Article

Ancient gravity fed hydrology and irrigation system of Majapahit civilization 14th century in Java island and its impact on vegetation health during 2019 El Nino using NDVI analysis

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Abstract. Majapahit is one of vast kingdoms and civilizations in Southeast Asia in 14th century. The kingdom and its capital city are centered in present Trowulan suburban, east Java and bordered by mountain range in the south and river in the east and north. Regarding the geological condition then Majapahit kingdom has a challenge especially to provide the water managements for its agricultural practices. In here, this study aims to assess the hydrology systems developed by Majapahit civilizations and how this system is effective in maintaining vegetation health. Based on the results, the gravity-fed hydrology systems consist of networks involving river, dam, underground and surface water canal and reservoir pond. The water from upstream was managed using dams and channeled into streams and collected inside the ponds. This network spans approximately 10 km from the first dam to the last 6.49 Ha reservoir built in the middle of city. The water channeled from dam to reservoir pond was using natural streams and 2.4 km underground canal. This 40 cm depth man made canal was a water source for agricultural soils since it was used to irrigate the nearby paddy field. During past El Nino in 2019 that has caused prolong drought, the Majapahit irrigation system has provided water for the adjacent paddy field. Based on the vegetation health analysis measured using Normalized Difference Vegetation Index (NDVI), paddy field watered by man made canal shows higher NDVI values or at least has same values compared to the field watered by contemporary canals. Then, the 14th century irrigation system developed by Majapahit civilization is a valuable heritage that needs to be preserved considering its important functions even in this contemporary era.

Keywords: ancient, canal, irrigation, Majapahit, NDVI reservoir

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1.Introduction

Triumph of ancient civilization is marked by its capability to manage water and develop sophisticated hydrology systems. The needs for developing hydrology systems started since humans settled and created permanent settlements around 10000 years ago. When they have settled, human start to adopt an agrarian way of life and this dependency on water in one way or another means that leads to needs for hydrology systems (Vuorinen et al. 2007). An established a unique relationship between humans and water can be seen in most of the ancient civilizations including Indus Valley, Egyptian, Mesopotamian,

and Chinese, since they settled at places where water required for agricultural and human needs was readily available whether in the vicinity of springs, lakes, rivers, and seas (Yannopoulos et al. 2015).

An evidence of hydrology management can be seen in Dujiangyan city considering the settlers living there have practiced hydrology. This based on the findings of 3 statues of 2.9 m tall stone-man with the graduations from foot up-to shoulder found at the canal head of Dujiang Weir project. This project was a famous irrigation project constructed in 211-207 BC ago. The stone-men were used as a depth gauge to measure the water level of canal head and to determine inflow discharge at canal head. Then this is regarded as the earliest hydrology practices in the form of water level observation in ancient China (Guowei 2011).

Vast ancient structure regarding hydrology can be seen in aqueduct and canal development. An ancient canal can be seen in Mesopotamia and ancient Crete (ca. 3300–1100 BC), ancient Egypt (ca. 3000–67 BC), Indus valley civilization (ca. 2600–1900 BC) and Pre-Columbian cultures (ca. 2600 BC–early 16th century AD). While in historical times, hydrology structures have been constructed by Chinese dynasties and empires (ca. 770 BC–1911 AD), Hittite empire (ca. 1700–1180 BC), Urartu kingdom (ca. 1000–700 BC), Persian Empire (550–331 BC) and Etruscan civilization (ca. 800–100 BC) (Giovanni 2013). One of ancient hydrological structures that still functioning in the 21st century is the aqueduct developed by Roman empire (Deming 2019).

In Southeast Asia, there were also numerous kingdoms with their civilization and vast marvel in hydrological practices since agriculture is common practices for Asians. In Indonesia, Majapahit is known as a vast kingdom with its civilizations. This civilization lies on trading and agricultural practices (Noviandi et al 2015, Safitri 2015). For supporting the agricultural practice then this civilization has to develop irrigation system. In here this study is aimed to assess the irrigation systems developed by Majapahit civilization and how it is still effective today in term of dealing with drought caused by 2019 El Nino impacted on agricultural practices.

2. Methodology

The evidences of ancient hydrology and irrigation practices related to the Majapahit civilizations in the forms of structures were obtained through the excavations. The structures were ranging from rock statues to the large size structures like temples. The evidences of Majapahit kingdoms were also collected to assess the border of this kingdom. The evidences usually were buried and submerged below soils and surfaces then excavation and information from local people were collected. The geolocations of each archaeological structures found were recorded using GPS and this was for the purpose of mapping.

The presences of ancient hydrology structures then were overlayed with the surrounding land use. The land uses mainly consist of plantation, paddy field and sugar cane fields then were assessed to determine their health. The vegetation health analysis was based on the NDVI analysis. NDVI stands for Normalized Difference Vegetation Index and used to determine vegetation greenness value obtained from the digital signal processing brightness value data (brightness) of some Landsat bands. This NDVI can distinguish the vegetated and non vegetated areas based on its value. The NDVI value is calculated based on the difference between the maximum absorption of radiation in the red band as a result of the pigment chlorophyll and maximum reflectance in the NIR band as a result of the cellular structure of the leaves. The NDVI formulation is as follows (Sukmono & Ardiansyah 2017):

$NDVI = (\rho_{NIR} - \rho_{Red}) / (\rho_{NIR} + \rho_{Red})$, with ρ_{NIR} = reflectance value of NIR band and ρ_{Red} = reflectance value of red band.

3.Results and Discussion

This part covers 3 important aspect consist of landscape, irrigation network and vegetation health.

Majapahit landscape

The Majapahit kingdom and civilizations were established from 13th to 15th century in the province that today known as east Java (Figure 1). In east Java and based on the archaeology structures found, the areas of Majapahit were estimated covering 3 districts in the present time and centered in Trowulan area. In 1924, Maclaine Pont, an explorer has succeeded to estimate and sketch the Majapahit capital (Mahatmo 2002). From the drawing, the capital was divided into several blocks separated by roads and probably water canals (Figure 1A). More accurate sizes of Majapahit kingdom can be estimated using a rock statue. This rock statue known as *Yoni* (in local language) with length x width x height sizing of 1.1 m x 1.0 m x 1.2 m also has a function to mark the border of the kingdom. Based on the excavations, 4 *Yonis* have been found and located almost symmetrically in north east, north west, south east and south west. Based on the geocoordinates of those *Yonis*, the Majapahit kingdom has a rectangular shape and located on the north of 3339 m Arjuna mountain and bordered with 11 m width river Pikatan in the east side. It is estimated that the size of Majapahit kingdom was 10.26 km x 10.8 km for its length and width (Figure 1B). The south border of Majapahit kingdoms was located only 2 km from the mountain. This geolocation situations make the Majapahit has a landscape with varied elevations. The southern parts were at higher elevation (75 m above sea level/asl.) than the northern parts (28 m asl.) (Figure 1C). The center of Majapahit kingdom was at 42 m asl.

This hilly landscape makes Majapahit civilization has to deal with the natural phenomena especially from the mountain range in the south. Higher landscape with mountainous ranges in south will lead to

the volume of surface run off and water channeling through the rivers. High rainfall in the mountain can increase the flood volume of river Pikatan in the south of Majapahit. Increasing river volume can lead to inundations of Majapahit lands especially in the southern parts bordered with the hill and mountain.

The location of Majapahit landscape was strengthened by the findings of 4 *Yonis* representing 4 wind directions as a border for the kingdom. Those *Yonis* are different in the shape and form and named based on the location where those *Yonis* were found (Figure 1D).

Figure 1. (A) Majapahit city (inside the kingdom) sketch drawing by Maclaine Pont in 1924 and now located in Trowulan; (B) Majapahit kingdom landscape bordered by 3339 m Mt Arjuno on the south; (C) Majapahit kingdom contour; (D) 4 *Yonis* representing Majapahit borders in north east, north west, south east and south west.

Majapahit irrigation networks

Figure 2 presents the comprehensive of elaborated irrigation systems developed by Majapahit civilizations. This sophisticated system including man made irrigation structures and natural streams. It uses the gravitational irrigation system since the systems starts by constructing a dam at R. Pikatan stream at 97 m asl. The water then channeled further to the north and ended up in reservoir ponds at

44 m. The irrigation systems combining natural and man made structures spans over 10 km. This gravity –fed drip irrigation uses in 14th century was comparable to the contemporary systems. This kind of irrigation is suitable in mountainous areas using gravity flow (Oad & King 1991) for the hilly terraces. To support this system, usually a reservoir is installed within the irrigation network downstream to provide uniform emitter discharge on several terraces with varying elevations and irregular shape (Bhatnagar & Srivastava 2003). Considering the Trowulan landscape where Majapahit civilization has been established, the southern areas of Trowulan were hilly landscape as parts of Mt Arjuno.

The most striking characters of Majapahit irrigation system are related to several aspects (Figure 2). First, it combines the natural streams with manmade dam and underground water canal. Second, the system combines a network spans over several kilometers. The last one, the irrigation structures were decorated and built as a temple. In a dam structure, the civilization is also building a temple as can be seen in Baureno dam (A) that also known as Limo temple. Apparent evidence is also can be observed in reservoir that was a common part of the irrigation system used in here. The reservoir structure was in the form of pond built using red clay brick. The pond is collecting and channeling water using the underground water canal. In reservoir B, the civilization has built a temple on the top of it with the name of the temple is Tikus temple. The temple structure is a triangle with the reservoir pond built at the bottom of the temple. This triangle shape represents the shape of a mountain that symbolized has poured water to its surrounding area. Point C within the system is known as Kunitir dam. Whereas recent excavation has exposed more man made structures in Kunitir dam.

Main principle of the Majapahit irrigation system is water control and collection. High volume of water from river as the source of gravity-fed irrigation was controlled using Baureno dam and small amount of water was channeled to the next systems (B-F). Majapahit civilization was located in tropical geographical area with prolong drought and even torrential rainy season. Tropical rain generates high volume of water in the river stream and Majapahit civilization has realized this condition by first developing a dam in its upstream irrigation systems to have a control for the high volume of incoming water.

Another character of Majapahit irrigation system is the mitigation system. Unpredictable tropical climate has led this civilization to prepare back up irrigation system. This can be seen where the water from Baureno dam was divided into north and south routes. In south route, the water was channeled from Baureno dam to Tikus reservoir (B) and from Baureno dam to Kunitir dam (C) for north route. This divided irrigation system aims to anticipate huge water volume during rainy season. If the water volume

is too high it can be collected in Tikus reservoir or by opening Kunitir dam. Conversely, during drought season, the Kunitir dam gate can be closed to collect the water.

The marvel of Majapahit irrigation system can be observed from point C and B. From Tikus reservoir (B) and Kunitir dam (C), the water was channeled to the center of the Majapahit city to provide the water for the residents and watering the paddy field. Since the natural stream was absent in this area, Majapahit civilization has built an underground water canal. This hidden network of water canal was found in 1980 from excavations. The canal was built under the vegetation and soil layers and has a depth of 40 cm (Figure 3) as can be seen in Nglinguk canal. The banks of the canal were made of red clay brick. This underground canal is channeling water collected from the pond in Tikus temple to paddy field and also to central Segaran reservoir. There are 3 underground canals that were built in parallel with east to west directions with length of each canal is 2.43 km. This canal received water from Tikus temple reservoir. Underground canals are the common ancient structure used to manage the water in the past time. The oldest underground canal or known as Qanat can be seen in Hawarin. According to local legend this Qanat was built by Queen Zenobia (267-272 AD) to carry freshwater from Laboue to Palmyra in central Syria, the capital of her kingdom. Qanats collect subsurface groundwater and convey it by gravity to their outlet, sometimes several miles away (Lombard 1991). They are used for irrigation and domestic purposes.

Another marvel can be seen in a 6.49 Ha reservoir built in the city. This red clay brick pond was known as Segaran pond receiving water from Kunitir dam in the east. The water from this dam then channeled using man made canal to Segaran. This pond is the largest ancient reservoir that ever found. The pond also has additional 2 reservoirs built in the south within the 100 m distance. Currently, only pond in the west side that still present and east pond is already disappeared. This pond in the past time has function as the terminus of irrigation networks in term of collecting water. Second, the pond also distributes the water to the north.

Besides canal, reservoir in the form of ponds is one of structures can be found in ancient irrigation systems. Segaran pond made by Majapahit civilization is comparable to other reservoirs built by ancient civilizations. Almost in the same period, Karnataka civilization in between of 1335 AD - 1565 AD has developed irrigation system consists of wells, anicuts, canal systems, tanks, ponds and combined with sources of water like rivers and streams (Deb 2020).

Figure 2. Majapahit civilization irrigation systems and networks (rotate clockwise: the networks, the structures and the contour).

Figure 3. (From left to right) Nglinguk underground canal, Segaran pond 1924 sketch and actual condition

Figure 4. 5 year period of air temperature in study area with 2019 El Nino

Vegetation health above underground canal

Upper layers of the underground canal were now covered by the paddy fields. In this study, an analysis to measure the impacts of those canals on the paddy fields in terms of vegetation health has been performed. This is considering that those canals were built in the past to provide irrigation and water for the paddy field and deal with tropical climate especially during El Nino drought season. In here, the analysis was based on the drought season during 2019 El Nino observed in east Java. Year 2019 has a higher air temperature since last 5 years related to the El Nino (Figure 4).

The vegetation health of layer above the underground canal was present in the Figure 5. A 110.93 Ha paddy field was observed on the top of underground canals. This paddy field received water from the canals. The NDVI analysis on this field was performed from July as onset of El Nino to August 2019. In June 2019, it is apparent that the designated fields have NDVI values equal to paddy field in other areas that do not have underground canal below. When El Nino started in July, the NDVI in fields above canal was still the same even though the area was reduced. August 2019 was the peak of El Nino and this has affected all paddy fields. Whereas, some fragments of fields watered by underground canal still show high NDVI values.

Figure 5. Vegetation health status indicated by NDVI above underground canals during El Nino in June, July and August 2019

4. Conclusion

Ability of ancient civilization to develop irrigation system along with hydrology structures have been documented from aqueducts in Rome to the Angkor Wat. In here the study elaborates and assess the irrigation systems of Majapahit civilizations developed in between of 13th-15th century ago. The systems were exceeding from the border of Majapahit kingdom since the systems have built the monitoring dam in the upstream areas. The 10 km Majapahit irrigation systems started with dam, pond, canal and ended up with large ponds in the middle of the city. The characteristics of this system can be seen on the some underground water canals functioning to watering the nearby paddy fields. Based on the NDVI analysis, those canals are still functioning to support vegetation health mainly during 2019 El Nino. This function and performance were not changed since the irrigation system was built in 14th century.

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