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Strategies for Improving Irrigation Systems Based on Lamasba Regulation: A 2024 Field Study in Hoba Farms, Southeastern Algeria

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Abstract
In the Algerian province of El Oued, south-eastern Algeria, the irrigation system plays a vital role in supporting agricultural production, particularly in oil palm plantations, which have experienced significant expansion in recent decades. The development of irrigation techniques in the region dates back to antiquity, with the *Lamasba* system, discovered by Émile Masqueray in 1877 in the Belzma plain, being one of the most prominent examples of efficient water resource management. This ancient Roman system, which used precise schedules to distribute water from permanent sources, meticulously determined the quantities and times of water flow, reflecting a high level of social and economic organization at that time. During the French colonial period between 1957 and 1959, the Hoba area in the Righiba commune of El Oued province experienced a remarkable growth in oil palm plantations, with the implementation of advanced irrigation techniques, inspired by the ancient Roman system but modified to suit local conditions. As the project expanded, new challenges arose related to water distribution, particularly in fields far from water sources, leading to the construction of small, taller water towers to improve distribution efficiency. This study analyzes the current irrigation system in the Hoba region, focusing on the technical challenges these systems face, such as obsolete valves and the presence of weeds in the irrigation channels, which slow down the water flow and prolong the irrigation time. The study also examines the use of a new 5-meter-high tower that partially solved the problem of low water flow, while providing additional improvement suggestions to ensure the sustainability of agricultural production in these desert areas. The objective of this study is to offer a comprehensive vision on how to improve irrigation systems to meet the needs of modern agriculture and increase productivity in arid environments.
Keywords: Irrigation system. *Lamasba*, palm groves. El Oued province. irrigation technology. productivity improvement.

1. Introduction

The study of rural hydraulic systems in the ancient world provides a general understanding of the development and operation of these systems by gathering literary and archaeological data. Although a general understanding of principles cannot replace the detailed analysis of the social and technical functions of each system, detailed information about landowners, the technologies used, the size of land holdings, crops, and water allocation methods is essential for a comprehensive understanding of the systems. However, it remains difficult to obtain accurate data on individual irrigation systems in the arid region extending from Morocco to the Iranian highlands, except for some riverine civilizations such as those along the Nile and the Tigris and Euphrates rivers, which relied on permanent water streams. Among the rare discoveries that contributed to providing detailed information about these systems are the inscriptions discovered by Émile Masqueray in 1877 in the Belsam Plain in Algeria, where he found two stone slabs containing details of a large-scale irrigation decree during the reign of Emperor Elagabalus (218-222 AD). These inscriptions, found in Ain Merwane, provide details about the functional, social, and organizational structures of an ancient irrigation system. The original decree was inscribed on a large rectangular stone, of which four parts remain, outlining the organization of irrigation and water allocation for agricultural lands during the winter months. These parts reveal the organizational and social structures of irrigation systems, even though the remaining inscriptions represent only a small portion of the original document. Nonetheless, these remnants are sufficient to extract valuable information about how the entire system operated (Shaw, 1982).

From here, the prominent role of the historical development of Roman law and legislation becomes clear, forming the cornerstone in the construction of the legal system of the Roman state and significantly contributing to establishing an integrated legal framework aimed at achieving justice and maintaining social order. Through various mechanisms for developing the law, the Romans were able to build a flexible legal system adaptable to political, social, and economic transformations. This development included a set of laws and regulations that organized daily life, whether at the level of personal relationships or commercial and real estate activities, leading to the establishment of a solid legal structure based on principles of justice and fairness. In addition to regulating disputes between individuals, Roman legislation contributed to solidifying the concept of citizenship and individual rights, determining the role of public authority in society. It also created effective methods for resolving disputes through courts and legal procedures, helping to achieve stability and protect civil rights. This book, through its review of the historical developments of Roman law, reflects how these legislations deeply influenced modern law and shaped the legal structure of many contemporary judicial systems (Attia, 2023a).

Historical studies have recorded that in rural Roman areas, there were two main ways to obtain water: through community cooperation agreements and servitudes. Historical evidence indicates that communities in semi-arid and dry climates, such as North Africa, gathered to form agreements on how to share water sources, especially for irrigating agricultural lands. An example of this can be seen in *Lamasba* in Numidia (modern-day Algeria) between 212-218 AD, where multiple communities cooperated to establish a collective plan for distributing water according to a specific schedule across different farms. A council consisting of three members representing the governors of settlements and citizens oversaw the implementation of this program. Although this and other examples have been documented through inscriptions, there is a strong possibility that similar arrangements were made orally as simple agreements between different parties. This type of cooperation among rural communities appears to have been common and widespread throughout the Roman Empire, reflecting a relatively consistent pattern of social solutions to practical problems related to rural water supply (Rogers, 2018).

Academic studies have proven that there were laws governing irrigated agricultural areas and that the *Lex Rivi Hiberiensis*, one of these irrigation laws, helped prevent conflicts over water use and ensured the fair distribution of water among farmers. This was similar to the *Lamasba* law found in Africa. The *Lamasba* inscription in Numidia preserves details of the water distribution system from a spring called Aqua Claudiana in a relatively dry area. The inscription presents a solution to a dispute over water rights, based on time allocation (Malouta and Wilson, 2013). The use of water was supposed to be non-controversial, as water was considered public property with open access for all. However, the inscription reveals a dispute over the allocation of water for irrigation. When examining the irrigation decrees of *Lamasba* in Africa and the *Lex Rivi Hiberiensis* from Spain, it becomes clear that the control of natural resources, such as water, was managed under the authority of the law as an expression of Roman dominance. These laws reflect the Roman practice of relying on proportional distribution, where the typical legal arrangement for water distribution was a shared right (Propium Ius), and it involved dividing water among users in proportion to their land holdings (Ius Aquae Ducendae Pro Modo Agri Detenti). Both inscriptions address the same issue, a conflict between users of a shared canal, with the main difference between them being the type of water sources (a spring in *Lamasba* and the Ebro River in Spain). The similarities and differences between the two inscriptions highlight how water rights were understood and how Roman laws were interpreted, documenting legal settlements aimed at resolving disputes related to water allocation, reflecting the role of law in building the shared culture of the Roman Empire (Attia, 2023b; Vossing, 1998).

Another challenge faced by the laws was the availability of legal sources. A research study relies on studying Roman law based on the sources available to us, which represent only part of what was available in the past. This suggests that some legal sources considered local may have been applicable across the entire Roman Empire. For example, although the set of regulations for the irrigation community in Spain (*Lex Rivi Hiberiensis*) specifies its geographical area of application in the Ebro Valley, it may have been inspired by more general rules. Similarly, other sources, such as the Theodosian Code (438 AD), may be limited to general legal provisions without delving into more local rulings. This hypothesis is not far-fetched, especially given that Justinian's Code, adopted nearly a century later (534 AD), prohibits the use of local legal rulings and imperial constitutions not included in it in courts. In other words, the previous regulatory framework before Justinian was inadequately fragmented. Returning to the *Lex Rivi Hiberiensis* as an example, it may be tempting to say that the discovery of a local law shows that Roman water legislation did not follow a one-size-fits-all approach. Previous literature has argued for the existence of multiple specific laws at the expense of a harmonized Roman water law (Quintavalla, 2022).

According to clauses 1.6-8, decisions regarding the operation of the irrigation community should be made by the pagans in the assembly (i.e., the council, clauses 1.41, 50 ff.) based on majority votes and proportional to each member's right to water. This right was determined by the amount of land each person needed to irrigate, according to imperial provisions such as those issued by Antoninus Pius and Lucius Verus around 161 AD, in addition to documents addressing water distribution among farmers, such as the *Lamasba* inscription in 220 AD. Bruns Egon indicates that votes in the council were not equally weighted but were proportional to the aquae ius (water right), and thus the size of each participant's land holdings, which aligns with modern Spanish irrigation regulations, where the number of votes depends not only on the land area irrigated by each user but also on their contributions to taxes and labor. This system also seems to have been in place in the Rivi Hiberiensis irrigation community. In summary, the Pagan assembly, the primary body for deliberation and decision-making in the irrigation community, determined tasks and contributions based on majority voting, with this vote adapted to the size of each member's land holdings, reflecting a fair distribution of water and tasks according to the area of irrigated land (Beltrán Lloris, 2006).

After the Roman conquest of North Africa, Roman strategic objectives expanded beyond merely seizing fertile lands to include exploiting the interior regions near the desert. This expansion led to the displacement of local populations, giving the Romans the opportunity to establish a sophisticated irrigation network, enabling them to control water resources across the region. To achieve this, they built water reservoirs, diversion dams, and storage basins. Subsequently, irrigation canals were developed to distribute water across agricultural fields, with these systems being particularly prominent in the southeastern areas of the Aures (Algeria) near the desert. Remnants of these Roman engineering projects still exist in many provinces, demonstrating a wide variety of designs and methods used. As a result, Roman authorities enacted laws granting farmers and landowners the right to access water for their lands, affirming the public nature of this infrastructure created under Roman rule. This historical legacy continues to influence land use and water rights to this day Mansouri, F. (2023).

In 1984, a research study addressed several aspects of water management for irrigation in North Africa. This study provided a significant understanding of water management and exploitation in rural areas of Roman North Africa, but some of Shaw's conclusions need to be reconsidered, especially in light of archaeological evidence. Among the important questions that need to be addressed are: how water was exploited for agricultural production, who was responsible for that, and whether there was a conscious policy to develop Africa's agricultural capacity either by expanding existing hydraulic technology or introducing new water management techniques. The research tackles these issues by analyzing the archaeological evidence from the Kasserine survey, focusing particularly on data related to irrigation systems in both the highlands and lowlands. The research focuses on the late antiquity period and the transition from Roman to Vandal rule, tracing the continuity of land exploitation and irrigation technology. By combining archaeological evidence and ancient texts, including a private archive from the Vandal period known as the "Albertini Tablets," the investigation explores irrigation systems and the private use of water in light of Roman legislation (Leone, 2012).

This study aims to highlight the application of Roman irrigation law, specifically the *Lamasba* Rivi law, to a model farm in the region under examination. While existing literature offers a theoretical analysis of the development of Roman irrigation legislation and its rural applications, our research focuses on how this law practically influenced local water resource management. By analyzing a specific farm, we seek to provide insights into the effectiveness of ancient Roman laws in contemporary agricultural settings and their adaptation to current environmental and economic challenges. The study explores practical aspects of irrigation law in water distribution, resource management, and farmer dispute resolution, emphasizing the real-world implications of these regulations. Additionally, we assess how farmers utilized Roman legal principles to enhance water management strategies, increase agricultural productivity, and promote water sustainability. This analysis aims to deepen understanding of historical law applications in modern contexts, potentially offering new solutions to rural water management issues.

2. Methodologies

2.1. Roman Irrigation Laws of Lamasba (Lamasba)

Figure 1 depicts the famous inscriptions from *Lamasba* in Algeria discovered by Émile Masqueray in 1877 in the Belzma plain. These inscriptions date back to the reign of the Roman Emperor Elagabalus (218-222 AD) and consist of two stone tablets that detail an extensive irrigation decree. The table within the inscriptions provides precise data on the organization of irrigation using water from a perennial spring, specifying the landowner's name, the allocated amount of water, and the specific time of day for directing water flow to their land. These details reflect an advanced level of social and administrative organization for irrigation systems during that era, demonstrating how agricultural communities relied on permanent water streams to ensure equitable and efficient distribution of water resources. These inscriptions are among the rare archaeological finds that offer a clear understanding of the functional and organizational structure of ancient irrigation systems, showcasing how Roman communities in North Africa effectively managed natural resources, highlighting the technological advancements of that period in water management.

Figure 1 - Famous inscriptions from *Lamasba* (Algeria) (Shaw, 1982)

2.2. Operation Principle of Lamasba Irrigation

The *Lamasba* irrigation system operates from September 25 to November 17 for over 54 days (Boualam, 2022). characterized by a complex irrigation scheme that relies on a network of descending and ascending channels. The descending channels direct water with a natural slope, resulting in a rapid and powerful flow that reduces the time needed for irrigation, even if the irrigated areas are equal. In contrast, the ascending channels rely on water flow directed upward, leading to slower and less forceful flow, and thus the lands irrigated in this manner require more time for irrigation due to the lower flow rate, as shown in Figure 2. This system demonstrates a high adaptability to different geographical and hydrological conditions, with varying hourly water volumes between estates based on the type of channels used, ensuring equitable and efficient water distribution according to land needs and water availability. This precise water flow management highlights the system's flexibility and its importance in supporting sustainable agriculture during critical periods.

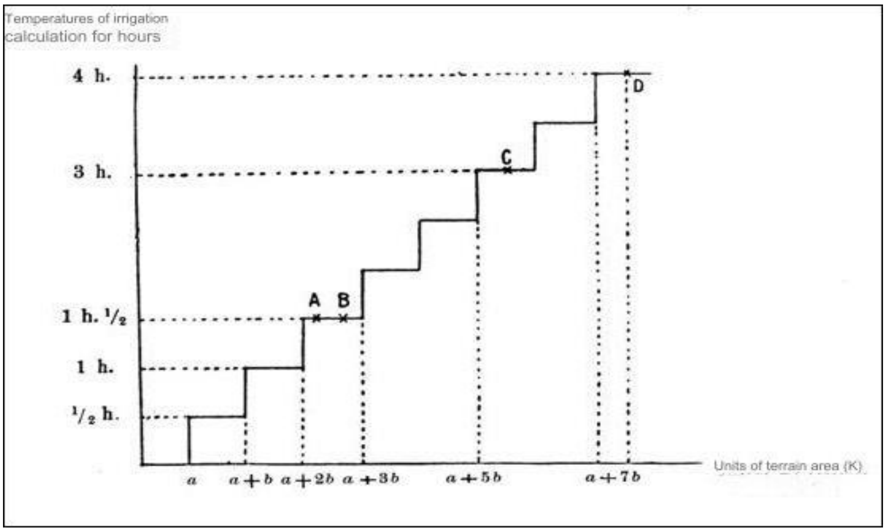

Figure 2 - Terrace irrigation diagram (Shaw, 1982)

3. Field Study of the *Lamasba* Legislation

3.1.Study Location

The Wilaya of El Oued is situated in the southeastern part of Algeria, with geographical coordinates ranging between 32.5 to 34.0 degrees north latitude and 5.5 to 7.5 degrees east longitude. It covers an area of approximately 44,585 square kilometers, with an average elevation of about 80 meters above sea level. It is bordered to the north by the Wilaya of Biskra, to the west by the Wilaya of Ouargla, to the east by Tunisia, and to the south by the Wilaya of Illizi, as shown in Figure 3. The region is characterized by sand dunes, deserts, and oases, and is known for its traditional agriculture in "ghoutan," depressions that protect date palm orchards. The climate is hot and arid desert, with hot summers and relatively mild winters. The economy of the Wilaya relies heavily on agriculture, particularly date palm cultivation such as the "Deglet Nour," as well as protected crops like tomatoes and potatoes. It features an irrigation system based on groundwater using the "Fouara" method and is connected to other Algerian cities by a national road network and an airport.

The region of Hoba, located within the municipality of Rgueiba in the Wilaya of El Oued, is renowned for its date palm farms, which are a key component of local agricultural activity. The area heavily relies on date palm cultivation, especially the "Deglet Nour" variety, which is among the best types of dates in Algeria. Agriculture in Hoba depends on traditional irrigation systems such as "fouaqir," which extract water from underground wells through subterranean channels, helping to conserve water in the arid desert climate. The date palm farms in Hoba support the local economy by producing high-quality dates and providing job opportunities for residents. Local efforts are also focused on improving irrigation systems and increasing productivity using modern agricultural techniques to enhance agricultural sustainability in the face of water scarcity challenges.

Figure 3 - Geographic Location of Date Palm Groves in Hoba, Wilaya of El Oued

3.2.Historical Overview of Date Palm Farms in the Hoba Area

Date palm farms in the Hoba region of the Municipality of Rgueiba, Wilaya of El Oued, have been established for many years, with local populations relying on date palm cultivation due to its suitability for the desert environment. Traditional techniques such as the "Fuqaqir" irrigation system, which involves extracting groundwater through shallow wells connected by underground channels, have helped sustain agriculture in this region. Local communities have played a significant role in preserving this agricultural system across generations by sharing agricultural knowledge and expertise, supporting the local economy, and providing food for the population. Over time, efforts have been made to modernize agricultural and irrigation systems using advanced techniques to improve water resource efficiency and increase date palm productivity, while preserving traditional methods that are part of the region's identity.

During the colonial period, specifically between 1957 and 1959, the Hoba area in the Municipality of Rgueiba, Wilaya of El Oued, saw significant expansion in date palm cultivation, with palm farms appearing in large and intensive numbers. This agricultural project evolved notably between 1960 and 1966, becoming economically and commercially significant. During this period, the irrigation system followed the ancient Roman *Lamasba* legislation, which was used in the Batna region, Algeria. Its application in Hoba was easier and more convenient due to the uniformity of the farms in terms of area and number of palms, leading to nearly equal water distribution and greatly facilitating the irrigation process. As the project expanded, new farms emerged further from the original water sources, prompting officials to adapt to this expansion by developing solutions to provide water to the distant farms, such as extending irrigation channels and improving water resource management to ensure project sustainability and meet the needs of ongoing agricultural expansion.

3.3.. Irrigation Systems in Hoba Farms, El Oued

Figure 4 illustrates the irrigation system in the date palm groves of the Hoba area, Wilaya of El Oued, Algeria, showing the water path from the main well to the fields. The system begins with massive electric pump lifting water from the well to a large main water tower. From this tower, water is distributed to smaller water towers through a network of channels. The figure displays one of these channels, where water flows to a small tower 3 meters high, then exits through a long main channel extending across several fields, starting from Field 1, passing through Field 2, and reaching Field 18, the final field.

Each field is equipped with a central water valve controlling the flow of water into the field. Irrigation starts with Field 1, which typically takes about four hours, with the valve opened to allow water flow. Upon completion, the valve is closed to direct water to the next field, and this sequence continues from one field to the next until reaching Field 18. This system provides precise control over water distribution, ensuring each field receives the required amount of water, reflecting high efficiency in water resource management and meeting agricultural needs in the area.

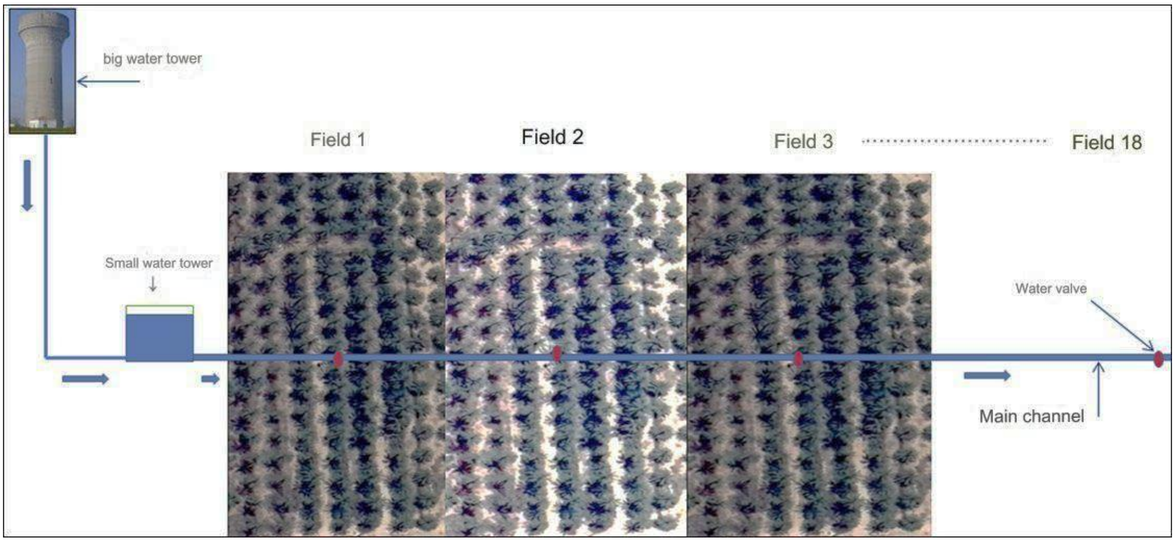

Figure 4. Irrigation System in Date Palm Farms in Hoba, El Oued

3.4.Water Distribution from the Small Tower to the Last Field

Figure 5 illustrates the distribution of water flow quantities through the fields served by the main channel extending from the small water tower. According to hydraulic principles, as the water level in the tower increases, the pressure at the bottom also increases, resulting in higher water exit speed and, consequently, increased flow. However, the water flow decreases gradually as the distance from the small tower increases until it reaches a point where water movement ceases in the channel. This point is where the red line touches the level ground, which is at the same level as the water outlet from the tower, leading to flow cessation due to equalized pressure at zero.

At the project's inception, this issue was considered, and fields close to the small water tower were designed with slightly higher elevations compared to the more distant fields. This elevation gradient allowed Field 18 to receive water smoothly without any issues. In the diagram, water flow is represented by the black arrow between the red line and the valves. The arrow extends along the channel to the last field, indicating continuous water flow. If the ground were at the same level as the water outlet from the tower, flow would have stopped at Field 18. This slight elevation gradient in the design provided a cost-effective and efficient solution to the problem.

As the project expanded and the number of fields increased annually, the length of the main channel also grew, prompting field owners to seek an alternative solution to avoid the flow cessation point. The solution involved increasing the water level by constructing smaller water towers with greater heights of up to 5 meters, thereby extending the flow cessation point and allowing the addition of new fields. The diagram shows the blue line extending from the top of the new 5-meter-high water tower, highlighting the difference between it and the valves indicated by the red arrow, where there is a significant difference in flow compared to the green and black arrows. At Field 18, the flow represented by the red arrow surpasses that of the black arrow, while the flow represented by the green arrow is negligible. The increased flow is attributed to the height of the new tower, enabling the addition of new fields and improving the efficiency of the irrigation system.

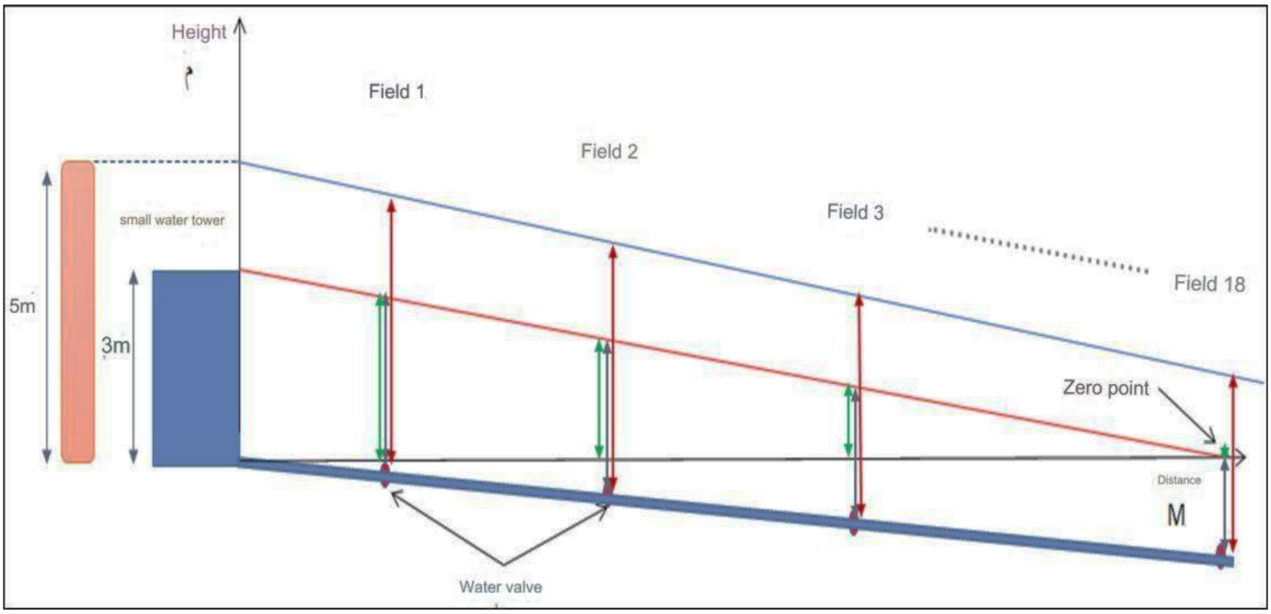

Figure 5 - Distribution of Flow Quantity Across Fields

3.5.Challenges in the Irrigation System

Figure 6 illustrates a range of challenges faced by the irrigation system in the date palm farms in Hoba. A significant issue is the aging valves, which have not been replaced over time, leading to incomplete closure and water leakage, thus reducing irrigation efficiency. Additionally, the farm experiences problems with irrigation channels where weeds and plants accumulate, obstructing smooth water flow. For example, Field 1 shows a channel filled with weeds, which slows water delivery and increases irrigation duration. In contrast, Fields 2 and 3 have clean channels, allowing for easier and smoother water flow.

This issue poses a major obstacle affecting all fields, resulting in longer and delayed irrigation. To improve the situation, a new 5-meter-high water tower was introduced, replacing the old 3-meter-high tower. This upgrade somewhat alleviated the problem by increasing water pressure and flow, helping water pass through channels clogged with weeds, as shown in Figure 6. However, cleaning the channels remains the biggest challenge impacting irrigation efficiency, along with the outdated water channels that no longer meet the system's needs effectively. Therefore, continuous improvements are required in the irrigation system to ensure more effective water flow and significantly reduce irrigation duration.

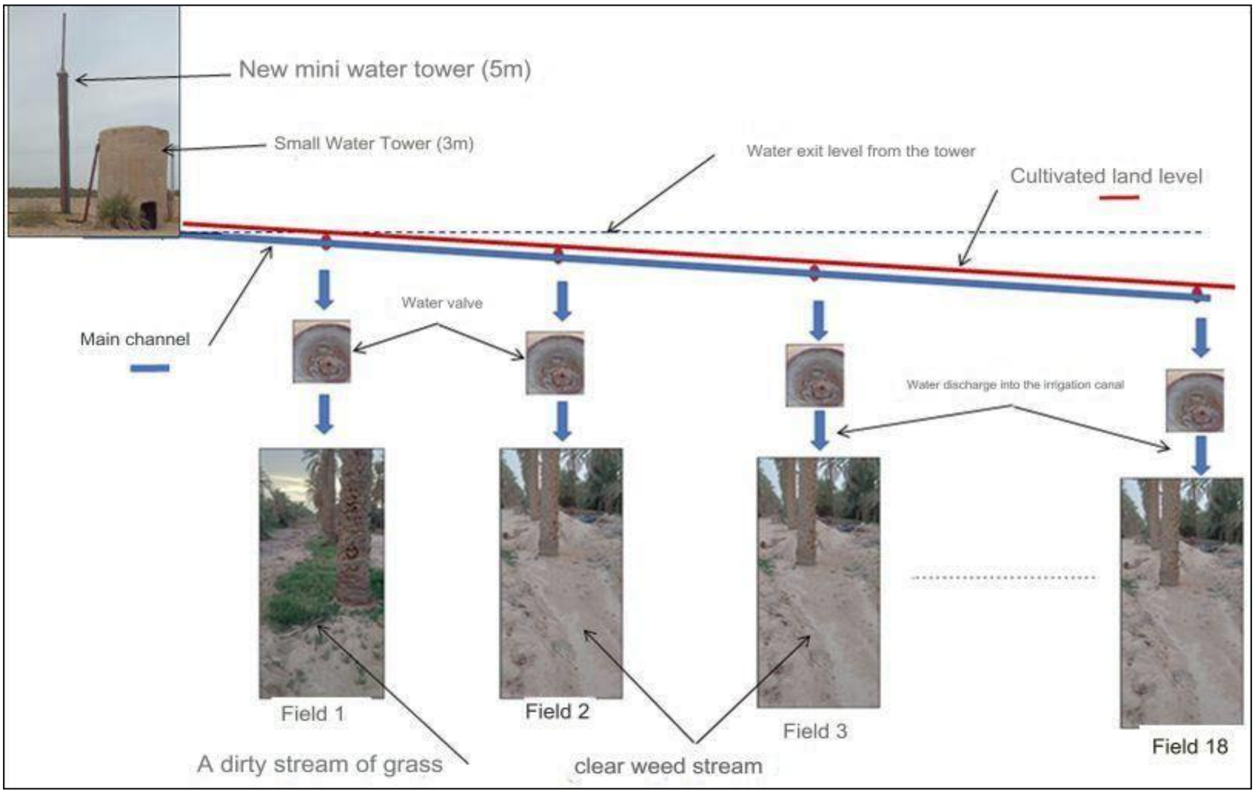

Figure 6 - Distribution of Flow Rates Across the Fields

Conclusion

The date palm farms in the Hoba area face several technical issues with their irrigation system, which is inspired by the historical *Lamasba* system. One of the main challenges is the old valves, which have not been replaced and thus fail to ensure complete closure, leading to water leakage. Additionally, accumulated weeds in the irrigation channels obstruct smooth water flow, increasing the irrigation time required for each field. This is particularly evident in Field 1, where the accumulation affects the speed and efficiency of water flow.

To address these challenges, new water towers with heights up to 5 meters have been introduced, replacing the old 3-meter towers. This upgrade has enhanced water pressure and partially alleviated the issue of prolonged irrigation times. However, problems with channel cleaning and valve updating remain significant challenges affecting system efficiency. The need for innovative and cost-effective solutions highlights the necessity to adapt the irrigation system to the ongoing agricultural expansion.

Through analysis and study of the current system, this research aims to offer practical technical solutions, inspired by the historical *Lamasba* system but adapted to the current reality of date palm farms in Hoba. This will contribute to improving water resource sustainability, increasing agricultural productivity, and supporting sustainable development in the region. The research represents an important step toward enhancing and evolving traditional irrigation systems to meet modern challenges in arid environments.

Modern technologies such as solar energy and smart valves are expected to significantly improve the irrigation system in the date palm farms. These technologies will address many current issues, including reducing irrigation hours that require farmers to stay late into the night to manually switch valves. Remote-controlled electronic valves will save time and effort, while solar panels will help reduce electricity costs. Integrating this technology will greatly enhance irrigation efficiency and ease the burden on farmers, contributing to improved productivity and sustainability in the future.

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