Duality of seasonal effect and river bend in relation to water quality in Chao Phraya River

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Abstract: The present study conducted field survey of water quality along the Chao Phraya River during the past three years. The objective was to better understand the spatial-temporal variations of water quality in this waterway by investigating the difference in water quality between the starting and ending periods of rainy season and how the water quality is affected by river bend. It assessed the water quality in terms of chemical parameters, bacterial and phytoplankton. The results revealed a duality of seasonal effect for nutrients. Rainy season degraded the water quality by increasing nutrient concentration in the waterway in the beginning and cleaned it up by dilution in the end. However, this duality did not apply to Escherichia coli (E. coli). Another duality found by this study is that there was no statistically significant difference in water quality in terms of chemical parameters between a river bend and the straight channel shortcutting the bend, but significant differences in the level of E. coli and phytoplankton community structure was observed between the two. Of particular note, the present study revealed a coexistence of a saproxenous species (algae found in clean water) with a harmful species in the bend river reach.

Keywords: Chao Phraya River, water quality variation, E. coli, phytoplankton, river bend

1. Introduction

Although river water quality has been studied either routinely by river management authorities or for various specific objectives by researchers, our understanding of spatial-temporal variations of water quality is still far from perfect. The present study conducted field survey of water quality along the Chao Phraya River during the past three years. The Chao Phraya River is the largest river in Thailand. Its basin covers an area of 159,000 km², accounting for 30% of Thailand’s land surface area, hosting 40% of the country’s population and generating 66% of the Gross Domestic Product (GDP). Chao Phraya basin is influenced by the south western monsoon and also the north eastern monsoon and, therefore, it creates three seasons in the area. Rainy season starts from May to October. Cool season is from November to the mid of February. Hot season starts from the mid of February to the beginning of May [1]. Up to now, the flood disaster is the central theme in studies related to the river. The water quality of the river was much less studied than flood and water resources management although the pollution is serious.

The main river from the confluence of four upstream waterways to the river mouth is 396 km long, which can be divided into three sections in terms of river classification based on water quality standards: lower (river km (RKM) 7 to 62), middle (RKM 62 to 142) and upper (RKM 142 to 379). Water quality standards in Thailand were established in 1994 and the surface water quality standards are classified into five classes, as shown in Table 1. The water quality standards are centered on dissolved oxygen (DO), biochemical oxygen demand and total coliform bacteria.
The Thai government’s Pollution Control Department (PCD) has been monitoring the water quality of Thailand’s major rivers over the past several decades. Monitoring data during the period 1984-1995 showed that water quality in the upper region of the Chao Phraya River was better than in the middle and lower reaches, as shown in Table 2 [2-3].

### Table 1 Water quality standard of Thailand

<table>
<thead>
<tr>
<th>Water quality parameter</th>
<th>Standard value for different class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved Oxygen (mg/L)</td>
<td>Class 1: Natural, &gt;6; Class 2: &gt;4; Class 3: &gt;2; Class 4: Very poor, not classified in class 1-4</td>
</tr>
<tr>
<td>Biochemical Oxygen Demand (mg/L)</td>
<td>Class 1: Natural, &lt;1.5; Class 2: &lt;2; Class 3: &lt;4</td>
</tr>
<tr>
<td>Total Coliform Bacterial (MPN /100 mL)</td>
<td>Class 1: Natural, &lt; 5,000; Class 2: &lt;20,000</td>
</tr>
</tbody>
</table>

### Table 2 Classification of Chao Phraya River by standard

<table>
<thead>
<tr>
<th>Distance from River Mouth (RKM)</th>
<th>River Classification (Class)</th>
</tr>
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<tbody>
<tr>
<td>7-62</td>
<td>Class 4</td>
</tr>
<tr>
<td>62-142</td>
<td>Class 3</td>
</tr>
<tr>
<td>142-379</td>
<td>Class 2</td>
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Monitoring results from the period 1993–2003 also identified the four most heavily polluted waterways in Thailand: the lower Chao Phraya River, the lower Ta Chin River, the lower Lam Ta Kong River, and Songkhla Lake [4]. The lower part of the Chao Phraya River was seriously polluted, especially from organic contamination. The most alarming water quality problem in this part of the river was low concentrations of DO during the dry period. DO levels of most monitoring stations were lower than the regulated value in the established water quality standard for industrial use (not less than 2 mg/L). The average DO value in this section from 1978 to 1999 was 1.7 mg/L and the P20 (20th percentile) value during that period of time was only 0.5 mg/L.

Although distinct spatial differences in water quality along the Chao Phraya River were identified and found to be highly related to anthropogenic stresses [5], the existing data were still insufficient to provide the details of spatial and temporal variations of water quality of the river. In particular, how the characteristics of water quality in the river course change with the change of season and within a season is still poorly understood. Furthermore, considering the fact that the population in Bangkok has been steadily increasing and there is a large variation in population distribution within the watershed, another research question is how the population distribution is linked to spatial variations of water quality. To answer these questions, field surveys were conducted along the Chao Phraya River in different seasons. The objective is two-fold. One is to characterize the overall spatial and temporal variability of water quality in the Chao Phraya River at present, with a particular focus on the effect of rainy season on water quality and the water quality variation in relation to river bend. Another is to probe into phytoplankton communities in the river course, which has not been previously reported.

Rivers flowing over gently sloping ground begin to curve back and forth across the landscape forming river bends. In the past, many rivers have been straightened by cutting off meanders to speed up the drainage of water and control/limit the river bed movements. Channelizing was also a way to gain land for cultivation. Flow dynamics and sediment transport in bends have been extensively studied [6-7] and the importance of bends to river ecology is well recognized. In recent years, re-meandering of rivers has become a common and widely applied river rehabilitation measure [8]. In addition to improving conditions for the biological quality elements, re-meandering could also help to improve habitats for birds and mammals that prey on fish and invertebrates.
Although river bends have been an important research target in various fields from river engineering and geomorphology to river ecology, field data of water quality variations along bends remains limited and the effects of bends on water quality remain poorly investigated. Therefore, the present study serves the purpose of enriching scientific literature with regard to water quality variation in relation to channel morphology.

2. Materials and Methods

A multi angle approach was employed to provide the characterization of water quality in the river. It assessed the water quality in terms of chemical parameters of water quality, bacterial and phytoplankton composition. It was also intended to examine the relationship between populations, channel morphology and water quality. Six water quality measurements were conducted along the Chao Phraya River between 2016 and 2018. Two of them were conducted in December and March, respectively, which were in dry season. Two were conducted in August and September, respectively, which were in wet season, and another two were undertaken in May, which was the transition period between wet and dry seasons. The number of sampling sites in these surveys ranged from 15 to 28 along the waterway from Nakhon Sawan, the starting point of the main Chao Phraya River, to downstream point 16 km from the river mouth. Particular attention was placed on both the longitudinal and lateral variations of water quality in two river bends located in highly populated lower reaches of the river course. The measured water quality parameters include water temperature, pH, chemical oxygen demand (COD), dissolved oxygen (DO), electrical conductivity (EC), nitrate (NO₃-N), ammonium (NH₄-N), orthophosphate (PO₄-P) and *E. coli*.

The *E. coli* detection was conducted using MicroSnap™ *E. coli* Test Kit, which is a rapid bioluminogenic method for detection and enumeration of *E. coli* bacteria. Samples taken from the survey sites were incubated in growth media for six hours. Then, detection device was activated and samples were further incubated for 10 minutes. At this time, a specific substrate reacts with diagnostic enzymes to produce light. The light generating signal is then quantified in the EnSURE luminometer.

In May 2018, phytoplankton communities in the river course were surveyed at 17 sites. Phytoplankton are free-floating, photosynthesizing microscopic biotic organism with a size range of 20–2000μm. Phytoplankton account for approximately 50% of global primary production, providing a food source for higher order organisms such as zooplankton and small fish. Since phytoplankton respond rapidly to changes within the surrounding environment, they may serve as an important biomarker for assessing the quality of water, as well as being an indicator of water pollution. Seventeen sites were sampled from the middle stream of the Chao Phraya River to a downstream point 16 km from the river mouth. For every 1 L of collected water sample, 15 mL of Lugol’s solution was added for plankton preservation. Lugol’s solution is a harmless solution made from potassium iodide and iodine, which can add weight to cells to facilitate plankton settling and stains cells a dark brown color to make identification and counting easier.

For phytoplankton analysis, a Leica DM 750 Microscope was used for the identification and enumeration of phytoplankton species. Identification of phytoplankton species was based on morphological and other visible criteria with referencing to key literature and websites for phytoplankton identification. A plankton chamber with 400 grid boxes with a length of 0.5 mm was used for cell counting. The 10 times eyepiece and 20 times objective lens were used, allowing images with 200 times magnification to be obtained so that phytoplankton could be clearly observed and counted.

Mann-Whitney U and Kruskal Wallis tests were used to identify significant differences (p<0.05) in water quality between bend and straight channel.

It should also be mentioned here that the main attention of this paper was focused on nutrients, *E. coli* and phytoplankton in the river course, as less information of this type already exists. Moreover, the watershed population distribution map was used as the base map for all figures presented in the paper. Overlaying such information clearly shows how many people may live with degraded water.
3. Results

3.1. Overall patterns of spatial-temporal variation

Overall, the spatial variations of water quality in terms of chemical parameters in the longitudinal direction were similar to those reported in the 1990s. Water quality in the upper and middle reaches of the Chao Phraya River was better than in the lower reaches. Low DO concentrations in the lower reaches, as shown in Fig. 1, in particular remain a serious concern. Although DO was higher in the wet season than the dry season, it was still under-saturated, as shown in Fig. 2.

![Fig. 1 DO distributions at the beginning and later half of wet season](image1)

![Fig. 2 DO saturation](image2)

With regard to nutrient levels, previous studies [9-11] have reported the correlation between flow discharge and nitrate concentration. For nitrate in particular, since it is highly soluble, it may be expected that the concentration increases as water flow increases. However, the present study found that nitrate concentrations were high in dry season and at the beginning of wet season as well. At one downstream site, the nitrate concentration was very high at the beginning of the wet season, but decreased during the latter half of the wet season (Fig. 3). This suggests that flood waters have a diluting function, reducing nitrate concentration by the end of the wet season. The study by Thimakorn also reported high concentrations of nitrate at the river mouth and considered nitrate as the most significant factor in causing oxygen depletion [12]. The present study confirmed the occurrence of high nitrate in the downstream reach, but showed that nitrate was not correlated to low DO.
For NH₄-N and PO₄-P, concentrations along the river course in the latter half of the wet season in 2018 were much lower than concentrations at the beginning of the wet season in 2017 (Fig. 3). This again implies the cleaning function of flood waters.

Fig. 3 The spatial-temporal variation of NO₃-N

The spatial variation pattern of E. coli in wet season is sag-curved as depicted in Fig. 5. It is higher in the upper and lower parts than the middle. The reason for this is that there are inadequate and/or an unavailability of waste water collection and treatment facilities along the Ping and Nan rivers – the headstreams of the Chao Phraya River. The Chiang Mai Metropolitan Area has a population of nearly one million people and has been attracting over 5 million visitors each year. Therefore, during the wet season, large amounts of waste water could be transported into the waterways by overland surface runoff. It was reported that the total Coliform Bacteria at Ratanakosin bridge and Kanjanapisek Garden in Chiang Mai exceed 1.6 Million MPN/100 ml [13], which is at least 320 times the regulated standard surface water quality in Thailand. In the upstream, it was observed that some public toilets were even placed on the river bank and waste water was directly discharged into the waterway. It is also clearly seen from Fig. 4, the less populated upstream area has a problem with E. coli of the same magnitude as the much more populated downstream area, which is caused by contamination dispersion from headwater regions. In Bangkok, the high level of E. coli contamination was caused by the large population, as evidenced by the fact that the levels of E. coli upstream of Bangkok were very low. Such disproportionality between population and
contamination is an issue of environmental ethics. More rigorous river management should be
implemented in Chiang Mai Metropolitan Area for the well-being of residents in both Chiang Mai
Metropolitan Area and Nakhon Sawan Province.

During the dry season, however, *E. coli* were found to be at much lower levels. According to the
meteorological information for Thailand, sun hours are higher during the dry season than rainy
season (https://www.timeanddate.com/weather/thailand/bangkok/climate). In addition, cloudiness
is low during the dry season. Since the effect of sunlight exposure on pathogen survival has been
well documented, the low levels of *E. coli* present during the dry season may be explained by the
strong UV radiation occurring during the dry season, which may inhibit *E. coli* growth.

Figure 6 shows that there was a high spike of *E. coli* (880 CFU/ml) at the beginning of the rainy
season in 2018, at a downstream site located in the most populated area. It is similar to the first flush
effect for nutrients in storm water runoff from catchment. However, the rainy season did not
manifest the cleaning effect in the latter half of the season.

**Fig. 6** The spike of *E. coli* at a downstream site

3.2. Spatial-temporal variation along river bends

Koh Kret (sometimes spelled Koh Kred or Ko Kret) in Bangkok, where the natural landscape
domines and concrete paths are too narrow for cars, is an artificial island that was cut off from the
city by an 18th-century canal, a shortcut in a bend in the Chao Phraya River. In the Ayutthaya Period,
when boats were a major mode of transportation between the old capital and the lower parts of the river as well as the Gulf of Siam (now the Gulf of Thailand), travelling along this winding section of the waterway took a long time so in 1722 King Thai Sa ordered the construction of the shortcut, shortening the distance by 75%. Unlike many other shortcuts in waterways around the world, the bend was not turned into land. Therefore, it provides a good site to study how water quality in a bend may be different from that in a shortcut.

Downstream of Koh Kret, the Khlong Lat Pho Floodgate Project led to the construction of a shortcut through the river bend at Bang Krachao. It shortened the river bend from 18 km to only 600 m. The shortcut canal is gated on normal days and open when there is a large flood. Water quality measurements were conducted along the two bends and the straight canal at Koh Kret. However, the Klong Lad Pho canal was not surveyed due to its closure.

For chemical parameters of water quality, statistically significant differences in concentrations between the bend and straight canal were not found. However, *E. coli* levels behaved differently. At the beginning of the wet season in 2018, the levels of *E. coli* in the bend of Koh Kret were lower than in the straight canal (Fig. 7) and *E. coli* was not detected at all along the Bang Krachao bend. However, a large spike (880 CFU/ml) was detected at a location upstream of the bend. In the latter half of the wet season in 2017, the levels of *E. coli* in the bend of Koh Kret were also lower than the straight canal. It was also found that the level of *E. coli* in the Bang Krachao bend varied significantly from being low on the right bank side to high on the left bank side (Fig. 9). Since the largest slum in Bangkok is situated next to the left bank, the high level of *E. coli* on the left bank side may be attributed to waste water discharge from the slum.

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The sampling locations for the phytoplankton survey, and the number of species identified at each location, are shown in Fig. 8. On the left bank side of the Bang Krachao bend, the number of phytoplankton species was the highest among all survey sites.

Seven species were found in 16 of the 17 survey sites. These comprise (1) *Arthrospira platensis*, (2) *Oscillatoria* sp., (3) *Oscillatoria tenuis*, (4) *Aulacoseira islandica*, (5) *Cyclotella meneghiniana*, (6) *Cyclotella* sp., (7) *Scenedesmus acuminatus*.

*Arthrospira platensis*, also known as Spirulina, is a gram negative, non-toxic species of cyanobacteria and known across the world for its potential nutritional value. The most important factor that governs its growth is the presence of light. Although it is non-toxic, its excessive growth will produce an unattractive surface scum. Nevertheless, it is a very efficient producer of oxygen and, unlike other green algae, does not consume oxygen during the night [14]. Therefore, if this type of blue-green algae were removed, oxygen levels would drop further with the potential for major fish kill.
Oscillatoria is a genus of filamentous cyanobacteria common in freshwater environments, deriving its name from its slow oscillating movement, and comprising more than 100 species. Due to its capability to slide back and forth, Oscillatoria can orient itself towards a light source so that it can grow under less favorable light condition. In addition, it can produce both anatoxin-a and microcystins. Oscillatoria tenuis produces geosmin and 2-methylisoborneol (MIB) simultaneously, which account for many odor problems in freshwater water [15-17]. The Aulacoseiraceae family is one of the oldest freshwater diatom families, long and filamentous in shape [18]. Cyclotella meneghiniana is also a large diatom with a diameter of 5–43µm. Cyclotella sp. is a small, centric diatom with cells only 3-5 µm in diameter and that may be used as important indicators of environmental change. Unlike most of the colonial green algae that form long filaments, Scenedesmus acuminatus is a green alga having small chains of four cells, with the potential to be used for biodiesel production.

At the river bend of Koh Kret, the dominant species was found to be Oscillatoria tenuis, which is an odor-producing species. In the straight canal, however, the phytoplankton community was dominated by Botryococcus braunii, which is a green, pyramid-shaped planktonic microalga. Blooms of Botryococcus braunii have been shown to be toxic to other micro-organisms and fishes. However, Botryococcus braunii is regarded as a potential source of renewable fuel because of its ability to produce large amounts of hydrocarbons [19]. The use of algal hydrocarbons can greatly reduce the environmental impact associated with using coal and petroleum. Also, a study suggests that metabolic active biomass of B. braunii could be used for copper removal from solution while it produces appreciable quantities of hydrocarbons.

It was also found that, among the 17 survey sites, Cymbella affinis was present only at the bend of Koh Kret. As a saproxenous species (algae found in clean water), Cymbella affinis can be used as an indicator of river pollution [20-21]. Therefore, the bend of Koh Kret may be characterized as having the coexistence of saproxenous and odor-producing species. Further in-depth study of such coexistence is needed for better river management.

Figure 9 presents a zoom-in view of nutrients along the two river bends measured during the latter half of the rainy season in 2018. Nitrate concentrations were more or less the same along the two bends while the highest ammonium concentration occurred where the spike of E. coli was detected. It can also been noted that phosphate concentrations were high in the in the Bang Krachao bend where the number of phytoplankton species identified was the highest among all survey sites.
4. Discussion

The first flush phenomenon has been reported in previous studies. However, these studies were focused on a storm event. Therefore, a first flush usually refers to the initial surface runoff of a rainstorm when the first runoff has high concentration relative to runoff later in the storm event. The findings of the present study suggested this concept may also be applied to a rainy season, which can be termed as seasonal first flush. More importantly, the present study proposed a new concept of duality of seasonal effect. Expanding the notion of the first flush in such a way highlights both the negative and positive roles of rainy season, which may lead to better understanding of river dynamics and better river management as well. Besides, the present study also indicated that such a duality was not observed for E. coli. This implies a continuous loading of E. coli from the watershed to the river during rainy season. Because the flood risk along the Chao Phraya River is high, the E. coli-contaminated flood waters coming out the river channel will cause not only economic damage but also health damage. Besides, since Bangkok is one of the world’s top tourism destinations, and boat trip along the Chao Phraya river is a big attraction to visitors, high level of E. coli in the river can be considered a health risk to tourists. Nevertheless, the flood-related health issues have been largely overlooked up to now. On the other hand, since the number of visitors to Thailand peaks in August as shown in Fig. 10, the high level of E. coli in rainy season may be partially attributed to tourists. Therefore, tourists in Bangkok could be both the victims of E. coli and one of the causes of the contamination.

Furthermore, as shown by the present study, the high level of E. coli on the left bank side of Bang Krachao can also be considered as partially related to Khlong Toey, one of the largest low-income communities in Bangkok. Therefore, eliminating the health risk is not simply a matter of sewer construction. It requires innovative solution.
For the relationship between water quality and river bend, field data suggested another type of duality in relation to river bend. A river bend may be effective in reducing E. coli on one hand, but may host harmful algae on the other hand. In addition, the fact that the number of phytoplankton species in the bend of Bang Krachao, which is located in an urbanized and populous area, was significantly higher than all upstream sites is a proof that our understanding on river ecosystem is still very much limited.

Studies on river meanders have tended to focus on ecological functions of river bend and discussions on possible negative aspects of river bend are missing in scientific literature. The present study serves as a call for more comprehensive studies on river meanders ecologically and socially.

5. Conclusions

The present study revealed a duality of rainy season with regard to water quality. High water quality may cause water quality deterioration around the beginning of rainy season but improve water quality via dilution in the end.

For E. coli, the situation is different. While nutrient concentrations were diluted during the latter half of the rainy season, levels of E. coli remained high. During the dry season, however, the levels of E. coli were suppressed, probably owing to the high levels of solar radiation reaching the water surface. Besides, the spatial variation of E. coli along the main Chao Phraya River was found to be a sag curve, having high levels in the upstream and downstream.

The comparative observation between bend and straight canal found no significant differences in the chemical parameters of water quality. For phytoplankton, Oscillatoria tenuis, a harmful odor-producing algae, was identified as the dominant species at the bend. However, a saproxenous diatom species was found to coexist with Oscillatoria tenuis at the bend. In the straight canal, Botryococcus braunii, which can be used to produce biofuel, was dominant. A lesson learned here is that although a river bend is an important ecological habitat, it may also be utilized as a breeding ground by harmful species. On the other hand, as river restoration projects aiming to increase habitat heterogeneity by re-meandering straightened reaches have gained momentum, straight channels are perceived as being of low ecological value, the findings of the present study indicated that straight channels may have bioenergy-related beneficial values, which have not been previously recognized. The present study also suggests that the presence of Arthrospira platensis in the waterway can be considered beneficial due to its oxygen production in this oxygen-deficient river.

Author Contributions: Huang designed this study, carried out all surveys together with other authors and prepared this manuscript. Xue and Liu participated in all field works and data processing and Liu was also involved in phytoplankton identification and enumeration. Chaiwat and Thada contributed to this study by joining field works, advising on sampling site selection, some instrument preparation and logistics as well.

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References


