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Titel | Title

A bumpy road ahead: Achieving a secure access to clean water in rural Yemen
Can AI and innovative technologies help achieve the SDG Goal 6 (Clean Water and Sanitation)?

verfasst von | submitted by
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# Abstract

This thesis aims to create a better understanding of the potential challenges faced in addressing the critical needs of rural Yemen, in particular providing secure access to clean water and striving for the achievement of the United Nations' Sustainable Development Goal 6: Clean Water and Sanitation. Amidst a backdrop of political instability and infrastructural deficits, this research explores how advanced technology and Artificial Intelligence (AI) can optimize aid delivery and empower marginalized communities by sustainably improving their quality of life while dealing with multiple hurdles and feasibility restrictions.

Through a comprehensive literature review and qualitative analyses, the thesis examines the feasibility of AI-driven sanitation systems, the application of modern water clarification as well as cryptocurrency-based funding models as innovative solutions to Yemen's developmental challenges.

The study employs online interviews with representatives from global and locally based NGOs as well as experts in this field to navigate the impossibility of on-site research related to the ongoing conflict in Yemen. It aims to present a compelling case for the capabilities of AI and cryptocurrency to efficiently adapt to market changes, reduce fund transfer costs and accelerate progress in rural regions lacking financial access. Also, this research paper will examine the omnipresent hurdles of securing access to clean water in such regions to create space for and look into new innovative approaches to sustainable clean water generation in rural regions in Yemen.

The anticipated outcome is a set of strategic recommendations for the adoption and implementation of above technologies in Yemen's development initiatives, potentially serving as a model for similar contexts globally.

**Keywords:** *Clean water access, Sustainable Development Goals, Artificial Intelligence, Innovative technology, inequality, infrastructure deficits, rural (under-)development*

# Zusammenfassung

Diese Arbeit zielt darauf ab, ein besseres Verständnis der potenziellen Herausforderungen zu schaffen, denen sich moderne Technologien und Künstliche Intelligenz (KI) bei der Bewältigung der kritischen Bedürfnisse des ländlichen Jemen gegenübersehen, insbesondere bei der Bereitstellung eines sicheren Zugangs zu sauberem Wasser und der Erreichung des Nachhaltigkeitsziels 6 der Vereinten Nationen: Sauberes Wasser und Sanitäreinrichtungen. Vor dem Hintergrund politischer Instabilität und infrastruktureller Defizite untersucht diese Arbeit, wie fortschrittliche Technologie dies optimieren und marginalisierte Gemeinschaften durch eine nachhaltige Verbesserung ihrer Lebensqualität stärken kann, während sie vorhandene Hürden und Machbarkeitseinschränkungen umgeht.

Basierend auf einer umfassenden Literaturübersicht und qualitativen Analysen (Interviews) untersucht die Arbeit die Machbarkeit von KI-gesteuerten Sanitärsystemen, die Anwendung moderner Wasseraufbereitung und den möglichen Einsatz kryptowährungsbasierter Finanzierungsmodelle als innovative Lösungen für die Entwicklungsherausforderungen des Jemen.

Um die Unmöglichkeiten von Vor-Ort-Forschung aufgrund des anhaltenden Konflikts zu umgehen, wurden Online-Interviews mit Vertretern globaler und lokal ansässiger NGOs, sowie auch Experten durchgeführt. Die vorliegende Arbeit zielt darauf ab, ein überzeugendes Argument für die Fähigkeiten von KI und Kryptowährungen zu präsentieren, sich effizient an Marktveränderungen anzupassen, die Kosten für Geldtransfers zu senken und den Fortschritt in ländlichen Regionen ohne finanziellen Zugang zu beschleunigen. Darüber hinaus wird dieses Forschungspapier relevante Hürden beim Zugang zu sauberem Wasser untersuchen, um Raum für neue innovative Ansätze zur nachhaltigen Bereitstellung von sauberem Wasser in ländlichen Regionen im Jemen zu schaffen.

Ergebnis der Arbeit sind eine Reihe strategischer Empfehlungen für die Annahme und Implementierung obig genannter Technologien in den Entwicklungsinitiativen des Jemen, welche potenziell auch als Modell für ähnliche Kontexte weltweit dienen könnten.

**Schlüsselwörter:** *Zugang zu sauberem Wasser, Nachhaltigkeitsziele, Künstliche Intelligenz, Innovative Technologie, Ungleichheit, Infrastrukturdefizite, ländliche (Unter-)Entwicklung*

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Also, a huge thank you goes to my friends, colleagues and family. Your votes of confidence as well as critical thinking kept me motivated and striving for the best possible outcome. I am so happy to have you in my life and look forward to celebrating this milestone with all of you!

Thank you!

Simone Gstrein

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# List of Abbreviations

| | |
|---|---|
| AI | Artificial Intelligence |
| AWG | Atmospheric Water Generator |
| CERF | Central Emergency Response Fund |
| FAO | Food and Agriculture Organization |
| GHI | Global Hunger Index |
| GWP | Global Water Partnership |
| IOM | International Organization for Migration |
| IMF | International Monetary Fund |
| IWRM | Integrated Water Resources Management |
| LPI | Legatum Prosperity Index |
| MENA | Middle East North Africa |
| (I)NGO | (International) Non-Governmental Organization |
| OCHA | Coordination of Humanitarian Affairs |
| SDG | Sustainable Development Goal |
| SODIS | Solar Water Disinfection |
| SLR | Systematic Literature Review |
| UN | United Nations |
| UNDP | United Nations Development Programme |
| UNHCR | United Nations High Commissioner for Refugees |
| UNICEF | United Nations International Children's Emergency Fund |
| WASH | Water, Sanitation and Hygiene |
| WFP | World Food Programme |
| WHO | World Health Organization |

# Introduction

Over recent years, modern technologies have revolutionized the way things are approached globally. In particular, Artificial Intelligence (AI) and cryptocurrencies have emerged as transformative forces with the potential to reshape the landscape of development aid work across the world. This paper delves into the application of innovative cutting-edge technologies focusing on rural regions of Yemen, a country grappling with the challenges of poverty and underdevelopment (Coppi, 2017).

The Republic of Yemen, positioned at the southern tip of the Arabian Peninsula, is often cited as the poorest nation within the Middle Eastern and North African (MENA) region, with stark disparities between urban prosperity and rural hardship (El-Jardali et al., 2023). Yemen's struggle with poverty and underdevelopment is particularly acute in its rural areas, where the lack of traditional infrastructure and financial systems is further exacerbated by ongoing conflict and instability. This situation underscores the critical need for innovative and effective development aid solutions to bridge the central-peripheral divide and promote equitable development.

Not only in devastated regions, but also for all human beings, access to clean water represents a crucial need in daily life. In most developed countries, especially in Central Europe, access to clean water is mostly taken for granted. However, in a lot of regions worldwide, water is perceived as a luxury and accessible clean water seems far from reality. Long walks to nearby wells or a lack of clean drinking water only illustrate some ‘relevant issues. What is way more serious, are the consequences which a lacking access to clean water entails. Besides severe health issues of individuals stemming from malnutrition or diseases, it often embodies the root cause for the outbreak of epidemics and life-threatening diseases (IWA, 2020).

Therefore, it is crucial to identify the current spectrum of difficulties to subsequently provide feasible solutions for Yemen’s omnipresent water problem. Watergen as well as Wadi represent two modern approaches that focus on water clarification. Watergen, was created by an Israeli company that develops so-called atmospheric water generator (AWG) systems (Watergen, 2025) to clarify water. The application of this innovative technology allows the generation of water from air for people at any location, no matter how isolated the region is. As Watergen expanded its product worldwide and has participated in collaborations with various institutions/governments in countries with restricted access to (clean) water, the technology used by Watergen represents a great opportunity to help defuse the water issue in rural areas of Yemen (Ricky, 2022).

The technology used by WADI is a solar-powered UV measuring device that deals with and measures the process of solar water disinfection (SODIS) in transparent bottles. SODIS uses a natural process where the sun's UV radiation eliminates harmful pathogens, such as bacteria, protozoa and viruses, in water (WHO, 2015).

Although such modern technologies might be able to diminish the struggle around access to clean water, various challenges remain that prevent a sustainable implementation and, therefore, solution of the water issue in rural regions of Yemen. Moreover, questions around monitoring procedures as well as substantial financing issues still exist (Ripple, 2024). Although Artificial Intelligence (AI) and cryptocurrency have emerged as potential game-changers in the realm of development aid, offering novel approaches to address the complex challenges faced by rural Yemeni communities (Coppi, 2017), it remains largely uncertain whether these regions have the required technological infrastructure to implement such change.

However, AI, with its capacity for predictive analytics, can be used to identify urgent needs and optimize resource distribution, ensuring that aid is tailored to the unique cultural and socio-economic contexts of different communities (Goralski & Tan, 2020). In several developing countries, such as in Ethiopia and Kenya, AI is already being successfully utilized for development purposes, where it is used to support sustainable development in areas like agriculture, healthcare and education (UNDP, 2024a).

Moreover, the urgency of addressing the United Nations Sustainable Development Goals (SDGs) is paramount, with this research focusing on Goal 6: Clean Water and Sanitation (United Nations, 2024b). To achieve this goal, the implementation of smart sanitation systems is critical as they can play a pivotal role in much needed early disease detection and prevention. As a result, many countries have started adopting WASH (Water, Sanitation, and Hygiene) initiatives, recognizing the fundamental impact of sanitation on public health and well-being. For such initiatives, AI's predictive capabilities can quickly analyze sanitation data to identify patterns that may indicate the outbreak of diseases, allowing for early intervention and the allocation of resources to places where they are most needed. When integrated with cryptocurrency's ability to swiftly and transparently mobilize funds, these technologies have the potential to significantly improve living conditions in rural regions. For Yemen, where more traditional development efforts are currently hindered by a lack of infrastructure and limited financial access, innovative water clarification solutions using AI could represent a beacon of hope by providing a more effective and accountable means of supporting communities in their pursuit of a better future (Melle, 2019).

Despite all the benefits that might come with AI and its optimization of resource distribution, such modern technology is expensive due to high electricity demands and substantial energy consumption. This brings us to the question of how AI supported development projects can nevertheless be realized and realistically be funded?

Funding AI initiatives in challenging regions could be achieved in various ways. Besides conventional credits granted by a bank or international monetary institution such as the International Monetary Fund (IMF), cryptocurrency can be a modern approach of financing. Cryptocurrency, supported by blockchain technology, offers a secure and transparent mechanism for direct fund transfers, eliminating traditional financial bottlenecks and reducing corruption risks. Transactions are fast, do not require a bank, and have lower fees compared to conventional banking systems (CARE Yemen, 2022). Nonetheless, the negative aspects of using cryptocurrency, such as unstable legal regulations, limited acceptance both individually and economically within the country, and a lack of personal knowledge as well as the extremely high energy consumption, pose substantial challenges and, therefore, tend to outweigh the benefits. Given these challenges, a conventional credit granted by international institutions may today still represent a more viable solution for funding AI and other development projects in rural Yemen.

Concluding, this paper presents a brief overview of the various benefits the implementation of innovative water clarification tools in combination with the integration of AI as a modern technology into development aid could represent as such revolutionary approach not only aligns with the SDGs but also offers a viable solution for rural Yemen's pressing challenges. Besides all the possible positive impacts and opportunities modern technologies might have, it as well outlines that, although the feasibility of these innovations might look promising in theory, achieving sustainable success by implementing modern approaches in daily life scenarios remains an ongoing challenge. Therefore, on the one hand, this master thesis will explore the potential future impacts of modern innovations on access to clean water in one of the world's most vulnerable regions. On the other hand, it will also shed some light on the complexity of the research topic in question and explain why accessing drinkable water often still remains an unsolved issue, at least for now.

# Research Question(s) and their Relevance

In Yemen, the disparity between rural and urban life is a stark reality, with the rural-urban divide being a pervasive element of the country's socio-economic fabric. The situation worsened in 2015 when Yemen descended into a domestic conflict that quickly escalated with the intervention of a Saudi-led coalition, aiming to restore the internationally recognized government that had been ousted. Prior to this turmoil, Yemen was already the most economically challenged country in the Middle East, grappling with dire food insecurity, high rates of infant mortality, and widespread malnutrition among children (UN Yemen, 2023). The onset of conflict only exacerbated the nation's macroeconomic instability, leading to a sharp decline in economic conditions (Coppi, 2017). Despite a significant portion of Yemen's population living in agricultural communities, academic and media attention has predominantly focused on urban centers, often overlooking the rural plight.

Life in Yemen is fraught with challenges: the ongoing civil war, scarcity of vital resources like water, and severely limited access to basic services such as paved roads make it exceedingly difficult for Yemenis to enhance their living standards. The prospect of starting a successful, sustainable business to foster resilience and financial independence is a distant dream for many, as even fundamental needs like clean drinking water and sufficient food are not met (Laub, 2015). Although the current situation in Yemen is by far more complex than many may think and, therefore, cannot be solved overnight, with the aid of modern technologies, a foundation to bridge the rural-urban divide and support the creation of a secure access to clean water in the future is built.

While addressing basic human needs remains paramount, financial resources are essential for building infrastructure and providing critical resources and herein lies the importance of money. AI, cryptocurrency and modern technologies are not the end goal but represent cornerstones to achieve better future living conditions and development in Yemen's rural areas, with water being a key element, as access to clean water is foundational to sustainable development.

Despite the obvious benefits modern technologies and water clarification tools could have in isolated regions of Yemen, this paper will explore the existing challenges related to the provision of clean water in rural Yemen as well as suggest possibilities to overcome them in the future. Based on this, the central research question is the following:

> *'Can AI and innovative technologies help achieve the SDG Goal 6 (Clean Water and Sanitation)?'*

In order to deepen the understanding of the multifaceted ways where modern technologies could assist achieving a secure access to clean water, and therefore, improve daily lives in rural regions of Yemen, this paper will shed some light on the following sub-research questions:

- How feasible is the idea of solving the critical water issue in Yemen nowadays by implementing modern technologies and AI into the development of decentralized water, sanitation, and hygiene (WASH) facilities in the country's rural areas?
- In which ways can innovative water clarification tools help to create significant cornerstones for a better life in rural areas of Yemen?
- How can Artificial Intelligence contribute to the creation of sustainable smart sanitation systems in Yemen's rural settings?
- To what extent can cryptocurrency-based funding models represent beneficial advancements in constructing and maintaining sanitation facilities in Yemen's rural communities compared to conventional credit models?

# Methodology

Given the challenges posed by the ongoing civil war, which precludes on-site qualitative research, the study relies on the systematic examination of existing academic literature as well as online expert interviews. With on-site qualitative research not a feasible option, this research relies on and adopts a comprehensive literature review methodology to explore the potential impact of modern technologies and innovative water clarification tools on development aid programs in the rural areas of Yemen.

A so-called Systematic Literature Review, short SLR, differs from a normal literature review as it is centered around a specific research topic and involves a literature review approach that focuses on specific research question(s) (Fink, 2005). It involves identifying, evaluating, and synthesizing relevant studies to answer predefined research questions.

The SLR framework (Kitchenham, 2004) involves several critical steps, each essential to conducting a thorough and effective systematic literature review. The first step is formulating research questions. This covers a clear definition of the research questions that will guide the literature review. It displays a significant step as it sets the direction and scope of the entire research process, ensuring that the review remains focused and relevant to the objectives of the study.

The next step is the search for literature. This entails using various databases and search engines to find relevant studies. It encompasses identifying appropriate keywords and search terms related to the research questions and systematically searching academic databases, journals, and other credible sources to gather a comprehensive collection of literature.

Once a substantial amount of literature has been collected, the subsequent step represents screening and selection. This step entails applying inclusion and exclusion criteria to select the most relevant studies. Reviewing abstracts and full texts of the collected studies to determine their relevance and quality, ensuring that only the highest-quality studies are included in the review (Kitchenham, 2004).

After selecting the relevant studies, the necessary data from these studies must be extracted by systematically recording key information such as study objectives, methodologies, findings as well as conclusions, which will be used for further analysis. This is really crucial for organizing the data in a manner that facilitates comprehensive analysis.

The fifth, and final step focuses on synthesis and analysis of the extracted data to draw meaningful conclusions. Therefore, this includes comparing and contrasting the findings of different studies, identifying patterns and trends as well as integrating the results to provide a comprehensive understanding of the research topic. The synthesis and analysis process aids

to highlight gaps in the existing literature and suggest areas for possible future research (Fink, 2005). Besides applying the SLR framework, this thesis employs a qualitative exploratory research approach (Kvale & Brinkmann, 2009) to gain a deeper understanding of the topic by considering individual opinions and different societal norms (Kvale, 1996). Utilizing a mixed methods approach (Tashakkori & Teddlie, 1998), the combination of secondary research literature with primary research tools, such as interviews with (inter-)national NGOs and expert interviews, will help to capture facts, gain closer insights, and enhance the validity of the findings (Buber & Holzmüller, 2009; Yemen Aid, 2024; YDN, 2024). Furthermore, during this research, various experts in the field of the SDG Goal Nr. 6 'Clean Water and Sanitation' as well as AI and other innovative technologies were identified which would contribute valuable insights to this research. Therefore, a connection was created by sending some invites via the professional network LinkedIn to these experts who then accepted the invite and agreed to participate in online interviews.

Lyudmila Todorovska, an experienced digital and technology leader with more than eighteen years of international knowledge focuses her research on how AI can and will change the world. Her article 'From Zero-to-Hero: How AI Becomes the Potential Solution for Water Deficiencies' provides insights that add a great deal of value to this research.

Another expert in the topic around modern technologies and water scarcity is embodied by Martin Wesian, Founder and Member of the Board of 'HELIOZ Future Economy', a carbon offset provider and climate project developer. HELIOZ' innovative technological approach as well as project design ensures a crucial SDG impact, specializing in the modern water clarification device SODIS. Besides HELIOZ, Mr. Wesian also is the Founder and Chairman of the humanitarian organization GetWater, which focuses on enabling clean drinking water for low-income households.

After working for several years for one of the big four Consulting companies, Deloitte, with the focus on water strategy and social impact practice, founding various Institutions, such as Water Foundry, LLC, The Future of Water Fund as well as participating in leadership roles of FIDO Tech and also Earth Finance, Inc., all organizations that deal with the delivery of innovative solutions that enable a world without water scarcity, Will Sarni provides highly interesting perspectives relevant for this research.

In order to obtain a broad range of various perspectives, besides conducting interviews with experts in this field, NGOs had also been contacted to gain further insights on (inter-)national level. ZOA, an international relief and recovery organization that provides aid to people affected by violent conflicts as well as natural disasters in fragile contexts, agreed to share their knowledge during an online expert interview (ZOA, 2025). Here, Mr. Matthijs Wessels,

ZOA's WASH advisor, explained the critical situation in Yemen and how ZOA assists people in Yemen to fight the water problem.

To ensure that the valuable input from facial expressions and gestures is not lost, the additional use of supportive technology, such as video conferencing was applied. Interviews were conducted one by one, and not in a group, in order to observe a separated perspective and avoid the hazard of peer pressure. The insights gained from expert interviews as well as from discussions with (inter-)national NGOs were analyzed and referred to theoretical frameworks and literature. By doing so, similarities as well as differences were identified and correlations as well as findings were developed.

## Research Design

Therefore, a mixed methods research approach according to Philipp Mayring (Mayring, 2007) was applied where already existing literature about the clarification of water as well as modern technology supported development projects had been examined and combined with the insights gained from performing expert interviews. This approach not only enables the examination of the feasibility of the research topic in question but might also enlighten new aspects of possible ways to overcome the challenges of clean water access. Moreover, this approach allows for triangulation of data, enhancing the validity and reliability of the findings.

Furthermore, the qualitative content analysis method, as described by Mayring and Fenzl (2014), presents a structured and rule-governed approach to examining textual materials. This technique is particularly beneficial in empirical social research for interpreting intricate and detailed data. Its noted flexibility and adaptability make it applicable to a broad spectrum of research questions and contexts. A significant aspect of qualitative content analysis is the differentiation between inductive and deductive methodologies. The inductive approach involves generating categories directly from the data, which allows for the discovery of new insights and themes inherent in the material itself. This is especially advantageous when investigating new or less-explored areas. Conversely, the deductive approach begins with pre-established categories derived from existing theories or previous research, which is useful for testing hypotheses or applying theoretical frameworks to the data (Mayring & Fenzl, 2014).

Ensuring the validity as well as reliability of this research is crucial for producing credible and trustworthy results. Validity defines the extent to which the research accurately measures what it intends to measure, encompassing aspects such as construct validity, internal validity and also external validity (Cohen et al., 2017). Reliability, on the other hand, pertains to the consistency and stability of the measurement process over time, ensuring that the results are replicable under similar conditions. By thoroughly designing the study and employing robust

data collection and analysis methods, this thesis aims to enhance the validity and reliability of its findings, thereby contributing to the overall rigor and quality of this research.

Mayring and Fenzl (2014) underscore the importance of a systematic and transparent coding process in qualitative content analysis. This involves clearly defining coding rules and categories, documenting coding decisions and continuously refining the coding scheme based on the data. Adhering to these guidelines ensures that the analysis is rigorous and replicable, thereby enhancing the credibility and trustworthiness of the findings (Mayring & Fenzl, 2014).

To align with the specified research objectives, this study begins with comprehensive descriptions of AI and other innovative technologies, shedding some light on possible benefits and hurdles when implementing modern technologies to combat water scarcity in rural Yemen. Utilizing the latest data on global technological advancements, theoretical and empirical literature on the topic provides a robust framework for further research.

As already briefly mentioned above, a number of expert interviews were conducted, which illustrate a critical component of this thesis' research, providing practical insights as well as firsthand experiences. In order to conduct these interviews, experts from (inter-)national Non-Governmental Organizations, global organizations as well as academic or governmental institutions were identified and chosen based on their experience and knowledge in the relevant field.

## Data Collection

This research's data collection consists of a combination of primary data as well as secondary data (Heap & Waters, 2019). While a profound literature review classifies as secondary data, the performance of expert interviews illustrates primary data collection. The literature review entails the collection and review of academic literature (incl. various theoretical frameworks), reports as well as case studies related to the combat against water scarcity in rural regions of Yemen with the aid of innovative technologies. Such a profound review offers a detailed theoretical basis as well as shedding some light on the gaps in existing literature. Additionally, online interviews with experts in this field were performed to gain critical in-person insights which enriches the research with qualitative data.

Upfront, an interview guideline was created which entailed a set of semi-structured questions (Adams, 2015). This allows a balance between consistency across interviews as well as the opportunity for interviewees to elaborate on their responses, providing richer data through discussions. Due to the fact that in-person interviews in Yemen are not feasible at this point of time, the interviews were conducted online, using the video conferencing tool Zoom, lasting one hour each. Video conferences not only allow a bridge across geographic distance but also

enables researchers as well as interviewees to observe gesticulations as well as facial reactions which provide valuable non-verbal insights that enrich qualitative research. Visual observations aid to gain a more nuanced interpretation of emotions and attitudes that might be hidden behind responses. In order to facilitate the subsequent transcription, the audio of the interviews was recorded. Moreover, to ensure data protection as well as obtain the interviewed experts' confirmation, all interviewees were asked in the beginning of the interview session whether performing an audio recording was permitted.

By performing primary with secondary data collection, this research strives to combine theoretical with practical insights and, therefore, create a comprehensive understanding of the research topic in question.

## Data Analysis

After the expert interviews had been performed, the next step was the analysis of the collected data. The qualitative content analysis method by Meuser and Nagel (1991) provides a detailed approach to understanding expert knowledge within the context of societal changes and new forms of knowledge production. This method emphasizes the socio-cultural conditions, negotiation practices as well as the construction of expert knowledge. It begins with a pragmatic perspective, where the status of an expert is determined by the researcher based on the individual's role and knowledge within a specific field. The analysis involves examining the socio-cultural conditions under which expert knowledge is produced, highlighting the embeddedness of experts in their respective milieus and the heterogeneity of their interactions. Furthermore, it addresses the negotiation and communication practices that shape expert knowledge, recognizing that knowledge production is a collective process involving diverse actors (Meuser & Nagel, 1991).

This method is particularly useful for analyzing expert interviews, providing a structured but still flexible framework for data collection and subsequent interpretation. By doing so, researchers can uncover the underlying relevance and maximize guiding expert behavior by defining narratives and reports of decision-making processes. This involves systematic steps of data collection, transcription, paraphrasing, coding, thematic comparison and also sociological conceptualization, ensuring that the analysis remains grounded in empirical data while allowing for theoretical generalization. By integrating socio-cultural conditions, negotiation practices as well as the construction of expert knowledge, researchers might be able to obtain a comprehensive and nuanced understanding of the expert's role and contributions within their field.

In order to facilitate the transcription process, as already briefly mentioned above, the audio was recorded for all conducted online expert interviews. For the transcription, the free transcription software ‘Turboscribe’ was used. This enabled a time-effective conversion of the recorded audios into written texts, which are crucial for the next step, the data analysis.

For analyzing the data, the software MAXQDA is used (Kuckartz, 2010). MAXQDA is a software tool which is used for qualitative and mixed methods data analysis, offering researchers a robust platform to manage, analyze and also visualize both qualitative and mixed methods data. This is especially crucial in areas, where understanding complex issues often relies on qualitative insights. MAXQDA achieves this by featuring an intuitive interface that allows users to import a wide range of data types, including text documents, audio recordings, video files as well as images. This enables researchers to consolidate various data sources within a single project and therefore, streamlining the management of various datasets.

A major element of MAXQDA is its coding system, which allows researchers to assign codes to specific segments of data that represent distinct themes or concepts. Coding illustrates a fundamental aspect of qualitative analysis, as it allows for systematic categorization as well as organization of data (Guetterman & James, 2023). The software accommodates various coding strategies, such as open coding, axial coding and also selective coding that offers flexibility in tailoring approaches to fit specific research designs. After coding, users can engage with powerful tools to retrieve and analyze these coded segments. The possibility to extract all segments linked to particular codes facilitates the discovery of patterns and themes throughout the dataset. Additionally, the software supports the comparison of codes across different groups or conditions, enriching the analytical process.

MAXQDA provides tools that allows the visualization of various relationships between codes and categories, which might be beneficial in identifying patterns and connections within the data. However, generating a visual table for this research would not draw meaningful conclusions as only a few qualitative data points emerged from the conducted interviews.

In this thesis, MAXQDA was applied to facilitate the organization and systematic analysis of data gained during expert interviews. A coding framework, aligning with this thesis’ research questions, was created which enabled the identification of key themes as well as insights. As it is possible to apply an iterative analysis approach, which allows re-adapting codes and themes during the process, it ensures that this research’s findings remain closely tied to the data itself and integrates up-to-date statements as the data is modified when new insights arise.

## Coding of the Interviews

As mentioned above, the software MAXQDA was used to facilitate the systematic organization and interpretation of the collected data. The coding process started with a detailed review of the interview transcripts, involving multiple re-reading to fully gain an understanding of the discussions. An open coding strategy was adopted, generating initial codes based on the meanings present in the data. This iterative approach allowed for ongoing refinement and adjustment of the codes, ensuring that they accurately reflect the nuances of the participants' perspectives (Kuckartz, 2010).

Maintaining a clear focus on the research questions and objectives throughout the coding process is crucial as it not only guides the development of categories but also ensures their relevance to the study's overarching themes (Meuser & Nagel, 1991). Furthermore, remaining open to new insights that may arise during the coding procedure is important, as qualitative research often uncovers unexpected topics that could dramatically enhance the analysis.

Using MAXQDA for the coding process entails systematically reviewing the interview transcripts and allows the marking of relevant text segments with specific codes that align with the predetermined categories (Guetterman & James, 2023). This includes highlighting portions of the text and assigning them to the appropriate codes, which can be created and re-adapted within the software. Here, it has great importance that each code is applied consistently and accurately, allowing for a coherent organization of the collected data.

Selecting the coding categories was based on the key topics and issues discussed during the interviews, especially those related to water scarcity, innovative technologies as well as the role of artificial intelligence in addressing these challenges in rural Yemen. The first category, Water Scarcity and Quality Issues tackles the main challenges faced by displaced populations in accessing clean water, the risks of contamination and also the effects of inadequate infrastructure. This category was chosen to emphasize the urgency of the water crisis in Yemen and the complex nature of the problem, directly relating to the main research question about how AI and innovative technologies can serve as cornerstones in achieving secure access to clean water.

The second category, Innovative Technologies for Water Management reflects the discussions around various technological solutions, such as Watergen and the WADI device. This category was selected to highlight the potential of innovative technologies to address water scarcity and quality issues as well as practical considerations for their implementation in rural contexts. The inclusion of so-called ‘Smart Sanitation Systems’ as a sub-category further sheds some light on the importance of real-time monitoring and analysis of water

quality to prevent disease outbreaks, which re-connects to the sub-research question regarding how AI can aid in creating sustainable smart sanitation systems.

The Role of AI and Data Analytics embodies the third category and outlines the importance of data collection and monitoring in enhancing water management practices. This segment explores how a deeper understanding of how AI can improve decision-making processes, support proactive measures and be integrated into existing systems to address water quality challenges. The interview discussions underscored the necessity for robust data analytics to inform interventions and enhance overall water management strategies, thus addressing the feasibility of incorporating modern technologies and AI into the development of decentralized water, sanitation and hygiene (WASH) facilities in rural Yemen.

Last but not least, the fourth category Funding and Sustainability Challenges focuses on financial models and sustainability considerations necessary for the implementation of innovative water solutions. This division highlights the importance of technology funding as well as the urgent need for long-term investments in infrastructure to ensure sustainable access to clean water. Moreover, the emphasis on community engagement and capacity building within this category points out the importance of local involvement into water management initiatives to promote resilience and independence. This provides some answers regarding the sub-research question that tackled the extent to which cryptocurrency-based funding models represent beneficial advancements in constructing and maintaining sanitation facilities in Yemen's rural communities compared to traditional credit models.

By structuring the coding process around these above-mentioned categories, the objective strives to systematically analyze the qualitative data gained from the interviews and draw meaningful conclusions that enhance the overall rigor as well as depth of this thesis. This approach not only helps in generating an understanding of the participants' insights but also facilitates the identification of key topics which might inform future research and policy recommendations in the realm of water management and technology implementation.

# Limitations

The study acknowledges the limitations inherent in a literature review research approach. The rapidly evolving fields of AI and modern, innovative technologies mean that the most current developments may not yet be fully captured in the academic literature. The pace at which new advancements and breakthroughs occur in these fields can outstrip the publication cycles of academic journals, leading to a potential lag in the representation of the latest innovations.

Moreover, the specific context of Yemen's civil war displays very unique challenges that may not be directly addressed in the existing literature, necessitating a cautious interpretation of the findings. The complex socio-political landscape, ongoing conflict as well as the humanitarian crisis in Yemen create a set of circumstances that are not easily comparable to other regions. This uniqueness means that generalizations drawn from literature focused on different contexts may not be entirely applicable to Yemen. Thus, while the literature provides valuable insights, it is crucial to consider the distinctiveness of Yemen's situation when interpreting the findings.

Despite these limitations, the literature review provides a solid foundation for understanding the challenges of accessing clean water as well as potential future impacts of innovative technologies in enhancing sustainable development in Yemen's rural areas. The review combines existing knowledge regarding the key issues, such as water scarcity, damaged infrastructure as well as the role of technology in addressing these challenges with qualitative research. By applying this research approach, this thesis aims to identify potential pathways for leveraging AI and innovative technologies to improve water access and overall development outcomes in rural Yemen.

This paper solely relies on a literature review combined with online expert interviews. On-site interviews are not possible due to the fragile situation in Yemen. Consequently, this research acknowledges the possible limitations that might come with such a research approach, including the potential for bias in the data collection as it relies on remote sources. The absence of on-site data collection means that the understanding of the local context and the personal perspectives of the Yemeni population will be limited to some extent. The insights gained from a few expert interviews, while valuable, may not fully capture the diversity of experiences and opinions within the affected communities.

Besides the just mentioned aspects, it should be noted that every researcher has a confounding framework that represents a certain perspective and, therefore, is somehow biased. Although the goals should be, to conduct objective research, the risk of bias can never be fully eliminated.

These limitations will be kept in mind when analyzing the literature and it is important to note that the findings of this research paper cannot be generalized. The unique challenges of conducting research in a conflict zone necessitate a cautious approach to data interpretation as well as an urge for the recognition of the inherent constraints. Also, the conclusions drawn from this research should be perceived as preliminary and indicative rather than definitive.

# Theoretical Background

## Development Aid in General

The landscape of development aid has transformed remarkably over the years, shaped by various theories and practices aimed at tackling global poverty and inequality. In the aftermath of World War II, the focus was primarily on reconstruction, as seen in initiatives like the Marshall Plan, alongside the establishment of bilateral aid relationships. This period gave way to the Modernization Theory of the 1960s and 1970s, which emphasized economic growth as well as a top-down approach to development. However, as the limitations of this model became apparent, Dependency Theory emerged in the 1970s and 1980s, critiquing the notion of modernization and highlighting the risks of dependency on foreign aid, while advocating for necessary structural changes (Thorbecke, 2000).

Simultaneously, the Basic Needs Approach gained traction, focusing on human-centered development that aimed to meet the essential needs of the poor through active community participation. The 1980s and 1990s marked a shift towards Sustainable Development, which integrated environmental considerations and emphasized participatory methods in development planning (Thorbecke, 2000). This was followed by the Human Development and Capability Approach, which shifted the focus to improving human well-being and capabilities beyond mere economic metrics.

In the 2000s, Results-Based Management became a key focus, emphasizing the importance of measuring outcomes, accountability, and the effectiveness of aid interventions. More recently, the concept of Local Ownership has gained prominence, underlining the necessity of community involvement and empowerment in the development process (Yousuf, 2021). This evolution reflects a growing recognition that sustainable progress is best achieved when aid interventions are culturally relevant and tailored to the specific needs of local populations. Overall, the journey of development aid illustrates a complex interplay of ideas and practices that continue to shape the field today.

This overview of development aid practices displays that throughout the evolution of development aid, the perspectives on how assistance should be provided have undergone significant changes. In the past, aid was often delivered through a top-down approach, where external organizations and governments dictated the terms of support without fully considering the unique needs and insights of local communities. This method frequently resulted in projects that did not align with the actual requirements of those they aimed to help, leading to inefficiencies and, in some cases, outright failures (Alqatabry,& Butcher, 2020).

Today, there is a growing recognition of the importance of local ownership in the development process (Lie, 2019). This contemporary approach emphasizes engaging local societies in decision-making, acknowledging that sustainable development is most effective when those directly affected by aid initiatives are active participants. By empowering communities to identify their own challenges and solutions, development aid can become more culturally relevant and sustainable.

One of the critical aspects of this shift is the need to identify and address the challenges that arise between local and regional needs and the structures of international collaboration. Local communities possess invaluable knowledge about their own contexts, including social dynamics, economic conditions as well as environmental factors. However, these insights must be harmonized with broader international frameworks to create impactful solutions (Alqatabry,& Butcher, 2020). Achieving this balance requires international organizations to be flexible and willing to adapt their strategies to fit local realities, rather than imposing standardized solutions that may not work in every context.

It is also essential to differentiate between humanitarian aid and development aid. Humanitarian aid is typically provided in response to crises, such as natural disasters or armed conflicts, with the primary goal of saving lives and alleviating suffering. This type of aid is often short-term and focused on urgent needs. In contrast, development aid aims to address the root causes of poverty and inequality through long-term strategies that promote economic growth, education, health and infrastructure. By integrating local ownership into both humanitarian and development aid, organizations can enhance the effectiveness of their interventions, ensuring that they not only address immediate needs but also contribute to sustainable development goals (Shinoda, 2008).

In conclusion, the evolution of development aid from a top-down approach to one that prioritizes local ownership marks a significant advancement in the field. By recognizing the value of local insights and fostering collaboration between communities and international organizations, aid can be more effectively tailored to meet the unique challenges faced by societies. This shift not only enhances the sustainability of aid initiatives but also empowers communities to take charge of their own development, ultimately leading to more resilient and self-sufficient societies.

To address the complex issue of water scarcity in rural Yemen, a variety of theoretical frameworks offer important perspectives to the ongoing challenges. The Center-Periphery Concept highlights the differences between developed and underdeveloped regions, illustrating how these relationships shape development outcomes. Meanwhile, the Human Security Framework emphasizes the need to protect individual freedoms and overall well-

being. The Capability Approach focuses on enhancing human capabilities and tackling structural inequalities. Additionally, the Integrated Water Resources Management Approach advocates for a coordinated strategy to manage water resources effectively, while the concept of Technological Determinism points to the significant role technology plays in driving societal change. Together, these frameworks provide a comprehensive view of the intricate interplay between social, economic as well as environmental factors that influence access to clean water in Yemen, informing efforts to develop more effective and sustainable solutions.

## The Center-Periphery Concept

The Center-Periphery concept, which discusses the relationship between developed core areas and less developed outer areas, is relevant to understanding the disparities within Yemen. This concept is supported by various theoretical frameworks, including world-systems theory, dependency theories, and Neo-Gramscian, which examine the relationship between centers and peripheries (Wallerstein, 2016; Ayubi, 1995). The analysis by Immanuel Wallerstein and the extension by Andre Gunder Frank highlight how regions' statuses as centers or peripheries are significant determinants of their development or underdevelopment (Frank, 2016). Adam Morton's research emphasizes the importance of center-periphery dynamics in shaping intra-societal relations and the role of party relationships in establishing national hegemonies (Morton, 2010).

According to the United Nation, development aid is defined as a multidimensional undertaking to achieve a higher quality of life for all people, encompassing economic, social and environmental protection as interdependent components of sustainable development. In Yemen, the provision of fundamental infrastructure, such as access to clean water and sanitation, could not only drastically improve living conditions, especially in rural regions (United Nations Agenda for Development, 1997) but also provide basic human rights to people living in those areas (United Nations, 2024a).

## The Human Security Framework

Another approach besides the above-presented Center-Periphery concept embodies the Human Security framework which emphasizes the protection of the individuals' fundamental freedoms and well-being, entailing economic, personal, food, health, environmental, community as well as political security (UNDP, 1994).

Sustainable Human Security is built upon four key pillars *(see Figure 1)* that encompass our current understanding of human security, development, dignity as well as sustainability (UNDP, 2006). The first pillar, Freedom from Fear, focuses on ensuring human survival and

safeguarding individuals and communities from both natural and man-made disasters, as well as other forms of violence and conflict. This pillar emphasizes the importance of protecting people from immediate threats and creating a safe environment where they can thrive.

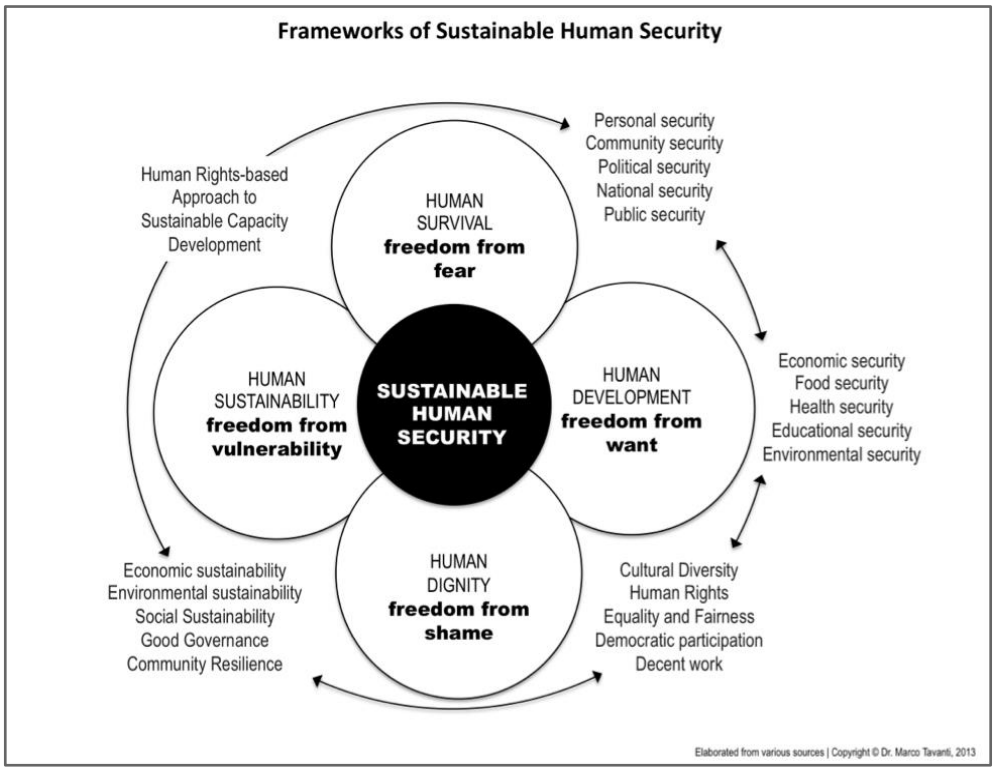


*Figure 1 Human Security Framework*

*(Source: https://www.weinstitute.org/human-security.htm)*

The second pillar, Freedom from Want, addresses human development and aims to eliminate extremes, recurring and also systemic poverty. It seeks to ensure that basic needs are met for all individuals, promoting a standard of living that allows people to live with dignity and pursue their aspirations. By addressing the root causes of poverty, this pillar aims to create a more equitable and just society.

Furthermore, the third pillar, Freedom from Shame, mainly focuses on human dignity by recognizing and protecting the fundamental human rights of every individual. It calls for respect and value for all aspects of diversity, ensuring that everyone is treated with respect and their rights are upheld. Freedom from Shame highlights the importance of creating inclusive societies where all individuals can participate fully and without discrimination (UNDP, 1994).

Last but not least, the fourth pillar, Freedom from Vulnerability, is concerned with human sustainability aiming to protect people from both immediate and long-term natural disasters, particularly by mitigating man-made threats to the environment. This pillar sheds light on the

importance of the need for sustainable practices that reduce environmental risks and promote resilience against future challenges.

These pillars are integrated into a broader framework of political, economic, social as well as environmental responsibility. They promote capacity building through a human rights-based approach as well as sustainable development strategies, ensuring a holistic and enduring approach to overall human security. By embedding these principles into all aspects of governance and societal development, Sustainable Human Security seeks to create a world where all individuals can live free from fear, want, shame and vulnerability (UNDP, 2006).

## The Capability Approach

When tackling water scarcity in Yemen, the Capability Approach (Sen, 1999) developed by Amartya Sen illustrates another crucial theoretical framework that helps to explain the issue in more detail. The capability approach emphasizes the importance of expanding human capabilities as well as choices rather than solely focusing on economic growth or utilitarian efficiency. This framework shifts the focus from mere volumetric measurements of resource availability to a broader context that considers human well-being and social justice. Furthermore, it highlights the need to address structural and institutional factors that contribute to inequalities, such as social norms, property rights and power relations, which often marginalizes poor and vulnerable populations. By concentrating on the actual living conditions and freedoms that individuals can achieve, the capability approach provides a more comprehensive understanding of development and resource management.

In the context of Yemen, where water scarcity is an urgent issue, the capability approach offers an important framework for addressing the multifaceted challenges especially faced by rural regions. Implementing this approach involves recognizing that access to water is not just about physical availability but also about ensuring that individuals have the necessary entitlements and freedoms to utilize water for their well-being and livelihoods. This means addressing the socio-political processes that lead to exclusion and discrimination and ensuring that water policies are designed to enhance equity and participation. Interventions in rural regions could for example focus on both improving local water management practices, investing in infrastructure that supports both domestic and productive uses of water, but also on empowering communities to participate in decision-making processes. By adopting this holistic perspective, the capability approach can help create sustainable solutions that not only provide immediate relief from water scarcity but also promote long-term human development and resilience in Yemen's rural regions (Mehta, 2014).

## The Integrated Water Resources Management Approach

Building on the previous frameworks, the so-called Integrated Water Resources Management (IWRM) approach provides a comprehensive and coordinated method for addressing water scarcity, particularly in rural regions of Yemen. IWRM can be defined as a process that promotes the coordinated development and management of water, land as well as related resources to maximize economic and social welfare equitably without compromising the sustainability of vital ecosystems (Xie, 2006). This approach highlights integration across various sectors, decentralization of management, stakeholder participation and also economic and financial sustainability. By considering the interdependencies between different water uses and the broader socio-economic and environmental context, IWRM offers a holistic framework for sustainable water management.

Unlike previous sectoral approaches, IWRM advocates a holistic strategy that balances economic development, social welfare and environmental protection. This method integrates the management of all water-related sectors, emphasizing the need to address social and environmental concerns sustainably. New institutions as well as policies are required to coordinate efforts across water supply, sanitation, agriculture, energy, industry and also environmental protection *(see Figure 2)*. Effective management also depends on comprehensive data collection and distribution across various physical and socio-economic measures (GWP, 2000).

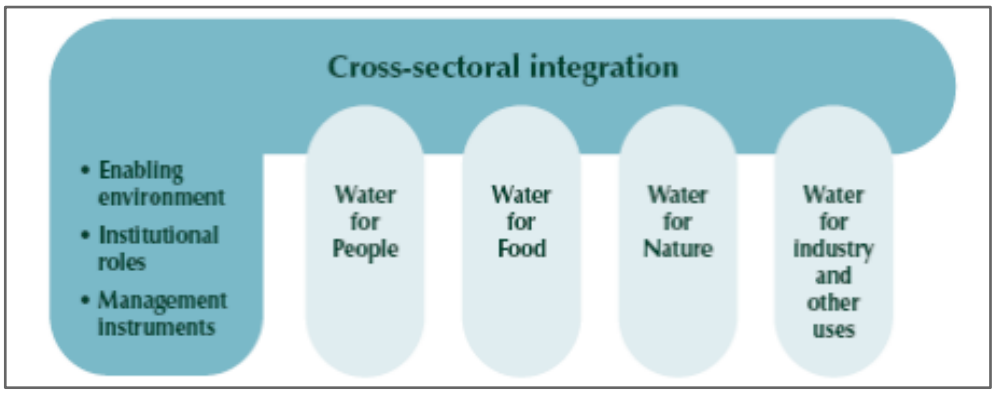


*Figure 2 Cross-Sectoral Integration*

*(Source: https://www.pacificwater.org/userfiles/file/IWRM/Toolboxes/introduction%20to%20iwrm/IWRM%20Introduction.pdf)*

In rural regions of Yemen, the application of IWRM might be able to address the multifaceted challenges of water scarcity by promoting both efficient and equitable water use. Introducing IWRM involves improving local water management practices, enhancing infrastructure for both domestic and productive water uses as well as fostering community participation in decision-making processes. This might help to ensure that water resources are managed sustainably

and that the needs of all stakeholders, including marginalized and vulnerable populations, are considered. However, challenges such as inadequate infrastructure, limited financial resources or weak institutional capacity may significantly hinder the effective implementation of IWRM. Despite these challenges, the benefits of adopting IWRM in Yemen could include improved water quality and availability, enhanced agricultural productivity and increased resilience to water-related conflicts and climate change impacts (Xie, 2006). By fostering collaboration and integrating various water management strategies, IWRM can contribute to long-term water security and sustainable development in Yemen's rural regions.

## The Concept of Technological Determinism

Last but not least, expanding on the earlier discussions, the concept of Technological Determinism offers a crucial perspective for addressing water scarcity in rural regions of Yemen. Technological Determinism claims that technology is the primary driver of societal transformation, influencing social changes and development (Hauer, 2017). According to this framework, advancements in technology, including innovations in water management and distribution systems, are able to significantly impact the way society's function and adapt to new challenges. By leveraging technological advancements, it might be possible to create sustainable solutions that address the unique water scarcity issues faced by rural communities in Yemen.

Applying the Technological Determinism approach in Yemen involves harnessing modern technologies to enhance water access and management in rural areas. This could encompass the deployment of advanced irrigation systems, water purification methods as well as efficient distribution networks. These innovations might be able to alleviate water scarcity by ensuring more effective and equitable usage of water resources. However, challenges such as the high cost of technology, inadequate infrastructure and limited technical expertise may pose obstacles to successful implementation. Despite these hurdles, the advantages of adopting a Technological Determinism approach include improved water quality, higher agricultural yields and also greater resilience to water-related conflicts and climate change impacts (Hauer, 2017). Incorporating technological advancements in rural regions of Yemen could achieve sustainable water management and long-term development.

Linking above theory with relevant methodology, this thesis explores the complexity of the problem around the access to clean water in rural Yemen. There is no doubt that modern technologies could provide innovative solutions to this issue. However, the current situation is so complex and intertwined that achieving a sustainable solution does not seem feasible at this point (USAID, 2018; Lee et al., 2023; Toetzke et al., 2022).

# Innovative Approaches to Development Aid

In an increasingly complex and rapidly changing world, the need for innovative approaches to development aid has never been more critical. Traditional methods of assistance often struggle to keep pace with the evolving challenges posed by climate change, urbanization as well as socio-political disruption (Freedman, 2000). As communities around the globe face unprecedented issues, including water scarcity and inadequate sanitation, development aid also has to adapt to such modern circumstances. Embracing innovative solutions, such as artificial intelligence and advanced water clarification technologies, can significantly enhance the efficiency and impact of humanitarian efforts.

By prioritizing innovation in development aid, not only immediate needs can be addressed but also resilience and sustainability can be created for the future. Based on this urgent need for modernization, this thesis explores the importance of integrating innovative strategies into development aid, particularly in the context of achieving the Sustainable Development Goal 6 (Clean Water and Sanitation). Also, this research highlights the transformative potential of such approaches in fostering secure access to clean water for vulnerable populations.

## Innovative Water Clarification Technologies

Drinking water is a critical component of human survival. Although in many, particularly developed, countries, having easy access to clean and safe drinking water is taken for granted, not having potable water still represents a serious problem (Wasseratlas, 2025), that millions of people have to face worldwide on a daily basis (*see Figure 3).* As illustrated in the Figure below, it can be seen that Yemen not only struggle with severe water scarcity at this point of time, but also, if no changes are implemented, it will be categorized as having ’extreme water scarcity’ in the year 2050.

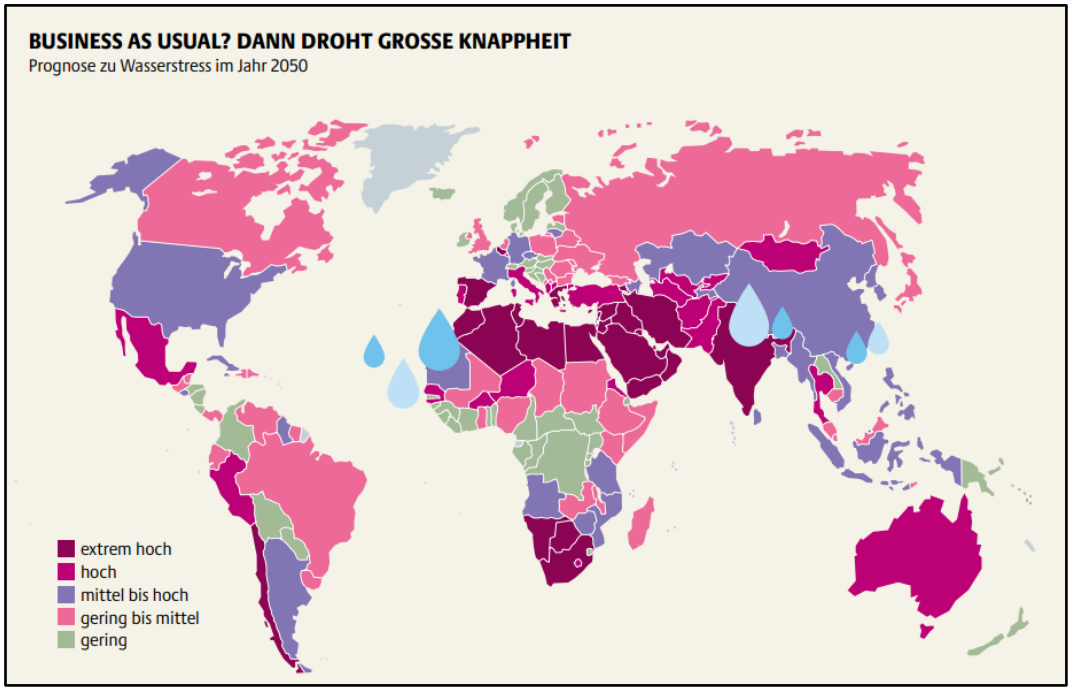


*Figure 3 Forecast For Global Water Scarcity In 2050*

*(Source: https://www.boell.de/sites/default/files/2025-01/wasseratlas-2025.pdf)*

Therefore, the question here is not only whether water is needed for life but as well how access to clean water can be quickly granted in rural regions of Yemen. Here, two modern water clarification technologies, Watergen and WADI's SODIS, might display possible facilitators.

Due to climate change, extreme weather conditions, such as droughts, floods or storms, have aggravated in recent years which drastically reshapes our daily living and intensifies water scarcity. Securing safe, clean drinking water becomes a bigger challenge that has to be faced worldwide (Watergen, 2025). For more than two billion people worldwide, having the ability to access (clean) water whenever required remains an unfulfilled dream. By providing clean water, innovative water clarification/generation technologies work on creating a worldwide climate resilience where water scarcity can be eliminated. In the following paragraphs, two of such technologies and their approaches as well as possible solutions to water scarcity will be introduced.

Watergen's Atmospheric Water Generators (AWGs) *(see Figure 4)* offer a revolutionary solution to water scarcity, particularly in dry and conflict-affected regions like Yemen. Watergen extracts water from the air by cooling it to the dew point, condensing the moisture and then filtering it to produce clean, drinking water. Leveraging the abundant humidity in the atmosphere, Watergen's AWGs are viable even in areas with limited water resources. Available in various sizes, from small units for households to large-scale systems for entire communities, these generators provide a reliable source of clean water and, therefore,

drastically reduce dependency on traditional, often contaminated, water sources (Watergen, 2025).

In order to best match the consumers' needs, Watergen offers its generators in various sizes (Watergen, 2025). GEN-M1 represents a medium-scale mobile AWG that produces up to 220 liters of fresh drinking water a day. During this process, it consumes 2.2 kW/hour and weighs 350 kg. Its next biggest device is called GEN-M PRO. This can generate up to 900 liters per day, which is almost four times the water volume GEN-M1 is able to provide. However, much more energy is required, 5.6 kW/hour, and the weight also increases to more than double, 780 kg. With a possible water creation of up to 6000 liters a day, weighing 2850 kg and requiring 60kW/hour, GEN-L presents the biggest water generator that Watergen currently offers (Mendoza-Escamilla et al., 2019). All of Watergen's devices effectively work in climate conditions from 15°C and a minimum of 20 percent humidity. A built-in air filtration system ensures high water quality by removing micro-particles and organic traces. Although these innovative water generating tools offer great potential, the cost aspect plays a crucial role which often decides whether a tool represents a 'do' or 'don't'. Prices for these above-mentioned generators vary from USD 40.000, for the GEN-M1, up until USD 189.000 for the biggest version, the GEN-L.

Another beneficial aspect is that all Atmospheric Water Generators are portable and only need an electricity source to successfully operate (Watergen, 2025). Energy can either be accessed by simply plugging the device in or, if this is not possible, generators or solar power also represent feasible solutions. Especially in regions, where the infrastructure is damaged or non-existent, or electricity is scarce, these two alternatives are oftentimes used for energy production. However, both options entail restrictions as a generator requires diesel which might be expensive or non-accessible. In order to generate electricity from solar panels, sufficient sun has to exist.

Besides the electricity component, Watergen's devices are very suitable for rural regions since there is no need for piping and neither time-intensive procedures are required.

*Figure 4 Watergen's Atmospheric Water Generator*

*(Source: https://www.watergen.com/mobility/watergen-mobile-box/)*

The Watergen process *(see Figure 5)* involves various steps: Air intake, filtration to remove dust and pollutants, cooling to condense water vapor and finally multiple stages of filtration to ensure the water meets the required drinking standards. The final product is clean water suitable for drinking, cooking as well as other fundamental needs. Watergen's innovative technology not only provides a reliable source of water but also gives people back a small piece of their independence and, thus, helps in setting foundations for a sustainable development and an increase in living standards.

An important question hereby is, where does Watergen's Atmospheric Water Generators obtain the required energy from? Plugging the generators into existing power sources oftentimes illustrates the applied approach to accessing energy. However, as in some scenarios, no stable power source exists, using solar-panels for energy production represents a feasible energy source, especially in more rural regions where infrastructure barely can be found (Mendoza-Escamilla et al., 2019).

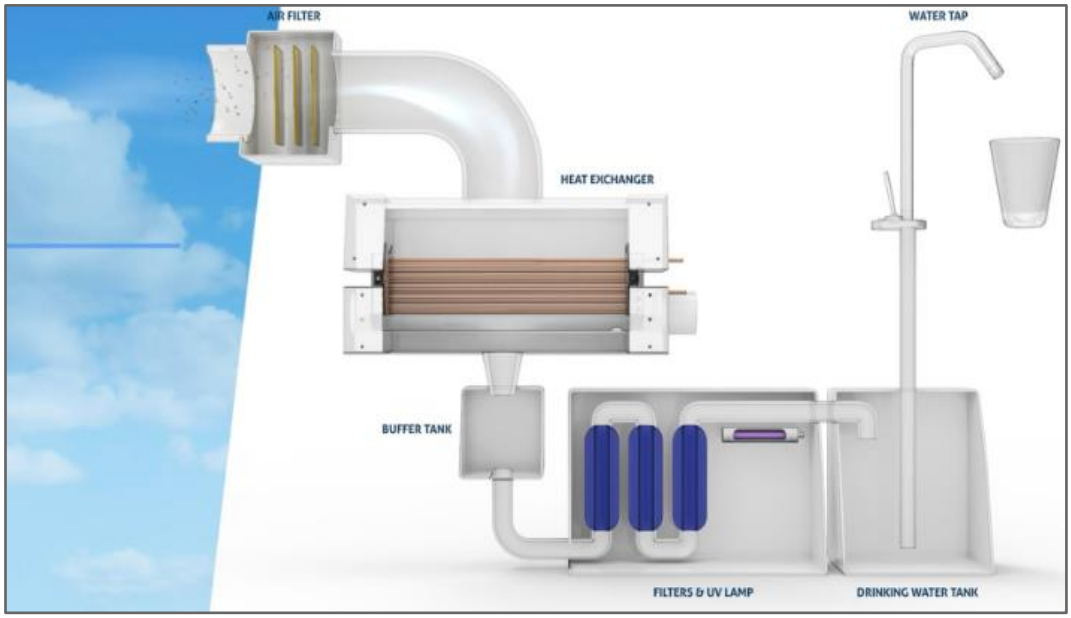


*Figure 5 Watergen's Water Generation Process*

*(Source: https://www.watergen.com/technology/)*

While Watergen creates water out of air, WADI's Solar Water Disinfection (SODIS) technology tackles the challenge of providing safe drinking water in regions with limited/damaged infrastructure by purifying unclean water. SODIs illustrate simple, cost-effective devices that use solar energy to disinfect water. Compromised of a transparent plastic bottle as well as a UV indicator, WADI allows users to fill the bottle with contaminated water and place it in direct sunlight for several hours. During sun exposure, the UV radiation from the sun kills harmful bacteria and viruses, making the water safe for consumption (WHO, 2015).

Using WADI is not only simple but also straightforward: Filling the bottle with water, placing it in direct sunlight for at least six hours if sunny (or up to 48 hours on cloudy days) as well as checking the UV indicator to ensure the water is disinfected. Since the WADI tool does not purify the water but rather measures UV rays for disinfection, placing one device in the area is sufficient for measuring the disinfection process of numerous bottles. The only requirement is that all bottles face the same amount of UV ray exposure.

*Figure 6 WADI Tool*

*(Source: https://www.helioz.eu/de/wadi)*

Initially, when unclean water is introduced, the smiley shows an unhappy face. As soon as the clarification process has finished, the unhappy smile turns into a happy one, indicating that the water is ready to drink *(see Figure 6 and Figure 7)*. This method is particularly effective in rural and/or remote areas where access to clean water and appropriate filtration systems is limited. WADI's SODIS technology has been widely adopted in various regions, demonstrating significant improvements in water quality and, subsequently, public health and daily living standards.


*Figure 7 WADI's SODIS Technology*

*(Source: https://www.engineeringforchange.org/solutions/product/wadi-solar-disinfection-system/)*

Over the years, several case studies have highlighted the effectiveness of Watergen's AWGs and WADI's SODIS technology in different contexts to test the feasibility of these innovative technologies. As an example, in a pilot project in a rural village in Yemen, Watergen's AWGs

provided a sustainable source of clean water, significantly reducing the community's reliance on contaminated wells and improving overall health outcomes (Watergen, 2025). Similarly, WADI's SODIS technology has been successfully implemented in a number of African countries, where it has helped reduce the incidence of waterborne diseases and improved access to safe drinking water (WHO, 2015).

Although a multitude of innovative technologies exists, this research paper focuses on Watergen and WADI's SODIS. Reasons for choosing these technologies are elaborated in the following paragraphs and can vary from a monetary perspective to the feasibility of the tool.

When comparing these two modern water clarification tools, what are the potential benefits and restrictions of them? A comparative analysis of these technologies reveals their respective strengths and limitations. Watergen's AWGs are highly effective in producing large quantities of water and are suitable for community-wide applications. However, they require a stable power supply as well as regular maintenance, which may be challenging in conflict-affected areas. WADI's SODIS technology, on the other hand, is simple, low-cost and easy to use which makes it ideal for individual households as well as remote communities (DerStandard, 2013). Yet, its effectiveness is limited by weather conditions and the availability of sunlight.

Furthermore, Watergen's AWGs utilize a patented GENius technology that maximizes water extraction efficiency. The process begins with air intake through a multi-barrier air filtration system that removes dust and pollutants. Then, the filtered air is cooled to the dew point, causing water vapor to condense. The condensed water undergoes several stages of filtration, including UV treatment, to ensure it meets drinking water standards (DerStandard, 2016). When the water is finally cleaned and safe to drink, it can be dispensed directly from the machine.

While Watergen represents a machine, WADI is a small user-friendly device designed for solar water disinfection that only needs a transparent PET bottle and is placed in the area around to work as an UV indicator. Users fill the bottle with contaminated water and place it in direct sunlight where the UV radiation from the sun penetrates the bottle and kills harmful pathogens such as bacteria, viruses as well as protozoa. As soon as completed, the UV indicator changes from an unhappy to a happy smiley to signal that the water is safe to drink. This process is simple, cost-effective and also does not require any additional chemicals or power sources.

Although it is evident that both Watergen's Atmospheric Water Generators (AWGs) and WADI's Solar Water Disinfection (SODIS) technology offer innovative solutions to address water scarcity or contamination issues, it cannot be generalized which tool is better, as each situation must be examined individually to determine the most suitable option. Factors such as the country in question, the local situation as well as the desired outcomes play crucial

roles in this decision-making process. Depending on the need, it has to be decided whether water is available but does not meet quality standards and therefore, needs to be purified - here WADI represents the solution - or whether no water at all is accessible, then Watergen should be chosen as it allows water generation from scratch. This shows that no unique best solution exists, but the decision has to be made based on a thorough assessment of the unique circumstances and needs of each context.

## The Role of Artificial Intelligence in Development Aid

Artificial Intelligence (AI) holds significant promise for enhancing the efficiency and effectiveness of development aid across many sectors. One of the main applications of AI encapsulates predictive analytics, which can drastically improve the distribution of resources. By processing extensive datasets, AI algorithms have the ability to anticipate where aid is most urgently needed which helps to ensure that resources are allocated in a timely as well as targeted manner. Especially in conflict-affected regions like Yemen, such capability is crucial since the scarcity of resources as well as the urgency of needs demand precise and rapid intervention. As an example, AI can forecast potential food shortages, disease outbreaks as well as other crises, allowing aid organizations to allocate resources proactively and mitigate adverse impacts (Rashid & Kausik, 2024).

In Yemen, where the agricultural sector is vital for not only the economy but also food security, AI-driven precision farming can represent a transformative role. By analyzing local soil conditions, weather patterns as well as crop health, AI tools are able to provide Yemeni farmers with critical insights to optimize resource use and, subsequently, enhance crop yields. This is particularly important in a region where water scarcity and soil degradation illustrate critical challenges. Applying AI technologies can aid Yemeni farmers to better decide about irrigation, fertilization as well as pest control, leading to more sustainable farming practices and improved food production. Furthermore, AI's ability to predict and quickly respond to environmental changes can help mitigate the impacts of climate change on agriculture, ensuring a more resilient food supply for the population (UNDP, 2024b).

There is no doubt that the ongoing crisis has serious effects on Yemen’s population, but children are particularly hard-hit. Many have lost their parents and are unable to attend school due to the destruction of infrastructure. Fulfilling basic needs such as food, shelter as well as safety must be prioritized before educational needs can be addressed. Here, AI has the potential to alleviate some of these challenges by providing targeted support and resources, thereby helping to rebuild and improve the lives of Yemen's most vulnerable population in the face of the challenges posed by the ongoing conflict (UNICEF, 2023).

Another area, where AI can have great impact, illustrates the healthcare sector as it faces significant challenges due to ongoing conflict and limited resources in Yemen. AI algorithms can analyze medical images and patient data, therefore, improving diagnostic accuracy and patient management as well as enabling timely intervention and treatment. Moreover, AI can predict disease outbreaks at early stages which allows healthcare providers to allocate resources efficiently and implement preventive measures. Such capability is particularly crucial in Yemen, where healthcare infrastructure is strained and rapid response to health crises is essential to save lives and improve health outcomes (Hatem et al, 2024).

Especially in regions where medical infrastructure is unstable, establishing early warning systems can significantly improve the health situation and even save lives. Smart sanitation systems illustrate another innovative application of AI which could drastically transform development aid. These systems utilize sensors and data analytics to monitor and manage sanitation infrastructure, ensuring efficient waste management and reducing health risks. Smart toilets illustrate a good example of this as they are equipped with sensors that can detect usage patterns and maintenance needs. This allows not only timely interventions but can prevent serious health issues, such as outbreaks of diseases. Additionally, smart sanitation systems are able to monitor water quality and detect contamination, contributing safer and more hygienic conditions (Rary et al., 2020).

An example of a successfully implemented smart sanitation system can be illustrated by the city of Pune, in India. Pune, a vibrant city in western India with a population of 6.4 million people, is implementing an innovative smart sanitation project designed to develop sustainable and resilient sanitation solutions. This initiative incorporates artificial intelligence (AI) to enhance the city's sanitation infrastructure by using real-time data collection and monitoring through sensors, along with advanced analytics. The integration of AI aims to improve the efficiency and effectiveness of sanitation services. This project supports several key Indian government initiatives, including the Smart Cities Mission, Swachh Bharat Mission, Digital India, the National Urban Innovation Stack as well as the National Strategy for Artificial Intelligence, all of which seek to improve urban living conditions, promote economic growth and also ensure universal sanitation coverage. Yet, the project also prompts important questions about the design and implementation of AI systems, particularly their impact on marginalized communities, such as Dalit women sanitation workers. It highlights the necessity of considering the societal context in which AI is deployed, examining how these technologies interact with existing caste and gender dynamics in sanitation labor. As Pune aims to become the world's first smart sanitation city, it is essential to ensure that technological advancements benefit all citizens equitably and uphold the rights and dignity of those at the margins. This

initiative has significantly improved sanitation services, reduced health risks and also enhanced the overall quality of life for these residents (Rashid & Kausik, 2024).

Even if unintended, humans employ different perspectives and therefore, as well unconsciously project them onto their research by ‘looking through certain glasses’. Due to this phenomenon, conducting unbiased research is almost impossible. In this regard, AI could possibly be used to identify and reduce human biases (Silberg & Manyika, 2019) as machine learning algorithms only consider variables that improve predictive analysis based on the data used. Based on this, it could be claimed that AI offers an ‘unbiased’ view. However, on the contrary, it can also be argued that AI systems may inherit biases from the data entered. Although it is true that AI operates the better, the more information is provided, the quality of the input data also greatly matters. Overall, no universal statement can be formed whether machine learning would improve or deteriorate the bias dilemma.

Despite the numerous advantages AI can offer, such as increased efficiency, highly predictive capabilities as well as improved outcomes in various sectors, it is crucial to remember the significant energy requirements associated with such modern technologies (World Economic Forum, 2024). The computational power required in order to run AI algorithms and process large datasets consumes substantial amounts of energy, which can have adverse environmental repercussions. In a country like Yemen, which is already facing severe energy shortages as well as infrastructural challenges, the application of AI technologies may not be feasible at this time. Also, AI requires a lot of data. The more data is fed to AI, the more efficient the created output will be. However, as briefly mentioned above, not only the quantity but also the quality of the collected data also has great significance. Consequently, one of the questions that needs to be answered deals with how a comprehensive and, at the same time, high-quality gathering of data can be ensured?

Although AI has great potential to transform development aid, its high energy demands as well as the existing infrastructural limitations in Yemen recommend that traditional approaches might be more appropriate for the present. As soon as the country has stabilized and infrastructure improved, the integration of AI technologies can and should be reconsidered to not only enhance living standards but also make development more sustainable.

## Cryptocurrency as a Funding Mechanism

Historically, traditional credits represented the main means of funding. Conventionally, a bank granted specific, pre-defined amounts of money to individuals and/or organizations in order to support investments. In recent years, especially with the rise of modern technological innovations, several new funding methods have emerged. Cryptocurrency represents a major revolution in terms of financial funding approaches, as it has potential to revolutionize the overall financial infrastructure.

Cryptocurrency combined with the modern blockchain technology, has the potential to significantly enhance financial transparency in development aid worldwide. By applying a decentralized ledger system, blockchain ensures that all transactions are recorded in a transparent and immutable manner. Such a level of transparency can help mitigate fraud as well as corruption, since every transaction is traceable and verifiable by all parties involved. In countries such as Yemen, where traditional financial systems may be compromised or inefficient, establishing a combined framework based on blockchain and cryptocurrency can offer a reliable and transparent alternative for managing aid funds (Melle, 2019).

The implementation of cryptocurrency in development aid brings several advantages which includes faster transaction times as well as lower or even no fees compared to conventional banking methods. Moreover, cryptocurrencies facilitate direct transfers to beneficiaries, bypassing intermediaries and reducing the risk of funds being misappropriated and/or manipulated. Such a direct approach is especially beneficial in conflict-affected areas where banking infrastructure is restricted or non-existent. Also, cryptocurrencies can promote financial inclusion for populations without banking access, allowing them to receive and manage aid funds through digital wallets (Bholane, 2021). Yet, in order to access digital wallets and generally speaking online banking, people are required to have not only a digital device but also a stable internet connection. These two factors might sound fundamental, however, in poorer as well as conflict-dominated countries fulfilling these basic requirements illustrates a serious challenge.

Despite all these above-mentioned benefits, the adoption of cryptocurrency in development aid as well entails several challenges. The volatility of cryptocurrency values can illustrate a significant risk since the value of funds can dramatically fluctuate in short periods. Based on this, this unpredictability may undermine the stability as well as reliability of aid disbursements. Furthermore, the regulatory environment regarding cryptocurrencies is continuously evolving, with many countries still lacking clear guidelines or legal frameworks for their application. Such uncertainty might create obstacles to the widespread adoption of cryptocurrencies in development aid (Pakhnenko et al., 2022).

When comparing cryptocurrency with conventional funding methods, for both funding approaches, strengths and limitations can be identified. Traditional funding methods, such as bank transfers and also cash disbursements, are well-established as well as widely accepted as they offer stability and predictability, which are crucial components for planning and implementing aid programs. Yet, these methods can be slow, costly as well as subject to corruption and inefficiencies. By contrast, modern funding methods, like cryptocurrencies offer speed, lower transaction costs and enhanced transparency but come with risks related to volatility and regulatory challenges (Bholane, 2021).

Yemen's ongoing civil war has intensified the humanitarian crisis, creating a highly intertwined scenario for the use of cryptocurrency as a means of international aid funding. Although the use of digital currencies, including one developed by the Iran-backed Houthi group, has increased in this conflict, their effectiveness and safety for delivering aid are highly questionable at this point of time. The country represents the lowest safety ranking globally, with a score of just 0.1 out of 10, indicating that using cryptocurrency in such a precarious environment is often more dangerous than relying on cash (Cuen, 2020). Besides the fact that many Yemenis struggle with unreliable internet and phone networks which makes it even more difficult to participate in cryptocurrency transactions, it would also expose Yeminis to potential coercion and surveillance from armed factions.

The lack of a regulated framework further complicates this issue, as most people cannot safely access or utilize cryptocurrencies. Given these significant challenges, cryptocurrency does not seem to represent a viable option for international aid funding in Yemen, as the associated risks and obstacles overshadow any possible advantages.

In summary, these paragraphs provide a short glimpse into the advantages as well as drawbacks that come with blockchain and cryptocurrency as well as with traditional funding. Although modern funding approaches entail promising advantages for enhancing financial transparency and efficiency in development aid, their adoption is not without challenges. Given Yemen's current context and situation, a cautious approach is highly advisable.

## Feasibility and Sustainability of Modern Technologies

Whether modern, innovative technologies can provide a feasible and/or sustainable solution for future development aid highly depends on energy consumption and infrastructure requirements. Advanced technologies, such as AI and blockchain, need considerable computational power which results in extremely high levels of energy consumption. In regions where not only energy but also the overall infrastructure is already under strain, such requirements pose a substantial challenge. Without a stable and reliable power supply, effectively implementing these technologies into a country's infrastructure becomes extremely difficult and also severely restricts their potential impact (Harris & Lee, 2024).

In order to assess the effectiveness of technological implementations, it requires not only robust monitoring but also an evaluation process which involves tracking performance, measuring impact as well as identifying areas for possible improvement (USAID, 2018). However, conflict-affected regions with limited infrastructure face difficulties in collecting and analyzing data. Yet, rigorous monitoring and evaluation are crucial in order to ensure that technological interventions also actually achieve their intended benefits and make informed decisions about further future implementations (Dixit & Gill, 2024).

When taking a look at the long-term sustainability of modern technologies in development aid, this hinges on various factors such as resource availability, local capacity for maintenance and operation as well as the adaptability of technologies to continuously evolving conditions. Extremely high initial costs, the need for ongoing technical support and also the risk of technological obsolescence display potential barriers to sustainability (Harris & Lee, 2024). Moreover, the socio-political context plays a significant role as regions that experience conflict, or political instability may find it particularly challenging to maintain and scale up technological solutions (Quereshi, 2024).

In conclusion, it can be said that while modern technologies offer significant potential for enhancing development aid, their feasibility and sustainability are significantly influenced by energy consumption, infrastructure requirements as well as the capacity for monitoring and evaluation. Addressing these challenges requires careful planning and consideration of local environments. In order to ensure long-term sustainability, not only during the initial deployment of technologies, the capacity for ongoing support and adaptation to changing conditions needs to be considered. By addressing these factors, development aid can however leverage modern technologies to achieve more effective and sustainable outcomes.

# Development Aid in Yemen

Development aid and humanitarian assistance in Yemen are largely driven by international organizations and non-governmental organizations, particularly in light of the ongoing conflict that has significantly weakened the Yemeni state's ability to provide essential services. While Yemen has received international aid for several years, the focus of support programs has often been concentrated on major cities. However, the civil war has driven many people to flee to the countryside, where they live in less well-serviced emergency camps and currently suffer from the world's largest humanitarian crisis (CARE YEMEN, 2024). This situation highlights the urgent need for targeted interventions in rural areas to address the disparities in aid distribution.

In response to these challenges, the Yemeni government has made some attempts to engage in development cooperation. However, the prevailing instability and limited resources have severely restricted its capacity to invest in infrastructure and social services. Consequently, most development aid is sourced externally, with international donors, humanitarian agencies, and private foundations stepping in to address the urgent needs of the population. For instance, from 2015 to 2021, the Delegation of the European Union and UNICEF initiated a local support program aimed at offering basic quality health and nutrition services to decentralized regions, thereby reducing inequalities between rural and urban areas (Sleiman-Haidar, 2017).

Moreover, the United Nations Food and Agriculture Organization (FAO) has sought to boost Yemen's livestock production by providing 'emergency livelihood assistance,' including backyard food production kits. These kits have been a lifeline for thousands, especially as destroyed roads and inaccessible cities have made traditional food sources unreachable (FoodTank, 2017). Despite these efforts, sustainable food security remains a challenge due to limited arable land and access to clean water (Delegation of the European Union to Yemen, 2019).

In this rapidly changing global environment, development cooperation must evolve to meet new challenges and leverage innovations. Traditional aid delivery models are increasingly scrutinized, as the complexity of crises like Yemen's necessitates more adaptive and responsive strategies. In particular, local and regional actors are essential in this context, as they offer critical insights into the specific needs and dynamics of their communities. Strengthening local capacities and fostering partnerships between international organizations and local stakeholders can enhance the effectiveness of aid efforts, ensuring that interventions are culturally appropriate and sustainable (Feedman, 2000). This collaborative approach not only empowers local communities but also leads to more sustainable outcomes.

CARE represents another global institution operating in Yemen, focusing on key thematic areas such as food security, livelihoods, water, sanitation, hygiene, reproductive health, education, protection, women's economic empowerment, and inclusive governance. Given the increasing importance of the United Nations' Sustainable Development Goals (SDGs), international organizations have re-centered their focus to incorporate strategies that support the sustainable attainment of such goals (USAID, 2018). For instance, CARE's WASH program strives to ensure access to clean water and sanitation facilities (SDG Goal 6) for marginalized communities, which is essential for improving health and hygiene in Yemen's rural areas. However, minimal funding often prevents the implementation or continuation of these programs (CARE International Yemen, 2024), and finding a comprehensive solution that promises sustainable access to clean water remains an unsolved challenge.

In this context, it is important to mention that two types of aid-providing organizations exist: international development organizations and international humanitarian organizations. The former provide help in various forms to people in need, aiming to scale success over the long term and enable sustainable, independent development. Conversely, humanitarian organizations focus on short-term objectives, intervening when urgently required. Humanitarian initiatives operate as relief and recovery support for people affected by violent conflicts and natural disasters (ZOA, 2025).

For example, ZOA operates in twelve regions globally that share characteristics of insecurity and volatility (ZOA, 2025). With a mission of 'from relief to recovery,' this institution aims to support people facing daily life difficulties due to armed conflicts or natural disasters by providing aid for rebuilding homes and livelihoods while ensuring peace and stability within local communities. Similar to CARE, ZOA also engages in the WASH initiative, where one of their goals focuses on creating a shift away from water trucking to integrated water management. Leveraging their extensive experience in various projects across Africa, Asia, and the Middle East, ZOA can contribute valuable knowledge to ease the water issue in rural Yemen. By creating water reservoirs, they currently enable locals to access water. However, it is not uncommon for the water quality to fall short of drinking requirements (UNICEF, 2023). Sometimes, filters are applied at water sources to improve water quality, but monitoring the lifetime of such filters often remains a challenge.

The regulatory frameworks governing development aid in Yemen are influenced by both national policies and international agreements. However, the fragile political landscape complicates the implementation of these regulations, often leading to gaps in coordination and oversight. As a result, this lack of structure can result in inefficiencies and overlapping efforts among aid organizations, highlighting the need for clearer guidelines and collaborative

mechanisms to streamline aid delivery (World Bank, 2020). Thus, addressing these regulatory challenges is essential for improving the overall effectiveness of aid.

In summary, Yemen currently receives support from various (inter-)national aid organizations. While some initiatives embody short-term crisis relief, others focus on creating a sustainable future, where not only an improvement of the current state but also full independence represent the end goals. Despite the multitude of support available, it remains unclear whether this aid is provided to the right areas in need, at the right time, and in the right amounts to those facing the most urgent challenges. Thus, there is an opportunity for data collection tools, as well as AI and other innovative technologies, to serve as potential cornerstones in decreasing the water scarcity issue and improving people's daily lives.

Ultimately, the evolving landscape of development cooperation calls for a reevaluation of strategies and approaches to effectively tackle the urgent challenges faced by Yemen. By embracing innovation and fostering collaboration among local, regional and international actors, development aid can be better positioned to meet the needs of vulnerable populations and contribute to sustainable development outcomes.

The apparent gap between the local/regional and international coordination combined with the urgent need to modernize Yemen's approach of development aid calls for action. As innovative technologies and AI can help decreasing the gap between global and local structures and simultaneously offer (more) local ownership while strengthening international cooperation, this thesis elaborates whether AI and innovative technologies can help achieving the SDG Goal 6 in Yemen.

# Background

The Republic of Yemen, part of the MENA region, stands as the poorest among its 19 member states, a status deeply rooted in historical, political, and economic complexities (El-Jardali et al., 2023; Springborg, 1993). The country's ongoing humanitarian crisis, which is considered the most severe in the world, has its roots in the aftermath of the Arab Spring in 2011. The subsequent power vacuum led to the rise of the Houthi movement and subsequently to a conflict that escalated dramatically in 2015 with the intervention of a Saudi-led coalition. This intervention turned the national conflict into a proxy war with broader regional implications, particularly involving Saudi Arabia and Iran (Coppi, 2018).

The war has led to widespread famine, disease outbreaks as well as an immensely high civilian death toll, with a blockade further restricting essential supplies and exacerbating the crisis (Laub, 2015). This blockade has significantly hindered the import of food, medicine and fuel which lead to severe shortages and drastically increased prices of basic commodities (World Bank Group, 2024). The destruction of infrastructure, such as hospitals, schools and also water facilities, has further aggravated the humanitarian disaster, leaving millions without access to essential services (OCHA Yemen, 2024). As Yemen's economy is highly reliant on remittances and international aid, it has been shattered by the conflict. The collapse of the banking system and the devaluation of the Yemeni rial have led to hyperinflation, making it increasingly difficult for families to afford basic necessities (World Bank Group, 2024). The country's agricultural sector, which employs a significant portion of the population, has also been severely affected which has led to reduced crop yields and food insecurity (FAO & WFP, 2024).

Furthermore, the vulnerability of Yemen to climate change further exacerbates the current crisis. Increasing temperatures, changing rainfall patterns and also droughts have caused severe water scarcity, affecting urban and rural areas (IOM, 2023). The lack of access to clean water has resulted in the spread of waterborne diseases, such as cholera, which has affected millions of people and strained Yemen’s already fragile healthcare system. The growing poverty and food scarcity have pushed many families to the brink, forcing them to resort to extreme survival strategies (UNDP, 2021; Alwadeai, 2021). Child labor, early marriage, and recruitment into armed groups have become coping mechanisms for many families struggling to survive (Save the Children, 2019). Although this crisis with such an extent affects the whole country, innumerable children do not only lack an educational opportunity but have also experienced trauma and dramatic living conditions (UNICEF, 2023).

Beyond the internal challenges, Yemen's strategic geopolitical position has attracted the involvement of numerous regional and international actors, further entangling the ongoing

conflict. For example, the rivalry between Saudi Arabia and Iran has played out on Yemeni territory, prolonging the conflict and making a resolution more elusive. The intervention of external powers has also resulted in an influx of arms into the region, exacerbating the violence and instability (UN Press, 2023). Despite numerous attempts at ceasefires and peace talks, a lasting resolution remains out of reach, and the humanitarian situation continues to deteriorate.

This short overview of the background situation of the Republic of Yemen demonstrates that the acute situation is a result of a complex interplay of historical, political but also economic factors, compounded by ongoing conflict, climate change as well as external pressures. The path to achieving secure access to clean water and other essential infrastructure in rural Yemen is filled with challenges, requiring both national and international stakeholders to address the root causes and provide sustainable solutions.

## Current Situation in Yemen

Yemen is currently facing profound instability and hardship, both socio-economically and politically. The civil war, ongoing since 2015, has led to widespread devastation and a severe humanitarian crisis. The conflict has fragmented the nation, with various factions competing for control, resulting in a complex and volatile political situation. This turmoil has deepened socio-economic disparities, pushing millions into poverty and displacing large portions of the population. According to the Coordination of Humanitarian Affairs, more than 80% of Yemen's population is in need of humanitarian assistance, with many suffering from acute food insecurity and malnutrition (OCHA Yemen, 2024).

The economic situation is critical, with essential services collapsed and the economy is in freefall. Additionally, extreme hyperinflation and the devaluation of the Yemeni rial have made basic goods unaffordable for many people living in Yemen. Unemployment rates have reached an extreme high and livelihoods have been decimated, particularly in rural areas where agriculture has been severely disrupted by the conflict (World Bank Group, 2024). The lack of access to education and healthcare further strains the socio-economic fabric of the country, exacerbating the cycle of poverty and vulnerability. Yemen’s critical situation can also be measured by looking at the Legatum Prosperity Index (LPI), where Yemen ranks second worst, occupying rank 166 out of 167 positions (The Legatum Prosperity Index, 2023). The LPI ranks countries based on various factors such as economic growth, health, wealth, personal well-being as well as quality of life. Concluding, a higher LPI rank implies a less favorable situation of a country.

Due to the ongoing conflict, Yemen's infrastructure has suffered extensive damage. Critical infrastructure, including roads, bridges, hospitals, schools and water facilities, has been

targeted and destroyed (OCHA Yemen, 2024). The destruction of transportation networks has isolated many communities, complicating the delivery of humanitarian aid and access to markets. War, malnutrition and a lack of access to clean water has undermined health conditions, requiring professional medical aid. However, as the healthcare system is on the brink of collapse, with many facilities non-functional and worsened by a severe shortage of medical supplies and personnel (CERF, 2022), the critical situation is dire.

Besides the lack of essential infrastructure, the financial system is also in disarray. The banking sector has been heavily harmed by the conflict, with many banks closing or severely limiting their operations. The Central Bank of Yemen has struggled to maintain monetary stability as well as the country faces a severe liquidity crisis. Also, disruptions to remittances which represent a vital source of income for many Yemeni families, have further exacerbated economic hardship (World Bank Group, 2024). A mal-functioning financial system severely hampers economic recovery and also the ability to rebuild infrastructure, perpetuating the cycle of poverty and underdevelopment.

The list of serious issues does not end: Besides financial instability and damaged infrastructure, Yemen also has to fight water scarcity which presents one of the most pressing challenges. Yemen is one of the most water-scarce countries in the world and as one could imagine, the conflict has only worsened this situation. The destruction of water infrastructure and the depletion of groundwater resources have left millions without access to clean water (UNICEF, 2023).

But why are the health implications of water scarcity so severe? Although the whole country faces the water issue, rural areas are particularly affected, with many communities relying on contaminated water sources which leads to the spread of waterborne diseases such as cholera and diarrhea (WHO, 2015).

The lack of clean water and appropriate sanitation facilities has contributed to the spread of infectious diseases, placing an immense burden on the already fragile healthcare system in Yemen. Malnutrition, combined with food insecurity and poor water quality, has led to high rates of child mortality and little to no growth in population (UNICEF, 2023). The ongoing conflict and displacement have further strained health services, further complicating the provision of adequate care and prevention of disease outbreaks.

Every ten minutes, a child in Yemen dies due to lack of sufficient nutrition. On a weekly basis, these numbers add up to several thousands of deaths, therefore, characterizing Yemen as one of the most difficult places to live for an infant (Alves et al., 2022). Components of Yemen's Global Hunger Index (GHI) record shocking numbers, with a mortality rate of children below 5 years of 5.8%. Approximately 370,000 Yemeni children face severe malnutrition where aid

programs, and therefore, health conditions vary greatly between urban and rural regions. No access to clean drinking water, poor vaccination coverage due to lacking infrastructure as well as severe weather conditions such as floodings, contributed to increased outbreaks of various diseases which can be life-threatening for all age groups.

Despite various efforts to improve the critical situation in Yemen, the crisis still remains one of, and possibly, the worst humanitarian crises globally. The displacement of millions of people illustrates a serious problem. According to the data stemming from 2024, currently 4.5 million people in Yemen were displaced amid floodings as well as the humanitarian emergency, thus, urgently requiring support (UNHCR, 2024). Due to climate change, the occurrence of extreme weather conditions has increased in recent years which compound the suffering of millions. Obliterated infrastructure, washed away shelters as well as blocked roads which have complicated if not prohibited vital rescue efforts.

A further serious challenge Yemen currently faces entails civil documentation. Most people do not even possess a national identity card as well as it is not rare, that the majority of children lack birth certificates (United Nations, 2024c). Without the possession of such documents, future entitlements to fundamental infrastructure, such as healthcare, education as well as several other rights is highly restricted. In order to break these barriers and offer not only a safer but also long-term sustainable future for people in Yemen, (inter-)national organizations work on the establishment of assistance programs that have the aim to provide IDs for people in Yemen as well as providing permanent shelter solutions. This might help building a future with hope. safety and fundamental living conditions.

Although various issues have been tackled, this paper illustrates only a brief overview of some of the severe difficulties Yemen faces on a daily basis in this multifaceted crisis characterized by socio-economic and political instability, failed infrastructure as well as financial system deficiencies and also serious water scarcity with critical health implications. Addressing these challenges requires a coordinated and sustained effort from both national and international stakeholders to provide immediate relief and work towards long-term solutions for sustainable development.

# Findings

During the online expert interviews, various topics were discussed. Some of these topics have already been mentioned in the theoretical or background sections of this thesis, while others newly arose during the interviews and following discussion. This section delves into the findings derived from the online expert interviews that focused on the multifaceted challenges as well as potential solutions for ensuring access to clean water in rural Yemen. Engaging with professionals from various fields, including technology, water management and also humanitarian aid, enabled to gain multifaceted insights into the highly intertwined relationships between innovative technologies, artificial intelligence and the urgent issue of water scarcity. The findings are thematically organized, reflecting this thesis' key topics that arose during the interviews which illuminated correlations and shared viewpoints but also differing perspectives among the experts.

## Water Scarcity and Quality Issues

Here, shared experts' opinions as well as expertise can help shedding more light on the water scarcity crisis in Yemen, notably in rural areas where the ongoing conflict has severely disrupted infrastructure. In his interview, Mr. Wessels mentioned that many communities depend on boreholes for their water supply, yet the quality of this water is often unclear, especially after the passage of some time. Contamination from cholera and other waterborne diseases poses threatening health risks, particularly in regions lacking adequate medical facilities. The absence of reliable data on water quality increases the complexity of this problem, as individuals may unknowingly consume unsafe water.

> *'The challenge remains: we need good data. If the data is poor, the outcomes will be poor. If you don't provide the system with quality information, your predictions will be inaccurate.' (Wessels, 2025)*

Moreover, the impact of climate change on water availability represented a greatly discussed topic. Here, it was pointed out that extreme weather events, including floods and droughts, exacerbate existing water scarcity challenges. While floods may temporarily increase water availability, they often introduce contaminants which results in a shift in water quality from drinkable to non-drinkable. The seasonal nature of water availability and quality creates significant hurdles for communities striving to maintain access to safe drinking water.

The critical need for effective monitoring and data collection systems was one of the main discussion topics. Every interviewee emphasized that without reliable data, it becomes not only inefficient but also very difficult to implement targeted interventions to address water

scarcity and contamination. As a possible solution, Mrs. Todorovska suggested that placing sensors in boreholes and water sources could facilitate real-time monitoring of water quality, enabling proactive measures to prevent disease outbreaks. This focus on data collection aligns with earlier discussions in this thesis regarding the necessity of understanding and subsequently, monitoring the current state of water access and quality in Yemen.

> *'You can have different sensors in strategic locations to collect data. Based on this data, you can analyze whether it's contaminated or not.' (Todorovska, 2025)*

Another discussion point that was brought up during the online sessions was the socio-economic implications of water scarcity as well as particularly how it affects vulnerable population segments. Many families are forced to spend a substantial proportion of their income on purchasing water from unreliable sources, which can lead to further financial strain. This economic burden exacerbates existing inequalities and hinders efforts to improve living conditions. The interviews highlighted the urgent need for comprehensive strategies that address both the technical but also socio-economic dimensions of water access. By integrating innovative technologies, communities can gain more control over their water management, ultimately leading to greater local ownership.

In addition, the conducted expert interviews revealed that an absence of clean water has broader implications for public health and community stability. It was pointed out that when water is scarce or contaminated, it can lead to increased rates of disease, malnutrition, and even displacement as families are forced to migrate in search of better living conditions. This interconnectedness of water access, health as well as socio-economic stability further highlights the urgency of addressing water scarcity as a multifaceted issue that requires coordinated efforts across various sectors.

## Innovative Technologies for Water Management

Concurrently with the water related issues, innovative technological solutions have also been investigated. During the discussion with various experts, it became clear that a growing interest exists regarding the application of Artificial Intelligence as well as smart sanitation systems as potential solutions to water scarcity and quality issues that currently prevail in Yemen. Experts discussed whether the implementation of AI-driven systems is capable of analyzing data from sensors placed in water sources. One of the benefits that such systems could provide are real-time insights into water quality which allows communities to promptly respond to contamination issues. This conception aligns with the thesis' emphasis on how innovative technologies could probably serve as foundational elements for achieving clean water and sanitation.

As an example, Mr. Wesian highlighted the importance of collecting data to inform AI algorithms, which could then predict potential water quality issues based on historical data as well as environmental factors. Such a predictive capability could tremendously enhance a community's ability to manage their water resources (more) effectively.

> *'AI can definitely be utilized for various topics, health, water scarcity, etc. [...] If you upload all this data into AI, it could work with this data, analyze it and make suggestions. The more data you feed to AI, the better.' (Wesian, 2025)*

The discussion centering around AI's role in predictive analytics and resource management contributes a new dimension to the thesis, demonstrating the technological potential to transform water management practices in rural Yemen. By leveraging AI, local communities can gain insights that enable them to take proactive measures in managing their water resources, thereby fostering a sense of ownership and responsibility.

Additionally, the dialogues shed some light on innovative water purification technologies, such as WADI or Watergen, which could present viable options for addressing water scarcity in Yemen. CEO of the WADI device, Martin Wesian, provided insights into the WADI device, which utilizes UV rays to disinfect water in PET bottles. This low-cost solution is particularly appealing for rural communities as it neither requires extensive infrastructure nor electricity. The emphasis on low-cost, accessible technologies aligns with the thesis' exploration of practical solutions for water purification in resource-limited environments.

Although Watergen's atmospheric water generators offer a more advanced solution by extracting humidity from the air to produce clean drinking water, the high cost of these innovative devices present a barrier to widespread adoption in Yemen.

> *'However, who is interested in financing this? How does this, compared to work ZOA engages in, work, where we focus on low-cost rehabilitation of water points and household filters? We struggle to secure funding for these initiatives. Working with companies is often not possible because they are not allowed to operate in Yemen, and there are significant security risks. It is very much a humanitarian context. Governments have insufficient capacity to support these initiatives. You can request smaller projects from them, but setting up large-scale monitoring networks is beyond their capacity.' (Wessels, 2025)*

ZOA's WASH advisor, Matthijs Wessels, explained that while Watergen could provide a significant water source, funding as well as maintenance still remain critical challenges. This

highlights the need for sustainable funding models to support the deployment of innovative solutions.

The question around the potential of integrating AI with these innovative technologies represented a focal point in the discussions. All interviewed experts expressed optimism about the ability of AI to actually enhance the efficiency of water purification processes as well as improve the overall management of water resources.

> *'The idea of collecting data in Yemen and analyzing it with AI, which requires significant energy, is crucial. Transferring data to Europe, where the infrastructure can support AI, is an important consideration.' (Todorovska, 2025)*

As an illustration, AI could be used to optimize the operation of water purification systems by analyzing data on water quality and usage patterns, thereby ensuring that resources are allocated effectively. The issue of the inefficient allocation of resources/aid is also briefly mentioned by L. Todorovska as follows:

> *'Aid oftentimes is provided but it can be allocated to the wrong place, in the wrong time if the urgent need is not identified.' (Todorovska, 2025)*

Moreover, the conversations pointed out that for any innovative solution to be successful, it must be accessible and understandable to the people who will be using it. This statement aligns with the thesis' argument that technology must be tailored to the specific needs and contexts of the communities it aims to serve.

Lastly, the discussions also touched upon the importance of scalability when considering the implementation of modern technologies. Possessing extensive local expertise, Mr. Wessels mentioned that while individual solutions may be effective, a broader strategy that encompasses multiple communities could yield greater benefits.

> *'The larger the scale, the more efficient it is to provide water at the community or village level rather than at the household level. So, I believe there is a benefit to scaling up rather than providing individual household solutions.' (Wessels, 2025)*

For instance, a network of water purification systems supported by AI could facilitate data sharing and collective learning among communities, enhancing overall water management efforts.

## Funding and Sustainability Challenges

As already briefly mentioned above, although brilliant innovative ideas may exist, financial barriers often hinder their implementation. On this point, the discussion focused on the necessity of sustainable funding models to support the deployment of technologies such as AI and water purification systems in rural Yemen. During the interview, Mr. Wessels underlined the importance of securing funding for both capital expenditures (CAPEX) and operational expenditures (OPEX) to ensure the long-term viability of such projects.

Cryptocurrency as a funding mechanism as well as its feasibility was also examined during the interviews. While the various advantages of cryptocurrency in terms of speed as well as transparency were acknowledged, caution regarding the current regulatory environment in Yemen, which may not be conducive to its adoption, was also brought up as a possible hurdle. Additionally, the lack of stable internet access and financial infrastructure further complicates the feasibility of using cryptocurrency for funding.

Another crucial aspect of sustainability discussed in the interviews was the need for community engagement and capacity building. Although these experts come from various professional backgrounds, they all shared the perspective that for innovative technologies to succeed, local communities must be involved in the planning and implementation processes. Such involvement would entail the training of community members to operate and maintain water purification systems as well as ensuring that they understand the importance of monitoring water quality. As already mentioned in the thesis, the water expert, Will Sarni, agreed that empowering local communities in taking ownership of water management initiatives is essential for fostering resilience and independence. By building local capacity, communities can better respond to water scarcity challenges and reduce their reliance on external aid.

> *'I completely agree with you on that. I mean, if they flip things around and invest in appropriate infrastructure, then the communities would be more sustainable and more resilient. So, it would not constantly be this emergency response.' (Sarni, 2025)*

The interviews highlighted the importance of collaboration among various stakeholders, including government agencies, NGOs as well as local communities. In this regard, the interviewed professionals confirmed that effective partnerships can enhance the impact of water management initiatives and ensure that resources are utilized efficiently. Such a collaborative approach is essential for addressing the multifaceted challenges of water scarcity in Yemen. Interestingly, it was noted that although local communities do play a crucial role in implementation, external support is often necessary to bridge gaps in funding as well as

technical expertise. This highlights the importance of fostering relationships between local communities and international organizations to create a more sustainable approach to water management.

While there were many areas of agreement among the experts, some contrasting perspectives also emerged during the interviews. Opinions regarding the feasibility of using cryptocurrency as a funding mechanism for water projects in Yemen highly varied.

> *'I would say cryptocurrency has a huge potential, especially because the infrastructure is rotten. If you have to build up the whole thing, it needs time. And as you say, especially if you build it up from scratch pretty fast, then there is a lot of corruption, especially at the beginning. And especially in Yemen, where you have several different interest groups, which is an issue.' (Wesian, 2025)*

The CEO of the WADI tool, Mr. Wesian, expressed optimism about the potential of cryptocurrency to streamline funding processes by simultaneously reducing corruption, while local expert, Mr. Wessels raised concerns about the regulatory environment as well as lack of infrastructure to support its implementation.

> *'For example, there is no electricity. Where do you get the electricity from? There is nobody who will support you. Additionally, there is no government that is stable enough to invest in these kinds of things. This situation is compounded by issues like corruption, even with cryptocurrency.' (Wessels, 2025)*

Another aspect where differing views could be detected was regarding the applicability of modern technologies, such as AI or Watergen, in a rural Yemeni context.

> *'[...] And as I think about technology solutions, it is certainly generating water, unconventional water production.' (Sarni, 2025)*

> *'I mean, with AI nowadays, everything is possible. It's a matter of investment and whether you want to do it or not. This includes satellite imagery, which means that from a satellite, you can take pictures. Based on these pictures, AI analyzes and tracks changes in water movement.' (Todorovska, 2025)*

> *'AI can definitely be utilized for various topics, health, water scarcity, etc. But I think, as you said, data needs to be collected in order to do so. [...] If you upload all this data into AI, it could work with this data, analyze it and make suggestions. The more data you feed to AI, the better. So especially if you have in a country several points where you collect data and put it together, this would be of high interest. [...]' (Wesian, 2025)*

As the above-mentioned expert quotes show, Mrs. Todorovska, Mr. Wesian as well as Mr. Sarni shared the belief that such technologies could actually play a vital role in addressing water scarcity. By contrast, Mr. Wessels cautioned that the high costs as well as pointed out that energy requirements may pose limitations to their feasibility in rural areas.

> *'[...] we need to calculate how much we can do or cannot do. I always assess the feasibility of a solution. I evaluate whether it makes sense or not. Additionally, we need to compare the costs per cubic meter of water produced.' (Wessels, 2025)*

The integration of qualitative data analysis by MAXQDA provides a comprehensive interpretation of the expert opinions and allows for the visualization of complex relationships among the identified themes. By employing this systematic approach, this research was able to uncover nuanced insights that may not have been apparent through traditional analysis methods.

Overall, it can be summarized that the findings from the expert interviews underscore the complexity of addressing water scarcity as well as quality issues in rural Yemen. While innovative technologies such as AI and water purification systems might be able to offer promising solutions, significant challenges remain in terms of funding, infrastructure and community engagement. Nonetheless, the insights gathered from these discussions provide a foundation for further exploration of how these technologies can be effectively implemented to improve access to clean water in Yemen. Moreover, as the situation in Yemen continues to evolve, ongoing research and collaboration between stakeholders will be crucial for developing sustainable solutions that address the pressing water challenges faced by these vulnerable communities. The combination of expert insights and qualitative data analysis as well as a greater focus on community engagement will be essential for fostering resilience and independence in the face of ongoing challenges.

# Discussion of Findings

Combining the qualitative research results with the above laid-out theory, this section explores the integration of theoretical frameworks into practical discussions about the water crisis in rural Yemen. The analysis synthesizes key research findings, particularly regarding the role of Artificial Intelligence, innovative technologies as well as decentralized WASH systems. The Center-Periphery concept (Wallerstein, 2016; Ayubi, 1995), the Human Security framework (UNDP, 1994), the Capability Approach (Sen, 1999), Integrated Water Resources Management (IWRM) (Xie, 2006) as well as the Technological Determinism (Hauer, 2017) guide the understanding of how rural Yemen, as a marginalized periphery, faces systemic

challenges in addressing water scarcity. This part of the thesis explores the numerous dimensions of these issues and examines the theoretical and empirical evidence, concluding with how AI and innovative technologies could represent possible cornerstones in overcoming these hurdles and achieving the United Nations Sustainable Development Goal 6.

## The Center-Periphery Concept and Its Relevance For Yemen's Water Crisis

The Center-Periphery theory, originally invented by Immanuel Wallerstein, suggests a socio-economic divide between developed core regions and underdeveloped peripheral regions, which in the case of Yemen, reflects the vast contrast between urban and rural areas (Wallerstein, 2016). The persistence of poverty and underdevelopment in rural Yemen can be framed within this context, as marginalized areas lack the resources, infrastructure and also political capital. The concept aids in understanding the systemic exclusion faced by rural regions, particularly in terms of access to basic needs such as water. In Yemen, the issue is aggravated by the ongoing internal conflict, which has disrupted the nation's infrastructure, including water supply networks.

Yemen's rural regions which are heavily affected by both internal conflict as well as a failing national infrastructure, face immense obstacles in securing adequate water supplies. The Center-Periphery framework highlights how these disparities prevent the necessary flow of resources, such as investment in water infrastructure, which is concentrated in the country's capital or in conflict-free zones (Ayubi, 1995). Rural areas, as a consequence, are often left to rely on rudimentary and unsafe water sources which further exacerbates their vulnerability to waterborne diseases and health crises. These water scarcity issues undermine efforts to meet the SDG 6 in Yemen, where ensuring access to clean water for all remains a significant challenge.

According to the interviewed experts Mr. Wesian and Mrs. Todorovska, innovative technologies as well as decentralized systems hold the potential to address this disparity. However, despite the promising benefits of these technologies, their adoption is often hindered by the entrenched political economy of Yemen, which is dominated by central governmental structures that have failed to prioritize rural needs. The lack of decentralization in governance and resource management perpetuates the center-periphery divide, preventing the efficient distribution of aid and the implementation of sustainable solutions. This exclusionary approach has resulted in a substantial urban-rural divide which hampers efforts to close the gap in water access. In such highly intertwined situations, AI and other modern technology can play critical roles in breaking this cycle by enabling more equitable resource allocation. When integrated

into water management systems, AI could facilitate better targeted interventions as well as quality control, ensuring that limited resources are directed to the most underserved regions, who require up-to-date and timely information. As decentralized systems become more accessible, rural communities can take control of their own water security. By relying on AI-driven models, these communities can not only improve their access to clean water but also actively engage in sustainable practices that promote long-term water security.

Although crypto-currency based funding models were regarded as critical, when tackling the funding aspect of such innovative projects, as mentioned already above by Mr. Wesian, modern cryptocurrency funding models are surprisingly still seen as an alternative to conventional credit systems. These models would allow for more decentralized funding mechanisms for water and sanitation projects. They would bypass traditional institutions which are often out of reach for rural Yemenis. Such an approach could be particularly beneficial in light of the political instability and fragmented governance structures in Yemen, offering a potential solution to issues such as corruption, inefficiency compounded by a lack of access to resources.

Summing up, these broader implications of the Center-Periphery theory for Yemen's water crisis demonstrate the entrenched nature of the predicament. By addressing these structural inequalities, Yemen establishes a more equitable water distribution system that focuses on decentralization, innovation as well as sustainability. AI technologies and decentralized funding mechanisms can bridge the gap between the center and periphery, creating a system where rural communities no longer suffer from isolation and can finally access the resources needed to improve their living conditions.

## The Human Security Framework: Ensuring Secure Access to Clean Water in Yemen

The Human Security framework, as outlined by the UNDP in 1994, emphasizes the protection of individuals' fundamental freedoms as well as well-being. Demonstrating the four pillars that intersect to guarantee human security - freedom from fear, freedom from want, freedom from shame and lastly, freedom from vulnerability - each is relevant to Yemen's water crisis (UNDP, 1994). This approach is particularly helpful in understanding how the lack of access to clean water in rural Yemen not only affects physical health but also undermines overall human security, encompassing social, political and also economic aspects of life (UNDP, 2006).

The first pillar, Freedom from Fear, talks to the need to protect individuals and communities from the threat of conflict and violence (UNDP, 2006). Particularly in Yemen, the prolonged

civil war has further aggravated the vulnerabilities of rural populations, who have already been struggling to access basic services like clean water. Ongoing insecurity and violence has disrupted the existing water infrastructure but also further add to preventing humanitarian aid from reaching the most badly affected regions. The data gained through discussions with various experts showed how water scarcity, compounded by insecurity, leads to displacement and migration which further negatively impacts local water resources.

Moreover, especially in regions affected by civil conflicts, fear becomes a central component that dictates the daily lives of many rural Yemenis. Besides constant uncertainty about safety, limited, unsafe or maybe even no access to clean water further increases the vulnerability of many people living in these affected areas. This shows that in this context, water scarcity is not only a matter of access but as well a matter of security. Adding on to that, rural populations often face the combined threat of violence as well as the lack of essential resources, which further limits their ability to rebuild and recover from crises.

Moving on to the second pillar, Freedom from Want aims to eliminate extreme poverty and strives to ensure that basic needs are met for all individuals. Especially with regards to water scarcity, this represents a central theme in discussions about the right to water (UNDP, 2006). Oftentimes, rural communities are stuck in a cycle of poverty that limits their access to water. Technological innovations, such as solar-powered water purification systems and mobile water apps that track water resources, can be critical in achieving the goal of equitable water distribution. As Mr. Wessels pointed out during the online interview, the introduction of low-cost, sustainable water solutions that are tailored to the local context can significantly lower the burden on rural populations and dramatically improve their standards of living. These technologies would provide rural populations with the means to access safe water even in remote areas where fundamental infrastructure is lacking.

Access to water is not only a fundamental human right but the general right to water is as well closely linked to the broader concept of human security (UNDP, 1994). Without reliable access to clean water, rural populations in Yemen face a greater exposure to life-threatening diseases, dehydration as well as severe malnutrition. Already small technological advancements, such as affordable water filtration systems or solar-powered pumps, can help to moderate some of these challenges by providing a clean and reliable source of water even in the most rural and isolated communities. These modern innovations not only support basic survival but offer an improved quality of life by making communities more resistant to external threats.

Freedom from Shame particularly highlights the importance of human dignity as well as respect for rights. In the context of water scarcity, Yemen’s rural communities often face

exclusion from decision-making processes related to water management (UNDP, 2006). Modern technologies can include participatory platforms for local communities to manage their water resources, empowering rural populations to take control over their water access. This empowerment, combined with AI tools to facilitate fair decision-making, could aid restoring marginalized individuals' dignity. Mr. Wessels agreed that the participation of communities in managing their water resources leads to a sense of ownership which substantially increases the sustainability of water projects.

Lastly, the Freedom from Vulnerability pillar addresses the mitigation of environmental threats. Yemen's water scarcity crisis is aggravated by the unpredictable impacts of climate change, which further complicates access to water (UNDP, 2006). The introduction of sustainable water technologies, like rainwater clarification systems or as well AI-driven climate adaptation tools, can, in these scenarios, play major roles in reducing vulnerability and, at the same time, improving resilience in decentralized, isolated regions. Modern technologies can offer greater self-sufficiency by enhancing peoples' capacity to adapt to climate variability and, thus, increasing overall human resilience. All four interviewed experts agreed that AI could offer crucial support by predicting climate changes as well as swiftly managing water resources to ensure that rural communities are prepared for future environmental challenges. Performing a transition towards data-driven decision-making could dramatically enhance the ability of local communities to manage water resources more effectively as well as in real time which, in the long run, contributes to greater, more sustainable human security and also well-being.

By integrating AI and other modern technological solutions, Yemen could significantly reduce vulnerabilities and empower rural communities to take ownership of their water resources. Furthermore, this approach could help align the goals of human security with practical, technological solutions that directly address the underlying causes of water insecurity in Yemen.

## The Capability Approach: Expanding Human Freedoms and Choices

As the title of this approach reveals, the Capability Approach (Sen, 1999) focuses on expanding individual freedoms and capabilities rather than simply addressing basic needs or economic growth. When applying this approach to Yemen's context, where water scarcity is a critical issue, the conversation is being shifted from merely ensuring access to water to ensuring that people have the necessary capabilities to manage as well as utilize water resources sustainably. This is explicitly paramount for empowering rural communities to take control of their own water sources and move beyond dependence on external aid.

Yemen's lack of access to clean water often originates from broader socio-political as well as economic inequalities. Structural hurdles such as limited infrastructure, a lack of education or the absence of social mobility create an environment where communities are unable to take advantage of the available water resources. Here, the Capability Approach suggests that enhancing individuals' ability to choose and act on their own behalf illustrates the solution (Sen, 1999). Empowering communities to make informed decisions about water use allows Yemen to commence breaking the cycle of poverty and insecurity that has plagued rural areas for ages.

Moreover, Sen's Capability Approach also emphasizes the significance of education or local knowledge as a crucial feature for achieving sustainable water management. When rural communities are provided with appropriate tools to understand and manage water resources effectively, a first step towards long-term sustainability is being set. Such a shift in perspectives allows communities to shape their future based on their own needs, values and priorities.

Consequently, Artificial Intelligence and modern technology could facilitate the expansion of these capabilities by supporting local water management and decision-making processes from a technical perspective. Technological advancements such as AI-powered water sensors and cloud solutions would allow rural communities to monitor their water consumption and, subsequently, adopt more efficient daily-life practices. Additionally, AI-based decision-support systems allow prioritization within the water allocation decision process, ensuring that resources are used not only efficiently but also equally. Providing real-time data that continuously adapts to changing circumstances, further advances the community's ability to manage water resources sustainably.

In essence, the Capability Approach highlights the importance of human leeway in addressing water scarcity (Sen, 1999). By expanding people's abilities to make informed choices about water use and management, Yemen could create a more sustainable and fair system which empowers rural communities to take control of their own water resources.

## Integrated Water Resources Management in Yemen

Concepts are often useless if not properly integrated into a relevant, working system. The Integrated Water Resources Management concept emphasizes that a coordinated approach to managing water, land as well as related resources is required in order to maximize social and economic benefits without compromising the sustainability of vital ecosystems (Xie, 2006). For this research paper, the IWRM represents an ideal framework for addressing Yemen's water crisis as it recognizes the interconnectedness of various sectors: Agriculture, sanitation,

energy and also environmental protection. In regions, where water resources are scarce, for human as well as ecological survival, an effective management can be essential.

During the online discussion, the need for a multi-sectoral approach to water management was underlined as the fragmentation of Yemen's water sector, exacerbated by conflict and economic hardship, called for integrated solutions that would consider the broader socio-economic as well as environmental settings. The application of IWRM in rural Yemen could involve creating decentralized systems that connected water supply, sanitation and also agricultural water needs, while also taking environmental sustainability into account.

A key component of IWRM illustrated stakeholder participation, which is particularly crucial in rural Yemen (Xie, 2006). The inclusion of local communities in decision-making processes ensured that water management systems are more efficiently aligned with the needs and preferences of those directly affected. Such a participatory approach fosters a sense of ownership as well as responsibility, which enhances the likelihood of successful implementation and long-term sustainability. Moreover, integrating AI into IWRM systems can facilitate real-time monitoring of water usage across sectors and identify areas of inefficiency or unsustainable practices.

Also, AI offers the tracking of water usage patterns, shortage predictions as well as the optimization of distribution systems which helps to prevent overexploitation of water resources. Through IWRM, Yemen can generate a more holistic approach to water management that balances the needs of different sectors while ensuring that water is used in a sustainable and equitable manner.

It should be mentioned that the implementation of IWRM in Yemen’s environment requires political will in addition to technical expertise. However, with the integration of modern technologies such as AI and data analytics, the country increases its chances of successfully overcoming many of the challenges that have hindered effective water management in the past. This might allow Yemen to shift towards a more integrated and sustainable approach to managing its water resources, which will be crucial in addressing the ongoing water crisis in rural areas.

## Technological Determinism and the Role of Innovation

The concept of Technological Determinism advocates that technology represents a key driver of societal change (Hauer, 2017). Applying Technological Determinism to the case of water scarcity in rural Yemen, technological innovations, in particular AI and water purification systems, could substantially transform how communities manage water resources. As noted during the expert discussions, technological advances potentially offer solutions for the problems of inefficient water usage, water contamination and unequal access by providing localized solutions as well as large-scale infrastructural improvements.

Modern technological advancements such as solar-powered water generators or water purification devices, mobile water apps for community engagement or even AI-driven smart sanitation systems are examples of innovations that can support water management in Yemen's rural regions. These technologies can help bridge the divide created by Yemen's underdeveloped infrastructure, offering sustainable alternatives that align with local needs. Particularly in rural areas, where water resources are quite limited, solar-powered systems offer a promising solution for providing clean water without relying on costly and unreliable electrical grids.

However, the adoption of these technologies also faces challenges, notably the high initial costs and the lack of infrastructure. Despite these barriers, the positive aspects of using technology in water management are compelling. Although technologies such as AI-driven water management systems and decentralized funding models have been successfully implemented in various countries to address similar water crises, the decision regarding the feasibility of the implementation of such innovative devices still has to be analyzed for each country individually.

In summary, by overcoming the above-mentioned hurdles, Yemen could harness technological innovations to drive sustainable development, improve water access as well as reduce the socio-economic gap between urban and rural areas. In addition, technological innovations can complement other frameworks such as IWRM (Xie, 2006) and the Capability Approach (Sen, 1999) by providing tools that enhance both local autonomy and long-term sustainability in water management. The incorporation of Artificial Intelligence and other innovative technologies not only enhances the efficiency and effectiveness of water resource management but also empowers local communities to take ownership of their water systems. This empowerment is crucial for fostering resilience and ensuring that solutions are tailored to the specific needs of rural populations. Ultimately, by leveraging these interconnected factors, Yemen can establish significant cornerstones towards achieving the Sustainable Development Goal 6, which aims to ensure access to clean water and sanitation for all.

# Conclusion

To reprise the answers to the initial research questions, this research thesis has critically examined the challenges associated with clean water access in rural Yemen and highlighted the role of innovative technologies and artificial intelligence in potentially overcoming them.

Despite Yemen's serious water scarcity as well as the associated public health issues, the research advocates that AI and modern technologies could indeed play central roles in addressing these challenges. They would be especially relevant in rural, marginalized areas where traditional infrastructure is either non-existent or severely limited. The central research question '*Can AI and innovative technologies help achieve the SDG Goal 6 (Clean Water and Sanitation)?',* has been addressed throughout the paper, emphasizing that technological innovations are not just necessary but essential to securing sustainable water access and, subsequently, improving lives in rural Yemen.

In order to answer the main research question, it is crucial to recognize that achieving SDG Goal 6 in Yemen - ensuring access to clean water and sanitation for all - faces multi-dimensional challenges. These challenges entail Yemen's ongoing conflict, which has severely disrupted infrastructure, economic instability, lack of investment in rural areas due to ineffective governance structures that prioritize urban centers over rural communities. Consequently, Yemen's decentralized regions suffer from poorly developed sanitation systems, a lack of reliable access to drinkable water and also need to confront severe climate impacts that threaten not only water availability but its security.

AI and innovative technologies have the potential to revolutionize water management, especially in regions like rural Yemen, where traditional solutions have proven ineffective. This paper demonstrates that these technologies could act as possible cornerstones in overcoming existing barriers by addressing both the supply as well as the demand side with regards to water access. AI-driven systems can facilitate better decision-making, optimize water distribution and also predict future shortages which help to ensure that water resources are allocated more effectively. Furthermore, decentralized water systems, driven by innovative technologies such as solar-powered pumps, mobile apps or AI-managed water clarification tools, can provide local solutions that bypass the need for centralized infrastructure that often fails to reach rural areas and increase local independence. This local independence fosters a sense of ownership among communities, empowering them to manage their own water resources effectively.

Through the application of such innovations, AI could optimize water usage, enhance the maintenance of water and sanitation systems. It could ensure sustainability by minimizing waste and providing equal access to clean water. By doing so, AI directly aligns with the objectives of the SDG Goal 6 by improving access to safe drinking water, promoting sustainable management of water resources and building resilient water supply and sanitation systems.

Moving on to the sub-research question that centers around whether cryptocurrency-based funding models could facilitate the funding for such water projects in rural Yemen, the findings remain ambivalent. While there is no doubt that cryptocurrency-based funding models offer several potential advantages, particularly in Yemen's fragmented and politically unstable environment, the conclusion has been drawn that traditional funding methods currently still represent the more realistic option. In spite of all the benefits that come with crypto funding, such as eliminating intermediaries and therefore, reducing the risk of corruption, increasing transparency and making the process faster and more secure, such innovative funding approaches undoubtedly have great potential in the future. Just for the time being now, expert discussion revealed that Yemen's current infrastructure is not ready yet for crypto funding. Moreover, while cryptocurrency could address funding issues, it does not directly resolve other water scarcity challenges such as climate change or inefficient local water management. Also, multiple challenges remain in terms of the infrastructure required to implement such funding models such as the need for more education and better awareness around the use of cryptocurrency. Nonetheless, it could still serve as an important piece of the puzzle in facilitating the implementation of technological solutions in rural areas in the future.

Innovative ideas often seem feasible in theory, yet unrealistic when practically applied. This brings us to the second sub-research question, 'How can Artificial Intelligence contribute to the creation of sustainable smart sanitation systems in Yemen's rural settings?'. This paper has demonstrated that AI technologies could play a transformative role in the management and optimization of sanitation facilities. In rural regions, where access to modern sanitation systems is limited, AI-powered solutions could provide real-time monitoring as well as predictive analytics to ensure an efficient use and maintenance of sanitation systems.

Moreover, AI can not only detect but can address issues such as water contamination or system failures before they escalate into larger crises, thereby increasing overall sustainability of sanitation systems. By supporting smart water purification units and mobile sanitation solutions, AI could help to ensure that these facilities can function autonomously which is crucial in regions that may lack the necessary workforce or infrastructure. Additionally, by using predictive analytics, modern technologies can support monitoring environmental changes, identify sources of pollution and provide solutions that align with local needs. For

instance, the expert interviews revealed that AI could use local data to predict seasonal water shortages or outbreaks of waterborne diseases, allowing communities to take preventative actions in advance.

Nonetheless, it becomes obvious that reality sometimes hinders progress. Although smart sanitation systems seem to have great potential in theory, according to Mr. Wessels, an expert operating in humanitarian aid on site in Yemen, such smart sanitation systems are not likely to be realized any time soon. This can be ascribed to the fact that oftentimes in rural Yemen, people do not have the luxury to take showers but rather wash themselves with small amounts of water provided in buckets.

While the application of smart sanitation systems does not seem to be a viable option with regards to Yemen's water scarcity issue, implementing sensors in combination with AI is regarded as feasible, highly efficient as well as game changing drivers in Yemen's rural regions. A main reason behind this is that AI could empower local communities by providing innovative tools to manage and improve their own water access as well as quality. Additionally, mobile apps and digital clouds can facilitate the reporting of issues, scheduling maintenance and also ensuring more efficient as well as safe water usage.

In order to address the question circling around how these innovative water clarification tools can serve as cornerstones for better lives in rural Yemen, collected theory was combined with extensive knowledge from experts and providers of such water clarification tools. Hereby, two cutting-edge water clarification/ generating technologies, WADI SODIS and Watergen, have been discussed in more detail. Innovations such as solar-powered water purifiers, portable filtration units, out-of-air-water-generating machines or low-cost desalination systems could revolutionize water access in Yemen's most remote areas. These tools are particularly effective because they are low-maintenance, energy-efficient as well as designed to be resilient in challenging environments. In addition, mobile filtration technologies, including low-cost, portable filters that can be deployed in emergencies, are highly adaptable to Yemen's rural settings. All these innovative tools represent essential cornerstones for improving the quality of life in rural Yemen.

In drawing this discussion to a close, the final sub-research question explores the feasibility of implementing modern technologies and AI into the development of decentralized water, sanitation and hygiene (WASH) facilities in Yemen's rural areas. Given Yemen's highly intertwined challenges, including political instability, infrastructural deficits and also limited access to modern technology, the implementation of such solutions faces numerous obstacles. However, as discussed throughout this research thesis, the use of AI and innovative

technologies in rural Yemen is not only feasible but necessary for achieving long-term water security.

While the omnipresent challenges of limited infrastructure, political instability as well as economic hardship cannot be ignored, decentralized systems and AI-driven technologies offer scalable solutions that can operate independently of Yemen's central government. A variety of mobile technologies, solar-powered systems and AI-powered water management tools are increasingly affordable and accessible, making them suitable for rural settings. By ensuring that these technologies are adapted to local needs, communities can take ownership of their water management processes, leading to more effective and sustainable solutions.

Although the practicality of these solutions highly depends on their alignment with local needs as well as whether governmental restrictions in the respective country exist, the actual success is often determined by the cost factor. This suggest the application of sensors in combination with AI and low-cost water purification tools like WADI SODIS may eventually represent a more viable solution compared to immensely expensive Watergen devices.

There is no doubt that implementing modern technologies in rural Yemen will require multi-stakeholder collaboration between local governments, international NGOs, technology providers as well as local communities. However, a successful implementation could dramatically transform Yemen's water access, ensuring a more sustainable and equitable water future, irrespective of the geographical location.

Overall, this thesis has highlighted the significant potential of AI and innovative technologies as initial cornerstones for overcoming the hurdles of achieving SDG Goal 6 in rural Yemen. By addressing the fundamental barriers to clean water access, it became clear which of these technologies can currently (or for the future) offer scalable, sustainable and adaptable solutions that can significantly improve the lives of rural Yemenis when successfully implemented.

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# Appendix

## Expert Interview Guideline

Introduction (2 minutes)

- Briefly introduce myself and the research topic.
- Explain the purpose of the interview and how the insights will contribute to the thesis.
- Assure the interviewee of confidentiality and obtain the experts' consent to record the conversation.

Section 1: Background and Expertise (3 minutes)

- Can you introduce yourself and describe your experience related to water access/scarcity as well as AI and innovative technologies in the context of development aid, particularly in Yemen?

Section 2: AI and Innovative Technologies in Water Access (25+ minutes)

2. In your opinion, can AI and innovative technologies help achieve the SDG Goal 6 (Clean Water and Sanitation) in rural Yemen?

- Follow-up: Can you provide specific examples of how **AI** has been utilized in similar contexts to improve access to clean water?
- How likely is the idea of overcoming the issue of **water scarcity** in rural regions of Yemen by implementing **innovative technologies**?
- How feasible do you think it is to implement AI-driven **smart sanitation systems** in rural Yemen nowadays? What factors would influence their success or failure?

Section 3: Cryptocurrency and Funding Mechanisms (7 minutes)

4. In your view, to which extent do you believe **cryptocurrency**-based funding models can enhance the construction and maintenance of sanitation facilities in rural communities compared to traditional credit models?

Section 4: Innovative Water Clarification Tools (10 minutes)

5. From your perspective, how can **innovative water clarification technologies** contribute to improving living conditions in rural Yemen? Are there specific technologies you believe hold the most promise?

Conclusion (5 minutes)

6. Is there **anything else** you would like to add that was not covered in the interview?

Expert Interview Transcript

# INTERVIEW Mrs. Todorovska

14. February 2025

Mrs. Todorovska – T

Mrs. Gstrein – G

G: Hey, good morning.

T: Hi, good morning. Nice meeting you.

G: Nice meeting you as well and thank you so much for taking the time.

T: No worries.

G: I was wondering before I start, is it okay if I record an audio so I can make a transcription afterwards?

T: Yeah.

G: Okay, perfect. Thank you. So, okay, maybe I will quickly introduce myself. I am Simone Gstrein and right now I'm doing a second master's thesis in international development and right now I'm writing a master's thesis about achieving secure access to clean water in rural Yemen. And the research question is like, can AI and innovative technologies help achieve the SDG Goal 6 (Clean Water and Sanitation)? So, this is the topic I am writing about currently. And I saw during my research that you are working in the field of AI, and I saw a paper From Zero to Hero, where it talked about how to overcome water deficiencies with AI and how it can change the world.

And I thought that would be perfect. So, maybe you can briefly introduce yourself, so I get a quick understanding of what you are doing. And also, I was wondering, is it for you, okay, if I mention you in the paper. I would send them to you, of course, before I would use them, so you can confirm if that's okay.

T: Let's do that.

G: Perfect.

T: Yeah. So, my name is Lyudmila. Actually, where are you based?

G: I'm based in Vienna, in Austria. You?

T: Okay, nice. I'm based in Amsterdam. I am from Bulgaria. My name is Lyudmila. Many people are calling me Lucy. I've been working for Heineken for, I think, eight years already. And currently, I'm leading the global digital and technology teams, which are looking after HR, legal and corporate affairs. Before that, I was working for, I mean, I had multiple roles in the company. Before that, I was working for Coca-Cola. And those are all companies, like big international companies, who are producing a product which requires water. So, Heineken has

an ambition towards certain sustainability goals related to water. So, this is also something that we are working on internally.

G: Okay, very interesting.

T: But, you know, like I saw that you sent me the questions, but I couldn't really look into them. Unfortunately.

G: No worries. Thank you for giving me a brief overview to understand what you're doing.

T: So, I'm mainly in technology. I'm an engineer by education. So, I have been in technology for 30 years and the technology which is used for making business. This is actually where I have been in between business and technology always.

G: Okay, okay. Very interesting.

T: Yeah, so my skill set actually is to understand very well how the technology is working and how you can apply that to resolve certain business challenges.

G: Yeah, okay. From a technology perspective, right?

T: Yeah.

G: Yeah. Well, because... So, my topic is about, like, water scarcity in Yemen. Especially in rural parts of Yemen. Because I think, maybe as you're aware, Yemen is called a failed state. And they struggle with various issues. And because of the war, a lot of people were sent to rural areas, right? So, they have those emergency camps and those refugee camps for people who were displaced. And there, of course, they have several issues. So, of course, they don't have infrastructure because the main infrastructure in the big cities was destroyed. In the countryside, there may be no infrastructure. Or only because of severe weather conditions, maybe floods or climate change. Like, those emergency infrastructures got destroyed. So, you can imagine, these people already struggle with various issues.

Like, being displaced, losing everything they have, financial issues, and then health issues, right? And having access to clean water is very vital for not only cooking, eating, and being healthy, but, of course, also to prevent disease outbreaks. In Yemen, cholera is a big issue. Having access to clean water is not only something people should have, but it's also a right, a human right to have clean water, which is also the Sustainable Development Goal Number 6, which is clean water and sanitation, says. So, for me, the question is whether with the combination of innovative technologies, the water scarcity issue can be overcome?

So, I did some research and looked into various projects. For example, in India, there is a project right now where they have smart sanitation systems, which means, if people have a shower, the water can be filtered, data collected and analyzed. I mean, it's more expensive to implement those showers, but in the long run, it makes more sense because then you prevent serious consequences. For example, there is no health system. So, if people have a disease or they don't even know that they have cholera, and then it breaks out and everyone gets it who lives there, then the adverse effects after are much bigger because then one has to treat the sick people.

So, there are those smart water sanitation systems, which means that, for example, people take a shower and then in the water that is being analyzed. So, it can be seen, if there is, bacteria or virus in the water, like coronavirus or similar diseases, and it can be detected if there's something for which people need to be treated, and then the resources from

international aid organizations can be allocated there where they are needed in order to prevent further outbreaks or in order to prevent outbreaks at all, right?

So, you have posted a paper about AI and how it not only can, I think, change the world in the future, but also how it deals with water scarcity or, like, water deficiencies. So, I was wondering, how AI and innovative technologies could illustrate cornerstones in overcoming the challenges of overachieving clean water and sanitation in those regions in rural Yemen.

T: Yeah, so my background is technology and, therefore, I know how technology is working. Normally, when you want to be successful with technology and implementation of technology, first, you need to be very clear what exactly is the problem. So, I think the first thing, if you want to resolve this big problem, you first need to start small and kind of, divide this problem into something smaller so you can tackle it. Or you can at least start somewhere, because you cannot just resolve everything at the same time. So, I think from my experience in working in various enterprises, this is the first thing I'll do. I will just collect a group of people with diverse skills and knowledge, and I'll try to, again, with all of them, to understand what exactly the main problem is and make sure that it is small enough that we can tackle it. And then you can think of how you can resolve it using technology or not, or it could be a hybrid way of resolving it.

One of the things related to AI is that you can use AI if you have data. So, then this is the other thing that you have to think about is where and what kind of data you can collect so you can get a little bit more insights to work with. The other thing I'm now thinking is that if you don't know that, you can also use AI or Gen AI for creating ideas. I don't know if you have done that, but there are a lot of AI engines that you can use. For example, one of them is called Perplexity. So, this is an AI agent that can help you to do research. So, this is an agent, like Google search, but next level. So, this is also something that you can try yourself, and I can actually show you how that might work. I'm using ChatGPT a lot, especially for health-related things. Okay, let me show my screen.

G: Okay as we can see, it's similar to what you also said as well. But how feasible it is for you to implement those AI-driven smart sanitation systems. Also, according to your statement, the feasibility depends a lot on data, no? Because you need data in order to work with AI, right? So, if there is no data, then it will be hard.

T: Yeah, yeah. So, when we have a look at what AI suggests, it says leak detection, smart water management, then we have water purification, desalination optimization. So, those are all ideas for smaller things that you can do in order to tackle the bigger problem. When we have a look at the possible issues, we see the following: Lack of real-time data on groundwater levels, surface water sources and rainfall patterns. AI solution, use satellite imagery plus AI-powered remote sensing to track changes in water bodies and identify overexposed areas.

G: Interesting. So, this is like one possible problem and a potential solution. Which of those solutions would you think is something where you think from the technology side, would be something that could be feasible?

T: I mean, with AI nowadays, everything is possible. It's a matter of investment and whether you want to do it or not. This includes satellite imagery, which means that from a satellite, you can take pictures. Based on these pictures, AI analyzes and tracks changes in water movement.

G: Okay, so this is what it means. But what else? Is there another option?

T: Predictive analytics for water demand. I will copy-paste that for you. You can use AI to explore such options. This is just one prompt I provided. If you start chatting with it, you can obtain much more information. You can validate if it makes sense or not. For example, an early warning system for floods and droughts. I don't know if they have this problem in the first place.

G: Yeah, they have that. I also mention this in my research thesis. For example, water quality monitoring and contamination detection is part of smart water sanitation. It allows you to detect contamination even before it becomes a problem. AI can analyze data to determine if the water you're drinking is safe.

T: You can have different sensors in strategic locations to collect data. Based on this data, you can analyze whether it's contaminated or not. You can also use AI-powered weather prediction models. By analyzing various data points from the weather, you can predict when floods or droughts might occur.

G: Yeah, that sounds interesting. For example, during the research or my thesis, I found out that many water sources are contaminated, leading to disease outbreaks. An AI-driven water testing kit can automate testing and continuously analyze data, preventing people from drinking contaminated water. And then, In Yemen a big issue is cholera where the issue of not being able to treat the disease originates from a lack of infrastructure. AI is one part, but innovative technologies are also crucial.

T: That is true. However, it should be noted that AI is not the solution to everything. It’s about how you can use it. There are different types of AIs, but you need to consider what kind of data you have and how to gather it. Then you can analyze the data with AI or other machine learning methods.

G: Mhm. Also, in my paper I mention different innovative water clarification technologies. Have you heard of Watergen?

T: What is that?

G: Watergen is a generator from an Israeli startup that works everywhere except Antarctica. It’s small and portable. Let me share my screen for a moment.

T: Okay.

G: This is the generator from Watergen. It works by drawing in air, filtering it, heating it up, compressing it, and then filtering it again through a UV lamp to produce clear drinking water. This technology is not related to AI, but it effectively generates water from humidity.

There’s another technology called WADI SODIS. It requires only a water bottle and a plastic bottle. You fill the bottle with water and place it in the sunlight. Depending on the sunlight, UV rays can clarify the water if it’s not contaminated. You let it sit in the sun for some hours, it’s then safe to drink. The device indicates when the water is safe by changing a smiley face from sad to happy. These are two innovative technologies I focus on in my thesis. They can be combined with a smart sanitation system, potentially using AI to analyze collected data to address water scarcity in Yemen. The costs of the devices vary but they represent possible long-term solutions. Therefore, the money spent can be seen as an investment.

T: What about funding?

G: Funding is a significant issue since there aren’t many financial institutions. Additionally, if people are displaced, their data may not be in the system. Infrastructure is needed to collect

data for AI analysis. Investment in data collection and AI analysis would be a significant step toward improving water issues.

T: What exactly is your proposal?

G: If investments are made to help collect data that AI can later analyze, it would be a substantial step in the right direction. Currently, water is sometimes pumped from wells, but if it's contaminated, no one may analyze the data. Pumps may also stop working due to lack of energy. AI requires a lot of energy. But how do you get the data from Yemen to Europe?

T: The sensors and detectors should be on-site to collect data and send it to the cloud. However, internet access is a concern. If the infrastructure is poor, they may not have internet.

G: International organizations could allocate resources to provide the internet, which could trigger the process.

T: Aid oftentimes is provided but it can be allocated to the wrong place, in the wrong time if the urgent need is not identified.

G: Exactly. Aid is often provided in the wrong ways or locations. If the need for the internet is identified, investing in it could help decrease the issue in the long term. With a smart water sanitation system, data can be collected and analyzed to monitor water quality. If contamination is detected, resources can be allocated to address health needs in that region. So, to conclude our conversation. One of the most important things is to determine what kind of information or data to collect.

T: Yes, and how to collect it. This is the first step to having data, and analyzing it comes afterward.

G: That's a good point. With machine learning and creativity, researchers can tackle bigger issues by starting with smaller ones.

T: Yes, and you can continue to explore various prompts. The more detailed your inquiries, the more detailed the responses.

G: I'm interested in understanding more about water quality monitoring. What kind of sensors could measure that?

T: Different sensors detect specific contaminants and quality indicators, such as pH sensors and turbidity sensors. Data is transmitted wirelessly to a cloud-based platform. Sensors should be placed at water sources, rivers, wells, and reservoirs to collect real-time data on water composition.

G: This sounds so interesting. This is what you have briefly mentioned earlier, right?

T: Yes, and there are portable handheld and lab sensors that play a role in AI and machine learning. You can gather a lot of information from just a few prompts. The idea of collecting data in Yemen and analyzing it with AI, which requires significant energy, is crucial. Transferring data to Europe, where the infrastructure can support AI, is an important consideration.

G: Thank you for your time and for sharing your valuable insights. I'll transcribe our discussion and send it to you for confirmation.

T: Perfect. Thank you. It was very interesting talking to you. Good luck with your thesis!

G: Thank you! Have a nice day and weekend.

T: Bye!

G: Bye!

# INTERVIEW Mr. Wesian

17.February 2025

Mr. Wesian - W

Mrs. Gstrein – G

G: Hello! Nice meeting you.

W: Hi! Nice meeting you too! Ah, perfect. German is also possible, right?

G: German is also possible, exactly. I just wanted to ask if that would still be okay for you in English, because I would then transcribe it. And that's why it would be better if I wrote the master's thesis in English, because then I would have it in English.

W: Yes, of course, no problem.

G: Okay, great. Good. So, thank you for taking the time to participate in one of my expert interviews.

W: Of course.

G: I found you while I did my research, because I've read a lot of papers, and then I wondered which people I could interview for my thesis. So, I found that you were into the water scarcity topic in Yemen. Or like, not in Yemen, but like in a lot of countries, right?

W: Yeah.

G: So maybe I will start quickly introducing myself before I give you maybe some minutes to introduce yourself. So, I am Simone Gstrein. I am currently writing my second master's thesis in international development at the University of Vienna. And my master's thesis topic is 'A bumpy road ahead, achieving secure access to clean water in rural Yemen. And Can AI and innovative technologies help achieve the SDG Goal 6 (Clean Water and Sanitation)? So, this is my research topic and of course, before I did some research regarding concepts, as well as papers, and if people already applied it, and what are the issues in Yemen. So, this is also the part where I kind of stumbled upon you, when conducting some research regarding water clarification technologies, such as SODIS WADI.

W: Purification, yeah.

G: Purification, okay. So, I was wondering, maybe you can give a brief overview of things like what you're doing, what your current job role is, and what correlation you have to that topic.

W: Okay, yeah, thanks. Quite funny, because actually, I have to separate it. Let's say like that, yes, you're right, I have invented WADI. It's an easy device for water disinfection. So, it uses the power of the sun, the UV rays of the sun to disinfect water. It is a device, especially developed for the base of the pyramid people, so people living from one, two dollars a day, something like that. And it was developed especially from my side with a cradle-to-cradle approach, so it is very long-lasting, no batteries to replace, no spare parts, nothing. It was really developed for people living in the rural area mainly, and having actually no money for continuous water disinfection, for example. Usually, they use chlorine tablets, but mainly it is actually replacing the boiling of water. I've sold about half a million of the devices so far. So,

you can see that about half a million, 2.5 million people are using it on a daily basis, so we have done some impact research as well. People are using it on a regular basis for years, so we achieved that the device is a long-lasting device. The oldest devices are 9-10 years, something like that in the field on a continuous approach. But the company itself was shut down some years ago, so there are no new projects right now, which is pretty sad actually, because the device itself was approved by the WHO and mainly by the local people, which is more important than the WHO, because it eases up their lives. And to build up the whole structure for WADI, I founded the Social Enterprise Helioz, which supported the whole thing. First, I had a CSR approach, so people bought some WADI for their responsibility. Just to explain you the business case, it was kind of, for example, Alpler is one of the largest manufacturers of PT bottles in the world, it's an Austrian company and for example, or I had with Siemens the same agreement. Siemens is building up a new power plant in Sudan, mainly the contractor is the government or the country itself actually. And they urge you to not only build up a power plant but have to do some social and environmental projects as well. Because it's a business for Siemens and therefore Siemens is good in building up power plants, but not good in doing or maintaining social projects. So, from the whole budget of some hundred million dollars for a power plant, they give some hundred thousand to a company which fulfills the whole social thing. So, this was one part of the business case, and the other one was carbon reduction certificates where we will be a little bit in AI. It’s because people are using the device, they avoid boiling the water and therefore there is no CO2 emission. So, we have a nature-based solution to reduce or to avoid CO2 emission. And therefore, I got some carbon reduction certificates and then those you can sell to companies. So, this was the business case.

G: That is very interesting. Because I was wondering, sorry to quickly jump in, since I've seen the device, it's like you have the device, you put it on the PET bottles and then you put it in the sun, right? It does not work with contaminated water that has a virus or bacteria in it, but just like dirty water, that works, no?

W: No, it's more the other way around. So, it's really for viruses and bacteria and protozoa, the three things. So, cholera and other diseases one can get on the kind of water, which is contaminated, it can be disinfected. The UV rays of the sun disinfect it. So, we've done a lot of tests first with the University of Bodenkultur in Vienna and afterwards I have results from more than 20 universities doing tests with that. Generally, it’s really the reduction of germs. The outcome is pretty the same if you chlorinate the water.

The UV rays are better in protozoa especially and not that good in viruses and chlorine is better in viruses. It’s based on a story because I got cholera by myself many years ago and therefore, I was really looking for a solution to get rid of waterborne diseases.

G: I can imagine. It is also a big issue in Yemen. Yemen has the issue of being a failed state and then a lot of people get displaced from the cities to rural areas where the soil is not very fertile and of course they don't have a lot of infrastructure. Due to the war, everything is destroyed and also there are just emergency camps. So, they don't have a lot of water access and if they have access somewhere, there might be a well a couple of hours away, but the well might be contaminated. So, even if there's a well and you have some pumps and they work and maybe the pumps stop working, that's another issue. There are chances that the accessed water is contaminated and then there is not the infrastructure to first of all detect it and then if you detect it, it cannot be treated because they don't have extensive medical

infrastructure there. So, I stumbled upon WADI and another device I'm tackling in my thesis which is Watergen. Do you know this one?

W: Yeah.

G: So, this is another solution or like a possible aid to overcome the issue. But for example the WADIS Sodis is very cheap because you only need the PET bottle and you only put the device on it and put it in the sun which in Yemen is very feasible but I think cholera is a big issue there so that's why it's good that you tackled that because I'm not saying that with AI and all the innovative technologies it's possible to eliminate the issue. I think, currently, this is not possible, but I think it might be one of the cornerstones or the initial steps to take for a solution where maybe water scarcity can be eliminated, or the daily living conditions of those people can be improved. In Yemen, international as well as national aid is provided. But sometimes the resources allocated, are allocated to the wrong place, maybe in the wrong time or for the wrong people.

That's the point where I want to introduce AI because there are those so-called smart sanitation systems and I've read about some cases already implemented in India where people introduced those smart sanitation systems. When you have a shower, one can detect contamination in the water. All it needs are some sensors, so the data can be collected and then analyzed with the aid of AI. So, before the disease outbreaks and infects thousands, hundreds of people you can already prevent a serious outbreak or like treat those people. So, of course AI needs a lot of energy, and you have to think about the funding as well in those countries. I have talked to another expert in the technology field where she recommended that the sensors have to be implemented in Yemen or the country in question but then the data can be analyzed and transferred via internet connection over a cloud and the AI databases or like where the AI kind of like takes the energy from can be Europe where energy consumption is not that big of an issue. So, do you think for example since you have a lot of knowledge in the water topic, that implementing such smart water systems in combination with AI and innovative technologies could represent a feasible option to improve the water scarcity issue in Yemen?

W: First of all, WADI is designed to be very simple and not too high regarding technology complexity. Also, the device is not put on but rather around the bottle(s). At the beginning, people thought that the device only disinfected the one bottle where the device is connected to, which is not true because actually the sun is the disinfectant. So, you can put out hundreds of bottles and one device in the middle so it's very cost effective and for example in Uganda we have women empowerment groups where they collect a lot of water, they do the disinfection process together so they disinfect hundreds of liters, thousands a day and then they sell the water on the market the disinfected water, so this is for example one of the works of the device.

G: But how does it work if you put the device for example in the center of like a hundred bottles how does the device know because I mean is there the condition that all bottles are laying in the same sun exposure because it says like you put the bottle in the sun and then depending if it's cloudy or not it takes of course like longer to disinfect like the water but for example if one is like in the dark sun and one is like a little bit under a tree then it takes longer right?

W: You're right so the device itself actually is not a disinfection device it's an indicator, so it measures the UV rays, and the UV rays are different especially not only there is UVA and UVB. There are different disinfection methods, and it measures continuously the UV rays and

calculates the reduction of the germs, so you're right if one bottle is in shadowy places, it doesn't work that well but if you make sure that every bottle receives the same amount of sun rays then you have all of them disinfected together.

G: Okay that changes a lot because I mean of course when I had a look at the possible solutions and innovative technologies such as Watergen and WADI and other innovative devices, it was clear that WADI is much cheaper because for Watergen you need a generator and it depends which size you get but here of course it generates water that's different because it generates water from air and WADI purifies water so of course it depends you can use the water from like rain or somewhere else but if you don't have the water at all, then maybe Watergen generates it for you because it works in those countries.

W: One just has to take care which solution fits to the local problem so WADI isn't a solution for every water problem you can have, so you need water you need access to water and you need sun of course so it's not working well in Norwegian areas for example, it works pretty well in Austria but not in Norway for example and Watergen is a humidifier, so it doesn't work it works well in special areas but it's wonderful because it produces water which is even better of course you have water scarcity it produces water which is quite good. I told you about that WADI disinfect large amounts of water and they sell it and this is especially for example in Uganda where I have built up projects so they collect and they have a PET bottle collection system built up there so they buy up 10,000 bottles a month, 2 liter each bottle, disinfect the water and sell them afterwards, so you can imagine how big it is actually 10,000 bottles that are about 20,000 liters a month. I was interested all the time to connect that and there's a lot of data that needs to be collected so it can be seen where the areas with contaminated water are. During the day you have several wells where you can fetch water from in the morning. One well is a good one and the other one is bad because it has contaminated water and in the evening it's the other way around. This kind of information would be of interest of course to be collected and used, especially for the people living in the affected areas.

G: Shortly adding to your point where you said it's a female women empowerment group that does the bottle selling of water right? Where was it again?

W: This one especially was in Uganda; the largest projects are in Uganda.

G: Okay that's very interesting because for my last master thesis I wrote something about female empowerment that's very interesting. That's another topic but access to water is highly relevant in order to obtain independence. When women purify the water and later on sell it, to whom do they sell it?

W: People on the street, so on markets and they share the duties of collecting the bottles of refilling it because actually it's pretty tough work, so they are busy the whole day and they fill it up and sell it.

G: Yeah but that's very interesting I just thought because you said the people or the women going to lead the project and then sell it, I think that's a very good thing because also in Yemen the people have a lot of financial issues because they were displaced, they don't have anything, they all their belongings but here I think it, maybe in the future that could present a way to boost the economy but right now I think the selling part will not be viable because the displaced people don't have money to buy the water. Currently, this part has to come from an international aid organization or like some institution or initiative that does what the women are doing in your project.

Yeah, but thanks, it's very interesting! So, moving on to the next topic. As already mentioned above, I have talked to another expert in AI and she said the same thing: There is a lot of data, you have a lot of possibilities to help those people. AI needs data in order to analyze it or in order to find solutions but in those countries or like for example in Yemen, due to the fact that a lot of people are displaced, or a lot of people are born in the countryside, you don't have the data registered in a system. Therefore, it is hard to capture and analyze data. Coming back to the well topic, it would be good to know in the morning which well is safe to use and which one is contaminated. If this can be foreseen, a lot of outbreaks or diseases or adverse effects could be prevented but you need the sensors for detection. Yes, it costs money but there should be some investments done by international organizations or private people in those sensors and AI. It is not a short term but rather a long-term solution because you also have to think that you don't want to only help people in the current moment, but you rather want them to become independent in the long run. If you only provide help for the next two years, they will always require your aid but if you make a long-term investment, it will be more costly, but it will allow them to rebuild their communities from inside out and establish a more sustainable future.

W: I'm really critical about development aid because I've seen many projects which have been done with a lot of money and they are not sustainable because people are kept as beggars actually so you give them money, you give them food and then they are dependent on you, which is not a nice move, especially not ethical and because if you said because of the financial part, if you're interested then I can make maybe an interview with you since I'm currently writing my PhD thesis. My topic is how to finance such projects especially with the data collecting because I started with my company collecting data at wells. People have mobile phones, so they have an app, and they can see in the morning where the next well with drinkable water is, what's the price of the water because you have to pay for it usually, if there is a queue of people, what's the waiting time and of course, what's the quality of the water. So, this is something, I have already started with several measurement points and in order to finance this, I would be interested in social impact bonds, if you know them so this is the topic of my PhD. Social impact bonds is actually a finance structure to finance something which brings impact social, economic impact on a later stage of the project. So, if you have someone who is not employed and not employed for several years, it costs money for the government system to spend money for that person and if you offer courses, the person becomes qualified, can get a job and pays back money to the government by paying taxes. So, you can finance the whole qualification by a fund and get the money back later on as soon as the person is working again.

G: That's very interesting. I am going to quickly jump the funding section and then come back after to the innovative technology part. The question around funding is also something I thought about because a lot of people don't have bank accounts because they don't have an ID, they are not in a system, and therefore, they cannot do online banking. This makes the performance of transactions more complicated as well as financial independence because one cannot be independent if one does not have a bank account. While doing my research, I found out that cryptocurrency might illustrate a possible option besides traditional credits.

I have gathered information regarding those two funding models, where one is the traditional with the bank credit or people and the other is cryptocurrency. Currently, I think cryptocurrency funding is very interesting but not a feasible option for Yemen yet. Maybe in other countries, there is for example Ripple which is one of the coins and it engages a lot in international development aid. So, for example, you as a person or I as a person, we can buy those coins

and invest for us personally in those coins and by doing so we generate money where people for example in Yemen can fund something. I think it's very interesting and has a lot of potential but right now it depends on a lot of factors like what are the restrictions of that country regarding cryptocurrency, is the internet available which is needed for cryptocurrency. I'm not sure how good the internet is in rural parts of Yemen. So, I think in the future when the situation is a little more stable, it could be an option where people think okay that could be or could present a possible option in the future because the feasibility can be observed in a lot of African countries where wells were being built based on cryptocurrency fundings. Do you think cryptocurrency-based funding is a feasible solution?

W: Oh yes, especially democratizing the financials is very interesting and usually they have the internet so of course again it depends on what the country in question is allowing or restricting.

G: Exactly. There's a wide range, but cryptocurrency is very cheap, very fast, and it's transparent. You don't need a physical bank institution, so that's also an advantage in those countries. You only need the internet. And what's very, very important, I think, for a lot of countries is you can really restrict, or like not eliminate, but really reduce corruption. So, the money invested more or less directly goes from the source to the end user.

W: I think that's very interesting. Usually, you have to exchange the money into the local currency, which is very expensive. And you have to do it with local banks. Even in countries like Ethiopia, it's very, very hard to work with local banks. Even in India, I have companies and bank accounts in India that needed half a year, eight months to build up the whole transaction. So, this is one thing. And especially the spending of the money, you can prove it as well. You can say, we have spent the money on these topics.

G: Another scenario that should be kept in mind is the following. Maybe there is a bank nearby, but maybe it's a four-hour drive away, depending on where you live. You will probably not walk three days to the next bank to get five euros out of your bank account, right? So, it really depends on the region you live in, what opportunities you have. But I think also in the future, that will not only decrease the risks of transactions, but also to allow people to be more financially independent. Regarding cryptocurrency-based funding, I think for Yemen, this topic is still somewhere down the road in the future. But it's something I want to consider in my thesis. I do think that in the future, it will have great potential for a lot of countries.

W: Oh, yes, I think so too. I've seen this where the infrastructure is pretty down. Malawi, I have one project running right now. And I had one in Sudan, for example, South Sudan, which was an issue as well, because as you know, they had the war and had several issues there. And the whole infrastructure was destroyed.

G: How did you, if I may ask, how did you fund or how did people fund your previous projects?

W: It was Siemens. So, the company paid us for doing the project. We equipped 6000 families with clean drinking water. So, Siemens built up their power plant. And every worker who is working at the plant receives clean drinking water as well. By employing local people, Siemens received labor and provided clean drinking water to the population. The other part was pretty easy, as my company was a startup, so I got a lot of money from investors.

G: So, was it governmental fundings and sponsorships? Or just private people who invested for example 20,000 in your project? Or how did it work?

W: It was more like several millions. But it was private. Yes. And I had some projects with development aid companies. Not the Austrian ones. With GIZ, for example, several projects with GIZ, with the Norwegian and the Swedish.

G: Okay. But you stayed within the EU? Or did you also receive funding from Non-EU countries?

W: As well. For example, from India. I've done some projects in India. In such countries, you have a large population, which is very poor, but you have some very rich people as well. And then you can approach them regarding funding interest. Some of them just gave me money as a donation. Others were interested in a share and in growing together the whole company. So, it was very different. And regarding development aid agencies, you know, you have to send them an application and then they decide to fund your projects or not.

G: So, going back to the question, how should the funding be set up? If not crypto, then more the traditional credit approach?

W: I would even say the other way around. I would say cryptocurrency has a huge potential, especially because the infrastructure is rotten. If you have to build up the whole thing, it needs time. And as you say, especially if you build it up from scratch pretty fast, then there is a lot of corruption, especially at the beginning. And especially in Yemen, where you have several different interest groups, which is an issue. I've seen this in Sudan, for example, or in Malawi. They're very slow in development because they don't have the money, actually. So, they have barriers with the financial institutions all the time and the banks want to earn money. And with cryptocurrency, you can eliminate the middlemen.

G: Yeah. And as you said, it's much faster because you don't have to wait for 10 people or 10 banking financial institutions to give go and be like, okay, let's move forward. The only thing I'm not sure about is the technological background or infrastructure in Yemen and whether it is ready for cryptocurrency. I'm not sure about that. Maybe not right now, maybe in 10 years, maybe in five years.

W: But what do you need, actually, you just need a mobile phone for buying and selling. The crypto currency is more than enough. And usually in every African country, all of them have smartphones. Actually, you just have to sell to buy and sell and document the whole thing.

G: That is true. Regarding the restrictions, like the governmental restrictions, I'm not sure about the situation in Yemen, because some countries are very open, and some countries restrict the use of cryptocurrency. So, I think that's also something that has to be looked into further. Thanks for the input.

W: Yeah, no, of course. Good for my PhD topic as well. And for my company. Interesting.

G: Going back to AI and innovative technologies. In my Thesis I am tackling how AI and modern technologies can illustrate possible cornerstones, because I'm not saying they're solving the issue. I'm just saying they could be possible solutions in the future to start with. So, one question is do you have examples of how AI can be utilized in similar contexts in order to improve the access to clean water?

W: Well yes. The whole AI thing is out there on the market for two years. Personally, I'm into AI and currently developing projects with AI in the health industry.

AI can definitely be utilized for various topics, health, water scarcity, etc. But I think, as you said, data needs to be collected in order to do so. So, in my case, I had about 25 measurement

points all around the world measuring the water quality, the UV rays, so I can analyze how long it takes, the average water price and other factors. If you upload all this data into AI, it could work with this data, analyze it and make suggestions. The more data you feed to AI, the better. So especially if you have in a country several points where you collect data and put it together, this would be of high interest. And I don't think you need huge computers for that.

In the healthcare industry, I'm working with someone, not a guy, simulating a patient. So, medical doctors can do training with them. And you don't need a real patient because it's AI that talks to you. So, I'm just developing a device which talks to you like a patient. It is AI on a chip in the device itself, therefore, you don't need an internet connection, or anything else. It's very interesting. And therefore, I believe that AI can be successfully implemented in Yemen as well in order to decrease the water issue.

G: So, concluding, you do think that AI would be a feasible option to apply in order to not overcome, but like help reduce the water scarcity issue, or the water contamination issue?

W: Yeah, sure. I'm not seeing it as the real solution, of course, but especially if you see the pace that the development is happening right now, imagine where we could be in two years? So yes, it would definitely represent a vital approach to tackle the issue.

G: Yeah, that's true. What I also wanted to ask is what do you think about how smart sanitation systems, AI and innovative technologies could improve the living standards or like the situation in Yemen regarding water scarcity?

W: Scarcity is a huge issue. Here, collecting data and putting it together in an app would be important and a great improvement. And therefore, I wanted to build up this app. People wake up in the morning, and the first thing they think about is how to fetch water or where to fetch water. What's the price? What's the quality? And so on. And that's a daily struggle in lots of developing countries. Imagine someone collecting data and the AI analyzing the data and displaying the collected data on the app.

G: Yeah, that's true. This would be of high interest. And also, regarding the smart sanitation systems, do you think it's a feasible option if the funding can be raised, so these systems can be implemented? Do you think it makes sense to introduce them because then, together with AI, you can analyze the data, and you can detect diseases before they break out? And as well, what factors do you think influence the success or failure of those innovative technologies as well as smart sanitation systems?

W: Again, data, and you could really especially detect, for example, a cholera outbreak before it’s getting worse. As I have told you, I've been in a cholera area and suffered from cholera by myself. It's not fun at all. This could be a part or where AI should be used.

G: I also believe that if you combine AI with smart sanitation systems and innovative technologies, like water clarification, purification technologies, it can drastically improve the living conditions in those countries. Do you agree?

W: Mm. Yes, I agree. And you can put other data into it as well, which was not considered before, for example, the data of the local weather. You can easily access it in every country, and for example, if it rains, there is more contaminated water than if it's not raining. So, the AI can take this into consideration when analyzing data.

G: I think the weather is a good point that you have just mentioned, because also the AI and the innovative technologies per se, or technology in general can include weather data. Due to climate change in recent years, floods, droughts, etc. became more recent and extreme in daily life. So, imagine if people knew, it's raining right now, we have to collect more because in the next two weeks is going to be super dry, or that the flooding contaminated the water and therefore caution with regards to cholera should be paid.

W: Yes. Okay. And natural disasters, as you just mentioned. Yeah, that's, because if you have a flood, then you know, the whole thing is coming up. And if you have AI detecting that there was a flood and right now, two days later, we have two cholera cases. Yeah, then you can pretty much expect that there is a cholera epidemic going on. This brings us back to the early warning systems that AI could provide.

G: Exactly. Also, the allocation of aid/resources can be better sorted out. If it's not that urgent, you can relocate the resources somewhere else, right?

W: Yeah. That’s a good idea. This discussion is highly interesting. I'm just thinking about where AI can help. I'm doing a project, it's the one in Malawi, and I want to bring it to India. Actually, it's a device. It's the same principle as WADI, and it's a water ATM. So, it disinfects and then sells water to the people. People go there and put some money into it and fetch some clean drinking water. I'm just thinking about how AI could help out here, especially in the microbiological part, but this is not my area. I worked a lot with microbiological tests, and it was pretty hard to have the results of all those data because it was too much. Several thousand wells were monitored, where three tests were daily performed. I'm very, very sure with AI, I can get more information out of this data.

G: Yeah. And I think it's not only that you can get a lot of information out of the data, but also AI can generate innovative solutions because of machine learning. The more data you give the AI, the more you get out of it. SO, if you obtain a lot of data, AI also helps because it can process a lot of data in minimal time. But if a person has to do it, it takes so much longer, it's more expensive because you have to pay the person. And for example, by the time you analyze the data, maybe you have another issue coming up and the data is already outdated. So, I think with AI, you can also make the process more efficiently, maybe costly as well as time sensitive, right?

W: For sure. I have a lot of data, and I was not able to extract the whole information I wanted to extract. And I know I could not because it was too huge. Also, if I have a look at this data, I'm biased. I think, okay, this has to be like that. And the AI is not biased.

G: That's a really good part. I haven’t thought about but of course, if a person looks at it, and let's imagine I've been working a lot with a specific project and like women, for example, then I would maybe have the women's glasses on, right? So, I would highlight specific data, but AI doesn't have that. Unless you tell it, please look at the perspective from a female empowerment organization, then it has the glasses on. But if not, then it's very objective and not biased. That's a very good point.

The last question maybe I have additionally would be, is there anything else you would like to add that was not covered where you think it might be viable or like, interesting to mention?

W: There's a lot of interesting topics, I guess. I've worked in many countries and right now, I'm wondering if every country tries to solve the problem with its own ideas and innovative

solutions. But the problem is very similar in most of the countries. I believe if countries start sharing their approaches to the problem, various countries could benefit from it.

G: That's a good point. Yeah. I think it's, as you said, similar issues must have been or maybe would have been somewhere else as well, but people just don't know about them, because there is no shared database that people can access.

Thank you so much for taking the time. Can I refer to your name in my paper? It's only for my master thesis, but I am okay with whatever you're comfortable with, of course.

W: Oh, I'm happy to share my name because especially if someone has an idea or question, just approach me because I live from information. So, the more information I get, the better.

G: Okay, great. Thank you. So, what I will do, I will transcribe the interview and then use some parts of it in my thesis. I was wondering, do you want me to send you a draft so you can confirm your statements before I publish my master thesis?

W: You can, but it's not mandatory. Thanks again for this really interesting discussion and have a great evening.

G: Alright. Thank you again for sharing your very interesting and highly valuable insights. Goodbye.

# INTERVIEW Mr. Wessels

19.February 2025

Mr. Wessels - W

Mrs. Gstrein - G

G: Hi, good afternoon. Thanks so much for taking the time.

W: No problem. Nice to meet you.

G: Nice meeting you as well. I have one question in advance. Is it okay for you if I record with an audio this interview so I can transcribe it after for my master thesis?

W: Sure, no problem.

G: Thank you. And of course, if you want to, I can send you the statements I would use so you can confirm them and say, okay, this is what you're happy with me sharing if you're okay.

W: Yeah, thanks. That would indeed be nice.

G: Perfect. So, are you right now in Yemen or in the Netherlands?

W: I just returned. So last week I was in Yemen. So that was why I was also a bit busy. But it was actually a nice coincidence, indeed, that you're working on Yemen. And yeah, I've been there for a bit over a week, visiting different projects in the south of Yemen. You're probably aware of the difficult situation that Yemen is in as an organization. We're working on both sides of the conflict, let's say. In the north, we have a program. And in the south, so I was in the south this time to visit the team and visit different WASH projects, such as water and sanitation and hygiene projects.

G: Ah yes, I've seen this when I did some research and I reached out to the ZOA organization, also one of your colleagues told me that you're the ZOA WASH advisor, no?

W: Yeah. So, I am the ZOA's global WASH and climate resilience advisor. I can say something about the organization in my role.

G: Sure, that would be great! Just quickly, because I saw in your last email that you said you don't want to be mentioned by name. Is it like something where you really don't want to be mentioned, like with your name and with the organization? Should I make it anonymous? Or is it okay for you to mention either your name or the organization name?

W: Yeah, so my name doesn't necessarily have to be mentioned, but you can mention my role as a WASH and climate resilience advisor. The reason that I was not sure if ZOA would be relevant to be mentioned is because I also am not sure if, I'm happy to talk to you, but I'm not sure if I can provide a lot of valuable insight. And this I think that I shared this over email, like the topic of AI and these kinds of things. Somehow, it's or perhaps a lot of struggling to really see how that could fit in the context of Yemen. So, this is why I was a bit like, yeah, of course, I can share a bit about what we do as an organization. I could share a bit about the work that we do in Yemen. But I cannot present ZOA as an organization that is on the forefront of AI and crypto and things like that. So, this is why I wasn't sure.

G: No, I totally understand that. And I've been talking to a couple of people already and some people had more knowledge about the water scarcity issue, sometimes not even in Yemen, sometimes just like generally on a global scale. Some people were more from the technology side, so they could provide more expertise regarding AI. So even if you don't have extensive knowledge in AI, that's okay. And also, as I'm aware, ZOA is not the leader regarding AI initiatives in Yemen. Maybe I'll tell you a few words about myself, to give a brief introduction. So, I am Simone Gstrein. I'm currently writing my second master's thesis in my master's program, which is international development in the University of Vienna. And the title of my master's thesis is a bumpy road ahead, achieving secure access to clean water in rural Yemen. And then the question I have, and that's why I say it's a bumpy road, is how AI and innovative technologies can represent possible cornerstones to overcome the hurdles of achieving the SDG goal number six, which is clean water and sanitation.

I'm aware of AI and all of the possible opportunities it could or may offer in various countries. For me, I picked Yemen because the water issue is a huge issue. But of course, I'm saying it's a bumpy road with a lot of hurdles ahead. I'm not saying it might be feasible right now, maybe in 10 years, maybe never. This is why I thought I should interview you to hear what you think are the opportunities for AI so I can learn from that. Maybe you want to also say a couple of words about you, your role and maybe what you're doing in Yemen. Of course, you are the expert in this topic, so I don’t need to tell you the background about Yemen but maybe I can give you a short overview of what people with AI background have told me before and what potential they saw. Based on this, you could maybe tell me what you think, with the knowledge and expertise in Yemen, about this and whether it could be something that could be implemented?

W: Yeah, perfect. Let's do it like that. And then we just see where we end up. And let's, let's, I think we can expect a bumpy road. But that's good. That's what we hope for.

Okay, so I have, I can share something. Also, I hope you see my screen. Because every now and then I'm asked to say something about also specifically the situation of Yemen. Recently, I was talking to the Minister of Water of Yemen, and this is where I also shared a bit of the work of ZOA. So, we are a humanitarian organization, called ZOA. We are not a development organization. I think this is important to mention. We step in to help those in urgent needs. So, this has to do with the situation of conflict. We work mostly in the context of conflicts as well as in areas that are affected by climate disasters.

For example, floods, or droughts are two cases that lead to hunger. The reason that I'm saying this is that often we are not in specific locations for a long time. So, we don’t have a long-term engagement, which is more common in development organizations. We come for life saving activities, and we do this in 12 different countries where we have country offices. So, this is more or less where we have a more like a permanent presence and then see what needs there are in the country. And based on that, we react. We do this with money from NGOs, from the EU, from the UN, from the USA, from different places. On the left, you see the different sectors that we work in. So, food security, livelihoods (FSL), peace building, wash, education and shelter.

G: Because of the wash initiative, that's why I think you are a good fit, even though you don't tackle AI which is a big part in my thesis as it also comes with smart sanitation systems, as well as wash initiatives. So, interviewing an expert like you could provide valuable knowledge.

W: Okay, we can talk about the wash initiative. I am a wash and climate resilience advisor for ZOA International. And part of what I do is to support Yemen. This is also one of the reasons why I've been visiting wash projects last week.

In Yemen, we are already present for over 10 years, specifically working on this topic of wash and FSL. So, it's not that we do everything in Yemen, but we specifically engage in these two topics, as said with different donors, different projects, and also working with ministries and things like that. We work both in the north and the south, which are under different authorities, which you will know, which is quite which has quite a different political context. Also, because of that, we are not able to work in all places. Yeah, because of security reasons as there are still active conflicts in Yemen.

G: I can imagine. How do you fly there? Because there is no flight? Do you fly to another country and then enter by car or how do you manage a trip there?

W: So, for example, the month after the next month is Ramadan. But in April, I will travel to Syria. And for Syria, I travel first to Lebanon, and then I drive by car. In this case, Yemen, it was using a humanitarian flight from the UN. So, the UN offers flights every once a week, where you fly into the country and fly out of the country. So, we have a program in the north, working Haja, Al Mahwid and Sanaa at the moment. And we have a project in the south, in Aden, Lach and Aldala. This is where we work on the following three things: Water supply, sanitation, hygiene promotion, and a bit of everything but done in public facilities.

Regarding your thesis, I think what is most relevant, perhaps in this conversation is not specifically the hygiene promotion aspects, but sanitation and water, water supply. We take water from boreholes, which we pump. And if we talk about innovation, I think for Yemen, this is innovation, or in the humanitarian context is innovation. We do it all, or we try to do it all solarized as there's no electricity in many places. Otherwise, you're reliant on fuel generators, for which you would need diesel to get water. And if there is no diesel, there is no water. So, we use solar panels for that. We're now piloting desalination which means generating sweet water from seawater.

G: Very interesting. Thank you for the overview. So, there were a couple of topics mentioned by you, which I already thought about as well. And when I did some research, I also stumbled upon the fact that electricity is a big issue since the infrastructure seems to be in a really bad condition, if existent. So, in many areas, specifically in rural Yemen, there is no electricity.

W: Yeah, exactly. There are really no electrical grids. You might find some electricity in district centers, but many people live in the mountains, in very remote areas that are difficult to reach and very scattered. So, there are not a lot of people, resulting in a low population density in the area. For example, I was staying in one of the big cities, Aden. I could not stay in the other governorates because of security reasons; it was just too dangerous. At the time I was in Aden, there were only between two and four hours of electricity a day.

G: And how was it generated? Was it by solar power or something else?

W: Oh, yeah. If you have a generator, then you have electricity. But otherwise, there is no electricity. So, that means that for the last few months, electricity has been generated by oil. I don't know if they put oil or fuel, but they generate electricity for the city that way. However, there are fuel shortages, which means that there are only a few hours of electricity a day. If you don't have a generator yourself, then there is no electricity. So, everything that is electrified will not work.

G: Okay, understood. How about the internet? Do people in the regions you're working with have smartphones or internet connections?

W: There are rural areas where there is no network reception at all. You won't even be able to use your phone to call or receive text messages. However, if you move towards the bigger cities or even the villages within districts or governorates, you will find mobile phone connections and mobile networks.

G: Okay.

W: Internet connectivity depends very much on the area. I don't know what kind of phones people are using. In my organization, it's quite common for people to have smartphones, but many of the project participants may not have them. If you're living in an area with no mobile phone reception, then there is no reason to have a smartphone. So, it very much depends on your target group and the specific location you are asking about. In more densely populated and developed areas, you will find people with simple phones as well as smartphones. However, in the rural mountainous areas, which are many, there is often no network at all.

G: Yeah. Okay, because I did a master's before and had a scholarship where I went to India for five weeks to conduct research on how COVID influenced the work-life balance of informally working women in slums. There, I worked with women in slums, and I realized that many people had phones with internet access. However, the difference in New Delhi was that they had connections, and it made sense. For instance, if one out of ten people had a smartphone, they could share it because there was reception. But if you're in a place without reception, then it doesn't help you, right? So that's a good point as well. Okay. I would like to give you a brief overview of what I heard from others in the technology field, as well as what I found during my research, and then maybe we can connect it.

There is a huge issue with water scarcity in Yemen, right? From my research, I found that we have the issue of water scarcity, and we also have the issue of cholera, which is a waterborne disease. First, you need to find a water source or generate water. If you find water, I thought, how drinkable is it? It doesn't make sense to invest in a well if the water is contaminated. If you have a well and people start drinking the water, it could be contaminated, leading to cholera outbreaks. I was focusing on general rural regions in Yemen, not just a specific area, because of the war, and people have been displaced to emergency camps or moved out of the city. In those camps, the infrastructure is either non-existent in rural areas or may have been destroyed, depending on where they moved. But for me, the question was, once you have the water and drink it, what happens? This is where the idea of AI came into my mind. In different countries, they have those so-called smart sanitation systems. They use them in India and sometimes in some regions of Africa, where investments were made by organizations or the government to build a smart sanitation system. For example, when people shower, the water is analyzed with sensors. Cholera or other bacteria or viruses can be detected before the disease even breaks out. Instead of having people drink potentially contaminated water, you could already say, ‘Okay, this water is contaminated’, by putting sensors into water sources in Yemen.

I spoke with an AI specialist who mentioned that AI performs better with more data. So, what it needs is data and a lot of electricity, right? I wondered how you can establish AI-supported research in countries where electricity is a significant issue. One suggestion was to put sensors in wells or water sources to measure water quality, which is not that expensive. For that, you would need some internet. She suggested that the data could be transferred to more

stable countries, like Europe or the United States, where there are bigger cities. There researchers could have a computer or network system that analyzes the data. So, the AI could use energy from countries that are more stable or do not have electricity issues. This was one suggestion they made. I also thought that if cholera is detected—maybe if people shower before it even breaks out—and you don't have the medical resources to treat it, it could be detected before it becomes an outbreak. For example, with the recent extreme weather conditions, there have been many droughts and floods in Yemen and other countries. With floods, yes, you have more water, but that water also brings up a lot of bacteria. So, while there may be more water, it might not be drinkable.

Another IT specialist mentioned that funding for the sensors is necessary. But if you get the funding, how is it funded? During my research, I found out that cryptocurrency might present an option. For example, Ripple is a coin that mainly engages in international aid projects. People all over the world can buy or invest in Ripple coins, generating a funding budget for investments in Yemen. This approach is already being implemented in some countries worldwide. The question with cryptocurrency is that it depends on the country; some countries have restrictions on it. They might say, ‘We don't work with that’, as governments have different policies and restrictions. But I think it represents a good option for the future, however, it needs to be determined whether Yemen allows it, which I don't know. Additionally, is it feasible? Maybe in ten years, it could be a good option for funding, but right now, I don't think it is. Another point mentioned is that in many countries where corruption is a significant issue, cryptocurrency can eliminate that because there is no person or institution in between. This means that people who fund or invest in those coins can see directly where the money goes. However, as you mentioned, when people get displaced, they may be in rural regions or mountains without internet connection. They cannot access financial institutions because they might be a few hours' drive or a long walk away. If there is an option to just have an internet connection, and maybe they don't even have an ID or bank account, then in the future, if internet access becomes more stable, just having an internet connection and maybe a smartphone could eliminate that barrier, allowing them to access cryptocurrencies directly.

Regarding water generation or purification, I am tackling innovative technologies in my thesis. I am not sure if you have heard of Watergen, which is a device that generates water from humidity in the air. It is mobile and can be set up anywhere, but it does not work in Antarctica because it is too cold. It essentially sucks in humidity, compresses it, and heats it up. The water generated from the air is purified using UV rays. The only requirement is electricity. Some people use solar power, while others use diesel generators. I also spoke with someone about a water disinfection device, called WADI. It is a device that measures the UV rays. By placing contaminated water in a plastic bottle and exposing it to the sunlight, it gets purified. WADI assists in this process as it measures the UV rays and indicates when the water has reached drinking quality. I believe these are two innovative technologies that could help. Of course, it depends on the resources available, and both technologies require funding. Watergen is quite expensive, especially with the generator, but it does not need water since it takes it from the air. However, for purification, you need a water source.

So, I think that is the general concept I had in mind regarding how sensors, AI, and innovative technologies could help, but they may not eliminate the issue of scarcity in Yemen. What do you think about that?

W: Thanks for the brief overview. This is interesting. So, there are a lot of different topics to consider. Sometimes, it's easier to think about solutions when you're not there. When you're

on-site, you see different hurdles that people might not consider when they are not actually there right now. Currently, we use water filters in Yemen. I think it has to be considered what kind of innovation is feasible in Yemen at this moment. For example, there is no electricity. Where do you get the electricity from? There is nobody who will support you. Additionally, there is no government that is stable enough to invest in these kinds of things. This situation is compounded by issues like corruption, even with cryptocurrency. Who will go after the people that exploit the moment that a crypto value is turned into actual assets or something physical? Alos, people do not use showers; they just water themselves with a bucket. There are no shower facilities available.

The sensors in boreholes could be doable. However, contamination from cholera often occurs after water is taken from a water point. It has to do with how the water is stored in households. If you do not cover your water or take proper precautions, contamination can occur later. I do feel that there are opportunities to place sensors in locations to monitor how water quality is changing, which could trigger alerts. For instance, if the water quality is now insufficient for certain standards, there should be a trigger mechanism. However, this also means that there needs to be feedback to the user. There needs to be a way to communicate with the person consuming that water.

G: Okay, I understand. Since electricity seems to be a big hurdle, would the WADI tool, which you place in the sun to measure the UV ray exposure, illustrate a feasible option? Another water expert, I was talking to, also emphasized that such devices need to be user-friendly in order to be successful. He suggested building an app connected to the sensors. However, this requires a smartphone and internet connection. This may not be relevant for the most rural areas, but it could work for people who do have access, allowing them to see if the water quality is poor. This would be a step forward. However, this also needs to be implemented in the future, as I have not heard of such systems being in place right now.

W: Yes. I think there are other contexts where there is more constant monitoring of water. So, I think it can be done. To me, it would be interesting to research what enabling environments are required for such systems to work. One aspect is connectivity, another is energy sources. Additionally, financing is crucial. Who is financing this, and for whom? I understand the potential of cryptocurrency as a funding tool. However, who is interested in financing this? How does this, compared to work ZOA engages in, work, where we focus on low-cost rehabilitation of water points and household filters? We struggle to secure funding for these initiatives. Working with companies is often not possible because they are not allowed to operate in Yemen, and there are significant security risks. It is very much a humanitarian context. Governments have insufficient capacity to support these initiatives. You can request smaller projects from them, but setting up large-scale monitoring networks is beyond their capacity.

G: Yeah, okay, I can understand what you mean. Coming back to the power supply. You mentioned that the lack of electricity is a significant issue. Can I share my screen to show you something? Let me know when you can see it.

W: Yes, I can see it.

G: Great. This is Watergen. They have different generators, including a small mobile box that can be placed on a car. You can set it up anywhere, and it works with solar power or a generator, so you don't need a stable power source. If you have a generator with diesel or solar, it could work, but it is expensive. Yes, the funding issue is a concern, but I was

wondering if you could find someone to sponsor it. For example, the largest model is the Gen L, which can produce up to 6000 liters of drinking water from the air. Putting aside the funding issue, do you think something like that would work in Yemen?

W: I think it's worth checking under what conditions it can produce 6000 liters per day. This is something to investigate further. It depends on the climate conditions.

G: According to the specifications, it works in a wide range of climates, starting from 15 degrees and 20% humidity. It can function in most countries, but not in Antarctica.

W: We also need to address who is financing it. Another point is who will take care of the operation and maintenance. Who will cover the costs to ensure durability and sustainability? If we take 6000 liters per day, let me do some quick calculations. That is only 250 liters of water per hour, which is very minimal. If only 400 people can benefit from this, and we take the bare minimum, according to humanitarian standards, we provide at least 15 liters per person per day. With this system, if you divide 6000 liters by 15 liters, only 400 people can benefit.

G: Yes, that is correct.

W: If the average household size in rural Yemen is around seven people, which means only 50 families can benefit from this system. That is not a lot when you consider the context. It would be interesting to make comparisons regarding the costs per amount of water produced. If you know the cost of such a system, you can determine how many people can benefit and what the cost per cubic meter of water is, which is 1000 liters. This would allow you to compare it against other technologies. This approach would help evaluate the financial perspective and determine the best way to address the issue.

G: I just looked it up, and the system that produces 6000 liters costs around 189,000 US dollars. So, almost 190,000 dollars.

W: If we calculate, 190,000 divided by 6000 liters gives us about $31 per liter. This is extremely high. This cost exceeds the monthly income of a household in Yemen.

G: If they have to pay for it, that is a significant burden. However, if someone funds it, they may not have to pay.

W: Yes, but there will still be maintenance costs. You have to consider CAPEX and OPEX—capital expenses and operational expenses. The capital expenses are 190,000 dollars. Then there are also the operational expenses. We often say that for a humanitarian organization, we try to secure funding for the CAPEX. We try to find funding for the 190,000 dollars, and then we see if the community can fund the OPEX themselves. Otherwise, after we install the system, they may not use it if it breaks down because they lack the funds to operate it. It would be interesting to check studies for Yemen regarding the expenses people incur for water.

We work in areas where people have to buy water via trucks because there is no water available. Recently, I visited a community paying 6000 rials per cubic meter of water. That translates to about two and a half dollars for one cubic meter. That is already a significant amount, especially in extreme situations. To operate effectively, the operational costs need to be one dollar or below, ideally well below one dollar per 1000 liters to make it attractive. That is true for operational costs. If you find funding, that is a positive aspect. However, the maintenance costs are also a concern. If we consider the 190,000 dollars for what we discussed—50 families—we could easily support a larger number of families. It depends on

the situation, but we could potentially support ten times that number. This would make it much more attractive for someone funding the project to support 500 families instead of just 50.

G: Yes, that is true. As you mentioned, last week, there was no water available. Do you think the device that uses PET bottles to purify water with UV rays is feasible? Or do you think it is difficult because there is no water to purify?

W: It depends on what you are purifying. If you only use UV light from the sun, which is what you mean, right? Yes, but it can eliminate bacteria and viruses. However, bacteria and viruses are not the only contaminants in the water. Most devices use UV treatment, which imitates sunlight. In Yemen, if there are clouds, the system will not work. But it can work, especially in coastal areas with high temperatures and plenty of sunlight. However, it also depends on the season. It is important to consider the starting point of 15 liters per person per day. If that is the minimum standard from a humanitarian perspective, then how large does the system need to be? How do we compare technology, innovation, and impact? You always try to balance achieving the highest impact. If this UV system is low-cost but slow, it needs to be exposed to sunlight for a long time.

G: In full exposure, it takes around six hours to purify the water.

W: So, that is still six hours, right?

G: Yes.

W: For solar installations, we typically count a day as having six sun hours. If we design a solar system, we say it will provide six hours of water because there are six hours of sunlight, and the remaining hours do not provide any power. Therefore, six hours equals a full day for this UV system, as there is no sunlight during the other hours. So, if the system can treat water during those six hours, that is the capacity it can handle for a full day.

G: The advantage of this system is that if you have water and PET bottles, the device itself is not expensive. It was mentioned that you can place one device in the middle and surround it with many bottles, as it does not need to fit on each bottle. It simply measures the UV rays, and if the conditions for the bottles are the same, that is acceptable. So, you do not need 100 devices for that. I can show you another picture if you want. If I share my screen again, you can see the generator I showed you before from Watergen. This is just a small one; they have larger models. This is how it works: the air goes in, gets compressed, heated, and then purified with UV rays. As you mentioned, they do not have sunlight in some areas, which is why they use artificial light. WADI however, only measures UV rays, serving as a water disinfection tool. You fill the water, place the device, and it indicates the water quality with a smiley face. If the water is just filled in, it shows a sad smiley. After placing it in the sun, it changes to a happy smiley, indicating that the water is safe to drink after a certain time, depending on sunlight exposure.

W: Alright. Now, going back to calculations, if we assume a PET bottle is 1.5 liters, every person requires 15 liters per day. This means that each person needs about 10 bottles per day. For a family of seven, that totals 70 bottles every day. They can be refilled, but the question is whether the quality of the bottle will deteriorate. For a family to drink water for one day, they would need 70 PET bottles, correct?

G: Yes.

W: So, I think there is also the question of whether you could assume the bottles are reusable. At some point, there will be a buildup of contaminants. This is why we install filters for villages. Instead of providing filters for each household, we install one filter for the village, which has a capacity of about 50 cubic meters, or 50,000 liters. This approach often reduces costs due to economies of scale. The larger the scale, the more efficient it is to provide water at the community or village level rather than at the household level. So, I believe there is a benefit to scaling up rather than providing individual household solutions.

G: That makes sense. To summarize what I've mentioned, since you have local knowledge, what do you think might be the most feasible option if you funding can be secured? You have mentioned that the sensors could be feasible with further research. What are your thoughts? Also, Watergen is a great option if funding is available, but without funding, it is not feasible, right? Or do you think the filters for the community would be more appropriate?

W: Yes, we install the filters and conduct tests before and after installation to ensure water quality. We have devices for testing, but we take them with us. At times, we can also send samples to labs for testing. Since we take the devices with us, testing is not done every day.

G: So, is there a set schedule for testing, like every six months or every three months?

W: Yes, we conduct follow-up tests after project installation. After that, we try to hand over responsibilities to local authorities. If there is the General Authority of Water Supply Projects, they can conduct follow-up tests, ensuring it does not solely depend on us as an organization. I apologize for being critical, but...

G: No, no, that is a crucial point. People often overlook this.

W: For years, I worked as a university lecturer on water management, and I would sometimes say that some solutions seem like they are looking for a problem. There is a risk that the proposed solutions do not fit the local context.

G: Yes. The sensors for measuring water quality are relevant, as you mentioned. However, how often do you follow up on the water quality?

W: We do not follow up anymore after implementation; we assume it is sufficient. After that, it is up to the community. However, the community does not have the necessary sensors. They lack the measuring equipment. I think combining sensors with energy sources, such as pumps, could be beneficial. The pumps already have electricity sources, so they can be integrated. This could be helpful. If the sensor can send alerts, that would also be beneficial. For example, if we install a large filter at the community level, a sensor could send a message to our office, which has electricity and internet access. If the sensor detects an issue with the filter, that would be helpful. It might not be necessary to provide feedback to the community directly. Instead, it could go to the implementers or monitoring bodies, increasing the efficiency of monitoring. By doing so, you can do it remotely and only visit the site when there is a notification of an imbalance in expected water quality. For instance, we create reservoirs on top of mountains, allowing water to flow by gravity to different villages. This eliminates the need for extra pumps, reducing electricity requirements.

G: Yes. You have the borehole where the water comes from, and you place solar panels and a pump to fill a large reservoir. From there, everything flows by gravity.

W: Right.

G: If you place a sensor in the reservoir, it could provide feedback to ZOA or a monitoring authority.

W: This could be very useful.

G: As I mentioned, AI could be efficient in this context. If a notification indicates something is wrong, that would be helpful. If the data is sent and something is wrong, you receive a notification. AI can collect data more quickly than humans. When you receive a notification, you can respond quickly, especially with international aid. You mentioned that you only respond to urgent needs, but there is international aid available in Yemen.

W: Yes, that is what our organization does. There is a clear distinction between development and humanitarian assistance. Humanitarian work focuses on immediate responses to people lacking food and water. This is less about long-term changes and more about immediate needs.

G: I believe that if organizations provide medical assistance, such as medication, and the sensor indicates a problem, you can identify the location of the issue without needing to check every six months. You can respond immediately when there is a problem. You can allocate medical resources to the affected area based on the notification. This is much more efficient than waiting for a scheduled check-up. I don't want to overstep, as you are the expert, but I believe this approach is valuable.

W: We work with early warning systems and anticipatory action. Anticipatory action relies on trigger mechanisms to predict risks, such as floods, before they occur. This is based on AI technology and predictions.

G: Yes, I think Google has a Flood Hub that alerts users to potential floods.

W: Exactly. We are exploring whether we can intervene before a disaster occurs to mitigate its impact. Often, we are just not in time to act. You understand the urgency, but sometimes the situation is already unfolding. We need faster trigger mechanisms or alerts to identify patterns before they become crises. We often look back and realize we could have anticipated the situation, but we weren't fast enough to act. There is much to explore that could benefit not only our organization but all humanitarian efforts. The challenge remains: we need good data. If the data is poor, the outcomes will be poor. If you don't provide the system with quality information, your predictions will be inaccurate.

G: Introducing sensors could generate continuous data, which is essential for AI.

W: Yes, that is true. The question is what to measure and where to measure it. Based on that, we can determine what we can learn. There are many steps to consider. It may seem simple, but finding a solution is not always straightforward. I believe this could be a step forward, allowing for further research and exploration.

G: The sensors are low-cost. I am taking cholera as an example. If you could place sensors in an area to detect a cholera outbreak, you could anticipate the need for intervention.

W: This could be an interesting area for further exploration. Are there ways to predict cholera outbreaks and the necessary data points for reliable predictions?

G: If cholera breaks out and could have been prevented, then medical support would not be needed. While it may cost something for the sensors, preventing outbreaks could save money on treatment.

W: Yes. Even if there is no infrastructure and medication is hard to obtain, prevention is key.

G: That is true.

W: As a humanitarian organization, we focus on disease outbreak prevention. The cholera example is particularly relevant. Yes, I would like to see how we can prevent such outbreaks in the future. Yes, we need to calculate how much we can do or cannot do. I always assess the feasibility of a solution. I evaluate whether it makes sense or not. Additionally, we need to compare the costs per cubic meter of water produced.

G: Yes, that is a good point. Thank you for the engaging discussion. I think this discussion was very important and eye-opening as sometimes, people have good ideas from afar, but when you speak with someone on-site, they can provide valuable insights and explain why certain ideas may not work in practice.

W: Right, I agree. I see your enthusiasm for these topics, and I appreciate your insights. I don't want to critique everything, but Yemen is indeed a challenging context. I don't know how you decided to focus on Yemen, but it is a very difficult environment. This is a complex situation that is hard to grasp. One simple reason is that you cannot travel there easily. It is challenging to gain a full understanding of the situation.

G: I totally agree. When choosing the topic, I was aware from the beginning that my university could not support sending me to a war-torn country at this point in time. Therefore, I thought about a good alternative option, which was the performance of expert interviews. Talking to specialists and experts from various fields would give me various valuable insights, expertise and on-site experience. Ideally, I would find someone like you who can provide insights and say, ‘These are great ideas, but this is not how it works.’ or ‘This idea does not sound feasible, but this other one could be a possible option’. So, it is great that we have connected.

W: I agree.

G: Thank you for your time.

W: If you would like to check any numbers or calculations, feel free to reach out. I'm happy to help.

G: Thank you. Since you mentioned in the beginning that you are unsure how your organization fits into this, I was wondering, now having discussed the topic a little as well as clarifying the connection of my thesis and ZOA, if I can mention you or the organization by name.

W: Yes, I believe it is clear what my views are on the topic. It is a very difficult context to work in, and many of the activities in the country are low-cost. Low-tech solutions are often the most practical. I think this is the most important aspect, and I stand by it.

G: Perfect. I really appreciate your time and insights. Have a nice evening.

W: Thank you for this interesting interview. Have a great evening too!

# INTERVIEW Mr. Sarni

26.February 2025

Mr. Sarni - S

Mrs. Gstrein - G

G: Hi. Nice meeting you! How are you?

S: Hi. Nice meeting you too! Well, you know, I live in America. So, it's questionable how well I'm doing, but personally I am well.

G: Oh, I am happy to hear that you are personally well. Thanks, first of all, for taking the time. I assume you're quite busy as well. Before starting, I want to ask, is it okay for you if I record this interview with an audio, so I can transcribe it later for my master's thesis?

S: Oh, yeah.

G: Perfect. Thank you. And also, if it's okay for you, I would transcribe the interview and then send you the interview forehead, so you can confirm the statements, if that’s in your interest?

S: Yeah, absolutely. That'd be great. Thank you.

G: Perfect. Good. So, thanks, first of all, for taking the time. I will give you a brief introduction about what I'm doing and maybe about myself. And then give you time to introduce yourself and your role. This might explain why I think that you are a good fit for my master's thesis interview.

S: Perfect. Sounds great.

G: Perfect. So, my name is Simone Gstrein. I am currently doing my second master's thesis in international development and the topic I'm writing about is, I'm just quickly reading the title to you ‘A bumpy road ahead, achieving secure access to clean water in rural Yemen. Can AI and innovative technologies help achieve the SDG Goal 6 (Clean Water and Sanitation)? I've talked to various people, and some people had extensive expertise in various fields. Some people had a lot of knowledge about water or water scarcity, some had more technological background. And then there were people, for example, from an international humanitarian organization, ZOA, in Yemen, which had more local knowledge.

Maybe you can give a brief introduction about what your role is and what you're doing and which topics you're engaged with.

S: Yeah, sounds good. So, my background is a technical background in hydrogeology, so groundwater, water supply projects, remediation programs, but I have spent the recent part of my career focusing on sustainability strategies. And in particular, water strategy for US and non-US multinationals, but I have also been working with technology companies and investors, and also have made my own investments in innovative water tech.

I've got a particular interest in digital technologies, you know, remote sensing, on the ground sensors, things like that. And, you know, I've worked for large multinationals, such as Coca-Cola, Pepsi, lots of food and beverage companies, but also apparel companies and

manufacturing companies. So, really where I fit is at the intersection of corporate strategy, technology, innovation, and investing or financing.

G: Very interesting.

S: So, I agree with you, it is a bumpy road ahead. I think that's a priceless title. I don't know much about Yemen other than what I read on the news, but I assume Yemen suffers from water scarcity, water stress, poor quality, lack of infrastructure and lack of investment.

G: Exactly. If you want, I can give you a brief overview of the issues that are being faced in Yemen right now. This will not only shine some light on the multiple issues existing in rural Yemen but also create room for a discussion about where AI and other innovative technologies could display great benefit here. In my thesis, I am focusing on two specific devices which are linked to water generation and purification. The first one, I want to mention, is called WADI. It's a water purification tool. It is a small tool. If you want, I can share my screen and show you if you're interested.

S: Yeah, that'd be great. Thank you.

G: Good. The tool per se does not disinfect the water. The tool is just measuring the UV ray exposure. You need some PET - plastic bottles - where you fill the contaminated water in. Then, you put the water bottles into the sun and place a tool nearby.

Depending on the level of sun exposure, the time varies by the UV rays required to purify the water. So, the good advantage about this tool is that it is very cheap. I have also talked to the CEO of this tool, and he explained that one does not have to put the tool on the bottle but rather can just place it nearby, which means like you can have various bottles equipped with one single tool. As long as they have the same weather condition, which means the same exposure to UV rays. When the water is filled in, the smiley is sad. And after some time, depending on the UV exposure, the smiley turns to like a happy smiley and then people know, okay, it's drinkable. So that's one tool, which I found very interesting and also seems to be quite cheap. But of course, here you need to have water, right? So, if you don't have water, it cannot be clarified or purified. The second tool I tackle is Watergen. Have you heard about that?

S: Yeah.

G: Perfect. As you may be aware, it's a device that generates water from scratch and it exists in various sizes. Starting from a very small portable generator up to very big machines that are installed somewhere. Of course you need an energy source, but it can either be with a generator or solar energy. This is crucial especially for very decentralized regions, where the infrastructure is barely existent or/and fragile.

Watergen can generate water in regions where water is a scarcity, this is a big advantage. The air is being sucked in, filtered and heated up. Then it is compressed and with the UV lamp purified. Voila, drinkable water is generated. Undoubtedly, it's more expensive than other purification tools. Two different solutions to different scenarios.

Also, when talking to a humanitarian organization, which operates in Yemen, it was said that both tools are smart and great. But the water generator is so expensive that unless someone funds it, it's not a viable solution right now for rural regions of Yemen. Currently, an example of what is being done in Yemen, is that holes are drilled into the ground, where water is pumped out of and stored in water tanks on hills. So, they don't need extra pumps because

they need one pump to pump the water out of the ground and from there, as the reservoir is located on a small hill, the water just naturally flows by gravity. Currently, a filter is placed on the pump water to filter the water.

S: I agree. It is true that Watergen is very expensive. But the category of air moisture capture is very interesting and has a lot of potential for delivering safe drinking water, essentially off grid.

G: I agree. Yeah.

S: There's a company by the name of Source, S-O-U-R-C-E. They're based in the U.S., and they have a hydro panel and it's truly off grid. You don't need to plug it in. You don't need solar panels. It has got a tiny solar panel that just runs a motor, and I believe each panel generates about four to five liters of safe drinking water per day. So, you can combine the panels in series and generate theoretically as much water as you want. It works in a very, very arid environment.

G: That's very interesting. I will conduct more research regarding this topic.

In order to give you a brief you a better understanding of the current situation in Yemen, I give you a short introduction. Due to the war a lot of people were displaced from cities to more rural parts were first of all, maybe there is no infrastructure, the infrastructure there has been destroyed, or they have just lived in really basic emergency camps. So, as you can imagine, the overall infrastructure is not the best there. Another issue that they have besides water scarcity, is that even if they have water, it might be contaminated. Also, due to climate change, more severe weather conditions increased. There have been a lot of droughts as well as a lot of floods. If there's a flood, yes, there is more water, but then also with more water comes more bacteria, so the water cannot be used. Also, sometimes communities have a well and people can get some the water pumped out of there, but no one knows if the water is contaminated. So, they started drinking, perform agricultural activities, wash themselves, etc. but the water is not safe to use.

This goes hand in hand with another big issue in Yemen: Cholera. So, even if people have water and they use it and then cholera breaks out, they don't have the medical infrastructure or resources to treat cholera. So, that's another issue, right? So, that's why I thought that first of all, water needs to be generated if it's not existent, or if it's existent, it needs to be monitored and analyzed to measure the water quality, to prevent or just decrease the diseases that can be categorized as waterborne diseases. Here, I thought AI and innovative technologies could come into place.

S: Yeah. So, yeah, I agree with all the issues that you've raised. And as I think about technology solutions, it is certainly generating water, unconventional water production. So, air moisture capture, for example, water reuse, the ability to treat the water that you have for other purposes, such as cooking, agriculture, etc. So, there are applications that can give communities an understanding of the quality of the water, the quantity of the water, etc. I don't know what smartphone adoption is in Yemen, but for example in Africa, mobile phones and smartphones are widely adopted, even though there's no infrastructure.

So, to the extent you can give data, provide data and actionable information to people in communities is also part of the puzzle. So, it's certainly providing safe drinking water, unconventional ways, air moisture capture, and treating water with modern technologies.

G: I definitely agree. When I conducted my first master thesis, I got a scholarship, and I went to India, and I worked with women in slums because I was researching how COVID influenced the work-life balance of informally working women in precarious households. And it was interesting because even in slums, most of those people had smartphones, or at least like in a community, a smartphone to share. According to the humanitarian organization in Yemen, sometimes people have phones which allow them to establish monitoring systems with AI or other innovative technologies but sometimes there is no connection/network, so having a smartphone does not help. So here, one can place sensors into water that is being generated from a well. It's not that expensive because usually the investment for a sensor is not that big.

The sensors are placed locally and then the generated data can be collected and analyzed with the aid of AI. AI works with a lot of data and the more data you feed the AI, the better it works, but then AI needs a lot of energy. So, I was talking to a technology AI specialist, and she recommended that with internet connection, the collected data could be transferred via a cloud to Europe, the United States or another location with a more stable environment, internet connection and somewhere where energy is not that big of a scarcity.

S: Yeah, that's a smart idea. So, for places like Yemen, it comes down to how you can deliver safe drinking water but also water for agriculture.

G: Exactly.

S: The livelihood and public health categories and off-grid water solutions like air moisture capture and other innovative treatment technologies; local treatment technologies. I mean it's unlikely that one is going to build centralized infrastructure in Yemen as people have in Europe or the United States, or other more developed/stable countries. So, the ability to determine water quality for in-home treatment, neighborhood treatment, and also using digital technologies for agriculture in terms of how much water you're using, how does that impact crop productivity or basically anything that'll take the risk out of production.

G: I think this is a good point you're mentioning because I spoke to an international humanitarian organization. The difference between them and international development organizations is that humanitarian organizations only interfere when there is urgent need. So, it's more or less short-term. And then you have the development, which is like long-term.

S: Right. I completely agree with you. I think it's shocking. It's really shocking.

G: People in my studies, international development, always say that it is so important to not only provide short-term help but also ensure long-term independence. Otherwise, they will always be dependent on you. And that's not an aim that should be achieved.

S: Right. I completely agree with you on that. I mean, if they flip things around and invest in appropriate infrastructure, then the communities would be more sustainable and more resilient. So, it would not constantly be this emergency response.

G: Exactly. Coming back to the crops, when you mentioned that they need water for agriculture and the water used is contaminated, then there are high chances that the end-product, that grows, also is contaminated.

S: Right.

G: For example, for vegetables. Here, it does not make sense to use water if it's contaminated. So, what I thought could present a viable as well as quite cheap solution illustrates the use of sensors. Combining the application of sensors with the implementation of an app that can

check water quality, access and so on would be great if doable. As an example, if one detects the water quality and identifies cholera before it breaks out, then you don't have to, first of all, treat the affected people because there is no outbreak and (inter-)national aid organizations can allocate resources where really needed. Also, it reduces unnecessary travelling costs of international aid projects. Oftentimes, when wells are created for water generation, the quality of water is not frequently checked. However, with the app and the use of the sensors, a proactive reaction can be set, when required. Compared to before, this would not only react to emergencies but actively act to prevent such crises. Here again, the application of AI might be helpful as before humans collected and analyzed data from sensors. AI is much faster than a human and therefore, enables the delivery of output much faster which then again allows aid initiatives to shift from reaction to action.

So, I think that's also something that could really help improve the critical situation in Yemen.

S: Right. Yeah, I agree with that. You know, this sort of gets also into satellite data acquisition and analytics. There are companies that measure surface water quality on a real time basis and use AI for forecasting. So yeah, I mean, that would also be a way to deliver data to a person's smartphone.

G: Exactly. During my research for this thesis, I have also come across the term smart sanitation systems. Have you heard about that?

S: No.

G: Okay. For example, when you take a shower, the water that is being rinsed off the body is analyzed. And based on this data one can determine the quality of the water or identify diseases. This also allows them to detect diseases before they break out. It's more expensive because you need the sanitation system and then the AI or innovative technology part. Also, according to the organization in Yemen, people just don't shower. They don't have showers. They just wash themselves with a bucket of water. And then, of course, I think it's a nice idea, but it's not viable in this environment right now. What do you think about it?

S: Oh, I think it's very clever. It gets into public health and personal health. It was really interesting talking to you, but unfortunately, I need to get on another Zoom call.

G: No, that's alright. Thanks for taking the time, though.

S: Yeah, I hope it's helpful. Please, send me the transcript and I'll take a look at it.

G: That would be very nice. And thanks again for the insights.

S: My pleasure. Good luck.

G: Thank you. Have a very nice day.

S: Thanks, you too. Take care.