

Comparison of Fecal Coliform Before and After Wastewater Treatment Facility: a Case Study near a Coastal Town in the Southeastern USA

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Abstract A central wastewater treatment facility was built in 1997 for the town of Suwannee that eliminated 850 inadequately operating on-site sewage treatment and disposal systems. During a study in 1989–1990, *Salmonella* were detected in Suwannee River water samples upstream and downstream of the town of Suwannee. This study presents the findings of fecal coliform distribution between the years 1996 and 2009 in canals and the main stem of Suwannee River near the town of Suwannee, a coastal area in southeastern USA. Fecal coliforms were measured and assessed to evaluate the water quality before and after the installation of the central wastewater treatment facility. In the canals nearby the town of Suwannee, significant differences in fecal coliform concentrations were detected between the samples collected before and after the operation of the central wastewater treatment facility. Average fecal coliform of 537 most probable number (MPN)/100 ml in the canals in 1996 was reduced to 218 MPN/100 ml after the operation of wastewater treatment facility. The fecal coliform levels in canals decreased significantly in the last 13 years. Even though the average fecal coliform levels in the river was reduced from 170 to 86 MPN/100 ml before and after the installation of

the wastewater treatment facility, respectively, the difference was not statistically significant.

Keywords Fecal coliforms · Suwannee Sound · Coastal ecosystems · On-site sewage · Indicator bacteria

1 Introduction

Pollution, floral and faunal changes, and physical alteration of the environment in coastal ecosystems are under increasing stress from a variety of human activities (Vitousek et al. 1997). Recreational and commercial uses of bays, inlets, estuaries, and rivers affect surface waters of coastal areas. Bacteriological contamination is a major problem in such areas. Pathogenic enteric bacteria enter the environment from human or animal excreta (Dadswell 1993). Fecal coliform bacteria are a constituent of human sewage and animal waste and can be found in natural waters. A few strains of coliform bacteria can cause serious human illness, but their abundance is primarily used to assess the potential for the presence of other more virulent pathogens associated with sewage (Smith 2000).

Degradation in water quality from fecal contamination may increase health hazards to recreational users (Gersberg et al. 1995). Both direct contact with contaminated water and consumption of contaminated oyster and shellfish can lead to human illness and even death (US Food and Drug Administration 1995; Ford and Colwell 1996). In aquatic environments,

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fecal coliforms are used as indicators of enteric pathogenic organisms (Noble and Fuhrman 2001). Bacteriological contaminations are regularly monitored to ensure that water bodies meet established surface water quality standards (Chigbu et al. 2005). Fecal coliform bacteria density count is the current standard for detection of fecal pollution in surface waters (Kelsey et al. 2003). Important sources of fecal coliform bacteria in water bodies include wildlife, sewage effluents, failing septic systems, and runoff from farm animal feedlots and agricultural lands (Hunter et al. 1999; Crowther et al. 2002).

In surface waters, fecal coliforms peak after a rain event (Ferguson et al. 1996; Mallin et al. 2001). These coliforms decrease or disappear from the water column through death and sedimentation processes and can concentrate in sediments at high densities (Bergstein-Ben Dan and Stone 1991). Coliform bacteria can be resuspended after sedimentation in shallow waters. Resuspension of these coliforms may be caused by winds and tidal movements (Bordalo 2003), storm surge (Field and Pitt 1990), dredging (Grimes 1980), recreational activities such as boating, and increased stream flow (Crabill et al. 1999).

The Suwannee Sound area near the town of Suwannee is one of the most important oyster-producing areas in Florida. In 1997, a central wastewater treatment facility (WWTF) was built for the town of Suwannee, eliminating 850 inadequately operating on-site sewage treatment and disposal systems (OSTDS) closest to the shellfish harvesting areas. Shellfish harvesting for the area has been reopened; however, nonpoint source pollution has not been eliminated and is still considered a threat to this important shellfish harvesting area. Glatzer (1990) investigated an incident of gastroenteritis in Florida during the fall and winter of 1989 to 1990. At least two of the cases were indicative of salmonellosis. Samples of oysters from Louisiana and Florida were analyzed for *Salmonella*. Approximately 39% of the oysters tested positive for *Salmonella*; approximately 90% of these oysters were from Suwannee Sound and adjacent areas to the north and south—Horseshoe Beach and Cedar Key, respectively. In addition, *Salmonella* were detected in water samples taken upstream and downstream of the town of Suwannee. Due to the proximity of the OSTDS to local shellfish harvesting grounds in the Suwannee River Sound, the failing of these systems were considered potential

sources of bacteriological contamination found in oysters harvested from that area in 1989–1990. However, Glatzer (1990) identified the bacteriological contamination sources as the waterfowl and wildlife in the area.

Of the earlier literatures specific to the Suwannee River and estuary water quality, Hu (1983) noted that the highest total coliform counts were observed at the main channel of the Suwannee River about 0.8 km upstream of the town of Suwannee and in a dredged canal in the center of a newly developed housing area containing septic tanks in the town of Suwannee. Fellers (1993) summarized water quality data collected in the Suwannee River between February 1989 and January 1992. These data indicate that fecal coliform was higher at a location just downstream of the town of Suwannee. Elsewhere in the Florida region, Miller (1992) studied the migration of OSTDS effluent in the Northern Midlands area of Palm Beach County, Florida. The study found that in shallow wells, total Kjeldahl nitrogen (TKN) from OSTDS decreased from 4.2 mg/L at 7.3 m from the source to 3.3 mg/L at 11.6 m from the source. The study demonstrated that the TKN concentration in groundwater is elevated in the vicinity of an OSTDS and that TKN can migrate with only minimal attenuation over distances.

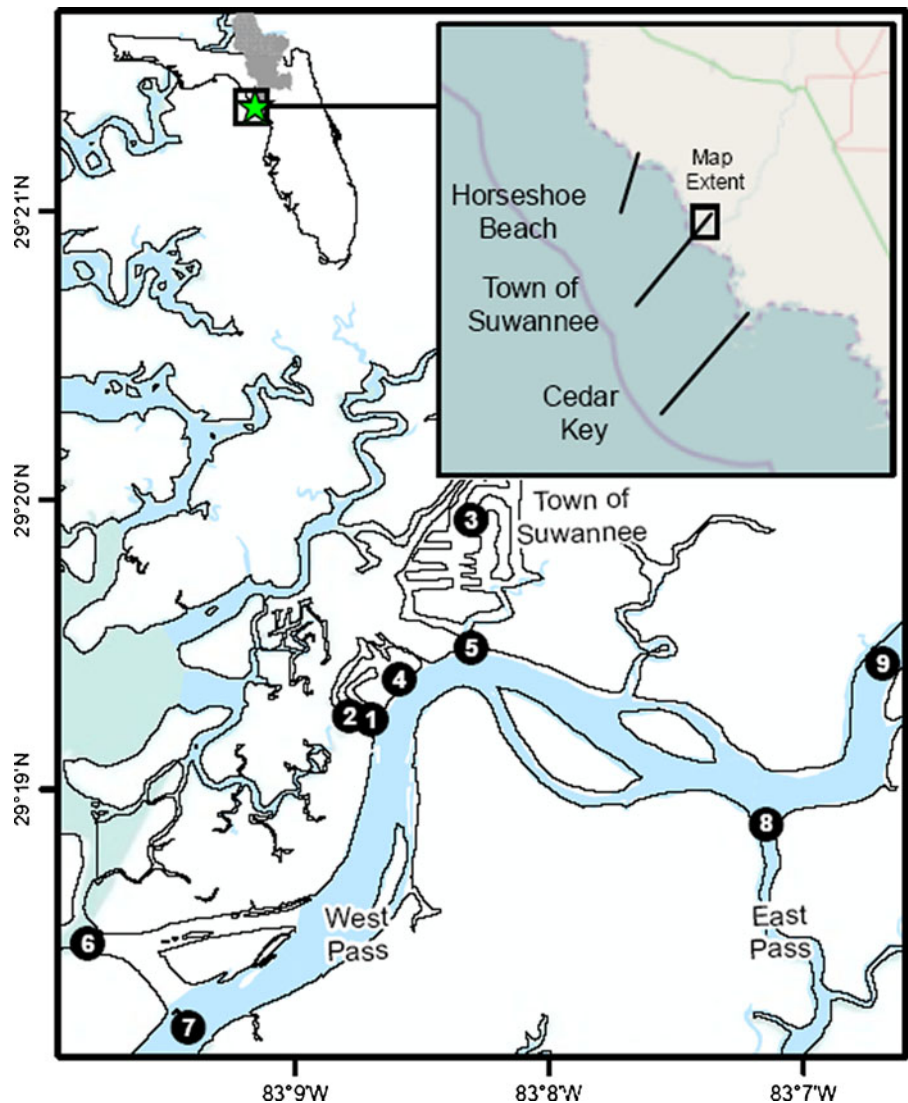
One of the most important factors of water pollution is microbial pollution, especially the pathogenic organisms (Karaboz et al. 2003). In this study, fecal coliforms were measured in the Suwannee Sound in the vicinity of the town of Suwannee. The main aims of this study were to assess the bacteriological contamination and to evaluate the water quality in the Suwannee River around the town of Suwannee before and after the installation of the WWTF.

2 Methods of Study

2.1 Study Area

The town of Suwannee is located near the Suwannee estuary in northwest Florida, USA. The Suwannee estuary, of which Suwannee River is the largest tributary, consists of the lower reach of the river, two major branches (East and West Passes), Suwannee Sound, and the adjacent coastal waters stretching from Horseshoe Beach to the Cedar Key (Fig. 1). The estuary

Fig. 1 Project area and sampling stations. *Stations 1–5* are within the canals. *Stations 6–9* are in the main stem of Suwannee River



of Suwannee River is the largest and most extensive river estuary in the Florida Gulf Coast, and it supports extensive recreational and commercial fisheries.

Land use and land cover surrounding the project area mainly consist of urban area, forested wetlands, saltwater marshes, and wet prairies. The climate in the project area is warm and humid with mean annual precipitation of approximately 150 cm, where more than half of the annual precipitation occurs between June and September. During the fall dry period, occasional tropical storms generate intense bursts of precipitation, causing rapid, but relatively short-lived, increases in river discharge. The deltaic estuary consists of the lower 25 km of the Suwannee River. The upper estuary is bordered by tidal freshwater

swamp and brackish marsh habitat. The lower and nearshore estuary is a mosaic of saltmarsh, tidal creeks, and mudflats.

The average daily flow observed in the downstream-most long-term stream-gaging station in the Suwannee River, which is located approximately 40 km upstream from the project area, is 287 m³/s. The annual average flow ranges from 93 to 695 m³/s. Stream flows typically are lowest in November and December and highest in March and April.

2.2 Data Collection and Analysis

A total of eight consecutive weekly sampling events were conducted to collect water quality samples in

1996 (November–December), before the installation of WWTF. Immediately after the operation of the WWTF, a sampling event was conducted during November–December of 1997. After a long period of time of approximately 12 years, another two sets of data were collected during May–June and November–December of 2009. A total of nine stations in the Suwannee River near the town of Suwannee were sampled (Fig. 1). Five of these stations were distributed on the canals near the town of Suwannee (stations 1–5 in Fig. 1, hereafter referred to as canal stations), where stormwater runs off from the town of Suwannee. These canal waters eventually drain to the river. The remaining four of these stations were along the main stem of the Suwannee River (stations 6–9 in Fig. 1, hereafter referred to as river stations). Each weekly sampling event was scheduled so the surface water sampling duration would bracket the projected time of a low slack tide to minimize the tidal effects.

Each water sample was collected as surface grab samples from within the top 1 ft of the water column. The sample was collected using a pre-cleaned 1-L sample bottle provided by the laboratory. A new sample bottle was used at each station precluding the need to decontaminate the sampling device between stations and avoiding the potential for station cross-contamination. Each station's sample bottle kit was stored in a sealable (e.g., Zip-Loc®) bag prior to and following sampling to prevent station cross-contamination. Samples were placed in an icebox immediately following collection and until delivery to the laboratory. Samples were delivered to the laboratory within the 6-h holding time required for the bacteriological parameters. Fecal coliforms were analyzed using standard methods (American Public Health Association 1992, 1999).

The physical parameters including water temperature, pH, dissolved oxygen (DO), and specific conductance were measured in situ at all stations during each sampling event. In situ measurements were conducted using a Yellow Springs Instrument® Model 556 multiparameter system.

For each station, fecal coliforms and physical parameters were averaged for before and after WWTF operation. The data were also summarized to assess the contribution of fecal coliform from canal stations and river stations separately. As the stormwater runs off from the town of Suwannee via canals to the

Suwannee River, arguably more apparent changes in water quality in terms of fecal coliforms can be seen in canal stations. River station data were treated as the representative baseline ambient conditions near the project site. Average values of fecal coliform and physical parameters were also used in the statistical analysis.

2.3 Statistical Analysis

Analysis of variance (ANOVA) was used to compare the changes in the water quality with respect to fecal coliforms. For the before and after analyses, a one-way ANOVA was used to compare the fecal coliform concentrations in individual stations as well as canal and river stations. All pairwise multiple comparisons were performed using Student–Newman–Keuls method. Differences in individual stations as well as canal and river stations were tested at a significance level (p value) of 0.05. Pearson product moment correlation procedure was used to determine the relation between fecal coliform and various physical parameters in canal and river stations. The procedure provides a measure of the intensity of association between two variables, R . These R values range between -1 and $+1$; a negative value indicates an inverse relation between the data ranks. Pearson's correlation coefficients were considered statistically significant where p values were less than 0.05.

3 Results and Discussion

The physical parameters as well as fecal coliforms in canals in the vicinity of the town of Suwannee and the main stem of the Suwannee River showed variations during the study periods. Fecal coliform and specific conductance variations were prominent both before- and after-WWTF operation. Before WWTF operation, the highest concentration of fecal coliform was observed at station 4 with 635 MPN/100 ml, followed by stations 5, 2, and 1 (Table 1). These stations are within the canal systems. High concentrations of fecal coliform and specific conductance prior to the establishment of the WWTF suggest that the water quality in the canal segment of the project area had been affected by large amounts of domestic as well as agricultural inputs from the town of Suwannee for decades. When compared to the river data for after-

Table 1 Summary of before- and after-WWTF fecal coliform and physical parameters (average±standard error) at each sampling station

Stations	Before-WWTF					After-WWTF				
	Fecal coliform (MPN/100 ml)	Temperature (°C)	pH	DO (mg/L)	Specific conductance (µmhos/cm)	Fecal coliform (MPN/100 ml)	Temperature (°C)	pH	DO (mg/L)	Specific conductance (µmhos/cm)
1	493±137	17.3±0.74	7.3±0.09	7.11±0.17	695±89	242±39	19.8±1.21	7.3±0.10	6.38±0.26	680±128
2	542±234	17.2±0.70	7.3±0.14	7.07±0.24	1143±404	174±40	19.8±1.18	7.2±0.09	6.39±0.27	722±197
3	433±177	16.8±0.91	7.2±0.11	6.31±0.20	767±62	161±26	20.3±1.21	7.3±0.14	6.78±0.55	845±164
4	635±230	17.1±0.65	7.1±0.08	7.09±0.20	1652±922	311±71	19.8±1.20	7.2±0.08	6.27±0.26	1369±457
5	583±171	16.8±0.68	6.9±0.08	6.24±0.20	669±180	201±38	19.8±1.17	7.2±0.08	6.08±0.25	539±134
6	232±73	17.5±0.64	7.4±0.09	7.39±0.16	1252±469	105±19	19.8±1.17	7.3±0.10	6.63±0.25	858±233
7	162±45	17.5±0.61	7.4±0.10	7.39±0.17	838±246	94±24	19.8±1.16	7.2±0.10	6.69±0.24	553±155
8	202±110	17.7±0.57	7.3±0.11	7.24±0.16	302±11	77±16	19.6±1.12	7.2±0.11	6.67±0.25	235±26
9	86±31	17.8±0.58	7.4±0.08	7.23±0.16	306±11	69±8	19.6±1.11	7.2±0.11	6.75±0.26	226±23

WWTF condition, fecal coliform and specific conductance were generally higher. In terms of fecal coliform, canal stations show a greater shift from before to after WWTF when compared to that in the river stations (Fig. 2).

The canal stations displayed higher fecal coliform concentration compared to the river stations. Prior to the installation and operation of the WWTF, the canal average concentration of fecal coliform was 537 MPN/100 ml, which decreased after the operation of WWTF to an average of 218 MPN/100 ml showing a 59% reduction. A comparison of individual station's fecal coliform data (not presented here) showed a significant decrease in fecal coliform in a few pairs of individual canal and river stations. Similarly, river average fecal coliform concentration also decreased from 170 MPN/100 ml (before WWTF) to 86 MPN/100 ml (after

WWTF) with an average reduction of approximately 50% (Table 2).

Over the years, fecal coliform concentrations were decreased in the canal as well as in the river. Even though fecal coliforms after the installation of WWTF slightly decreased in the river as compared to 1996, these decreases were not as high as those seen in the canals (Fig. 2). The reduction of fecal coliforms in the canals may be attributed to the closing of OSTDS. On the other hand, these reductions in the main stem of the river may be attributed to the nonpoint pollution prevention practices upstream of the river over the past decade. Higher reductions in fecal coliforms are reported for different municipal treatment wetlands (e.g., Gersberg et al. 1987; Reed et al. 1995; Kadlec and Knight 1996). Song et al. (2006) reported a 99.6% reduction in fecal coliform from a full-scale

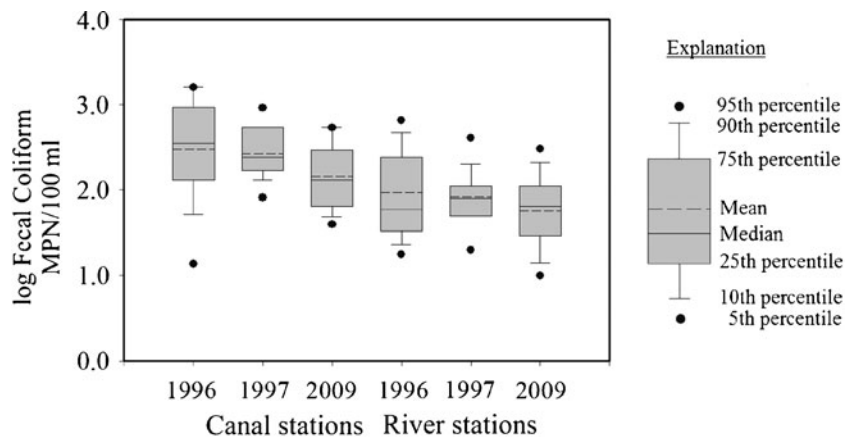
Fig. 2 Distribution of fecal coliform in canal and river stations

Table 2 Summary of fecal coliform and physical parameters (average \pm standard error) before and after WWTF in river and canal stations

Parameters	Units	Before-WWTF		After-WWTF	
		River	Canal	River	Canal
Fecal coliform	MPN/100 ml	170 \pm 35	537 \pm 83	86 \pm 9	218 \pm 21
Temperature	$^{\circ}$ C	17.6 \pm 0.29	17.0 \pm 0.31	19.7 \pm 0.57	19.9 \pm 0.52
pH		7.4 \pm 0.05	7.2 \pm 0.05	7.2 \pm 0.05	7.2 \pm 0.04
DO	mg/L	7.3 \pm 0.08	6.8 \pm 0.11	6.7 \pm 0.13	6.4 \pm 0.15
Specific conductance	μ mhos/cm	674 \pm 145	991 \pm 206	468 \pm 76	831 \pm 112

constructed wetland in China. Similarly, Kacar and Gungal (2010) showed a 96% reduction of fecal coliforms in western Turkey following the operation of a wastewater treatment plant.

Statistical analyses showed that the water quality in canal stations before WWTF changed significantly ($p < 0.001$) with respect to average fecal coliform concentrations after the installation of WWTF. However, these concentrations in individual canal stations 2, 3, and 4 were not significantly different at $p < 0.05$. Stations 5 and 6 showed a significant difference at $p < 0.05$. This discrepancy may be explained by the locations of these sampling stations. Station 4 is within the town, and stations 3 and 4 are further away from the main canal where the influence of storm-water runoff is minimal. Stations 5 and 6, on the other hand, are located in the main canals carrying these discharges. Even though there was reduction in average fecal coliform before and after WWTF installation in the river stations, the reduction was not significant ($p = 0.11$).

The correlations between fecal coliform and physical parameters were also evaluated. Water temperature and pH were generally negatively correlated with fecal coliform concentrations, whereas DO and specific conductance were positively correlated. Analyses showed that there exist significant negative correlations

of fecal coliform with temperature ($R = -0.24$) and pH ($R = -0.26$) in canal stations. Fecal coliforms were positively correlated ($R = 0.16$) with the canal's specific conductance (Table 3). On the other hand, fecal coliforms in river stations show significant positive correlations with DO ($R = 0.27$) and specific conductance ($R = 0.26$). Fecal coliform in the river stations was negatively correlated with water temperature ($R = -0.15$).

This study's negative correlation of fecal coliform and temperature is consistent with the past studies. For example, Anderson et al. (1983) reported a negative relation of enteric bacterial survival with temperature suggesting the survival duration of *Escherichia coli* depends on the temperature in the absence of eukaryotes in coastal waters of Virginia. Similarly, Rhodes and Kator (1988) showed that the *E. coli* mortality rates were inversely correlated with temperature. Negative correlation of pH with fecal coliform is consistent with the similar correlations found in selected Wyoming streams (Clark and Norris 2000). On the contrary, this study's positive correlations of fecal coliform with specific conductance and DO are not consistent with those reported for selected Wyoming streams. Clark and Norris (2000) reported negative correlations of fecal coliforms with specific conductance and DO.

Table 3 Spearman rank correlation coefficients (R) between fecal coliform and physical parameters

Stations	Number of samples	Temperature ($^{\circ}$ C)	pH	DO (mg/L)	Specific conductance (μ mhos/cm)
Canal	159	-0.24*	-0.26*	0.11	0.16*
River	128	-0.15	0.01	0.27*	0.26*

Pairs of variables with positive correlation coefficients tend to increase together. For the pairs with negative correlation coefficients, one variable tends to decrease while the other increases

* p value < 0.05 represents significant correlations

4 Conclusion

In this study, fecal coliform concentrations have been measured and evaluated in four different occasions between 1996 and 2009 in Suwannee River near the town of Suwannee. Prior to the installation of WWTF in 1997, prominent presence of fecal coliforms was observed in the inner canals, which eventually discharge to Suwannee River. In the canals nearby the town of Suwannee, significant differences were detected in fecal coliform concentrations between the samples collected before and after the operation of WWTF. The fecal coliform levels decreased significantly in last 13 years. Nevertheless, there are still some problems to solve, such as uncontrolled direct inflow of nonpoint source pollution from the surrounding area to the canals and to the river itself. However, in the river, no significant decrease in fecal coliform concentration was observed after the establishment of WWTF. Although this study attempted to isolate the removal of the OSTDS as the only variable for testing between the before- and after-WWTF water quality in terms of fecal coliforms, potential affecting factors such as river flow, rainfall, groundwater movement, and seasonality were not considered. Future studies should be attempted to take account of all the factors that can affect the fecal coliform population in a water body.

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