np.unique(UP)

print("Unique Values: ", unique)
print("UP Matrix size: ", np.shape(UP))


#Create vector of all houses + indicate UP, access, inaccess
print("\nCreating Housing record data")
rows = np.shape(waccess)[0]
cols = np.shape(waccess)[1]

house_rec = []
for r in range(rows):
    for c in range(cols):
        if resid[r][c] == 1:
            UPi = UP[r][c]
            X = r
            Y = c
            acc = waccess[r][c]
            house_rec.append([UPi,X, Y, acc])

print("Housing record size: ",np.shape(house_rec))

np.save("PATH DIRECTORY \\housing_record", house_rec)



#Load Housing record:

house_rec = np.load("PATH DIRECTORY \\housing_record.npy")

Xi = 0
for m in house_rec:
    if m[3] == 1:
        Xi += 1
mu = np.around(Xi/len(house_rec), 3)
print("True Percentage: {} %".format(mu))


#Import primary units to sample from
print(" ")
```

```
UP = misc.imread("PATH DIRECTORY \\Safi_Youssoufia_UP1.png", mode= 'I')

UP = UP[200:-200,:]
for r in range(np.shape(resid)[0]):
    for c in range(np.shape(resid)[1]):
        if UP[r][c] == 255:
            UP[r][c] = -1


print("Unique UP values: ", np.unique(UP))
print("UP Matrix size: ", np.shape(UP))

unique = np.unique(UP)


#Create vector of all houses + indicate UP, access, inaccess
print("\nCreating Housing record data")
rows = np.shape(waccess)[0]
cols = np.shape(waccess)[1]

house_rec = []
for r in range(rows):
    for c in range(cols):
        if resid[r][c] == 1:
            UPi = UP[r][c]
            X = r
            Y = c
            acc = waccess[r][c]
            house_rec.append([UPi,X, Y, acc])

print("Housing record size: ",np.shape(house_rec))

np.save("PATH DIRECTORY \\housing_record_old", house_rec)


#Load Housing record:

house_rec = np.load("PATH DIRECTORY \\housing_record_old.npy")

Xi_pop = 0
for m in house_rec:
    if m[3] == 1:
        Xi_pop += 1
mu = np.around(Xi_pop/len(house_rec), 3)
print("True Percentage: {} %".format(mu))

g_UP = []
for u in unique[1:-1]:
    UP_extentV = []
    UP_extentH = []
    for r in range(rows):
        for c in range(cols):
            if UP[r][c] == u:
                UP_extentV.append(r)
                UP_extentH.append(c)
```

```
    Y_top = max(UP_extentV)
    Y_bot = min(UP_extentV)
    X_East = max(UP_extentH)
    X_West = min(UP_extentH)
    # print("\nExtents for UP{}".format(u))
    # print("Top extent: ", Y_top)
    # print("Bot extent: ", Y_bot)
    # print("Left extent: ", X_East)
    # print("Left extent: ", X_West)
    diag = sqrt((Y_top - Y_bot)**2+(X_East - X_West)**2)
    gauge = int(diag/2)/4
    g_UP.append([u,gauge])

print("Gauge distances between initial samples in each UP were determined")

np.save("PATH DIRECTORY \\gauge_distance_UPi", g_UP)


UP_g = np.load("PATH DIRECTORY \\gauge_distance_UPi.npy")



#Create segments for each UP:

print("Please wait, this might take a while")
print("\nCreating samples from old methodology: 12 in all UP's")
print("Confidence interval results: ")
print("-------------------------------------------------------------------
")


#Looping------------------------------------------------------------
N1 = 12
replications = 200


cover = 0

Xn = []
S = []
for n in range(replications):
    full_sample = []
    Xi_mat = []
    for u in unique[1:]:
        seg = []
        for x in house_rec:
            if u == x[0]:
                seg.append(x[3])

        seg_len = len(seg)
        seg_ind = range(seg_len)

        if seg_len != 0:
            sample_ind = np.random.choice(seg_ind, N1, replace=False)
```

```
            for z in sample_ind:
                Xi = seg[z]
                Xi_mat.append(Xi)
                full_sample.append(Xi)
            sample_len = len(full_sample)

    Xibar = sum(full_sample)/sample_len          #Sample mean
    Xn.append(Xibar)

    resid_Sq = []
    for x in Xi_mat:
        resid_Sq.append((x-Xibar)**2)

    sVar = sum(resid_Sq)/(sample_len-1)          #Sample variance

    S.append(sqrt(sVar))

    z = st.norm.ppf(0.95)
    conf_bot = np.around((Xibar - sqrt(sVar)*z/sqrt(sample_len)),4)
    conf_top = np.around((Xibar + sqrt(sVar)*z/sqrt(sample_len)),4)
    print("{} - [{} , {}], mu = {}".format(n+1,conf_bot,conf_top,mu))
    if conf_bot < mu and conf_top > mu:
        cover += 1

np.save("PATH DIRECTORY \\SY_old_waccess_MC.npy", Xn)

cov_percent = cover/replications
print("Percentage coverage: {} %".format(cov_percent))



Xn = np.load("PATH DIRECTORY \\SY_old_waccess_MC.npy")


#Final stats

Xnbar = np.mean(Xn)
Xnsigma = np.std(Xn)

#expected_std_dev = np.around(np.mean(S),3)
#print("\nExpected sample std. dev: {}".format(expected_std_dev))


#----------------------------------------------------------------------------
------------------
# Visualization

plt.suptitle('Safi Youssoufia Estimates, {}  Uniform Water 
Access'.format(np.around(mu,2)), fontsize = 14, fontweight= 'bold')
plt.figtext(0.65,0.65,'Mean = {} \nstd dev = 
{}'.format(np.around(Xnbar,4),np.around(Xnsigma,4)),
                bbox=dict(facecolor='white', alpha=1))

plt.hist(Xn, bins =30, color = 'blue', alpha= 0.5)
plt.axvline(x = mu, color = 'orange', linewidth = 8)
```

```
plt.axvline(x = Xnbar, color = 'red', linewidth = 8)

plt.show()

print("\nSimulation over, {} replications".format(len(Xn)))
print("Total runtime: ", (time.time()-start_time)/60, " minutes")
```

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