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Rainfall-Temperature-Dissolved oxygen nexus to fish kill occurrence at Buhi Lake

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Abstract
Buhi Lake serves as the main source of livelihood but despite the success in the aquaculture industry the lake often suffers from serious massive fish mortality called fish kill. This study investigates rainfall, atmospheric and water temperature, and dissolved oxygen as indicators of fish kill occurrences in Buhi Lake from 2013 to 2017. Monthly rainfall and atmospheric temperature data were obtained from Buhi Weather Forecast while water temperature and DO using Hobo data logger model U26- 001 at two sampling stations. Descriptive statistics and regression were used for the statistical analysis.

Results of the study revealed that most fish kill events occurred from June to December 2013-2017, the months of August and November in particular when most typhoons occurred in Buhi. Findings also showed an increasing rainfall trend from 2013 to 2017, which correspondingly affects fluctuations in atmospheric temperature. The correlation analysis between DO, surface water temperature, and rainfall showed that the correlation was not significant (_P 0.5%). Results of regression show a weak relationship between rainfall to temperature (R^2 = 0.46), rainfall to DO (R^2= 0.04) and surface water temperature to dissolve oxygen (R^2= 0.37). The weak relationship of these parameters indicates that fish kill occurrence was believed due to the level of organic waste and triggered by the typhoon with strong winds because of the upwelling process.

The study recommends proper management in feeding and waste disposal of dead fish and water hyacinth and the development of preventive strategies designed to reduce the occurrence of fish kills in the lake.

Keywords: Fish kill, rainfall, temperature, dissolved oxygen

Introduction

Water temperature's physical properties depend on climatic variables such as air temperature (Webb *et al*., 2003; Mohseni and Stefan, 1999) [21, 15], dissolved oxygen (DO) (Sinokrot and Gulliver, 2000) [19], and precipitation. (Hoyer *et al*., 2009) [12] These climatic variables have a vital influence on biochemical reactions that occur within the water. Sudden changes in these variables may be indicative of the changing conditions of the water. (Hacioglu and Dulger, 2009) [10]. Water temperature is one of the important physical characteristics of the environment.

The amount of oxygen that can be held by water depends mainly on the water temperature (Garg, 2006 Agunwamba *et al*, 2006) [9, 1]. Water temperature is inversely related to the DO concentration. Any changes in the bodies of water, the water temperature varies its DO concentration. DO is inversely proportional to water temperature hence sudden increase in temperature will result in a low level of DO. However, another environmental factor such as rainfall may affect the condition and level of DO and temperature in the water. The effect of increases in air temperature and variability in precipitation on the tropical rivers will change the water temperature conditions. The decrease in rainfall mostly influences likely changes in water temperature. (Bello *et al*., 2017). DO is related to temperature and rainfall positively affects DO concentrations in the water (Munoz, 2015) [16]. Too much rainfall may decrease water temperature. The increase in water temperature is the decrease in DO.

Oxygen dissolves easier in cooler water than in warmer water. If DO concentrations drop below a certain level, fish mortality or fish kill rates will raise.

A fish kill occurs when a large number of fish in an area of water die off. It can be species-based or water-wide mortality. Fish kills can occur for several reasons, but low DO is often a factor. Oxygen depletion is one of the common causes of it. This hypoxic event may be brought on by high temperatures (Oregon State University, 2006) [17].

Some of the other factors are easily monitored and ruled out or blamed for fish kills, as the case may be. For example, ammonia and nitrite toxicities to milkfish have before been examined, and discounted, as causative factors of milkfish kills (Almendras, 1987; Cruz, 1981) [2, 5]. Literature suggests that most fish kills are brought on by climatological events that change the water chemistry of the receiving water (Barica, 1978; Mericas and Malone, 1984 Townsend *et al*., 1992) [20].

The fish kill is one of the major problems that harden every fish cage operator of Lake Buhi. According to Sallenave, 2013, this is suffocation due to a lack of sufficient oxygen. While in Buhi the most common cause of fish kills are depletion of DO, high surface water temperature, rainfall, algal blooms, and pollution. Buhi is not just known for Lake Buhi, but it is likewise the home to the world's smallest commercial fish locally known as the *sinarapan* (*Mystychtis luzonensis*). It has an area of 18 square kilometers (6.9 square miles) and has an average depth of 8 meters (26 ft). Lake Buhi serves as the main source of livelihood for the residents of Buhi because most of them are solely dependent on the lake for fish cage farming. The lake provides for many uses such as fishery, navigation, water reservoir for irrigation, hydroelectric power, and domestic water supply. The lake became the producer and supplier of cultured tilapia in the Bicol region and another adjoining province of the Philippines. Despite the success in the aquaculture industry, the lake often suffers from serious massive fish mortality or popularly known as a fish kill. BFAR Region 5 reported that in the past years Buhi Lake suffered from Fish Kill Occurrence since 1998 (Lake Buhi Water Quality Monitoring, 2013 - 2017).

Buhi has a tropical climate. There is a great deal of rainfall in Buhi, even in the driest month. The average annual temperature is 26.6 °C in Buhi. The rainfall here averages 2560 mm. Effects of temperature are generally sub-lethal, but in extreme cases, temperature and associated stressors can directly cause fish mortality (Beitinger *et al*., 2000). The most commonly reported instances of mortality attributable to high water temperatures are among fishes that become isolated in streambed pools for extended periods (Tramer, 1977; Matthews *et al*., 1982; Mundahl, 1990) or in receding lakes (Bailey, 1955). This study investigates rainfall, temperature, and DO in Buhi Lake and fish kill occurrences for the last five years (2013-2017). It will likewise investigate the relationship between surface water temperature, DO, and rainfall during the 6 months daily monitoring of Lake Buhi.

Study Area

Lake Buhi is situated at Buhi, Camarines Sur with geographical coordinates from 13°26'N, 123°30'E to 13°29'N, 123°31'E.

Fig 1: Buhi Lake shows the sampling stations.

Two sampling stations were selected on the lake based on the number of cages and frequency of fish kill occurrence. Station 1 is located between Barangay Tambo and Barangay Iraya at 23 meters and near Barangay Salvation at 14 meters deep. Station 2 is located between Barangay Ipil and Barangay St. Cruz with a depth of 10 meters; located at the center of the lake at 12 meters and the site between Barangay Tambo and Barangay Iraya at 23 meters and Station 4, near Barangay Salvation at 14 meters deep.

Materials and Methods

The average monthly precipitation and air temperature data year 2013-2017 in Buhi was obtained from Buhi Weather Forecast. The fish kill damage data were obtained from records on files of the Bureau of Fisheries and Aquatic Resources (BFAR), Lake Development Office (LDO), and Local Government (LGU) of Buhi and also from the news articles published on the internet.

The surface temperature and DO during the actual monitoring were collected using the Hobo Data Logger Model U26- 001. Measurement monitoring was done 3 times a day (6:00 am, 12:00 noon, and 6:00 pm) from June to December 2017. The data collected were subsequently analyzed using the Hobo Software. Rainfall and air temperature over the past years, 2013-2017 were included to discuss the possible causes of fish kill occurrence over the past 5 years. Descriptive statistics and regression were used for data analysis.

Results

Over the past years, Buhi Lake experienced this natural phenomenon called fish kill. It was due to low DO and high water temperature (BFAR, Lake Buhi Water Quality Monitoring, 2013 - 2017). The fish kill is locally called by the fishermen in Buhi “kanuba” for the sulfur smell that accompanies the phenomenon. The Kanuba is traced to upwelling, a sudden influx of warm water in the lake.

Monthly Analysis of Rainfall and Temperature, 2013-2017

The average maximum and minimum temperatures in Buhi Lake in the last five years were both highest in the summer month, May 2013-2017. The rainy season occurred mostly from June to December 2013-2017. During these months, fish kill occurred especially in August and November when most typhoons occurred in Buhi, Camarines Sur

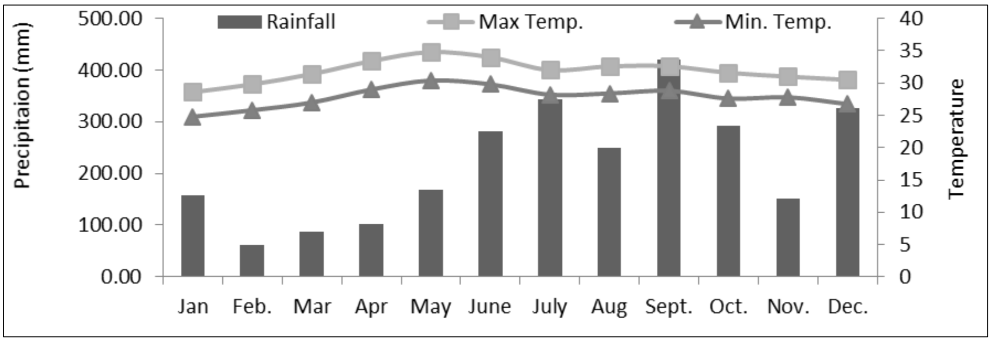

Fig 2: Mean Monthly Rainfall, Maximum Air Temperature, and Maximum Temperature last 2013-2017 at BuhiCamarines Sur (Buhi Weather Forecast, 2013-2017)

The peak rainfall month was September and the least amount of rainfall was experienced in February (Fig. 2). The period from February to May was a dry season because it’s the summer season in the Philippines. The highest temperature was 34.4 0C in May with a maximum of 34.8 0C and a minimum of 30.40C, while January was the coldest month with an average temperature of 28.2 0C. For the last 5 years (2013-2017), the months of June to October were the months recorded with the highest amount of rainfall. Often these months were the typhoon season in the Bicol Region.

Temporal Data Analysis

The time-series data from 2013-to 2017 on temperature and rainfall are shown in Table 2. The year 2016-2017 turned out the cooler years and is associated with more rainfall mainly in terms of the frequency of occurrence and abundance. It is also these years where fish kill occurred especially in the months when there were heavy rains and storms.

Table 1: Mean Rainfall, mean air temperature, minimum air temperature, and maximum air temperature last 2013-2017 of Buhi, Camarines Sur (Buhi Weather Forecast)

Period	Rainfall (mm)	Average Temp (^{0}C)	Min. Temp. (^{0}C)	Max Temp (^{0}C)
2013	193.80	30.83	30.83	27.00
2014	206.50	31.50	31.50	28.00
2015	186.71	32.50	32.50	28.08
2016	233.04	32.75	32.75	28.25
2017	275.77	30.00	31.82	28.09

The analysis also showed increasing trends in rainfall from 2013-to 2017 with the corresponding fluctuation in atmospheric temperature. Annual rainfall was cross-correlated with annual average atmospheric temperatures resulting in a moderately positive correlation (0.5 at 95% confidence limits).

Relationship of Rainfall and Temperature during Fish Kill Occurrence last 2013-2017

Rainfall and temperature were interrelated to the fish kill occurrence at Buhi Lake. Figure 3 showed the average monthly rainfall and temperature during fish kill occurrence from 2013-to 2017. Observation showed that most fish kills occurred from August to December when most rainfall was experienced.

The months of August to December had the highest amount of rainfall with a mean rainfall of 207.31mm compared to the months Jan-July (169.8) without fish kill occurrence (Figure 3). Months with fish kill had a relatively higher temperature (31^{o}C). Months without fish kill were the months with high atmospheric temperatures (32 ^{o}C).

During summer, the surface waters of the lake get warmer but the bottom water remains cold. Winds are mild and no longer strong enough to mix the whole water column or the deeper part of the lake. The cold water in the depth part of the lake can hold more oxygen than warm water. However, the need for microorganisms for biological oxygen demand (BOD) to decompose uneaten feeds, dead fish, and algae in the deeper part of the lake, depletion of oxygen was observed. This depletion is due to competition

Findings also showed that tropical storms often result in fish kills as evidenced by fish kill occurrences after Typhoon Maring (August 2013), Typhoon Lando (Oct. 2015), Typhoon Karen (Oct. 2016), Typhoon Salome (Nov. 2017), and Typhoon Urduja (Dec. 2017).

In 2013, thousands of fish cage operators were affected by the fish kill, according to BFAR, DO depletion was the causative factor possibly as a result of upwelling or lake overturn, which was triggered presumably by heavy rainfall associated with the prevailing southwest monsoon. A total of 120 MT of tilapias were devastated a few days after the oxygen level in the lake was nearly depleted. The oxygen was almost depleted and was aggravated by Typhoon Maring.

In 2015, another typhoon hit Buhi that eventually resulted in a fish kill event. Typhoon Lando caused an upwelling at the bottom of Lake Buhi, resulting in a massive fish kill of cultured tilapias. A total of 114 MT of tilapias were lost as a consequence of the typhoon. The typhoon deposit heavy rains into the lake, stirring decaying matters at the bottom that caused the generation of ammonia and the depletion of oxygen in the water.

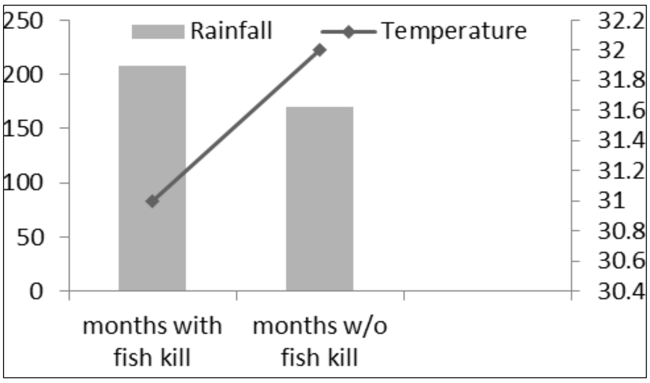

Fig 2: Mean Rainfall and Air Temperature of months with and without fish kills, 2013-2017 (Buhi Weather Forecast)

In 2016, Lake Buhi again suffered from massive fish kill with losses estimated at 148 MT. The losses were due to the aftermath of Typhoon Karen. Another fish kill occurred immediately after Typhoon Salome on November 9, 2017, and Typhoon Urduja on Dec 19, 2017, which brought 4.95 MT and 35 MT tilapias losses.

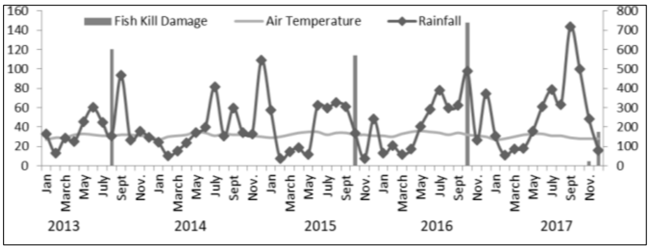

Fig 3: Relationship Air temperature and Rainfall to Fish Kill Damage during fish kills Occurrence over the past 5 years

The vast majority of fish kills in Buhi Lake occur between August and December which coincided with the month when there was the greatest monthly rainfall recorded. The months between January to July were the months without fish kill occurrence. Mean rainfall and air temperature were average to know their relationship during months with a fish kill and without (Figure2). Months with fish kill had a higher amount of rainfall (207.31mm) compared to those months without the fish kill. But on the contrary, the air temperature was lower compared to months without the fish kill.

Relationship of Dissolved Oxygen and Rainfall during Fish Kill, 2017

Actual daily lake monitoring in the lake for DO and surface temperature from June to December 2017 reveals that August to December 2017 were also the months with the most recorded fish kill occurrence. The mean DO and rainfall from June to July 2017 (without fish kill) and August to December 2017 (with fish kill) were obtained to analyze the relationship between the two variables. DO was lower during the rainy season and higher during months with less recorded rainfall.

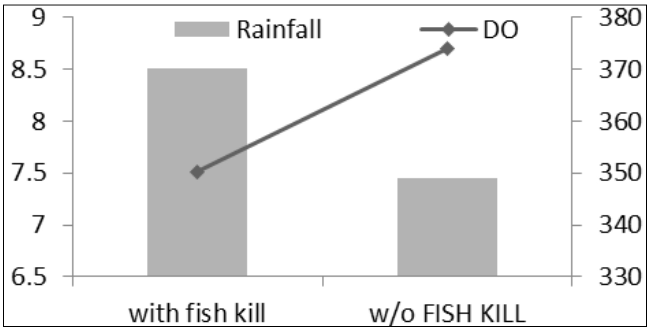

Fig 4: Mean Rainfall and Dissolved Oxygen of Months with and without fish kills, 2017

Analysis of Rainfall, Surface Water Temperature, and Dissolved Oxygen Before, During, and after Fish Kill at Buhi Lake

The daily surface water temperature and DO before, during, and after the typhoon from November 8 to10 and December 18 to 20, 2017 are shown in Table 2. According to the report of the Bureau of Fisheries and Aquatic Resources, fish kills occurred after the typhoon because most post storms were the result of low levels of DO in the water ("Philippine Daily Inquirer", 2016). Storms can wash large amounts of organic material into the water and the decomposition of organic matter consumes oxygen.

Table 2: The daily surface water temperature and DO before, during, and after the typhoon from November 8 to 10 and December 18 to20, 2017

Period	Rainfall (mm)	Dissolve Oxygen (ppm)	Surface Temperature (^{0}C)
11/08/17	0	8.4775	28.595
11/09/17	100	7.765	28.2875
11/10/17*	2	7.8175	28.06
12/18/17	11	7.38	27.61
12/19/17	28	7.53	26.6
12/20/17*	3	8.195	27.11

* Days when fish kill observed

During the lake monitoring, fish kill occurred immediately after Typhoon Salome on November 10, 2017. The partial fish kill event was noticed at around 4:00 to 6:00 A.M. at Barangay Ipil affecting 60% of the stock, most of which are fingerlings and adults and ready to harvest.

The second fish kill occurrence was noted on December 15, during Typhoon Urduja which caused damage to 21 fish cages in Barangay Iraya. The fish kill event was noticed early at around 5:00-6:00 A.M. A total of 35 metric tonnes of tilapias were affected. A huge number of water hyacinth was also noted in the area with a redolent smell where fish kill occurred. Rapid changes in DO and surface water temperature were also noted.

Results of regression showed a weak relationship between rainfall to temperature (R^2 = 0.46), rainfall to DO (R^2= 0.04) and surface water temperature to dissolve oxygen (R^2= 0.37).

Discussion

For the last five years (2013-2017) fish kill events occurred mostly during the rainy season from June to December. Most fish kills occurred in August and November which coincided with typhoons occurrence. It should be noted that between August through December, the monthly mean rainfall (207.31mm) was the highest. Based on recorded rainfall from 2013 -to 2017, an increasing rainfall trend is noticeable, hence, the corresponding fluctuations in atmospheric temperature.

The natural occurrence of mass mortality of fish can be related to physical processes (rapid fluctuation in temperature), water chemistry changes (low DO and/ or changes in pH) or they can be biological (viruses, bacterial infection, and/ or parasites (Hoyer *et al.*, 2009) [12]. But in the present study, tropical storm or post-storm scenario had a major role in fish kill occurrence in Buhi Lake. Storms can trigger fish kill as has been experienced after Typhoon Maring (August 2013), Typhoon Lando (Oct. 2015), Typhoon Karen (Oct. 2016), Typhoon Salome (Nov. 2017), and Typhoon Urduja (Dec. 2017). Abundant rainfall can dramatically change the water chemistry of a lake in many ways, so several mechanisms probably work independently or in concert to produce a fish kill. (Hoyer *et al.*, 2009) [12]. The typhoon or abundant rainfall caused an upwelling at the deeper portion of the lake, resulting in a massive fish kill of farmed tilapias. Upwelling is a process in which in the deeper part of the lake, cold water rises towards the surface. This cold water can hold more dissolved oxygen than warm water. The amount of oxygen that can be held by water depends mainly on the water temperature (Garg, 2006, Agunwamba *et al*, 2006) [9, 1]. There is also the reverse process called downwelling when the surface water eventually sinks toward the bottom. The upper part of the lake has a high water temperature with a low DO concentration. Moreover, typhoons also deposit heavy rains into the lake, stirring decaying matters at the bottom caused the generation of ammonia and the depletion of oxygen in the water. On September 22, 2007, the fish kill was blamed on sulfur dioxide from the nearby volcanoes that drain into the lake brought about by heavy rains from the southwest monsoon. Unfortunately, BFAR's findings were rejected by the Philippine Institute of Volcanology and Seismology (Phivolcs) (GMA News, 2007) [7].

The same situation was reported in Donkey Camp Pool, Australia, where a massive fish kill was caused by a large storm that increased an organic load with a high oxygen demand (Townsend *et al.*, 1992) [20]. Another documented fish kill was in Florida, where almost two million fish were killed in Rodman Reservoir after a storm brought almost 35mm of rain (Hoyer *et al*., 2009) [12]. In Florida, fish kills occurred in every month, in all three types of water, (canals, creeks, lakes) and the majority of fish kill events was associated with heavy monthly rainfall and the highest water temperature which decreases the ability of water to carry oxygen (Hoyer *et al.*, 2009) [12].

The actual data monitored both from the surface temperature and DO last June to December 2017 showed that rainfall and temperature had a weak relationship to the condition of the DO. DO was lower during the rainy season and higher during months with less rainfall. The present study contradicts the study conducted by Munoz *et al*., (2015) [16], which reported that DO values during the rainy season were higher than those during the dry period and significantly different.

The weak relationship between DO and surface water temperature indicates that the condition of DO in the lake sampling stations was believed due to the level of organic waste and not the surface water temperature. It was confirmed by the Bureau of Fisheries and Aquatic Resources, a fish occurrence at Buhi Lake was caused by toxic substances due to upwelling/overturned bottom soil that mixed with unconsumed feeds/feces (BFAR, Buhi Lake Monitoring, 2013-2017)

Meanwhile, the highly polluted water of Lake Buhi was the main cause of fish kill last 2010. A test was done by the BFAR, based on the results; the lake had very low DO and very high ammonia nitrogen concentration. Moreover, very high traces of hydrogen sulfide were detected (Philippine Information Agency, 2010). Ammonia is the major end product of protein catabolism excreted by fish. The unionized is highly toxic and when ammonia accumulates to toxic levels, fish cannot extract energy from feed efficiently. The fish will become weak and eventually fall into a coma and die if the ammonia gets high enough. (Hargreaves and Tucker, 2004) Ammonia is caused by decomposed organic matters like unconsumed feeds, industrial and domestic wastes, dead fishes, and the decomposition of phytoplankton.

In addition, hydrogen sulfide is another factor that contributes to the massive fish kill. It is a poisonous gas that arises from a by-product of decaying and decomposed organic matters like excess feeds, plant debris, dead phytoplankton, and fish feces (Philippine Information Agency, 2010).

During storms, there is a mixing process that happens at the depth part of the lake. Storms can wash large amounts of organic material into the water and the decomposition of organic matter consumes oxygen. This assumption is similar to the study of Akaahan *et al*.,(2016) that the low concentration of DO was not due to surface water temperature but due to the level of organic waste in River Benue. Hence, DO in the lake was independent of the surface temperature but the organic wastes from the excess feed. These wastes depreciate the concentration of DO from the activities of microorganisms on the brake down of the wastes. Another factor that contributes to the depletion of oxygen is the algae bloom. An algal bloom was observed before the fish kill occurrence. Water hyacinth contributed to the depletion of dissolved oxygen by blocking the sources of oxygen such as photosynthetic activity by phytoplankton and wind aeration. (Philippine Information Agency, 2010)

However, during algal die-off, decomposition uses oxygen in the water that would be available to fish in the lake. A similar situation was reported in Estoni where the fish kill was attributed to a combination of algae bloom and high temperatures in 2002 (Estonian Academy Publishers, 2005). Just as an algal bloom can lead to oxygen depletion, the introduction of a large amount of decaying biological material to a body of water leads to oxygen depletion as microorganisms use up available oxygen in the process of breaking down organic matter. (Contaminated Water Kills Fish in Central Illinois, 2016).

Fish kills generally occurred during the post-storm, triggered by the strong winds. Analysis like these will help fish cage operators understand and potentially predict the occurrences of fish kills and be able to exercise good aquaculture practices.

Conclusion and Recommendations

Months with high rainfall or typhoon were the months when most fish kills occurred at Buhi Lake while in dry months there was no fish kill observed.

The low level of dissolved oxygen was indirectly affected by rainfall, increase temperature (water and atmospheric) rather it was affected by the organic loads which are toxic to fish. This is because these parameters show a weak relationship. These organic loads, depreciated DO and heavy rainfall, and strong winds trigger the upwelling process which causes fish kill.

So, therefore, proper management in feeding and waste disposal of dead fish and water hyacinth and the development of preventive strategies designed to reduce the occurrence of fish kills in the lake was highly recommended.

References

1. Agunwamba JC, Maduka CN, Ofosaren AM. Analysis of pollution status of Amadi creek and its management. Journal of Water supply Resources Technol AGUA. 2006; 6(55):427-435.
2. Almendras JME. Acute nitrate toxicity and methemoglobinemia in juvenile milkfish (*Chanoschanos* Forsskål). Aquaculture. 1987; 61:33-40.
3. Biology and Ecology.Estonian Academy Publishers. p. 67.
4. Contaminated Water Kills Fish in Central Illinois Archived 15 April at the Wayback Machine, 2016.
5. Cruz ER. Acute toxicity of un-ionized ammonia to milkfish (*Chanoschanos*) fingerlings.Fish. Res. J. Philipp. 1981; 6:33-38.
6. Donigian AS, Crawford NH. Modeling Nonpoint Pollution from the Land Surface; US EnvironmentalProtection Agency: Athens, GA, USA, 1976.
7. Escandor J. GMA News TV, (2007, Sept. 22), Fish Kills hits Lake Buhi in Camarines Sur. Retrieved from, 2016, http://www.gmanetwork.com/news/news/regions/61561/fish-kill-hits-lake-buhi-in-camarines-sur/story/
8. Estonian Academy Publishers. Proceedings of the Estonian Academy of Sciences, 2005.
9. Garg SK. Sewage Disposal And Air Pollution Engineering. Environmental Engineering 18th edn. Vol. II. Khanna Publishers, New Delhi, 2006, pp. 228-278
10. Hacioglu N, Dulger B. Monthly variation in some physico-chemical and microbiological parameters in Biga stream (Biga, Canakkale, Turkey). Afri. J. Biotech. 2009; 8(9):1929-1937.
11. Hargreaves JA, Tucker CS. Managing Ammonia in Fish Ponds. SRAC Publication No. 4603, 2004.
12. Hoyer MV, Watson DL, Willis DJ, Canfield DE. Fish Kills in Florida's Canals, Creeks,/ Rivers and Ponds/ Lakes. J. Aquat. Plant Manage. 2009; 47:53-56.
13. Juneng L, Tangang F, Chung JX, Ngai ST, Tay TW, Narisma G, Singhruck P. Sensitivity of Southeast Asia rainfall simulations to cumulus and air-sea flux parameterizations in regCM4. Clim. Res. 2016; 69:59-77.
14. Lake Buhi fish kill brings P178M in loss. *Philippine Daily Inquirer*, Retrieved from, 2009, http://newsinfo.inquirer.net/827723/l ake-buhi-fish- kill-brings-p178m-in- loss
15. Mohseni O Stefan. HG Stream temperature/air temperature relationship: A physical interpretation.J. Hydrol. 1999; 218:128-141.
16. Munoz, Hipolito Orozco, Saturnino Vera, Andrea Suarez, Juan Garcia, Edelmira Neria, Mercedes Jiménez, José. Relationship between Dissolved Oxygen, Rainfall and Temperature: Zahuapan River, Tlaxcala, Mexico. Tecnologia Y Ciencias Del AGUA. 2015; 6:59-7.
17. Oregon State University. Deadly hypoxic event finally concludes" Archived 14 March 2011 at the Wayback Machine, 2006.
18. Philippine Information Agency. Lake Buhi's massive fish kill caused by highly polluted waters. Retrieved from, 2010, http://archives.pia.gov.ph/?m=7&r=R05&id=6277&y=2010&mo=11
19. Sinokrot BA, Gulliver JS. In-stream flow impact on river water temperatures. J. Hydrol. Res. 2000; 38/:339-349.
20. Townsend SA, Boland KT, Wrigley TJ. Factors contributing to a fish kill in the Australian wet/dry tropics. Water Res. 1992; 8:1039-1044.
21. Webb BW, Clack PD, Walling DE. Water-air temperature relationships in a Devon River system and the role of flow. Hydrol. Process. 2003; 17:3069-3084.