# Ancient science and irrigation systems in Sri Lanka

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## Origin of science in the world

Scientific thinking probably evolved parallel to the development of language over the past two million years as the human brain, growing in size and complexity, conferred a selective advantage to the hunter-gatherer ancestors of humans. During the New Stone Age (18,000 to 5000 BC), the invention of agriculture and animal husbandry marked the beginning of human civilization as well as the emergence and rapid development of mathematics and technology. However, it was the invention of writing about five thousand years ago that provided the means to store a permanent body of knowledge.

The written knowledge is an absolute prerequisite to the development of science. A culture with stored knowledge may have records of tangible causes and effects to explain nature, the essence of proto-science, whereas nonliterate societies tend to rely on supernatural explanations. However, the simple knowledge of cause and effect is not sufficient to transform supernaturalism into science. What is required is, to demonstrate that the controlled effects can be produced by manipulating their causes. Then the explanations move from the realm of religion to the realm of science. As more facts become scientifically known and the law of controlled causation covers more cases, the need to seek supernatural interpretations shrinks proportionately.

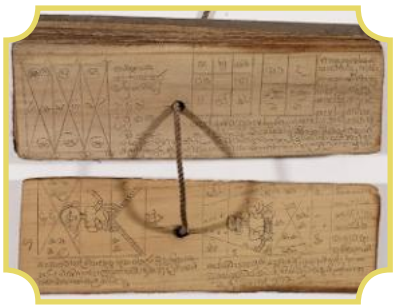
The transformation of primitive humans from Neolithic hunter-gatherers to urban dwellers occurred in three primary locales in the West *viz*., Mesopotamia, Egypt, and the Indus Valley. An important trait of this revolution was the creation of mathematics (arithmetic and geometry) and proto-astronomy as well as the complete absence of natural science. Geometry, as its name (literally "earth measure") indicates, originated with land measurements. Astronomy began with observations of the stars in order to determine the optimum time for planting and harvesting, but an obsession with predicting the future convoluted astronomy into astrology.

Arithmetic, geometry, and proto-astronomy evolved in the earliest cities because they were essential to the development of the urban revolution itself. Arithmetic was essential to keep the inventories and account books of the merchants and traders, under the guardianship of the priests who ruled the cities. Geometry was required by architects and engineers for the construction of the monumental structures that characterized these civilizations. Astronomical observation was indispensable to the development of an accurate calendar for agriculture, due to the reason that without sufficient food, the growing city-states would have collapsed. These sciences, which conformed to the prevailing belief system of officially sanctified superstition, provided the infrastructure necessary to support the urban revolution. City

residents willingly submitted to the priests who maintained power by their monopoly on astronomical and mathematical knowledge. Performing simple arithmetic was an act of religious ritual, and geometrical diagrams appeared as mysterious hieroglyphics decipherable only by the priests. As long as astronomy remained embedded in religion and was the sole domain of priests, it could never progress from the realm of embryonic protoscience to a natural science based on objective rational inquiry.

### Numeral systems used in Sri Lanka

The base for ancient science can be traced from the archaeological evidence, remains of physical structures, and written records from ancient palm-leaf manuscripts. In Sri Lanka several numeral systems have been used for ancient science such as *Sinhala Illakkam* (Sinhala Number), *Lith Illakkam* (Lith Number), *Pansal Hodiya* (School Alphabet) etc. Buddhist monasteries and temples have been the custodians of numerous ancient manuscripts including literature on spirituality, rituals, history, culture, medicine, and folklore of Sri Lanka. These manuscripts were available in palm leaf bundles, where various numeral systems have been recorded corresponding to changing governance in the island. The numeral systems reflected the linguistic and sociocultural transformation of the region. The *Sinhala Illakkam* was said to be the oldest numeral system found in the palm leaf writings during 1754-1825 AD. It was specifically used for Pali and literary contents. The *Lith Illakkam* was next to *Sinhala Illakkam* and was used for astrological and native medicinal content in the palm-leaf manuscripts.



The most prominent numeral system was *Pansal Hodiya*, which was later replaced by the Indo-Arabic numeral system, which took place gradually since the 16th century.

### Language development

In Sri Lanka, it is believed that the writing and numbering systems had developed concurrently during the Anuradhapura period. Ancient records, including the Pali chronicles like the *Mahavamsa* (Great Chronicle) and the *Dipavamsa* (History of the Island), suggest that both spoken and written languages were established as early as the 5th century BCE, following the arrival of Prince Vijaya from India. Historical evidence indicates that the Sinhalese people began using the plant leaves as writing material around this time. The evolution of these practices was significantly influenced by Venerable Mahinda Thero, who introduced the Brāhmi script to Sri Lanka and further promoted the literacy and the spread of Buddhist teachings. The first documented use of the palm leaf as a writing medium in Sri Lanka occurred in the 1st century BCE. Five hundred monks undertook the monumental task of inscribing the Tripitaka (Buddha's teachings) in Pali on Talipot palm (*Corypha umbraculifera*) leaves at Aloka Viharaya (*Aluvihare*), Matale. In such a voluminous literary task, it is necessary to have the numbering and indexing systems that would ensure sequence and connection among those palm leaf manuscripts.



### Watershed-based governance

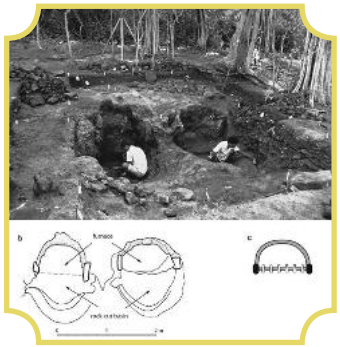
On top of all, it is curious that the ancient Sri Lankans divided the country into 10 administrative divisions namely Rakungiri, Upulwangiri, Kawasthalabha, Neelagiri, Kewesastha, Chalaka, Dhumaka Kaddeera, Mahagiri, Agni, and Indra. The Sanskrit word giri means the mountain. History of inhabiting these mountains dates back to pre and pro to historic times. When these 10 ancient administrative locations are placed on a watershed map of Sri Lanka, all these points are found on the uppermost rocks of river basins in the country.

### Iron technology in ancient Sri Lanka

In 1847, the British rulers observed that iron ore occurred in large deposits and veins in Sri Lanka. Recently an additional iron ore deposit has been discovered in Buttala in the Monaragala District, closer to the litho-tectonic boundary between Highland Complex (HC) and Vijayan Complex (VC).

British rulers mentioned that the quality is singularly fine, and it is easily smelted and very pure when reduced as to resemble silver. Converted to steel, it cuts like diamond. Samples that were sent to London had 68.7% and 79.5% of ferric oxide, which were equivalent to 48% and 55% of metallic iron.

The iron industry in Sri Lanka dates back from about the 2nd century BC. This is, particularly, an early period for iron production of this scale and quality. The iron smelting 'factories' found at Sigiriya indicated the industrial level production for use beyond the Sigiriya-Dambulla region. From the remains of the techno-cultural activities within the settlements unearthed from the excavations



at the Ibbankatuwa cist burial site, which belonged to the settlers of the ancient megalithic tradition, a clear picture emerges of their iron using agro-economic culture and well-organized social system. Sri Lanka had the hematite, limonite, and magnetite needed for good iron. Furnaces of this period avoided magnetite, as it was difficult to process. But Sigiriya furnaces had used magnetite. These charcoal-fired furnaces were constructed so that the temperature could be controlled. Some furnaces had four or more bellows and eight nozzles for sending in the air. The bellows were made of two large inverted terracotta pots covered with animal skin.

Crucible cast steel had been manufactured in Sri Lanka several centuries before it was produced in the West. Near Samanalawewa, researchers discovered, for the first time in the world, unique wind powered iron smelting furnaces capable of producing high quality steel for large-scale production. Its process of smelting and converting steel was faster than any other recorded for ancient furnaces. The furnaces were able to produce high carbon steel even in amateur hands.

### Ancient clay industry

Sri Lanka had extensive clay deposits, occurring in the flood plains of the major rivers, old river channels, *owitas*, tank beds, and in the deep weathered zones of the crystalline rocks. These deposits were utilized in ancient times. The characteristics of different clay varieties were known, and the clays were used selectively for different purposes. The nozzles in the iron furnaces at Sigiriya were made of clay that could withstand a higher temperature than the clay used for the furnace walls. Clay was used as the binding mortar in stupas such as *Jetawana, Abhayagiri*, and *Ruwanveliseya*. Clay bricks are the most common construction material used in historical buildings and structures in Sri Lanka. Various sizes of clay bricks were employed in the buildings constructed in different kingdoms of Sri Lanka. Thin slurry of clay was used to keep the bricks pasted in position and the stupa was totally covered with a thick lime plaster protecting the clay body from natural elements.

Clay was used in sluices and sometimes around culverts as well. Well-tempered clay 'puddle' (*kiri mati*) of excellent quality was placed around masonry that was subject to water pressure. Clay was sometimes used as the main ingredient for plaster, carefully mixed with many other materials such as sand, sulphur, lime, gums, glues, resins, and fibre. Mirror wall of Sigiriya, is a fine example of good quality clay plaster. Kudiramalai had a well dated to 11th century AD, lined with perfectly circular cylinders made of baked clay placed one above the other in a stratified fashion. Sigiriya had retaining walls of brick built on rock. The prominence of the Sigiriya kingdom as a zenith of technological advancements in ancient Sri Lanka stimulates a meticulous inquiry into the coating technology employed by

its artisans. The preceding scholars have initiated inquiries into the constituent materials of Sigiriya paintings, thereby inciting scholarly discourse on the applied coating techniques.

**Ancient brick industry**

The bricks manufactured by the ancient Sinhalese have come in for particular praise. The crushing strength of the ancient bricks is more than that of the present-day machine-made bricks. The bricks used for the *Maduru oya* sluice, dated sixth century AD, have been exceptionally strong. They could take a load of as high as 2077 pounds per square inch or 385 kilograms per square centimetre. It was not the usual type of clay, and the bricks were probably fired at exceptionally high temperatures. Such sophisticated kilns were not common in this period. The bricks used for the *Jetavana* stupa consisted of 60% of silty sand and 40% of clay. They had been fired very well and could withstand very high heat. The bonding material for the bricks was superb. Not even the point of a penknife could be inserted between two bricks. There is no mortar joint, so that the brick shape remained as it was. The mortar even today is in perfect condition. This skill has now been lost.

Lime was used as a hardener for mortars and plaster. Shells, corals and dolomite limestone have been used for burning lime. In the Polonnaruwa period, they had used three methods for hardening slaked lime *viz*., a) exposing into atmosphere (calcium carbonate), b) mixing with burnt brick powder (silicate of carbon), and c) mixing with milk (calcium carbonate). The lime concrete used in the anicuts was analyzed by the British in 1898. The cement was of superior quality. It had 7.1 % silicate of lime, while a sample of the 3rd century Roman mortar yielded only 2.5%. The high content of silica in the mortar indicated that the ancients knew that the addition of silica to lime gave it the ability to withstand the action of water.



**Stone technology**

Stone was an important building material. In the past, the stones had to be quarried, dressed, transported, and set. They were cut out by means of wedges and there-after chiseled. The well packed, dressed rubble retaining walls built in the 5th century still hold the earth embankments at Sigiriya. *Lowamahapaya* had 1600 stone columns that supported a multistorey timber building. These ancient buildings (or structures) were constructed without the modern machinery available today, and yet are perfect in dimension, and structurally sound. Ancient builders of Sri Lanka have taken great care in the selection of the sites, geometries, architecture, structural stability, materials, setting out, construction supervision and management, and sustainability during the design and construction of ancient structures. The British commented that the technique of shaping large granite pillars introduced into Britain in the 19th century had been known in Ceylon long before that.

A stone bridge found near *Kala Oya* in 1826 was built of stones 8 to 14 feet in length, laid in rectangular lines, some jointed to one another, each course receding from the one underneath, giving additional strength, to the bridge. *Eth Pokuna* was constructed out of large blocks of stone (Figure 1). This giant pond is actually man-made and is almost 160 meters in size. Dating back to the 5th century, this pool has a canal system that draws water from a nearby tank (*Perimiyan Kulama*) and fills it up. The best part of it is that the canal system still works. During the rainy season, the tank still gets filled by the water from the same tank.



**Figure 1: *Eth Pokuna*** in Anuradhapura

The *Kalawewa* spill was formed of hammered granite. The anicut across the Mahaweli River at Kalinga used the massive, square

hewn blocks of stone, weighing two or three tons. The outer wall of the *Ridibandi ela* dam on the *Daduru oya* constructed by King Parakramabahu 1 was built with stone blocks, which are so intricately fitted that the joints are only-a quarter of an inch wide, while its inner core was formed of undressed rubble laid in -lime concrete. The sluices were invariably of square cut stones. At the *Sorabora wewa*, they used soft rock to create the two sluices.

Construction of large reservoirs required the handling of huge stone blocks weighing up to ten tons. At *Urusita wewa*, off Ridiyadgama, the blocks of dressed stone were so large that no modem implements could lift them. For the embankment at Padaviya, about 600,000 cubic yards of earth had been brought to the construction site. The movement of colossal quantities of earth, over appreciable distances would have called for the development of sufficient earth moving machinery, probably drawn by elephants.

Our soil is one of the hardest in the world. Our granite, particularly gneiss, is also hard and difficult. Even our timber is hard. As a result, iron and steel tools were developed in Sri Lanka, a thousand years ahead of the West. The drip ledges and inscriptions on caves confirm that the ancient engineers had tools of superior steel. By the 3rd century BC, the Sinhalese were using the fixed drill and lathe as well. The ancient technologies were labour intensive.

**Origin of water civilization**

Ancient sailors had the tradition of travelling during the North-East monsoon by crossing the island for exchanging goods. They entered into the island from the natural habour known as '*Alli Rani*' in Arippu area and travelled to Anuradhapura trade nucleus. They hired carts and bought foods from Arippu. Many small tanks were built for irrigating rice cultivation around the habour. The tank bed and the paddy lands were synchronized according to water availability and it can be postulate that '*thawulu govithena*' (tank bed cultivation) might have been evolved in this area. However, due to shortage of water, they had to move for a large upstream storage for supplying water to the downstream small tanks. This reveals that the construction of *Yodha wewa* (Giant Tank) dates back to 600 BC. This is believed to be the ancient *Manamatta* tank mentioned in *Mahawamsa*. It was said that the tribe 'Naga' first built up the *Yodha wewa* to feed sailors coming to the country from *Alli Rani* habour. Since the reservoir catchment area (42 $km^2$) was not adequate to fill the reservoir, King Dhathusena (459-477AD) constructed a dam (*Tekkam Amuna*) across *Malwathu oya* or *Aruvi Aru* to divert water to the Giant Tank. Subsequently, King Parakramabahu I (1153-1186 AD) rehabilitated this reservoir to improve the storage. Even at present, the farmers practice the *thawulu govithena* using 162 tanks although it is not legally permitted.

**Water management master plan**

The ancient water management master plan had been operational at all levels (from country level to field level) as given below.

i. Country level - river basin-based governance (as discussed above).
ii. Inter-river basin level - examples: *Dambulu Oya - Malwathu Oya* diversion canal (860 AD); *Malwathu Oya - Kanadara Oya* diversion canal (860 AD); *Yoda Ela - Nachchduwa* feeder canal (540 AD).
iii. Inter-reservoir level – examples: *Kalawewa - Thisawewa Yodha Ela* (470 AD); *Nachchaduwa - Nuwarawewa* feeder canal (290 AD); *Balaluwewa - Siyambalangamuwa* feeder canal (290 AD); *Basawakkulama - Maha Vilachchiya* feeder canal (470 AD).
iv. Sub-watershed or tank cascade level
The sub-watersheds were utilized without harming the environment and constructed structures (tanks, lakes, anicuts etc.) to absorb rainstorms. They reused water of tank above, to store water in the tanks below, while utilizing water for paddy cultivation in between. The arrangement of these tanks is in some areas led to form tank cascade systems.
v. Village level
The land use in a village was wisely utilized for hamlet, paddy fields, forest, and chena

farming while keeping various micro-land uses for ecological and conservation purposes.

vi. Field level
This is an integrated approach with rainfall, tank water and groundwater. During the water scarce year, they adopted *bethma, kekulama, thawulu govithena, ellanga* cultivation etc., to mitigate the impact of drought.

**Giant canals**

The water management in ancient Sri Lanka was of multi-purpose and multifunctional activity, which was not meant only for food production through irrigation and water management. They managed the water resources for other human needs such as settlement, drinking water, bathing, recreation, and other domestic needs etc. Rainwater harvesting systems were planned and constructed to meet the requirements of cities and agriculture. Most importantly, our ancestors sincerely ensured the existence of the environment (flora, fauna, and environs). Historical evidence shows that early water management planners had thought of planning cities such as Anuradhapura, Polonnaruwa, Sigiriya etc., based on water availability. They developed parks and landscapes with water springs and ponds for human attraction. Water related natural disasters such as flood, drought, windstorms, epidemics etc., had been minimized through proper management of water and environment.

The ancient engineers knew the topography, patterns, and soil properties of the island. There would also have been a system of measuring heights and distances. The *Jaya ganga* was planned because the ancient engineers knew what the levels at Kalawewa and Anuradhapura were, and that it was feasible to think of diverting water from the *Kala Oya* to Anuradhapura. The *Minipe Ela* turned the waters of the Mahaweli at a bend in the river, where the water entered a narrow channel. Brohier, himself a surveyor, stated that the ancient engineers were highly skilled at surveying. They were able to accurately work out heights and distances and were able to determine even small differences in elevation. They also knew levelling. One method may have been to use two clay pots separated by a rod. The level surfaces were ascertained by filling this with water. Inscriptions indicate that there was some sort of surveying organization.

Brohier strongly believed that the ancient irrigation engineers had worked according to design. He said "They planned beforehand. It is unlikely that work was started before determining heights and distances. Judging from the account of the construction of *Lowamahapaya*, in *Mahavamsa*, the plan drawing was practiced by the 2nd century BC."

Among the canals identified in the Sri Lankan irrigation industry, Anuradhapura's ancient "*Yoda Ela*" (from *Kalawewa* to *Thisawewa*) is considered a special irrigation design. All canals, except Minipe, Kalinga, and Elahera, are crucial as they are designed to distribute water in a managed routine. For instance, concerning the starting point of the Minipe Canal, Brohier highlighted that "a narrow canal was formed by an island on the edge of the bank at a bend in the Mahaweli River". A large body of water was drawn from the river into the canal, and at the other end of the stream are two stones. The water of the canal falls back from these two stones, so the water is somewhat trapped there; these two stones are connected by a dam. The *Yodha Ela* originates from a sluice located at a high altitude in the *Kalawewa* and traverses the upper valley of the *Kala Oya*, crucial for settling the inter-region. Therefore, it is evident that the *Yodha Ela* is not merely a means of water transport designed to meet the water needs of the capital but also an irrigation industry designed to provide water to the settlements in the inter-region.

The *Yodha Ela* is a long canal of about 54 km miles runs from the *Kalawewa* tank to the *Tisawewa* tank in the Anuradhapura city. Historians believe that the canal has been made to provide necessary water for the Anuradhapura city. However, many researches have shown that the purpose might be irrigation water supply for a vast irrigable area where no other water sources were available. According to the contemporary irrigation works and spatial distribution, the *Yodha Ela* has been constructed in the 3rd century during the period of Anuradapura kingdom (Figure 2).

The canal started at the point of sluice where water from the tank was released. At the beginning, the *Kalawewa* was a small tank, but with time, they realized a considerable amount of water in *Kala Oya* could be impounded. Thus, it is evident at several times in the history *Kalawewa* has been expanded under the patronage of King Dhathusena (459-477). In modern times in 1977, the first phase of Mahaweli Development Program implemented in this area, and instead of the *Yodha Ela*, a new canal (*Jaya Ganga*) was constructed starting at a new sluice from the *Kalawewa*. The old *Yodha Ela* has been damaged at some places and at some sites the *Jaya Ganga* connects to the *Yodha Ela*. However historical, archaeological and field investigations show that there had been a marvelous water management system based on the *Yodha Ela*.



**Figure 2: Old sluice of the *Kalawewa***

### Ancient rainwater harvesting

Since the scarcity of water in good quality has been an issue for human beings from the time immemorial, and the ancestors did every attempt to use water for almost all purposes, the rainwater harvesting must have been given a priority at every scale.

Pidurangala is a massive rock formation located a few kilometers north of Sigiriya in Sri Lanka. It has an interesting history closely related to that of the Sigiriya Rock Fortress. Both Sigiriya, and Pidurangala rocks were formed by volcanic activity. Whilst Pidurangala appears larger than Sigiriya, its upper surface is steeply sloped and is of solid rock. The rocky outcrops that surround the Pidurangala rock gives an indication of how

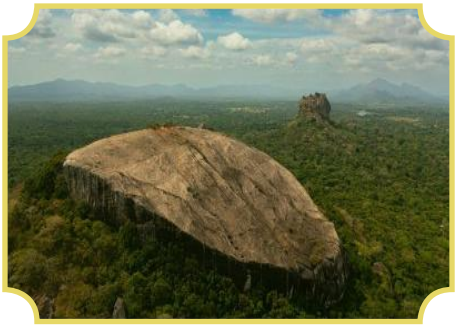


**Figure 3: Surface configuration of the Pidurangala rock**

they altered the rock to become the surface like rainwater collecting flow path concentrating to a point at the lowest (Figure 3).
It is obvious that due to the presence of hard water around Sigiriya, they must have needed clean drinking water. Once the kingdom was established they would have thought of having two ways to fulfill the water requirement. One was the rainwater harvesting ponds constructed on the top of Sigiriya rock. The other option was to convey water from Pidurangala (324 m amsl) to the octagonal pond (212 m amsl). The

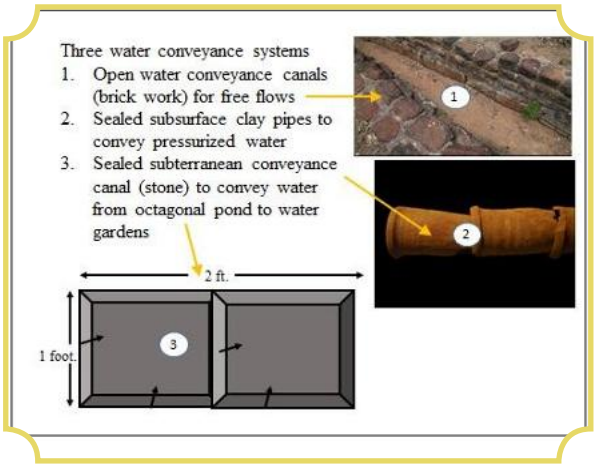



**Figure 4: Three water conveyance systems (Pidurangala – Sigiriya)**

elevation difference is 112 m. The evidence indicates that they have used three different conveying methods selecting according to the appropriateness (Figure 4).

### Precision of irrigation marvels

The calculations made by the ancient irrigation engineers were found to match the modern calculations. The *Kalawewa* spillway meets the modern criteria for a spillway in all respects. The sluice barrel at Kantale increased from the upstream end to the down stream end by a factor of seven. This agreed exactly with modern criteria. The modern sluices and anicuts ended up exactly where the ancient sluices and anicuts were. This happened at the *Urusita wewa* sluice near Ridiyagama, in the 1960s and *Maduru oya* in the 1970s. The *Urusita* and *Maduru* sluices were dated to the 5th and the 6th centuries, respectively. The modern anicuts and modern headworks use the same ancient canals.

The modern-engineers have agreed with ancient solutions. The *Kirindi*

*oya* dam was built at an oblique angle of nearly 45 degrees, instead of going across by the shortest possible route. It has now been found that this action greatly increased the discharging power and the ability to take shocks.

Some of the British engineers marveled at the ancient irrigation scheme. They made detailed drawings of the sluices saying that they could still be used. But the official attitude was not complimentary. The British took the position that the ancient engineering achievements were based on intuitive or practical thinking.

A distinction has been made between the scientific knowledge of the ancient world and the 'mature science' of the 16th century Europe. This is a false distinction. Science and technology began when man decided to control his environment. Each civilization thereafter developed some sort of science. There was mathematics in Mesopotamia, irrigated agriculture in Egypt, and medical systems in India and China. The Pythagorean Theorem was known before Pythagoras was born. Scientific ideas were transmitted from community to community, until they were picked up by the Islamic civilization of the 7th century AD and transferred to Europe from there. The knowledge relating to tropical conditions would have been dropped along the way and those relevant to Mediterranean and temperate conditions would have been retained. Europe was not the first to develop a scientific perspective. In fact, it was the last.

Ancient Sri Lanka's scientific achievements are labelled 'ethnoscience'. There is nothing 'ethno' about it. It is science in the modern sense of the world. The ancient engineers had a theoretical knowledge of the phenomena they were dealing with.

Ancient science was neither accidental nor intuitive, but was the result of experimentation. They tested out their ideas, and developed methods and standards. It had been observed that between the 3rd and the 7th century AD, the ancient engineers were experimenting with the design of the sluices with regard to the size of the cisterns, the gradient and the tapering of the outlet conduits. There has been experimentation with the use of obtuse angled elbows when releasing water. The reservoirs of Pavatkulam, Periyankulam, and Maduru oya illustrated such attempts to making changes. The indigenous sailing crafts were developed through the use and experimentation.

Ancient Sri Lanka's industries such as glass smelting, and bead manufacture also involved science and technology. It is now suggested that carnelian found at archaeological sites was manufactured locally and not imported from Gujerat as believed earlier. Sewwandi (chalcedony) is readily available in Ratnapura, Nivitigala, Kahawatte, Pelmadulla and can be easily converted to carnelian through heat.



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