Assessment of water quality variation in Amite River watershed under changing climate and land use

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Abstract Water quality in the Amite River watershed in southeastern Louisiana, USA, has experienced significant spatial and temporal variations over the past decades due to the impacts of land-use change and climate change. To identify water quality variation trends in the watershed under the combined effects of land-use and climate change, a temporal trend analysis and a spatial variation analysis were conducted using a statistical approach and long-term time series data for land use, flow, and water quality parameters including water temperature, dissolved oxygen (DO), total suspended solids (TSS) and total organic carbon (TOC). To understand spatial variation in water quality, the data were split into upstream (Darlington) and downstream (Port Vincent) sets. To understand temporal variation in water quality, the data were split into two groups corresponding to the means of the two periods 1975–1990 and 1990–2005. Results of the statistical analysis show that the global warming has led to an increasing trend in water temperature and a decreasing trend in instream DO, especially in summer months. The mean DO concentration at Darlington dropped from 8.35 mg/L before 1990 to 5.90 mg/L after 1990 due to climate change. The DO concentration at Port Vincent further dropped from 6.76 mg/L before 1990 to 5.75 mg/L after 1990 due to combined effects of land-use and climate change. The DO variation follows a normal distribution. The TSS concentrations were higher at downstream sites in general due to urban development, but no significant temporal variation trend was observed. The TOC concentrations increased over the past decades. Land cover and land-use change also produced a significant increase in TOC concentrations from upstream to downstream sites. The resuts demonstrate that land-use and climate change may adversely affect water quality and the impact of land use and climate change should be taken into account in Total Maximum Daily Load development and water resources management.

Key words watershed; water quality variation; land use; climate change; Amite River, USA

INTRODUCTION

The Amite River watershed is located in southeastern Louisiana, USA, and it encompasses a drainage area of approximately 3435 km^2, as shown in Fig. 1. The Amite River flows generally southwestward to the Lake Pontchartrain estuary that is connected to the Gulf of Mexico. The watershed experiences the typical subtropical humid climate with mild winter and abundant rainfall (1500 mm/year). The monthly maximum temperature is observed in July, averaging 27.8°C, and the monthly minimum is recorded in January, averaging 11.7°C. Land use in the Amite River watershed is characterized by hardwood forest in the north and swamp and urban in the south. The 1992 land use classification by USGS–GIRAS shows that nearly 47% of total area is forest land while agricultural and urban areas account for 25% and 6%, respectively. The agricultural area mainly includes rice, sugarcane, soybean and wheat. The Baton Rouge metropolitan area is also in the watershed. The Amite River is the east boundary of East Baton Rouge Parish and most wastewaters from the parish drain into the Amite River because an extensive levee system along the Mississippi River limits the drainage from East Baton Rouge Parish into the Mississippi River. The Amite River watershed has experienced significant changes in water quality due to the impacts of land-use change and climate change. As a result, the Lower Amite River (Subsegment 040303) is on US EPA's 2006 Impaired Water 303(d) List because it was "not supporting" its designated use of Fish and Wildlife Propagation. The Lower Amite River is impaired for dissolved oxygen, nitrate/nitrite, chlorides and total phosphorus. The suspected causes of impairment were organic enrichment. The Amite River was subsequently scheduled for the development of a Total Maximum Daily Load (TMDL). The draft TMDL report is still under US EPA's review and thus no pollution reduction measures have been taken to reduce the impairments. While point and nonpoint source reductions were recommended in the TMDL report and major efforts have been made to restore the Amite River (Mishra & Deng, 2009; Jung &

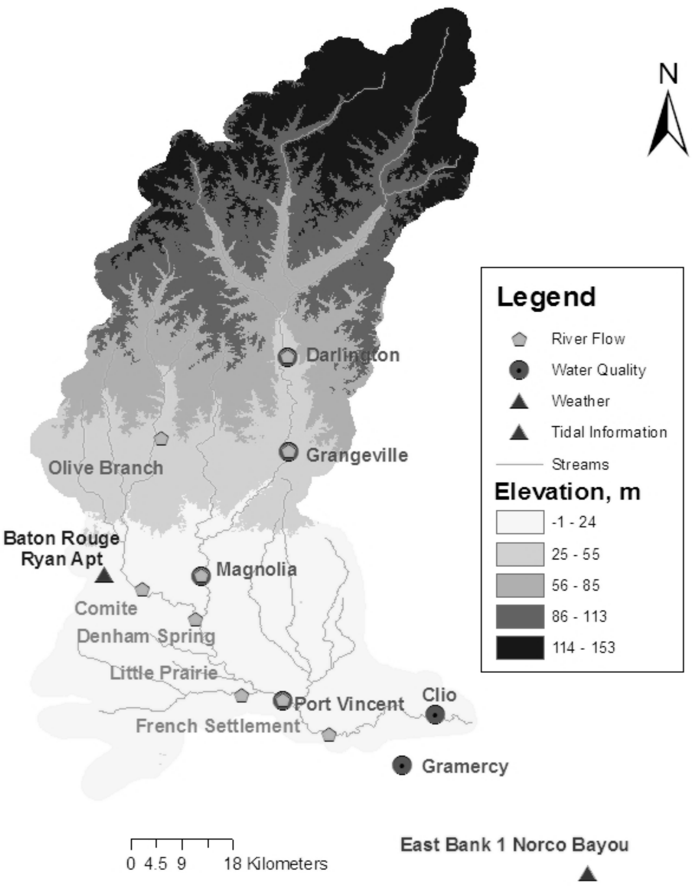

Fig. 1 Map of the Amite River watershed.

Deng, 2011; Patil & Deng, 2011), effects of climate change on water quality are rarely taken into account in TMDL calculations.

The overall goal of this paper is to assess water quality variation trends in the Amite River watershed under the combined effects of land-use and climate change. The specific objective of the paper is to understand the temporal trend and the spatial variation in water quality in the Amite River watershed.

MATERIALS AND METHODS

The water quality variation in the Amite River watershed was assessed by conducting two types of data analysis: a temporal trend analysis and a spatial variation analysis. The temporal trend analysis was intended to assess the impact of climate change on water quality. The spatial variation analysis was implemented to evaluate the effect of land-use change on water quality. The area upstream of Darlington is primarily forest land without significant anthropogenic disturbances. Any temporal variation trend in environmental parameters at Darlington is attributed to the effect of climate change, while water quality change in downstream areas may be caused by combined effects of land-use and climate change. Both the temporal and the spatial analyses require long-term time series for environmental data including water quality, streamflow and hydrometeorological data. The data covering different periods during 1939–2010 were collected from various sources such as the USGS, the US EPA, and the Louisiana Department of Environmental Quality.

The temporal trend analysis of long-term data such as water temperature, peak streamflow, and land-use change was conducted on an annual basis. To understand temporal variation in other water quality parameters, the data were split into two groups corresponding to the means of the two periods 1975–1990 and 1990–2005 for the Amite River. To understand spatial variation in water quality, the data were split into upstream and downstream sets for the river. The spatial analysis involves two steps: (1) frequency analysis was performed by plotting histograms of the occurrence frequency (%) of different concentration ranges for each water quality parameter; and (2) several probability density functions (PDFs) such as the gamma, general extreme value, normal, log-normal and Weibull distributions were used to fit the histograms. The best-fit PDF was selected based on the highest value of the Kolmogorov-Smirnov (KS) statistic. The KS statistic serves as a goodness-of-fit test and has been used in various hydrological studies (Patil & Deng, 2010, 2011). The statistical parameters such as mean, median and standard deviation for the best-fit distribution were determined using Easyfit and Minitab software to understand spatial variations in water quality. The PDFs were used to assess the watershed-scale water quality variation.

RESULTS AND DISCUSSION

Climate change

Louisiana's climate has always been variable and sometimes extreme—and global climate change may intensify this historical pattern. Average air temperatures in Louisiana and in the Amite River watershed have varied substantially over the past century, with a warming trend of about 1°F (Fahrenheit) since the late 1960s (Keim *et al*., 2008; Karl *et al*., 2009), leading to an increasing trend in water temperature especially in summer months from June to September, as shown in Fig. 2. Extreme rainfall events, primarily thunderstorms, have increased during the 20th century, causing a significant increase in peak streamflow discharges, as shown in Fig. 3. While rainfall totals have changed little, seasonal trends are apparent. Winter average rainfall has increased slightly and summer totals have decreased somewhat (Twilley *et al*., 2001). The climate change may have a profound impact on water quality in the Amite River watershed, as discussed below.

Land-use and land-cover change

Land use in the Amite River watershed was mostly forestry and agriculture in the 1950s. However, a latest survey has indicated a marked change in land use and land cover, as shown in Fig. 4. With the increasing urban development and agricultural land use, the forest land has dropped from 60% in 1954 to 27% in 1985. The drastic change in land use and land cover generally increases both streamflow and nonpoint source discharges of pollutants and nutrients to streams, causing the

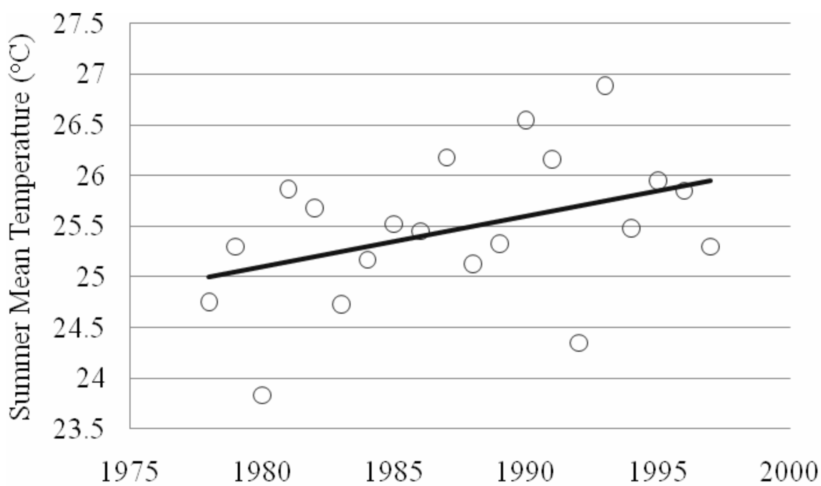

Fig. 2 Summer mean water temperature of the Amite River near Darlington, Louisiana.

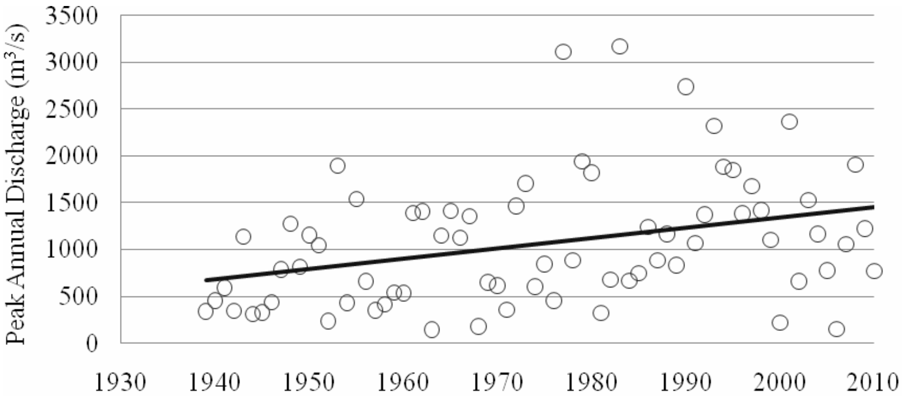

Fig. 3 Peak annual streamflow of the Amite River near Denham Springs, Louisiana.

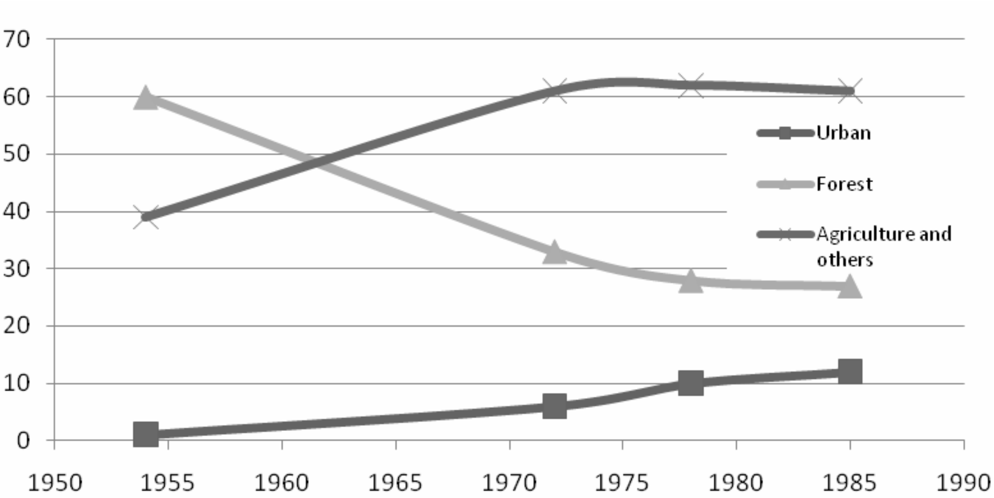

Fig. 4 Land-use (%) change in the Amite River watershed.

deterioration of water quality in the watershed. While the land use and land cover data for the period from 1985 to present are not included in Fig. 4, the variation trend in land use has not been changed significantly since 1980 (Jung & Deng, 2011).

Water quality variation

Based on the long-term water quality data, probability distributions (%) of water quality parameters including DO (dissolved oxygen), TSS (total suspended solids), and TOC (total organic carbon) are plotted against the concentration (mg/L) for both upstream (Darlington) and downstream (Port Vincent) sites, as shown in Fig. 5(a)–(f). Each plot contains probability distributions (%) for two time periods: 1975–1990 (dotted) and 1990–2005 (solid line). The dissolved oxygen is a function of temperature, which follows a normal distribution. Hence, the overall dissolved oxygen is normally distributed. Probability distributions for TSS and TOC vary in a wide range and follow a 3-parameter log-normal distribution. The skewed behaviour of these distributions can be attributed to precipitation, which follows the log-normal distribution. A higher runoff is often generated at high precipitation rates driven by climate change, leading to higher pollution loads to the Amite River. The probability plots confirmed that the data of each parameter fall into the 95% confidence interval zone of the respective probability plot, which confirmed the distribution selection.

The mean dissolved oxygen at Darlington dropped from 8.35 mg/L before 1990 to 5.90 mg/L after 1990. The marked decrease in DO, especially in summer months (Patil & Deng, 2011), was

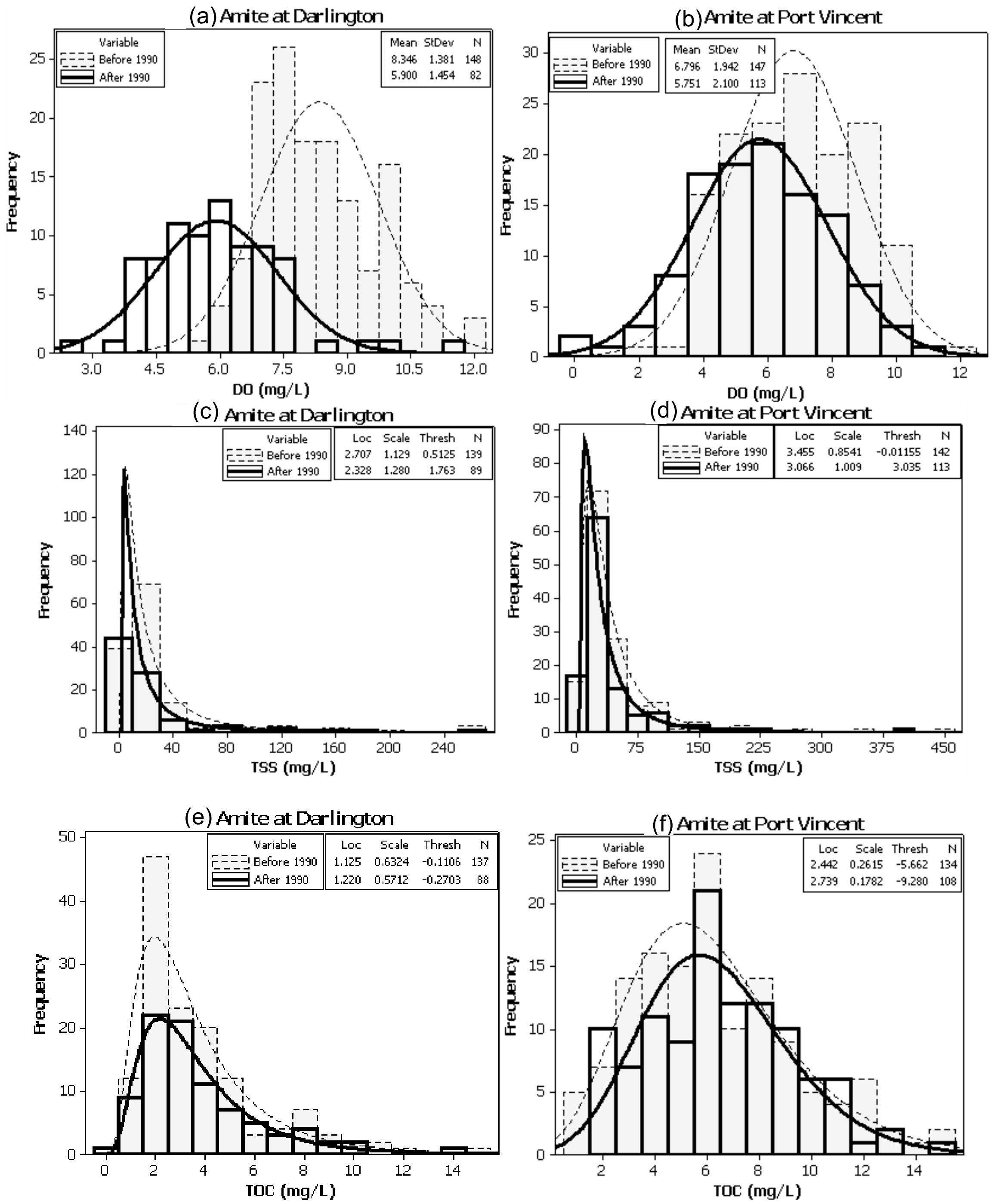

Fig. 5 Probability distribution of water quality parameters in Amite River watershed.

consistent with the increase in water temperature shown in Fig. 2 due to climate change. The DO at Port Vincent further dropped from 6.80 mg/L before 1990 to 5.75 mg/L after 1990 due to combined effects of land use and climate change. The PDFs for dissolved oxygen, Fig. 5(a) and (b) also showed that the high DO concentration at both stations varied around 12 mg/L while the low DO concentration at the Port Vincent was close to 0 mg/L. The low water quality in Port Vincent was primarily a result of urban discharges from the Baton Rouge Metropolitan area. The standard deviation at the upstream site (Fig. 5(a)) in the period 1990–2005 was higher than that of the period 1975–1990. As observed in Fig. 5, although the high limits were the same, the low limits were stretched towards zero, resulting in a higher spreading and hence a higher standard deviation and the shift of mean DO towards the left of the graph.

The sediment discharges were driven by rainfalls and hence have high variability due to the instantaneous stormwater runoffs and urban drainages. The erosion and flushing of stormwater carry sediment loads to streams. The TSS had a high limit at the downstream site (Fig. 5(d)) than the upstream site (Fig. 5(c)). In other words, the mean TSS concentration increased significantly from the upstream site to the downstream site, indicating the effect of land use on water quality. The high TSS concentration represented the effect of stormwater runoff from the southern urban areas including Baton Rouge. No significant temporal variation trend was observed in TSS.

Figure 5(e) and (f) indicated that PDFs for TOC varied in the same concentration range at both upstream and downstream sites. While the TOC concentration at each site had increased slightly with time due to climate change, the TOC concentration increased significantly from the upstream to the downstream sites, demonstrating the effect of land-cover and land-use change in the watershed. This spatial variation trend was clearly seen in the shapes of histogram at upstream and downstream sites (Fig. 5(e) and (f)). The PDFs for TOC concentration shifted from 3-parameter log-normal distributions at the upstream site to normal distributions at the downstream site. This shift was observed due to consistent carbon loading from watershed in the same range of concentration.

CONCLUSIONS

Water quality in the Amite River watershed has experienced significant spatial and temporal variations over the past decades due to the impacts of land-use change and climate change. The global warming has led to an increasing trend in summer water temperature and a decreasing trend in instream DO especially in summer months. Increasing urban and agricultural areas further decrease the DO levels. The mean DO concentration at Darlington dropped from 8.35 mg/L before 1990 to 5.90 mg/L after 1990 due to climate change. The DO concentration at Port Vincent fell from 6.76 mg/L before 1990 to 5.75 mg/L after 1990 due to combined effects of land-use and climate change. The dissolved oxygen variation follows a normal distribution.

The TSS concentrations were higher at the downstream site in general due to urban development, but no significant temporal variation trend was observed. Total organic carbon concentrations increased over the past decades. Land-cover and land-use change also produced a significant increase in TOC concentrations from upstream to downstream sites. The results demonstrate that land-use and climate change may adversely affect water quality and their impact should be taken into account in TMDL development and water resources management.

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