INVESTIGATING WATER SURFACE TEMPERATURE AT SHRIMP FARMS IN QUYNH LUU DISTRICT, NGHE AN PROVINCE BY USING REMOTELY SENSED DATA IN GOOGLE EARTH ENGINE

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ABSTRACT

Temperature is a fundamental environmental element of all aquatic ecosystems, including aquaculture ponds. However, the availability of in situ water temperature data typically only represent a small portion of shrimp farms' thermal profile, and this often leads to limitation in investigating impacts of global warming and climate change on shrimp farming. For this aim, satellite-derived water surface temperature (WST) at shrimp farms in Quynh Luu district, Nghe An province, Vietnam were investigated using Landsat data in Google Earth Engine. Results showed that there was a seasonal variation of WST at shrimp farms, with monthly mean WST ranged from 21.8°C (December) to 30.7°C (July). Annual WST at shrimp farms in Quynh Luu district showed an increasing trend from 2000 to 2022. A remarkable warming trend of WST was detected during shrimp farming season (often from April to October each year) and this may lead to high risk for shrimp farms there. Findings of this study indicate that greater awareness of shifts in WST regime at shrimp farms is required if this activity is to be sustainable under climate change.

Keywords: *Water surface temperature, shrimp farming, Landsat, Google Earth Engine.*

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1. INTRODUCTION

Temperature is a fundamental environmental element of all aquatic ecosystems in general and aquaculture ponds in particular. Water temperature affects the survival, growth, maturation and reproduction of all aquatic organisms - the majority of which are poikilothermic (cold-blooded) organisms that can only thrive when water temperatures are within their preferred thermal range [1, 2]. Water temperature also regulates many physical, chemical, and biological processes in water bodies, such as the maximum dissolved oxygen concentration, the percentage of toxic unionized ammonia form - NH_3, the rate of chemical reactions, metabolic rates and nutrient cycling [2, 3]. In addition, global warming and weather extremes due to climate change (e.g., heat waves and droughts) lead to increases in water temperature as well as changes of its seasonal patterns on the earth [4], especially for shallow water bodies [5 - 7]. Therefore, evaluating water temperature is essential to understanding its direct and indirect effects on aquatic ecosystem health as well as cultured species in the climate change context.

A conventional way to assess water temperature is by using in situ thermometers or sensors to measure temperatures at specific monitoring stations. However, this approach requires the appropriate infrastructure and fieldwork, which is time consuming and expensive, especially applying for large aquatic ecosystems (e.g., lakes, large aquaculture farms). In Vietnam, environmental monitoring programs for aquaculture have been using in situ

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measurement of water temperature and such programs are mainly implemented at some concentrated aquaculture areas with few times per year. Although the monitoring sites and frequency in environmental monitoring programs in aquaculture have improved and extended recently [8], in situ measurements are unable to cover for a vast number of aquaculture farms in Vietnam in general and shrimp farms in particular. Therefore, the availability of in situ water temperature data typically only represent a small portion of shrimp farms' thermal profile.

Besides conventional methods for water temperature measurements, data from satellite sensors may provide additional information on spatiotemporal variability of water surface temperature (WST), or "skin temperature" [9]. Several satellite sensors are capable of collecting thermal emission data which can be used for retrieving WST. Coarse spatial and high frequency satellite sensors (e.g., the Advanced Very High Resolution Radiometer (AVHRR), Visible Infrared Imaging Radiometer Suite (VIIRS) and the MODerate resolution Imaging Spectroradiometer (MODIS)) have been commonly used to retrieve and map sea surface temperature [10 - 14] and large lakes [15 - 17]. Recently, higher spatial resolution sensors have been used for retrieving and mapping WST in oceans, large lakes as well as small water bodies (e.g., smaller lakes and reservoirs, streams, rivers, ponds). For example, Tonooka and Hirayama (2010) used Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) thermal infrared data to retrieve WST in small Lake Senba in Japan [18]. Teggi (2012) developed an algorithm for improving the spatial resolution of ASTER from 90 to 30 m to map WST in coastal waters and of watercourses in Italy [19]. Moreover, the Landsat Data Continuity Mission program holds an impressive continuous record of imagery data, Landsat (i.e., Landsat 4 and 5 TM, Landsat 7 ETM+, Landsat 8 TIRS and Landsat 9 TIRS-2) is a prime platform for studies on thermal properties of waters [20 - 25].

In addition, the Google Earth Engine (GEE), a cloud-based platform for earth science data and analysis developed by Google has enabled to process large scale satellite images that available free for public, such as Landsat [26, 27]. GEE has been used to conduct various global and regional scale studies, on variety issues [26, 27], including WST [28 - 32]. Study of Pedreros-Guarda *et al.*, (2021) [28] also indicated that using the method developed by Ermida *et al.*, (2020) [33] to retrieve WST in small inland water bodies from Landsat 7 and 8 data in GEE produced the best results without calibration [28].

As with many coastal areas in Vietnam, shrimp farming has rapidly developed in Quynh Luu district, Nghe An province over the last two decades [34]. However, the availability of water temperature data at shrimp farms is sparse due to limitations of in situ environmental monitoring programs in aquaculture as mentioned previously. Therefore, this study aimed to investigate multitemporal WST at shrimp farms in Quynh Luu district, Nghe An province using Landsat data in GEE. The study will provide the first detailed record of WST information at concentrated shrimp farming areas, contributing to sustainable development of shrimp farming in Vietnam in the climate change context.

2. METHODOLOGY

2.1. Study area

Quynh Luu district is located in the Northeast of Nghe An province, in the North Central of Vietnam (Figure 1). The district is bordered by Hoang Mai town in the North, the East Vietnam Sea in the East, Dien Chau, Tan Ky and Yen Thanh districts in the South and Southwest, and Thai Hoa town and Nghia Dan district in the West. Quynh Luu district has a diverse topography, including plains, coastlines and low hills [35]. The district is characterized by the tropical monsoon climate, which is hot, humid and rainy during summer (May - September), and cool and dry in winter (October - April). Annual mean air temperature is about 30°C and the highest air temperature may be up to 40°C. Annual rainfall is about 1,459 mm (920 - 2,047 mm) [35].

Shrimp farming has rapidly developed in terms of land use and shrimp production in Quynh Luu district over the last two decades. Total area of shrimp farms in Quynh Luu district is about 786.15 ha in 2020 [34]. Shrimp farms are mainly located along tidal creeks of Mai Giang, Hau and Thai rivers in coastal communes of Quynh Luu district (Figure 1).

Shrimp farming is promoted by the local government for producing valuable aquatic products, raising local living standards and thereby contributing to sustainable development in coastal areas. According to the Master Plan for Fisheries Development of Nghe An province to 2020 for vision to 2030, Quynh Luu district is one of main districts for the development of coastal shrimp farming [36]. Based on data from Department of Fisheries of Nghe An province in 2020, total area of shrimp farming of the province was 2,234 ha, produced 7,896 tonnes of commercial shrimp production; of which, Quynh Luu district shared a vital part for both shrimp culture area as well as commercial shrimp production [37].

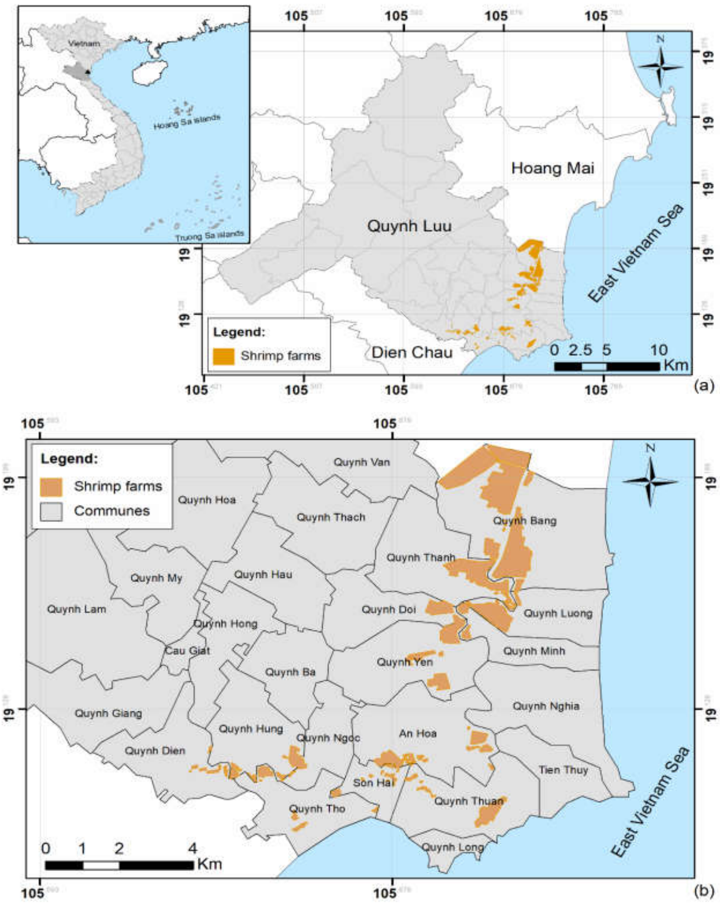

Figure 1. Shrimp farms in Quynh Luu district, Nghe An province, Vietnam in 2020 (a) and the enlargement showing communes with shrimp farms (b) (redraw from figure 1 and 4 in [38])

2.2. Datasets and methods

Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI/TIRS datasets in the GEE platform were used in this study (https:// developers. google. com/ earth-engine/datasets/catalog/landsat) [39]. Since shrimp farming in Quynh Luu district, Nghe An province has developed from 2000 [34], imagery data of the study area (paths 126 and 127, row 47), acquired from 01st January 2000 to 30th June 2023 were collected to retrieve land and water surface temperature (L/WST) (Table 1). In addition, Google Earth, digital topographic maps of the study area were used to provide ancillary data. A global positioning system (GPS) Garmin 72 was also used for ground truthing in the study area.

Table 1. Satellite, Google Earth Engine dataset, path/row of the study area, equator crossing time (ECT), and available period for each Landsat satellite

Satellite	*Dataset*	*Path/ Row*	*ECT*	*Available period*
Landsat 5 (TM)	T1-SR, T1-TOA	126/47, 127/47	10:00 - 10:30 AM (16-day)	01/01/1984 – 05/05/2012
Landsat 7 (ETM+)	T1-SR, T1-TOA	126/47, 127/47	10:00 - 10:30 AM (16-day)	01/01/1999 – present
Landsat 8 (OLI; TIRS)	T1-SR, T1-TOA	126/47, 127/47	10:00 - 10:30 AM (16-day)	11/04/2013 – present

Satellite data were processed by the method developed by Ermida *et al.*, (2020) [33]. JavaScript codes in GEE platform were used for extracting and analyzing L/WST in Quynh Luu district. The intersection of the geometries of L/WST and shrimp farming areas was applied to detect WST at shrimp farms in the study area (Figure 2).

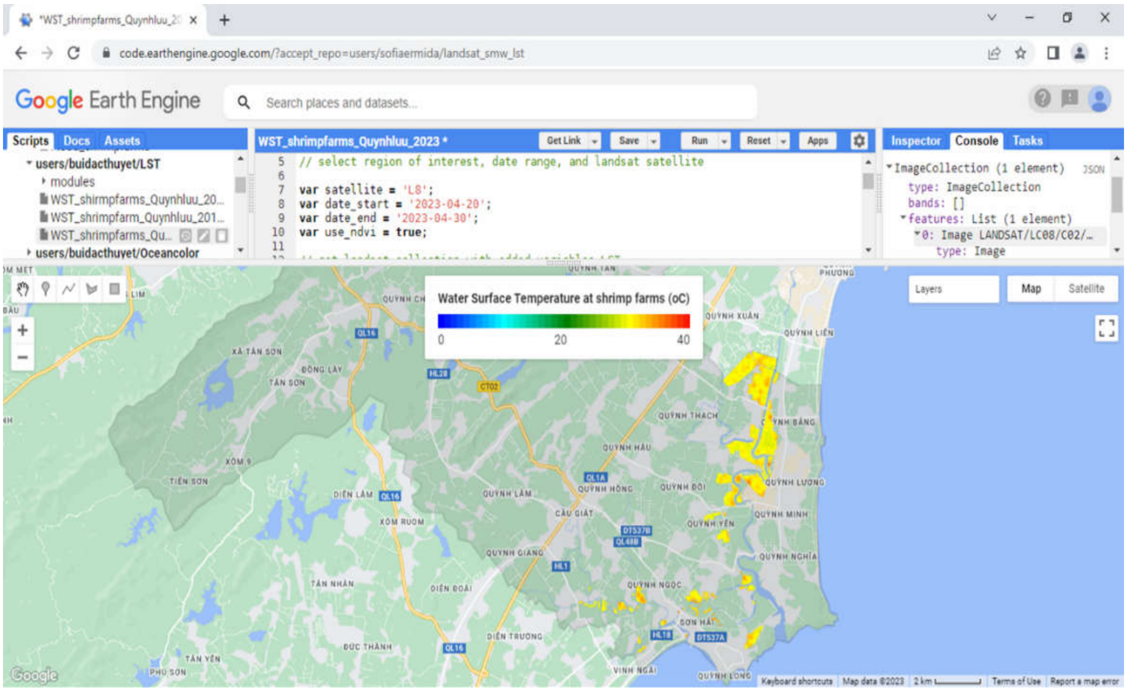

Figure 2. GEE platform interface of water surface temperature at shrimp farms in Quynh Luu district, Nghe An province, Vietnam

3. RESULTS AND DISCUSSION

3.1. Temporal variation of water surface temperature at shrimp farms

Satellite-derived WST at shrimp farms in Quynh Luu district ranged from 12.3°C to 39.4°C, mainly concentrated at 20 - 33°C (around 80% retrieved WST from Landsat data acquired 2000 - 2023) (Figure 3). WST was also found to show seasonal variation, reaching a maximum in July (defined as summer seasons) with monthly mean WST of 30.7°C, and its minimum in December (defined as winter season) with monthly mean WST of 21.8°C (Figure 4). Monthly mean WST at shrimp farms in Quynh Luu district aligns with the pattern of monthly mean air temperature in the North Central of Vietnam - Vinh Hydrometeorological Station in Nghe An province [40].

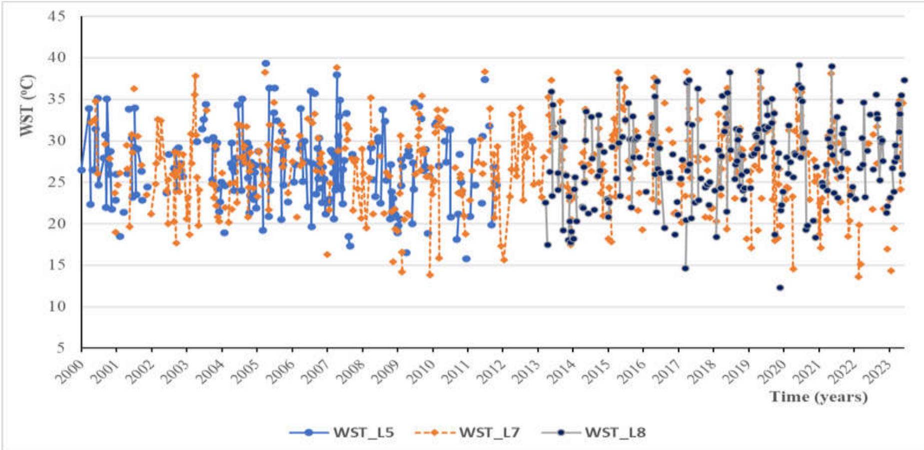

Figure 3. Water surface temperature (WST) at shrimp farms in Quynh Luu district, Nghe An province, Vietnam from 2000 to 2023. Data retrieved from Landsat 5 (L5), Landsat 7 (L7) and Landsat 8 (L8)

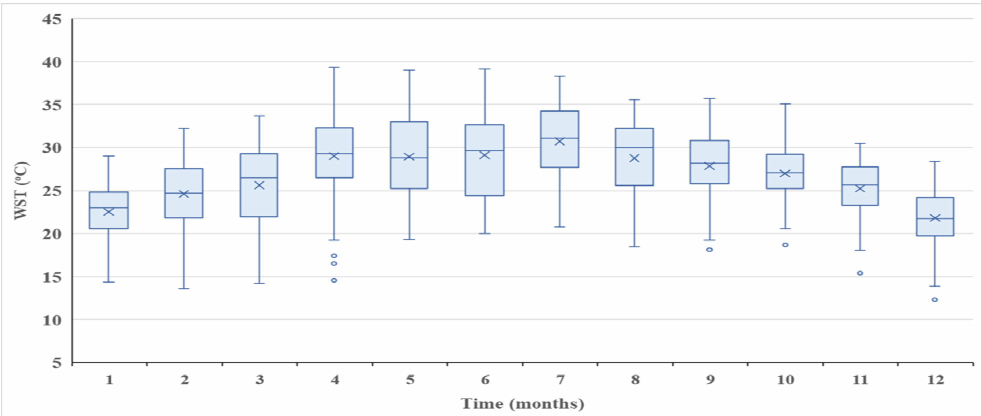

Figure 4. Boxplot of the monthly water surface temperature (WST) at shrimp farms in Quynh Luu district, Nghe An province, Vietnam. Data retrieved from Landsat 5, 7 and 8 from 2000 to 2023

Satellite-derived WST detected in this study was more fluctuated and higher at some certain days during summer months (e.g., reaching 38 - 39ºC in April 2005 and May 2021) in the comparison with in situ measurements of water temperature at some shrimp farms in Quynh Luu district (e.g., 28 - 34ºC in April - July 2015) [41]. This was due to WST retrieved from remotely sensed data was measured in the top layer of water bodies (i.e., approximately the upper 100 µm, called 'skin temperature') [9, 42] and it was highly affected by solar radiation and atmospheric temperature [43]. Thus, skin temperature may differ from the in situ temperature measured at depth, also known as (bulk) surface temperature [42]. Further study for assimilation of satellite-derived temperature observations with in situ monitoring data are therefore highly recommended in order to understanding water thermal patterns, contributing for water quality monitoring at shrimp farms in Quynh Luu district, Nghe An province.

3.2. Water surface temperature at shrimp farms under climate change

Annual WST at shrimp farms in Quynh Luu district was found to show a warming trend from 2000 to 2022 (Figure 5a). Using a linear regression model, the rate of change is defined by the slope of regression line which in this case was about 0.0103°C during the period of 2000 - 2022 (Figure 5a). The finding aligns with research on global warming and climate change of IPCC (2022) in which water temperature has increased both inland water bodies (e.g., up to 1°C per decade in rivers and 0.45˚C per decade in lakes) as well as sea water surface (0.68 - 1.01˚C from 1850 - 1900 to 2011 - 2020) [4].

In addition, there was a seasonal variation of long-term thermal trend at shrimp farms in Quynh Luu district from 2000 to 2022, in which WST has decreased in winter and spring seasons (Figure 5b) and increased in summer and autumn seasons (Figure 5c). This means that WST at shrimp farms in Quynh Luu district is warmer during shrimp farming season there (normally form April to October each year) in the context of climate change. Shifts in WST regime not only directly affects cultured shrimps but also causes changes of water quality in shrimp ponds due to its alteration in many physical, chemical, and biological processes (e.g., dissolved oxygen concentration, the percentage of toxic unionized ammonia form - NH_3, the rate of chemical reactions, metabolic rates and nutrient cycling) [2, 3]. In other words, shrimp farming in Quynh Luu district were found to be affected by climate change in relation to warming trend of WST during shrimp farming season.

Research revealed that global warming, reaching 1.5˚C in the near-term, and more frequent and intense extreme weather events (e.g., heat waves) has caused widespread adverse impacts to nature and people, across sectors and regions [4]. Based on climate change scenarios (RCP4.5 and RCP8.5) for Vietnam developed by Ministry of Natural Resources and Environment, mean annual temperature in Nghe An province is predicted to increase 0.8 - 2.2°C (RCP4.5) and 1.3 - 2.8°C (RCP8.5) in 2046 - 2065, and 1.0 - 2.9°C (RCP4.5) and 2.0 - 4.8°C (RCP8.5) in 2080 - 2099 [44]. Thus, aspect of global warming and climate change should be considered in planning for shrimp farming in Quynh Luu district, Nghe An province.

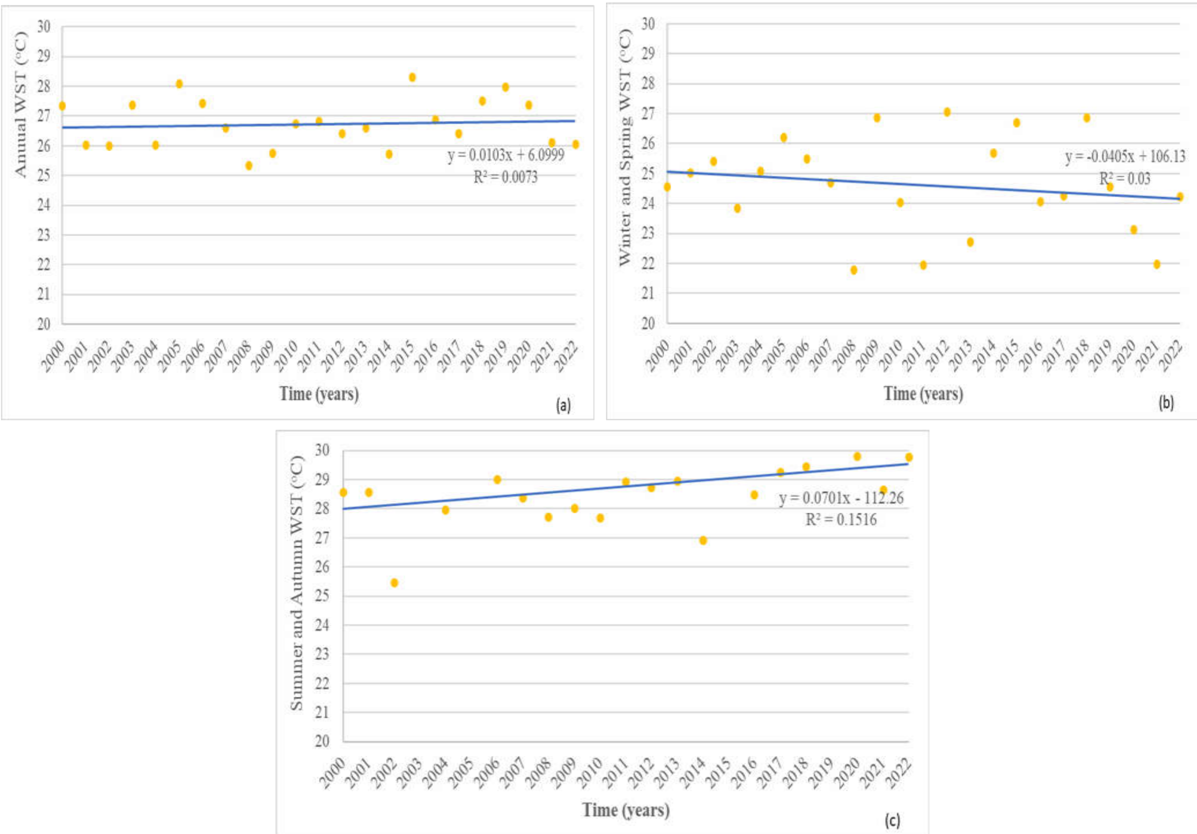

Figure 5. Water surface temperature (WST) trend at shrimp farms in Quynh Luu district, Nghe An province, Vietnam for the period 2000-2023: a) Annual; b) Winter and Spring; c) Summer and Autumn

4. CONCLUSION

Finding of this study showed that satellite-derived WST at shrimp farms in Quynh Luu district ranged from 12.3°C to 39.4°C. There was a seasonal variation of WST at shrimp farms in the study area with the highest monthly mean WST in July (30.7°C) and the lowest monthly mean WST in December (21.8°C). Annual WST at shrimp farms in Quynh Luu district showed an increasing trend from 2000 to 2022. A remarkable warming trend of WST was detected during shrimp farming season (often in April to October each year) and this may lead to high risk for shrimp farms there. Besides limited availability of in situ water temperature data, satellite-derived WST at shrimp farms in Quynh Luu district, Nghe An province has provided essential information to inform the sustainable development of shrimp farming in the context of climate change.

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