Evolution of Irrigation System, Tools and Technologies

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1 Introduction

Irrigation has played a major role in the development of ancient civilization. Despite the immense advance of civilization in the last few thousand years, irrigation practice has remained virtually at a standstill. It is astonishing that many current irrigation practices are almost identical to those used in ancient times. Egypt has large arid and semi-arid areas; ancient Egypt has some knowledge of irrigation practices. Today, Egypt has high techniques in modern irrigation methods.

The main objective of this chapter is to give vision around history of growth irrigation in Egypt, water lift techniques in ancient Egypt and some knowledge of a Nile River and its constructions.

2 Stages of Development

The use of Nile water for irrigation purposes is old in Egypt, where life has developed. Irrigation arts themselves have developed with the passage of ages and the wide circle of science and knowledge. They have used scientific methods to control, tame and restrain the Nile River and exploit its maximum resources to the limit [1].

The history of irrigation in Egypt can be divided into several stages. These stages are as follows [2]:

1. Pre-history.
2. Post-history in its extension until the early nineteenth century.

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3. Nineteenth-century stage.
4. The first half of the twentieth century.
5. The continuous storage of Nile water.

2.1 Pre-history

We can imagine the land of Egypt in the eras of history. It was in the form of desert barren, surrounded by a Nile River toward the outlet in the sea (Delta land). The Nile River was carry with flooding huge amounts of sand and silt, sinking to Upper Egypt until the desert hills on both sides. The flooding dumped the remaining sand and silt at its outlet in the sea, a component of Delta with the centuries. It is likely that the first population of Egypt had settled in Upper Egypt before the Delta, because Upper Egypt is characterized by the adjacent hills and the population were fleeing from the edge of the desert during the flood and then descended into the plains after its became dry and plants were appeared.

In the Delta regions, the Nile River was ravaged by a swarm of water, and it had many branches, wide wagons and lagoon (lakes). The Nile River swept most of the Delta lands in flood every year, leaving behind vast stretches of marshes, which are not as populated as it was in Upper Egypt.

The Egyptians knew how to cultivate the land. They threw their seeds into the wet soil after exposure, harvested the crops after their maturity and then ran to the edge of the desert before being overwhelmed by the flood.

This system of origin and instinct was the origin of the idea that was later inspired by the pharaohs when they laid the rules of basin irrigated irrigation on a sound engineering basis [2].

2.2 Post-history Stage

The kings of the pharaohs learned that the agricultural lands that extend in Upper Egypt descend slightly from the south to the north. Another slope descends between the banks of the Nile River and the desert on both sides. King Mina established the first of its kings a bridge on the left bank of the Nile River along its length, to prevent water from tyranny on this bank, and leave the right bank without modification.

Mina then proceeded to divide the canals through the high beaches to deliver the floodwaters to the lands far from the Nile River's bed. He also created vertical bridges on the Nile River's shore that extended up to the Libyan hills to hold the water in the basin and prevented it from flowing north. The ponds are natural and industrial and have enough time to sink the silt they carry.

When the kings of the Twelfth Dynasty ascended the throne of Egypt, they completed the right bridge, but they alerted to the imprisonment of the Nile River between

two high bridges might be destroy by the water of river during high floods. So that, they connected the Nile course to Faiyum depression, which was known as "Morris Lake" to descend the excess flood water in the Faiyum depression then return again to the river when the level water of the river was drop. This was the first human knowledge of storage projects.

The steps were followed by the consolidation of the basins irrigation that prevailed throughout the country until the early nineteenth century. The land was divided into a basin bordered by the Nile River on one side and the desert on the other. Also, the vertical bridges were built on the Nile to separate the basin from the other, and separated the high lands from the low bridges which are parallel to the Nile River. Then, the basins had divided into chains and the various canals which had different lengths, widths and levels and erected bridges and estuaries [1, 2].

2.3 Nineteenth-Century Stage

The nineteenth century was a major change in the history of Egyptian irrigation, which can be attributed to two main factors:

- Start the application of the permanent irrigation system;
- discovering the sources, determining the features of its basin and starting a hydrological study of the Nile River.

The system of permanent irrigation was the result of the desire to cultivate cotton, cane, fruit and some other summer crops, which are grown in the season of need.

The beginning of this system has not been easy without devising a method whereby these crops can be irrigated, especially during the months of the fall of the Nile River (February–July), and the decline of the species is significantly lower than that of cultivated land.

The application of this system began first with expensive means, which combined the two systems in the Delta provinces and based on the completion of the Nile River bridges in the Delta. The basis of the construction of multiple bridges on these canals is to raise the water in front of them to the extent that the expenses of raising the pellets to the cultivated land were low. The Delta lands under this system were considered to grow grain and alfalfa after the drainage of water that had been flooded during the flood [2].

In August, the canals were cut down to irrigate the lower parts of the soil. The highlands continued to be irrigated, and the corn was grown. Seventy days later, all the canals were completely filled with water on the drying land.

The depth of the excavation was no less than five meters in this period, and these strenuous processes were followed by unpaid workers called "Anfar al-Awna". The method taken in the early 1900s to circumvent the permanent irrigation system by combining it with the basin irrigation system was complex and overbearing.

Finally, thinking of building a large bridge (barrage) at the head of the Delta helps to raise the level of the Nile River as it descends, so that its water flows into the main

wind canals without having to be deepened, and the water flows high in the branch canal fed by these main canals [2].

It was started in 1843 and named after Al-Qanatir Al-Khairiya Society (Fig. 1). It was accompanied by the construction of three main canal branches (Monofy, Tawfiqy and Behery) that take water in front of it.

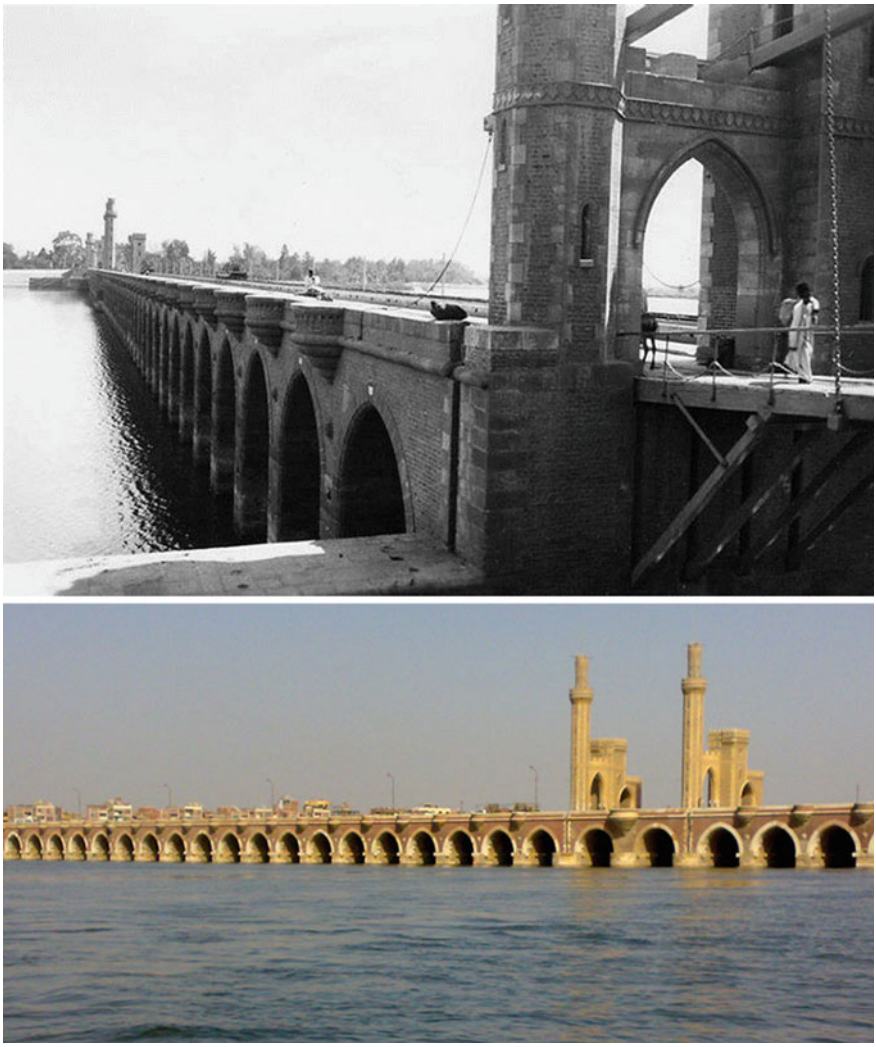

Fig. 1 Al-Qanatir Al-Khairiya in Qalyubia Governorate, Egypt. It is the location of the Delta barrages, the first modern irrigation structure across the Nile, located at the apex of the Nile Delta (https://en.wikipedia.org/wiki/El_Qanater_El_Khayreya)

Al-Qanatir Al-Khairiya was built in 1861, but its weak structure did not enable the officials to raise the water level to the required degree until it was strengthened at the end of the last century.

In 1873 the excavation of the Ibrahimiya canal, which takes water from the Nile River at Assiut and branched at Dirout after 61 km, was started in four branches: the Sea of Yusef, Dirutia, Ibrahimeya and Sahli.

The permanent irrigation system in Upper Egypt and in Middle Egypt was firmly established at the beginning of the twentieth century when it was supported by the major irrigation projects that have been implemented since then.

The past century has witnessed a great deal of effort by the pioneers and explorers until the features of the Nile River and its upper tributaries have become clear. The study of the Nile River and its basin has begun the study of the water sources, the monitoring of its movements and changes and the thinking of the projects of exploiting the Nile River's water [1].

2.4 The First Half of the Twentieth-Century Stage

At the end of the nineteenth century, when the need to expand the cultivation of the cotton crop by increasing the area under the permanent irrigation system, two major problems were risen as:

- The scarcity of water in the season of need (February–July) and the inability to meet the needs of summer crops.
- Lower levels of the Nile River in this season than the level of the cultivated land.

The scarcity of water in the Nile River's fall season has been overcome by storing part of the floodwater each year in low-capacity reservoirs and gradually releasing stored water in the season of the need to boost the Nile River's revenue to help meet the agricultural demands of summer crops.

The Aswan Dam was built in 1902 and its height was raised twice, the first in 1912 and the second in 1933. Jabal al-Awliya Dam was structured on the White Nile in 1937, bringing the total amount of water stored annually to about 7.5 billion cubic meters or about half the average revenue of the Nile River in the season of need.

It was also possible to overcome the problem of low levels of Nile in the season of the need to proceed in the structure of a group of major bridges on the Nile River at Esna and Nag Hammadi, Assiut, Zifta and Edvina, as well as the structure of the Delta bridge, which replaced Al-Qanatir Al-Khairiya.

In addition to these major projects, this period of Egyptian irrigation history is characterized by scientific research and extensive studies in irrigation affairs, especially concerning water measurement, fair distribution, river hydrology and the full utilization of its water. Egyptian irrigation has a good place and reputation around the world [2].

2.5 Stage of Continuous Storage of Nile Water

When the revolution in July 1952 and the government reviewed the water situation to increase the agricultural land for the development of national production, it found that the storage of the Aswan and Jabal al-Awliya tanks had been exhausted by the previous projects. Therefore, efforts were directed to study the High Dam project to store the floodwater, once in 1946. Once the validity of the project has been established, it has embarked on its implementation to achieve its enormous advantages.

However, the government did not want to stand idly by until the High Dam reaches its desired fruit, prompting the implementation of a range of urgent projects with the aim of raising some additional water resources to push the reclamation.

At the head of these projects was the use of drainage water for irrigation purposes after mixing it with the water of the canals and the depletion of underground water in the Egyptian soil inside the valley and in the desert.

As well as the development of a new policy for the implementation of public drainage projects and field drainage covered to achieve the expansion of agriculture vertically increases the yield of cultivated land and maintains the fertility of the land.

The implementation of the High Dam project is considered as the first step in the continuous storage of Nile water. Similar projects are being studied for continuous storage of the Nile River's water in the tropical lakes and Lake Tana [2].

2.6 Basins Irrigation System in Egypt

The basins system of irrigation was the prevailing system in Egypt until the beginning of the nineteenth century. Gradually, this system was reduced to the transformation of the system of permanent irrigation. The effects of the High Dam project have ended on the final regime that has existed for centuries since the dawn of history [3].

The cultivated land in Egypt until the early nineteenth century was entirely dependent on the Nile River's income in the flood season. If the flood is high and its water is high, it controls the Nile River in the ponds and submerges it, and then, the farmers start to sow their seeds in the land. After a few months, they harvested their winter crops. Under this system, the land used to produce only one crop every year except the basins whose owners supplied them with artesian wells to irrigate summer crops during the river's low water season [2, 3].

If the income is low, the country will be affected by disasters and drought, although this situation was dealt with in the twentieth century by erecting the Nile River bridges to raise the flood levels to the extent that helps feed the basins. In 1933, the Ministry of Works (currently the Ministry of Irrigation) developed a water policy that sets agricultural expansion programs within 20 years, not later than the water stored in the Aswan reservoir and the Jabal al-Awliya reservoir. This water policy included the conversion of about 524,500 feddan in Upper Egypt to permanent irrigation. However, the country was surprised by two dangerous floods in 1934 and 1938,

which reminded the need to turn away from the idea of conversion, considering the pelvic ground security valve for high flooding, reducing the climax of the pressure on the Nile River bridges in central Egypt.

It was possible to reconcile the high flood fears and the demands of agricultural development with the introduction of a new system of double irrigation by supplying the pelagic waters with the storage water to irrigate the summer crops and then prepare them to receive the flooding when the flood comes. This system was applied in an area of 114,200 feddan (1 feddan = 4200 m^2) [2, 3].

When the Second World War began in 1939, the need for grain was increased, and a similar system called cereal irrigation system was applied in an area of 257,500 feddan leaving about 590,800 feddan in Upper Egypt, except for the 11,000 feddan.

Since it is expected that the reservoir of the High Dam will only be able to meet the actual needs of the crops, the flood phenomenon on which the irrigation system is dependent will disappear, and therefore, all the migration should be transformed into a permanent irrigation system, which was implemented since 1959/1960 [2].

3 Ancient Egyptian Irrigation Tools

3.1 Shadoof

A *shadoof* or spelled *shaduf* is an irrigation tool. It is also called a counterpoise lift, well pole and well sweep. It is a hand-operated device for lifting water invented in ancient times and still used in Egypt, India and some other [3]. The *shadoof* was an early tool used in irrigation by the ancient Egyptians who lived around the Nile River. The *shadoof* was used to lift water from a river or lake onto land or into another river or lake. It is a long arm or pole with a bucket attached to the end of it [4–6].

3.1.1 Construction

The *shadoof* consists of a long, horizontal pole mounted like a seesaw. A bucket is hung on a rope from the long end, and a counterweight (a large rock) is hung on the short end [3] (Fig. 2).

The *shadoof* consists of a long, horizontal pole mounted like a seesaw. A bucket is hung on a rope from the long end, and a counterweight (a large rock) is hung on the short end. The operator pulls down the rope attached to the long end to fill the bucket with water and allows the counterweight to raise the bucket. To raise water to higher levels, a series of shadoofs are sometimes mounted one above the other [3]. At the end of each movement, the water is emptied out into runnels which convey the water along irrigation ditches in the required direction.

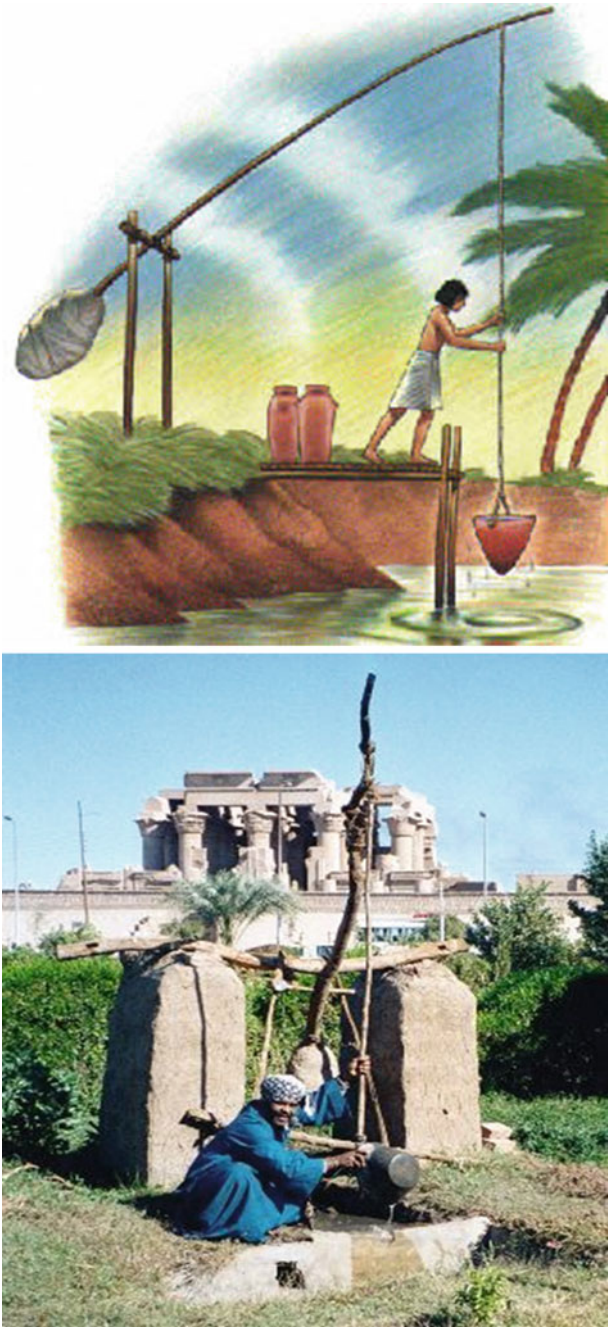

Fig. 2 Egyptian *Shadoof*, an early tool used in irrigation by the ancient Egyptians who lived along the Nile River. http://www.waterhistory.org/histories/nile/shaduf.jpg

3.2 Tanbour

The Archimede's screw also called the Archimedean screw or screw pump is "a machine historically used for transferring water from a low-lying body of water into irrigation ditches. Water is pumped by turning a screw-shaped surface inside a pipe" (Fig. 3) [7], http://windermeresun.com/2017/02/22/archimedes-screw-at-disney-springs-fl/.

3.2.1 Construction

It consists of a piece of wood in the form of a screw surrounded by a nestled disk. The lower part of the *tanbour* is placed in the water and rotated, causing the water to rise to higher levels, and today farmers still use it in times of low water levels [3].

The introduction of the *Saqia* was apparently during Ptolemaic times in the second century BCE, but the actual origin of *Saqia* is debated, with many saying that it was a Persian invention. This device was originally built from wood. The device consists of a large cogged wheel placed horizontally on a vertical shaft to which one or two of the animals are yoked. A series of clay jars (*qadus*) is attached to a vertical wooden wheel. Such jars were found extensively in the mains of Kulubnarti. The oxen then rotate the vertical beam, sending each of the clay jars into the water to be filled. The water is then emptied into a trough that carries the water by furrows into the cultivated field [8].

The functions of water wheels were water lifting for irrigation purposes and as a power source. When used for water lifting, power can be supplied by human or animal force or by the water current itself.

*3.3 Water Wheel (*Saqia*)*

3.3.1 Hydraulic Noria (*Naura*/*Saqia*)

A hydraulic noria (*Naura*) is a machine activated by water power and used for lifting water into a small aqueduct, either for irrigation or for the use in towns and villages.

According to John Peter Oleson, both the compartmented wheel and the hydraulic noria (Fig. 4) appeared in ancient Egypt by the fourth century BCE, with the *Saqia* being invented there a century later.

Also, there were other types of water wheels in Egypt. One of these types is called a *Nubian wheel*. It is a vertical wheel bearing a number of pottery vessels. When the wheel spins in the water, the pottery vessels are filled with water and then poured into the basin to be irrigated (Fig. 5). This wheel is connected to another wheel parallel to it and has wooden gears clipped in the wheels of another horizontal wheel. Connect

Fig. 3 Archimedean screw (screw pump) in ancient Egypt. It is a machine used for transferring water from a low-lying body of water into irrigation ditches. http://hesed.info/blog/simple-water-pump-diagram.abp

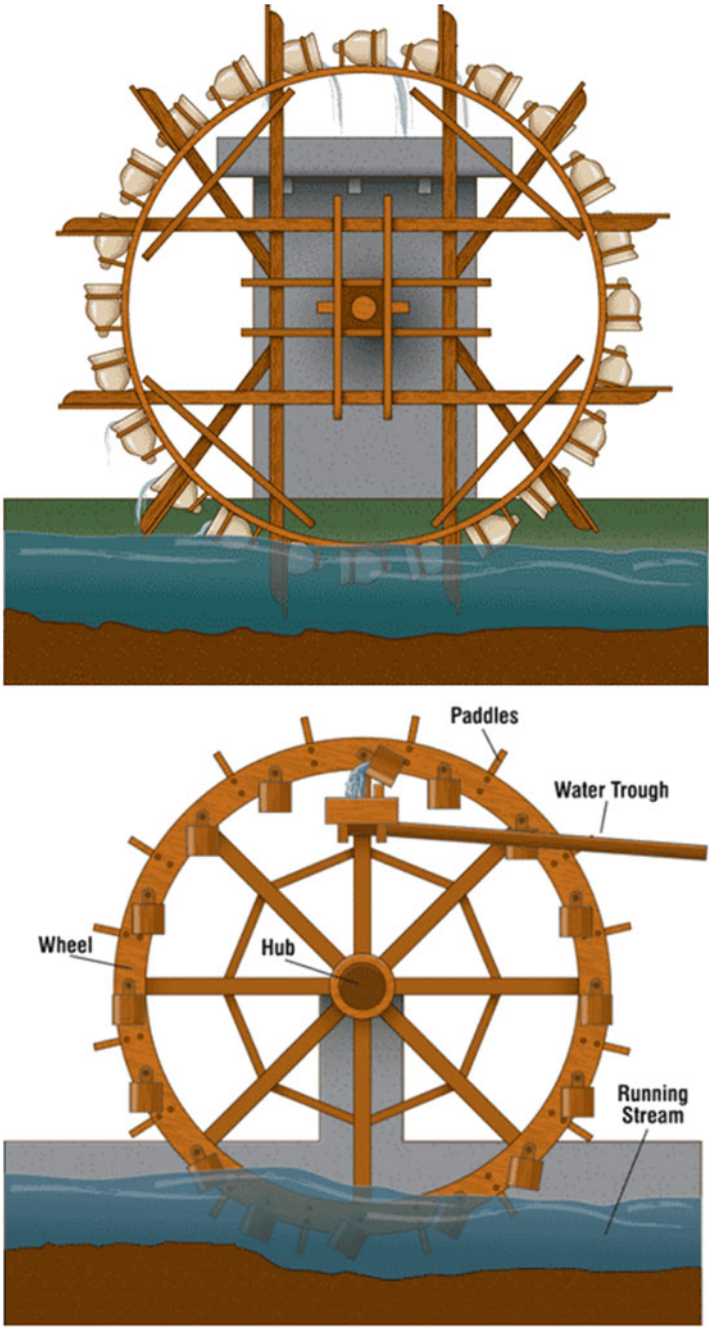

Fig. 4 Hydraulic noria (*Naura*) in ancient Egypt. http://asterion.almadark.com/wp-content/uploads/2008/12/noria2.thumbnail.gif

Fig. 5 Nubian wheel in ancient Egypt

the cow or buffalo or the camel in a connected arm, and when the animal revolves around the last axis of the wheel, the stem rotates accordingly.

In Faiyum, where water is increasing in some locations, drivers are driving with the water push, called the drivers of the roar. Some drivers are still in the heart of Faiyum (Fig. 6).

4 Irrigation in Egypt Today

In Egypt, food production is fully dependent on High Dam in Aswan that stores water for irrigation of the Nile valley and some of the adjoining desert and guarantees food supply to the population [9]. After the construction of the High Dam in Aswan, irrigation systems in Egypt have developed.

In Egypt, based on the method of applying water to the land, there are four categories of irrigation systems: (1) surface irrigation systems, (2) sprinkler irrigation systems, (3) localized (or trickle) irrigation systems and (4) sub-surface irrigation systems.

The sprinkler systems back to date 1800s in USA, major advances in sprinkler irrigation systems came with the introduction of wheel lines and center pivot. In 1960s, the semi-portable sprinkler irrigation systems were expanded in Egypt as a large project in reclamation lands. Also, set-move and hand-move were expanded. Today, the center pivot expansion on large-scale is at special form.

To improve the use of water in agriculture, farmers and irrigation professionals thought of two main points: (1) the water application directly to the root zone; (2) reducing evaporation from the soil surface by using the sub-surface water application as clay gar (or clay pot). These technologies were used by the ancient Egypt farmers [10]. In 1975, the first experiments on modern trickle irrigation by El-Awady were made, and after this time, the trickle irrigation with its different types was applied and expanded in reclamation lands [11].

Fig. 6 Al-Hader wheels (Sawaqi Al-Hader) in Faiyum Governorate, Egypt

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