Bacteria and Viruses in the Nile

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Abstract Microbial water quality along the River Nile varies with location and depends on flow rate, water use, population density, sanitation systems, domestic and industrial discharges, demands for navigation, and agricultural runoff. In Lake Victoria, bacterial indicators of sewage pollution and bacteria, morphologically and functionally close to *Desulfovibrio*, *Desulfobacter* and *Desulfococcus* have been detected. The growing population of Bahir Dar Town increasingly pollutes Tana Lake. The microbial load of the Blue and White Niles increases steeply at Khartoum, Sudan. Microbial conditions in Egypt often meet established water quality standards, but some areas are polluted by ca 34 industrial facilities, discharging to the Nile between Aswan and Cairo. Enteroviruses were isolated with a high frequency and positive results were high along 300 km in the south of Egypt. Deterioration is rapid in front of Cairo and in the delta (Damietta and Rosetta Branches), especially during low flow, due to municipal and industrial effluents and agricultural drainage. Here, the bulk of treated and untreated domestic wastewater is discharged to agricultural drains. Total coliform (TC) bacteria reach 10^6 (most probable number, MPN 100 ml^{-1}) in many delta drains, 200 times the Egyptian standard of 5×10^3 MPN 100 ml^{-1}. The Damietta Branch receives nutrients (primarily ammonia) and organics from the Delta Company for Fertilizer and Chemical Industries in Talkha, and agricultural drainage water in the vicinity of the Faraskour Dam. Raw sewage from villages also drains to the Damietta Branch. At ca 120 km downstream from the Delta Barrage, the Rosetta Branch receives polluted inflows from five drains (El-Rahawy, Sobol, El-Tahreer, Zaweit El-Bahr and Tala) and from industry at Kafr El-Zayat.

Abbreviations CBVs: Coxsackie B viruses; Pfu: Plaque-forming unit; WTPs: Water treatment plants; WQI: Water quality index; NRI: Nile Research Institute; MPN: Most probable number; HD: High Dam; TC: Total coliforms; Cfu: Colony forming units; FC: Faecal coliforms; FS: Faecal streptococci; TCC: Chromocult Coliform Agar; SASF: Sulphite-reducing anaerobic spore formers; TBCs: Total

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Bacterial Counts; NBI: Nile Basin Initiative; AHD: Aswan High Dam; WHO: World Health Organization

1 Introduction

The aim of this chapter is to discuss bacteria and viruses in the Nile. Much more is known about the Nile in Egypt than upstream, but some information on Lake Victoria, Lake Tana, and the White and Blue Niles is available. Such information is needed to evolve methods for an effective management of the river. A major problem in Egypt is that, because population and industry are centered on the Nile valley, all surface waters continually receive domestic sewage, agricultural drainage and industrial effluents (Abdel-Gawad, 1995; Dewedar et al., 1995; Rabeh, 1999; Rabeh et al., 1999; El-Shenawy et al., 2000; Sabae & Rabeh, 2000; Rabeh, 2003; Rabeh & Azab, 2006; Amer, 2007; Rabeh et al., 2007; Sabae & Rabeh, 2007).

The Egyptian Nile and its two branches are divided into four segments as follows:

1. Upper Egypt Segment
2. Greater Cairo Segment
3. Damietta Branch Segment
4. Rosetta Branch Segment

Each segment will be treated separately. In addition, information on Lakes Tana and Victoria, the White and Blue Niles, and the High Dam Lake (Lake Nasser–Nubia) is given.

2 Lakes Tana and Victoria

Little information is available on the bacteriology of Tana Lake. Most of the lake still appears to be in a rather pristine condition, yet a threat is posed by the growth of social and economic activities in the region of Bahir Dar. Here, the current practice is one of discharging untreated industrial, municipal and domestic waste into the lake, with adverse effects of this on the sustainability of the use value of the lake and on the livelihood of traditional communities living around the lake (Teshale et al., 2002). The major point sources of contaminants are pit latrines and septic tankers at the level of households, hotels, hospitals, municipalities, and recreational sites. As a result, coliforms (more than 180 cfu $100\,ml^{-1}$) and *Escherichia coli* have been confirmed at the periphery of the southeastern and southwestern parts of the lake, close to the sources of pollution (Adane, 2005).

Compared to Tana, more information is available on the bacteriology of Lake Victoria.

3 Lake Victoria

3.1 Bacterial Indicators of Sewage Pollution

Bacterial indicators near the shore of Lake Victoria at Port Bell range from 11 to 500 MPN 100 ml^{-1}, 0.3 × 10^3–8 × 10^3 MPN 100 ml^{-1}, 2 × 10^4–23 × 10^4 cfu 100 ml^{-1} and 0.4 × 10^2–13 × 10^2 MPN 100 ml^{-1} for faecal coliforms (FC), total coliforms determined with lauryl sulphate broth (TCM), total coliforms determined with Chromocult Coliform Agar (TCC), and sulphite-reducing anaerobic spore formers (SASF) (Byamukama et al., 2000). The concentration of FC at different fishing grounds of Lake Victoria ranges from <1 cfu 100 ml^{-1} water to >600 cfu 100 ml^{-1}. The maxima correspond with storm events and catchment-based activities such as urban discharge. FC bacteria concentrations, however, are lower than the US class A (WW) standard of 200 cfu 100 ml^{-1} water (Werimo, 2006).

3.2 Pathogenic Bacteria

Lake Victoria is used for bathing, washing, and watering livestock, leading to contamination with human and animal waste. However, *E. coli* contamination could not be detected near its shores at Port Bell from July to September 1998 (Byamukama et al., 2000). Investigation of a 1997 cholera outbreak in rural Western Kenya implicated water from Lake Victoria as a risk factor (Shapiro et al., 1999). From May 1997 through April 2001, drinking Lake Victoria water (the major source of water for all uses in rural Western Kenya) caused bloody diarrhea. The illness (27%) could have been averted by avoiding drinking lake water (Brooks et al., 2003).

3.3 Bacteria Involved in Biogeochemical Cycles

Sulphate-reducing bacteria (SRB) in water and sediment of Lake Victoria along the shores of Mwanza municipality resemble *Desulfovibrio*, *Desulfobacter* and *Desulfococcus* species. The MPNs for acetate-utilizing SRB were higher in sediments at water hyacinth-infested stations and at the Mirongo River mouth than in open water. Stations infested by aquatic weeds and the Mirongo River mouth had more formate-utilizing SRB than an offshore and open water station. Water hyacinth-infested stations had a slightly higher mean population, followed by the Mirongo River mouth. The offshore and open water stations had the lowest population of formate-utilizing SRB. Lactate-utilizers were the dominant SRB species in sediments at the water hyacinth-infested and Mirongo River mouth stations, while offshore, MPNs for lactate-utilizing SRB were much lower than those for acetate and formate-utilizing SRB. In addition, SRB densities correlated positively with nutrients in the sediments. The highest positive correlation was between

SRB and PO_4-P (r = 0.93) followed by SO_4-S (r = 0.83); the lowest was with NO_3-N (r = 0.17) (Muyodi et al., 2004).

4 White and Blue Niles

4.1 Total Bacterial Counts

Bacteriological examination of White Nile water at Melut, Upper Nile province, South Sudan during October–November 1983 showed high (10^7 cfu ml^{-1}) TBCs compared with the middle White Nile (Mascher, 1987). Bacteriological data at Khartoum in 1997–2003 (NBI, 2005) revealed higher TBCs (1.7×10^2–2.1×10^3 cfu 5 ml^{-1}) in the White than in the Blue (90–1.2×10^3 cfu 5 ml^{-1}) and main Nile (1.7×10^2–1.7×10^3 cfu 5 ml^{-1}).

4.2 Bacterial Indicators of Sewage Pollution

Bacteriological examination around Khartoum revealed contamination with TC and FC, with the White Nile as contaminated as the Blue Nile (Abdel-Magid et al., 1984). The White Nile at Melut, South Sudan, showed a high incidence of coliforms (92.8%) and of *E. coli* (31%), but the middle White Nile had a better bacteriological quality (Mascher, 1987). TC and FC of the Blue and White Niles at Khartoum in January–July 1984 was higher than upstream in the White Nile, while the east bank of the White Nile was more contaminated than the west bank. The microbial load of the rivers increases conspicuously as they pass through Khartoum (Mahgoub & Dirar, 1986). In the Blue, White and Main Nile, TC and FC peak during the flood, due to wash-in of faecal residues from fields, toilets and sewers (NBI, 2001). El-Hassan (2002) conducted a survey at Khartoum to identify sources of pollution. The highest value of coliforms in the Blue Nile (10×10^3 100 ml^{-1}) was at the confluence (17×100 ml^{-1}); bacteria in the White Nile were uncountable. Also, a survey at Khartoum detected colon bacteria (*E. coli*) in all White Nile samples, which were more polluted than the Blue Nile (Saeed, 2004). Data by the Khartoum State Water Corporation in 1997–2003 showed that the highest contamination (10–30 cfu 100 ml^{-1}) was in the White and main Nile (0.0–20 cfu 100 ml^{-1} TC); lowest values occurred in the Blue Nile (0.0–10 cfu 100 ml^{-1} TC). The reasons for this are that the White Nile is wide, and its speed and discharge lower than that of the Blue Nile. Furthermore, the presence of weeds, organic and colloidal material facilitate the growth of bacteria. Nine sampling sites in the Blue and White Niles and their confluence during 2002 and 2004 again showed the White Nile as more polluted than the Blue Nile (NBI, 2005). FC in northern Sudan ranged from 100 to 200×100 ml^{-1} during May, the hottest month, and from 210 to 625×100 ml^{-1} during October, the end of the rainy season. The higher counts in the wet season reflect the ‘flushing’ effect of the rains. The FC counts are not just from the local environment and rainfall, but are derived from the wider catchment and from tributaries (Musa et al., 1999).

5 The High Dam Lake

5.1 Total Bacterial Counts

During June–July 1975, TBCs of Lake Nubia in Sudan were surveyed from Wadi Halfa to Songa, 470 km south of the High Dam (HD). Samples from five stations (Table 1) showed that the south of Lake Nubia had lower TBCs than the north. In most cases, TBCs increased with depth. This aspect was also clear in Lake Nasser. Moreover, mean TBCs in Lake Nubia were higher than in Lake Nasser, either because more nutrients are carried by the Nile from Sudan or because recently drowned vegetation, provides bacteria with organic matter, encouraging their reproduction (Saleh, 1976).

From the main axis of Lake Nasser between Aswan High Dam (AHD) and Abu-Simbel, two sets of samples were taken; the first was collected from winter to autumn 1974, the second from winter to autumn 1984. The lowest TBC at 22°C (saprophytic bacteria) and 37°C (parasitic bacteria) was detected in winter. The highest was in summer (Table 2), and counts tended to increase by early spring. In summer, a renewal of nutrients carried by the flood provides bacteria with extra organic matter. There also was a decrease in TBC from south to north, but they increased again near the High Dam, where decaying material from fisheries activities abounds. The ratios of TBCs at 22°C and 37°C were over 1.0 and were narrow in summer and autumn, but wider in winter and spring (Elewa & Azazy, 1986). Twelve years later, TBCs in Lake Nasser ranged between 4×10^3 and 187×10^6 and between 3×10^3 and 52×10^3 cfu ml^{-1} at 22°C and 37°C. The highest counts were during spring, at high temperatures and abundant organic matter (Rabeh et al., 1999). TBCs at 22°C in subsurface water were from 0.12×10^5 cfu ml^{-1} at Khor Korosko during autumn to 933×10^5 cfu ml^{-1} during spring at Khor El-Allaqui. Those at 37°C varied from 0.06×10^5 to 650×10^5 cfu ml^{-1} at Khor El-Allaqi during autumn and spring. Similar results were obtained by Saleh (1976), Elewa

Table 1 Total bacteria Counts (TBCs ml^{-1}) and sulphate-reducing bacteria (SRB) (MPNs100 ml^{-1}) at different depths and in bottom water of Lake Nubia during 1975

Bacteria	TBCs ml^{-1}			SRB 100 ml^{-1}		
Layers stations	0.0	10 m	Bottom	0.0	10 m	Bottom
Songa	370	780	75×10^4	93	93	2.4×10^6
Aterry	260	440	1.6×10^6	3.6	3.6	1.1×10^6
Section 6	700	580	1.4×10^6	21	93	2.4×10^6
Sections 3	870	900	1.6×10^6	7.3	240	2.4×10^6
Halfa	470	1,070	1.0×10^6	21	240	2.4×10^6

Table 2 Changes in total bacteria Counts (TBCs) and specific groups of bacteria in the northern part of Lake Nasser during 1974/1984 (counts ml^{-1})

Seasons	Bacteria years	Total bacterial counts 22°C	Total bacterial counts 37°C	*Azotobacter*	N_2-fixing Clostridia	Nitrifying bacteria	Aerobic cellulose decomposing bacteria
Winter	1974	187	73	24	26	6	66
	1984	340	290	17	14	22	110
Spring	1974	414	188	170	58	8	130
	1984	750	360	110	46	39	330
Summer	1974	3,730	2,520	260	170	14	1,700
	1984	5,100	4,400	140	64	120	2,200
Autumn	1974	743	673	320	33	12	320
	1984	1,800	1,200	64	17	84	450

and Azazy (1986) and Rabeh et al. (1999). The increase in heterotrophic bacteria in the Khors during spring may also relate to development of phytoplankton: the lowest Secchi disc reading (1.54 m) was during spring, the highest during winter (Anon., 1996). In bottom waters, the bacteria counted at 22°C fluctuated from 0.06×10^5 cells ml^{-1} at Khor El-Ramla during autumn to 961×10^5 cfu ml^{-1} at Khor El-Allaqui during spring. The number of bacteria at 37°C fluctuated from 0.1×10^5 cfu ml^{-1} during autumn at Khor El-Ramla and Kalabsha, to 680×10^5 cfu ml^{-1} at El-Allaqi during spring. Khor El-Ramla showed the lowest average TBCs at 22°C and 37°C in subsurface and bottom waters (Rabeh, 2001), in harmony with a high transparency (2.5 m on average) and high dissolved oxygen (11.03 mg l^{-1} on average). Such a negative relationship between TBCs and transparency had previously been reported by Saleh (1976), Elewa & Azazy (1986) and Rabeh et al. (1999). These authors also found an inverse relationship between TBCs and DO, as bacteria consume considerable quantities of DO. Also, TBCs at both 22°C and 37°C were higher in bottom than in subsurface water. The ratio at 22°C to that at 37°C was low, slightly above or below unity. The lowest TBCs at 22°C and 37°C occur in winter, with a sharp increase during summer, reflecting the development of phytoplankton. Thus, lower transparency was recorded during summer than in winter (Rabeh, 2003). High bacterial density during summer might also explain the drop in dissolved oxygen near the bottom. Bacteria use DO in biological oxidations, and this oxygen is not compensated as long as thermal stratification lasts (Rabeh, 2003). The highest TBC were during autumn (flood), when new nutrients arrive, the lake level rises, and shore-land is flooded. The coastal zone contributes minerals to the lake, *inter alia* from drowned vegetation that provides fresh organic matter. Moreover, the flood carries an allochthonous microflora to the lake. In Lake Nasser, TBCs at 22°C and 37°C were higher in bottom than in subsurface water (Saleh, 1976; Rabeh, 2001). Changes in TBC at 22°C were associated with a similar change at 37°C (ratio slightly higher than 1). In non-polluted waters, the ratio of 22°C: 37°C counts is usually 10 or more; in polluted waters it is usually below 10 (APHA, 1980; Rabeh, 2000, 2003). Accordingly, subsurface and bottom waters of the lake are polluted (Rabeh, 2003). Similar low ratios were previously recorded for Lake Nasser by Elewa and Azazy (1986) and Rabeh (2001). However, it is not convenient to rely on this ratio only to get an accurate assessment of water pollution, especially in warm water (Hosny, 1966; Rabeh, 1993, 2001).

5.2 Bacterial Indicators of Sewage Pollution

During 1996, the MPN of TC and FC along the main channel of Lake Nasser ranged between 0.0 and 54×10^4 and between 0.0 and 33×10^4 $100\,ml^{-1}$ for TC and FC. The highest counts of indicator bacteria were recorded during winter. This may be due to tourism between the High Dam and Abu-Simbel, but other human activities add to the pollution, problem, such as the Aswan fish factory (Rabeh et al., 1999).

TC varied from 0.002×10^3 cells $100\,ml^{-1}$ in subsurface water of Khors El-Ramla. Kalabsha, El-Allaqui and Korosko during autumn, to 50×10^3 cells ml^{-1} at Khor El-Ramla during winter. Absence of FC was recorded during autumn at Khors El-Ramla, Kalabsha and Korosko; highest values (3.2×10^3 cells $100\,ml^{-1}$) fell during winter at Khor Kalabsha. The high coliforms during winter may be caused by intense fishing and tourism during winter, and/or high pH values (Rabeh, 2001), with a peak of pH 8.61 during winter (Anon., 1996). In bottom waters, TC were absent during autumn, to reach 90×10^3 cells $100\,ml^{-1}$ at Khor Kalabsha during winter. FC fluctuated from a complete absence at Khors Kalabsha and Korosko during autumn to 9×10^3 cells $100\,ml^{-1}$ at Khor Kalabsha during winter. With respect to spot-wise variations, Khor Toushka had the lowest average TC in subsurface and bottom waters, while Khor El-Ramla and Khor Kalabsha had the highest. Again, such variation was in harmony with average pH, with Khor Toshka showing the lowest average (8.17) and Khor El-Ramla and Kalabsha the highest (8.29 and 8.37) (Anon., 1996). Khor Korosko had the lowest average FC, while the highest was in Khor Kalabsha. The high TC and FC at Khors El-Ramla and Kalabsha is attributed to the activities of fishermen. El-Shahat (2000) reported 1,997and 6,841 fishing boats and fishermen in Lake Nasser during 1997. The high numbers of coliforms in Khor El-Ramla, against low numbers in Khor Tushka, is paralleled by a high concentration of ammonia nitrogen in the former ($26.94\,\mu g\ l^{-1}$) (Anon., 1996). Indeed, Hosny (1966) and Rabeh (1993) found ammonia nitrogen to be necessary for the multiplication of coliforms.

TC and FC were higher in bottom than in subsurface waters, concordant with Rabeh (1996, 2000). Also, the highest bacterial indictors (TC and FC) occurred at the High Dam. The lowest TC and a complete absence of FC were noted in the south of the lake during the flood. This might be due to dilution by the flood, although the flood water is an important source of bacteria. Conversely, high TC and FC during winter might reflect the polluting effect of cruise boats (which are really floating hotels) between the High Dam and Abu-Simbel. Another indicator is the high concentration of ammonia nitrogen during this season (3–171.36 and

24.05–345.74 µg l^{-1}) in subsurface and bottom water. As well, TC and FC were high in bottom waters. This relates to either lower bactericidal effects of solar ultraviolet rays on bottom water, sedimentation of suspensions containing adsorbed cells, higher bottom concentrations of ammonia nitrogen, or higher contamination with sediment bacteria (Rabeh, 2003). Indeed, Van Donsel and Geldreich (1971) found that the density of FC in sediments may amount to 100–1,000 times those in the overlying water.

Again, high TC and FC in the khors reflect fishing activities (Rabeh, 2001). FS in the main channel ranged from 1 to 1,900 and from 6 to 2,100 org. 100 ml^{-1} in subsurface and bottom waters, while counts in subsurface water of the khors were 2–2,100 org. 100 ml^{-1}. In the White Nile, the Sobat, the Blue Nile, the Atbara and the Main Nile, bottom water reached 3–3,900 org. 100 ml^{-1}. In the main channel, TC/FC ratios varied from 0.0 to 0.845 and from 0.025 to 0.791 in subsurface and near-bottom water. In the khors, this ratio was 0.25–0.77 in subsurface water and 0.25–0.68 in bottom water. At the mouth of El-Sheikh Zayed canal, TC an FC were 3–460 org. 100 ml^{-1}, 0.0–21 org. 100 ml^{-1}, and 23–9,300 org. 100 ml^{-1}, and 9–900 org. 100 ml^{-1} in subsurface and bottom water. Here, the ratios were from 0.0 to 0.18 and from 0.016 to 0.39 in subsurface and bottom water. The FC/FS ratio in the khors ranged from 1.4 to 2.25 and from 1.8 to 3 for subsurface and bottom waters, suggesting fishing activities and grazing cattle (about 20,000 heads) around the lake (Rabeh, 2003).

5.3 Bacteria Involved in Biogeochemical Cycles

In Lake Nubia, the MPNs of SRB were lower than in the north of the lake, and bottom water had higher numbers than upper layers (Table 1). In most cases, SRB increased with depth. This was not the case in samples from Lake Nasser. Moreover, MPNs in Lake Nubia were higher than in Lake Nasser (Saleh, 1976).

During the hot months (summer and autumn), a problem of odor may arise in some areas of Lake Nasser due to H_2S produced by sulphate-reducing, anaerobic bacteria (SRB). These bacteria are exceptionally high in anaerobic bottoms, after the consumption of oxygen by aerobic bacteria in the presence of organic matter (Saleh, 1976). SRB were completely absent along the main channel and in selected khors during winter. Low water temperature and aerobic conditions prevailing during this season inhibit these strict anaerobic bacteria. In contrast, the number of SRB in the main channel ranged from 0.21 to 0.64 org. ml^{-1} and from 1.2 to 450 org. cm^{-3} in bottom water and sediment. Khor Kalabsha showed higher counts than Khor El-Ramla. However, the lowest counts were at the source point station, and the highest at E1-Madiq station, in line with high organic matter (2.56–3.27%) and a high concentration of SO_4 (34.5 mg l^{-1}) (El-Shabrawy & Abdel-Regal, 1999). The situation reverses at Abu Simbel where low organic matter (1.53–2.6%, average 1.29%), low SO_4 (0.0–1.65, 1.09 mg l^{-1}on average) and, accordingly, the lowest counts of SRB occur.

The lake thermally stratifies during summer. Thus, the highest concentration of H_2S (6.56 mg l^{-1}) falls during summer, when anaerobic conditions prevail and stagnation prevents sulphide, from being oxidized (Rabeh, 2003). *Azotobacter chrococcum*, the predominant soil species, is also present in considerable numbers in High Dam lake water. *Azotobacter*, like TBCs, increases significantly in summer and autumn, while clostridial spore counts are lower in water than *Azotobacter*, in contrast to soils. These bacteria are unable to survive in the oxygenated water found in winter and spring. These findings are in harmony with data on dissolved oxygen and temperature.

Nitrifying bacteria (Table 1) are low. Aerobic cellulose decomposers evolve in parallel with organic carbon content: counts increase markedly in summer and autumn. As a drought period had begun in 1980 and water level fell from 178 to 158 m, changes in microbiological and chemical characteristics of Lake Nasser occurred. TBCs at 22°C and 37°C increased in comparison to 10 years earlier (Table 1). The activity of phyto and zooplankton and/or relative bacterial densities also responded to less water flowing from in the south, a result paralleled by organic carbon content, and confirming a result of Schmidt (1969). Nitrogen fixers (the aerobic *Azotobacter* and the anaerobic *Clostridia*) tended to decrease, perhaps due to less suspended material in flood water. Nitrifying bacteria (Table 1) increased in comparison to 10 years earlier, suggesting a rise in nitrifying activity related to a higher activity of total bacteria and confirmed by increased nitrate in the lake after the period of drought. Aerobic cellulose decomposers increased in summer, in parallel with TBCs and organic carbon (Elewa & Azazy, 1986).

6 Viruses

Little virological information is available on River Nile water. South and north of Abu-Simbel, enteroviruses ranged from 0 to 42 plaque-forming units (pfu) mg l^{-1}. Just south of the High Dam (1.5 km), enteroviruses were either completely absent or scored up to 7.2 pfu l^{-1} (Ali et al., 1996).

7 Upper Egypt

7.1 Total Bacterial Counts

Bacteria developing at 22°C in subsurface bank water ranged from 4.8×10^5 cfu ml^{-1} at Edfo during winter, to 22×10^6 cfu ml^{-1} at Luxor during summer. Those developing at 37°C varied between 3.75×10^5 and 68×10^5 cfu ml^{-1} l at the same sites during winter and spring. In mid-Nile, bacteria developing at 22°C and 37°C in subsurface water reached 1.2×10^5–31×10^5 and 0.06×10^5–48×10^5 cfu ml^{-1}.

In near-bottom water in mid Nile, they ranged from 2×10^5 to 30.2×10^5 and from 1.8×10^5 to 47.8×10^5 cfu ml^{-1}. In sediment in mid-River both cultures reached from 12×10^6 to 36×10^8 cfu g^{-1} and from 15×10^6 to 4.18×10^8 cfu g^{-1} (Sabae, 2004).

7.2 Bacterial Indicators of Sewage Pollution

TC in Upper Egypt fluctuated between 76 MPN 100 ml^{-1} at Aswan and 3.3×10^3 MPN 100 ml^{-1} at Nagaa Hammadi (El-Sherbini et al., 1991); FC ranged from 7.3×10^2 cfu 100 ml^{-1} at Assuit (544 km below High Dam) to 1.02×10^3 100 ml^{-1} 610 km below the High Dam. These values parallel those at drains in this area (Mahrous, 1997). The water quality index (WQI) derived from two campaigns conducted by the Nile Research Institute (NRI) during February and September 2000 showed that 71% of all sampling sites had a good quality during winter; the remaining sites had a medium quality. During summer, 43% of the sites maintained a good quality, the rest dropping to a medium quality. FC from the bank at a site where water was pumped, were much higher. This indicates the presence of untreated human waste (Ezzat et al., 2002). Similarly, MPN of bacterial indicators in subsurface water near the bank were $93–46 \times 10^2$, $23–14 \times 10^2$ and $40–15 \times 10^2$ 100 ml^{-1} for TC, FC and FS, while their MPN in mid-Nile ranged from 23 to 20×10^2, 0.0 to 2.4×10^2, 0.0 to 16×10^2 100 ml^{-1}. In mid-Nile sediment, they varied from 9×10^2 to 21×10^4, 0.0 to 12×10^3 and 0.0 to 36×10^3 100 ml^{-1} (Sabae, 2004).

7.3 Complementary Bacterial Indicators

Water treatment plants at Beni-Suif governorate receive water from the main river. The density of bacterial indicators in Nile water at the intake of these plants ranged from 0.3 to 8.9×10^3 and from 1 to 7.4×10^3 cfu 100 ml^{-1} for *Aeromonas hydrophila* and total staphylococci. Their average ranged from 7.4×10^2 to 1.6×10^3 and from 3.7×10^2 to 4.5×10^2 cfu 100 ml^{-1} for both bacteria (Shaban & El-Taweel, 2002).

7.4 Pathogenic Bacteria

Pathogenic bacteria in Nile water at the source points of water treatment plants at Beni-Suif ranged from 0.6 to 4.8×10^2, 0.2 to 2.3×10^3 and 1 to 8.8×10^2 cfu 100 ml^{-1} for *Salmonella*, *Vibrio* and *Listeria*. The average ranged from 95 to 3.5×10^2, 4.4×10^2 to 1.8×10^3 and 5×10^2 to 6.2×10^2 cfu 100 ml^{-1} for all three groups (Shaban & El-Taweel, 2002).

7.5 Viruses

Behind Aswan Dam (AD), enteroviruses amounted from 0 to 28.8 pfu l^{-1}. In front of Aswan city they were absent, reaching 10 pfu l^{-1} near the east bank of the river (Ali et al., 1996).

8 Greater Cairo

Monitoring of microbiological characteristics of the Nile prior to and after the High Dam construction, especially at Cairo, has been in progress since 1963.

8.1 Total Bacterial Counts

During 1963, TBCs at 22°C at Giza ranged from 15×10^2 cfu ml^{-1} in January to 955×10^2 cfu ml^{-1} in October; at 37°C they varied from 7×10^2 cfu ml^{-1} in February to 975×10^2 cfu ml^{-1} in October. In the next year, they fluctuated from 50×10^2 cfu ml^{-1} during May to 900×10^2 cfu ml^{-1} during October and from 17×10^2 cfu ml^{-1} during January to 2815×10^2 cfu ml^{-1} during September, at 22°C and 37°C. TBCs at 20°C and at 37°C markedly increased during the flood, when organic matter reached a maximum. Except during the flood, bacteria in Nile water during this 2-year period were relatively low: the ratio of counts at 22°C: 37°C ranged from 0.5 during September to 4.6 during June 1963, and from 0.17 during September to 3.2 during January 1964 (Hosny, 1966). The picture during 1964–1965 revealed that the rise and fall in bacteria followed seasonal changes, with highest counts (10^5–10^7 ml^{-1}) during the flood. Thereafter, a phase of decline (10^3–10^5 ml^{-1}) prevailed (Saleh, 1980a). But between June 1965 and August 1966, monthly average TBC rose to 10^3–10^6 100 ml^{-1}, and in October 1965, bacterial numbers were at their highest. TBCs during summer1965 were markedly higher than in the next year. No significant differences existed between the two incubation temperatures (El-Abagy, 1971).

After the filling of the High Dam, a cessation of the seasonal floods occurred, as well as a drop in bacterial counts at 22°C and 37°C (10^3–10^5 ml^{-1}) (Saleh, 1980b). About 10 years later, in 1984, TBCs at both temperatures had risen to 10^5–10^7 cfu ml^{-1} at El-Gezira (El-Deeb, 1986). During summer 1994–spring 1996, TBCs at 22°C and 37°C ranged from 1.0×10^3 to 7.8×10^5 and from 5.0×10^2 to 6.4×10^5 cfu ml^{-1} (El-Taweel, 1998). Similarly, the lowest TBCs at 22°C (7×10^4 ml^{-1}) and 37°C (6×10^4 ml^{-1}) were in subsurface water at El-Maadi, the highest at 22°C (214×10^5 ml^{-1} l) and at 37°C (187×10^5 ml^{-1} l) at Warraq El-Hadar, August 1997 to July 1998. Growth at 22°C and 37°C did not differ significantly (Sabae, 1998). Bacteria developing at 22°C and 37°C in subsurface water near the bank at Shoubra El-Kheima region ranged from 10×10^4 to 144×10^4 and 5.9×10^4 to 142.6×10^4, while in mid-Nile they ranged from 4×10^4 to 136×10^4 and from 3.1×10^4 to 170×10^4. Their densities decreased away from the bank and were higher in near-bottom than in subsurface water. Bank sediment TBCs ranged from 14×10^6 to 190×10^6 g^{-1} and from 10.3×10^6 to 189.1×10^6 g^{-1} at 22°C and 37°C. In mid-Nile, they varied from 4×10^6 to 180×10^6 g^{-1} and from 2.1×10^6 to 178.2×10^6 g^{-1} (Rabeh, 2000). TBCs at 22°C ranged from 1.3×10^2 to 4.2×10^5, while at 37°C they ranged between 1×10^2 and 3×10^5 ml^{-1} (February 2000–March 2001) (El-Taweel & Shaban, 2003).

8.2 Bacterial Indicators of Sewage Pollution

Before the filling of the High Dam, TC ranged between 13 ml^{-1} in July 1963 and 165 ml^{-1} in April, while they ranged from 13 ml^{-1} in July and September to 260 ml^{-1} during March 1964. In 1963, FC ranged from 1 ml^{-1} l in June to 26 ml^{-1} in March and from 1 ml^{-1} in June to 157 ml^{-1} in April (Hosny, 1966). Saleh (1968) showed that the middle of the river (subsurface, 5 and 10 m) contained faecal streptococci between June 1965 and August 1966. The old MPN-index of Nile water fell between 4.8×10^1 and 8.17×10^2 100 ml^{-1}. The new MPN readings were 1.19×10^3 (September 1965) when a rise in turbidity and C: N ratio occurred. During 1966, there was a decline in FS during February, with the MPN-index always below 10^2. Between March and August 1966, there was a fluctuation between log 1 and log 2, with occasional rise to log 3 at the 10 m level. Apart from a casual drop to a density below 10^2, uncharacteristic of Nile water, the MPN of coliforms fluctuated between 10^2 and 10^3 (1965–1966) with variations at different depths. Of subsurface samples, the majority gave coliform densities between 10^2 and 10^3 (El-Abagy, 1977).

After 1973, the complete filling of the High Dam Lake, a rise in coliforms and FS, and a higher incidence of untyped forms marked the river water. During 1975–1978, FS readings of 100–1,000 ml^{-1} were recorded in the Cairo segment (Saleh, 1980a). From October 1986 to November 1987, the densities of TC were 6×10^2–3.16×10^4, 3.5×10^3–3.9 10^4 and 1.02×10^3–10.01×10^4 at El-Tebbin, Giza and Rod El-Farag. FC reached 3–3.16×10^4; 1.3×10^3–3.7×10^4 and 7.6×10^2–1.8×10^4 at the same sites (El-Marazky, 1988). Moreover, TC along the Cairo segment was from 1.2×10^3 at El-Tebbin to 6.6×10^3 cfu 100 ml^{-1} at El- Maadi, while FC ranged from 5×10^3 to 5.8×10^3 cfu 100 ml^{-1} at both sites. The mean TC and FC increased from the entrance of Cairo to El-Qanater, reaching maxima of 3.8×10^3 and 2.8×10^3, 4.7×10^3 and 3.7×10^3 for TC and FC at El-Badrashin and El-Maadi (Table 3). Six drains (Ghamaza El-Kobra, El-Tebbin, Khour El-Sail Badrashin, El-Hawamdia sugar, Khour El-Sail Maasera, and Kotsica Starch) represent point sources of pollution in this area. The highest TC and FC were in the drains of El-Hawamdia Sugar, khour El-Sail Maasera, and kotsica Starch between El-Badrashin and El-Maadi. El-Hawamdia Sugar and kotsica Starch Drains are industrial in nature, and dense TC and FC (2.7×10^4 and 1.9×10^4 cfu 100 ml^{-1}) were recorded here. In contrast to coliforms, FS showed a decrease from Cairo to El-Qanater. The ratio of FC to FS was 1.1–1.9 at the entrance of Cairo, against 6.7–7.2 at El–Maadi (Abu-Shady, 1996). The range of TC, FC and FS at five sites of

Table 3 Classical and complementary bacterial indicators (×10^3 100 ml^{-1}) of River Nile along Greater Cairo segment

Stations	Total coliform	Faecal coliform	Faecal streptococci	*Staphylococcus aureus*	*Aeromonas hydrophila*
El-Ekhssas	3.1	2.1	1.2	4.4	3.4
El-Tebbin	2.9	1.8	0.86	3.7	2.8
El-Badrashin	3.8	2.8	0.94	4.8	3.5
El-Maadi	4.7	3.7	0.53	5.2	4.4
El-Qanater	3.3	2	1.1	3.4	3.4

Greater Cairo were 3.6 × 10^3–5.1 × 10^3, 2.0 × 10^3–5 × 10^3 and 2.2 × 10^2–2.6 × 10^3 cfu 100 ml^{-1} (Haeikal, 1994). El-Taweel (1998) found similar densities during summer 1994–spring 1996: 49 × 10^4–1.6 × 10^4, 2 × 10^3–5.2 × 10^3 and 20 × 10^3–1.4 × 10^3 MPN 100 ml^{-1} for TC, FC and FS. Compared with standards for drinking water (>50 and <5,000 for TC; >20 and <2,000 for FC and >20 and <1,000 for FS), the Nile is locally polluted (El-Taweel, 1998).

MPN of bacterial indicators in subsurface water near the bank ranged from 110 × 10^2 to 1,600 × 10^2, 35 × 10^2 to 900 × 10^2 and 23 to 175 100 ml^{-1} for TC, FC and FS, while MPN in mid-stream ranged from 3.4 × 10^2 to 350 × 10^2, 1.1 × 10^2 to 150 × 10^2, and 9 to 36 100 ml^{-1}. Bacterial indicators in near-bottom water were 15 × 10^3 –650 × 10^3, 8 × 10^3 –350 × 10^3 and 35–500 100 ml^{-1} for TC, FC and FS, while counts in mid Nile ranged from 4 × 10^2 to 425 × 10^3, 2 × 10^2 to 75 × 10^3 and 20 to 250 100 m^{-1} (Rabeh, 2000). Such findings confirm Fayez et al. (1987) who found similar TC near the bank and in mid-stream. Bacteria in near-bank sediment amounted to 110 × 10^3 –1,600 × 10^3, 64 × 10^3 –850 × 10^3 and 28 × 10^3–350 × 10^2 100 ml^{-1} for TC, FC and FS. MPN in mid-Nile were 110 × 10^3–1500 × 10^3, 42 × 10^3–650 × 10^3 and 23 × 10^2–250 × 10^2 100 ml^{-1}, higher than in water (Rabeh, 2000). In February 2001, FC fluctuated between 1.2 × 10^2 100 ml^{-1} at Maadi and 1 × 10^3 100 ml^{-1} at Shoubra El-Kheima (upstream of Ismailia Canal intake) (Ezzat et al., 2002), while El-Taweel and Shaban (2003) recorded MPNs of TC of up to 80 × 10^3 100 ml^{-1} at Branching Point, and FC's of up to 16 × 10^3 100 ml^{-1} at Branching Point. FS ranged between 40 100 ml^{-1} and 8 × 10^3 100 ml^{-1} at El-Gezira and Branching Point.

8.3 Complementary Bacterial Indicators

During summer 1994–spring 1996, the count of *Aeromonas hydrophila* at Cairo changed. *A. hydrophila* showed values from 1.0 × 10^3 to 2.4 × 10^5 cfu 100 ml^{-1}, higher in spring (1.5 × 10^5) than in other seasons (between 1.1 × 10^4 and 6.4 × 10^4 cfu 100 ml^{-1}) (El-Taweel, 1998). In contrast, *A. hydrophila* ranged from 2 × 10^3 100 ml^{-1} at El-Tebbin to 6.7 × 10^3 100 ml^{-1} at El-Maadi (Abu-Shady et al., 1996). It comprised 0.01–2.1% of TBCs and had no significant correlation with TC, FC, FS (El-Taweel, 2003). *Staphylococcus aureus* ranged from 1.5 × 10^3 100 ml^{-1} at El-Qanater to 6.7 × 10^3 100 ml^{-1} at El-Badrashin (Abu-Shady et al., 1996). Finally, total staphylococci around Greater Cairo occurred at mean values between 6.4×10^2 and 1.9×10^3 100 ml^{-1} (El-Taweel, 1998).

All along the Greater Cairo segment of the Nile, the mean counts of *S. aureus* and *A. hydrophila* exceeded permissible values.

8.4 Pathogenic Bacteria

Salmonella was detected in 25 out of 32 samples in summer 1994–spring 1996. Higher counts during summer and winter (1.6×10^3 and 1.4×10^3 cfu 100 ml^{-1}), contrasted with lower counts during autumn and spring (2.5×10^2 and 5.0×10^2 cfu 100 ml^{-1}). All reflect municipal and food processing discharges at Cairo (El-Taweel, 1998). Later, *Salmonella* were detected in 23 out of 28 samples collected from Cairo (from 18 cfu 100 ml^{-1} to 6.4×10^2 cfu 100 ml^{-1}with annual average 1.2×10^2–1.9×10^2) (El-Taweel & Shaban, 2003).

Vibrio's were present at Cairo during summer 1994–spring 1996. The highest value was detected during winter (1.6×10^4 cfu 100 ml^{-1}). During other seasons, it sunk to 1.1×10^3–5.7×10^3 cfu 100 ml^{-1}. According to a biochemical identification, *V. cholerae* represented 30–62% of total vibrios (El-Taweel & Shaban, 2003).

The *Listeria* group was also detected at Cairo, with *Listeria monocytogenes* representing up to 60% of the total. Higher counts, during summer and winter, were 2.5×10^4 and 3.2×10^4 cfu 100 ml^{-1}. During autumn and spring, values declined to 2.0×10^2–2.6×10^2 cfu 100 ml^{-1} (El-Taweel, 1998). Luppi et al. (1988) isolated *Listeria* spp. in 22% of river samples, whereas Bernagozzi et al. (1994) isolated *Listeria* spp. in 59% of surface waters from Italy; 72% were identified as *L. monocytogenes*.

The decrease in various microbial parameters in Nile water upstream of Cairo and at El-Qanater after leaving Cairo suggests that the river has an ability to purify itself, especially at high flow rates (ca 175 M m^3 day^{-1}).

8.5 Bacteria Involved in Biogeochemical Cycles

Before AHD, large numbers of *Azotobacter* (up to 11,000 ml^{-1}, average 2004) were found during the flood with TBCs and suspended matter content at their maximum; conversely, counts were low, ca 400 ml^{-1}, during low water. Clostridial spore counts ranged from 3 to 220 spores ml^{-1}, average ca 45 spores ml^{-1} (Hosny, 1966). MPNs of sulphate-reducing bacteria (SRB) were low at the industrial region of Shoubra El-Kheima. The highest counts were at the discharge point of Shoubra El-Kheima Electric Power Station, a site of thermal pollution enhancing bacterial multiplication. In addition, leaching of SRB from pipes of the cooling system may have occurred, since these bacteria may develop and cause corrosion to iron pipes. MPNs of SRB were much higher in sediment (20–1,600 g^{-1}) than in water (Sabae, 2000).

8.6 Viruses

Two strains of *E. coli* (ATCC No. 13706 and the local No. 3) were used as hosts for phages, applying the APHA and Kott-MPN procedures to raw River Nile water at El-Tebbin, Giza and Rod El-Farag during 1986 and 1987. The local isolate No. 3 had the highest susceptibility to phages, with plaque forming units 10^2 and 10^5 100 ml^{-1} of Nile water. The counts obtained by Kott-MPN ranged between 6 and 81 cfu 100 ml^{-1} at El-Tebbin, using the ATCC strain. With APHA, the same host and the same site, counts ranged between 66 and 1,130 pfu 100 ml^{-1}. When strain *E. coli* No. 3 (more sensitive to phage lysis) was used as host for the phage, the counts of coliphages were about similar to those obtained with the ATCC-host (47–1,470 pfu 100 ml^{-1}). In Nile water at Giza, coliphages with ATCC strain No. 13706 ranged from 102 to 3,890 and 9 to 275 pfu 100 ml^{-1} l, while coliphage counts with the local host ranged from 74 to 3,630 and 3 to 178 pfu 100 ml^{-1} using APHA and Kott techniques, respectively. Nile water at Rod El-Farag had a relatively high phage density (4,786 pfu 100 ml^{-1}), while El-Tebbin water yielded the lowest density (1,470 pfu 100 ml^{-1}). Comparing the two techniques, APHA gave higher counts than the Kott-technique. A similar trend was observed with ATCC No. 13706 as a host compared with local strain No. 3. The plaque-forming unit (pfu) using local *E. coli* No. 3 and ATCC No. 13706 as hosts was 10^2 100 ml^{-1} of Nile water. The mean counts of coliphages by APHA ranged between 63 and 4677 using ATCC No. 13706 whereas the Kott-MPN technique suggested 6–478 pfu 100 ml^{-1} (El-Marazky, 1988).

Enteroviruses, especially Coxsackie B viruses (CBVs) have been detected in water and wastewater by many investigators (Montserrat et al., 1994; Wyn-Jones et al., 1995). In the Nile, enteroviruses were studied monthly from November 1999 to October 2000 by RT-PCR (Ali et al., 2002). Enterovirus-positive samples represented 11/12 (91.6%), 8/12 (66.6%) and 4/12 (33.3%) at the intakes of El-Giza, El-Maadi and Mostorod water treatment plants (WTPs). Moreover, Coxsackievirus CB2 was present in 3/23 (14.2%) of enterovirus-positive samples (Table 4).

Table 4 Enteroviruses and Coxsackie viruses type B in Nile water at the intake of three water treatment plants (WTPs)

	Positive RT-PCR samples	
Stations	No.	Percent
El-Giza	11/12	91.6
El-Maadi	8/12	66.6
Mostorod	4/12	33.3
Total	23/36	63.8
No. of CB	3/23	14.2

9 Damietta Branch

9.1 Total Bacterial Counts

During 1977, TBCs at 22°C ranged from 1.3×10^3 cfu ml^{-1} at the intake of the water treatment plant of El-Mansoura to 5.15×10^4 cfu ml^{-1} in south El-Mansoura during April and September, while at 37°C they varied between 3.2×10^3 cfu ml^{-1} at Talkha Fertilizer Factory during January 1978 and 1.8×10^5 cfu ml^{-1} at the south El-Mansoura city during April 1977. No significant differences existed between 22°C and 37°C (El-Mongy, 1978). TBCs at 22°C at upper Damietta Branch during summer 1994–spring 1996 varied from 2.1×10^3 to 6.3×10^5, while at 37°C they ranged from 5.0×10^2 to 5.1×10^5 (El-Taweel, 1998). WQI during 2000 showed that water entering the branch in winter is of good quality; it deteriorates downstream but later regains a medium condition. Low flow during winter, in addition to pollution sources along the branch, explain the changes in WQI. Recently, TBCs have ranged from 10.8×10^7 to 150×10^7 cfu ml^{-1} and from 8.8×10^7 to 152×10^7 cfu ml^{-1} at 22°C and 37°C. The highest number occurs in summer, the lowest in winter. Site-wise there is an increase in bacteria from El-Qanater to Damietta, attributable to domestic, sewage and agricultural effluents. Statistically, TBCs at 22°C and 37°C correlate positively ($r = 0.82$) (Sabae & Rabeh, 2007).

9.2 Bacterial Indicators of Sewage Pollution

During January 1978, TC and FC was lowest (23 and 13 MPN index 100 ml^{-1}, respectively) at south El-Mansoura, with highest TC (9.2×10^2 100 ml^{-1}) at El-Khiyariya village (5 km north El- Mansoura) during October 1977 and of FC (3.5×10^2 100 ml^{-1}), at Talkha Fertilizer Factory during August 1977. During summer 1994–spring 1996, TC at the beginning of Damietta Branch was 49×10^4–1.6×10^4 MPN 100 ml^{-1}, with annual average 5.6×10^3 MPN 100 ml^{-1}, while FC varied from 8.0×10^3 to 2.3×10^3 MPN 100 ml^{-1}, with annual average 6.2×10^2 MPN 100 ml^{-1}. FS fluctuated between 20 and 4.1×10^2 MPN 100 $ml^{-1}$with annual average 1.2×10^2 MPN 100 ml^{-1} (El-Taweel, 1998). A monitoring trip in February 2001 indicated that FC ranged from 9×10^2 100 ml^{-1} at Zefta (upstream of irrigation intakes at Zefta Barrage, 1,058 km from AHD) to 3.5×10^3 100 ml^{-1} at 1,025 km from AHD. Except at Zefta Barrage, FC counts exceeded WHO (1989) guidelines for unrestricted irrigation (1,000 100 ml^{-1}) at all sampling sites. Discharge of human wastes in Damietta Branch is responsible for this (Ezzat et al., 2002). MPN of TC during 2005–2006 varied from 240 to 16×10^4 100 ml^{-1} and from 40 to 75×10^2 100 ml^{-1} for FC. FS fluctuated between 4×10^2 and 21×10^2 100 ml^{-1} at Damietta Branch and was highest at Damietta City. Highest TC, FC and FS occurred in spring and summer (Table 5). A positive correlation ($r = 0.74$) was found between TBCs and bacterial indicators. FC/

Table 5 Most probable number (MPN) of total coliforms (TC), faecal coliforms (FC) and faecal streptococci (FS) $\times 10^3$ $100\,\mathrm{ml}^{-1}$ at Damietta Branch

Seasons Bacteria	Autumn			Winter			Spring			Summer		
Stations	TC	FC	FS	TC	FC	FS	TC	FC	FS	TC	FC	FS
El-Qanater	0.24	0.021	0.012	0.43	0.04	0.004	0.900	0.400	0.093	0.270	0.070	0.075
Benha	0.44	0.090	0.46	0.46	0.043	0.026	2.400	0.930	0.210	1.500	0.390	0.400
Zefta	1.90	0.400	0.15	1.10	0.044	0.040	11.00	1.500	1.500	7.500	0.400	0.390
Talkha	2.00	0.700	0.24	2.10	0.44	0.040	15.00	2.100	1.600	21.00	2.000	0.440
El-Serw	9.30	2.100	0.24	1.50	0.36	0.040	15.00	2.100	0.430	39.00	2.300	0.460
Faraskour	11.0	0.700	0.46	4.00	0.46	0.150	46.00	2.400	1.500	110.0	7.000	1.100
Damietta	46.0	2.300	1.10	16.0	2.30	0.390	110.0	6.400	1.500	160.0	7.500	2.100

FS ratios were in the range 0.19–11, consistent with faecal pollution. (Sabae & Rabeh, 2007).

9.3 Pathogenic Bacteria

E. coli, the main indicator of faecal pollution, constituted 16% of gram-negative bacteria in Damietta water from autumn 2005 to summer 2006. Clearly, the water was subject to sewage pollution. *P. aeruginosa* was common (12%). Among gram-negatives, *K. pneumoniae* represented 14%, *Salmonella cholerasuis* 11%, *Shigella* spp. 9%, *Serratia liquefaciens* and *Proteus vulgaris* each 8%, *Acinetobacter* sp. 7%, and *Brenneria nigrifluens* 5%. Six other isolates were identified as *Flavimonas oryzihabitans and Chryseomonas luteola* (three isolates each) (Sabae & Rabeh, 2007).

10 Rosetta (Rashid) Branch

10.1 Total Bacterial Counts

In summer 1994–spring 1996, TBCs at 22°C at upper Rosetta Branch totaled 2.1×10^3–7.2×10^5 cfu ml^{-1}; at 37°C they varied from 7.0×10^2 to 5.2×10^5 cfu ml^{-1} (annual average 1.5×10^5) (El-Taweel, 1998). El-Rahawy Drain, receiving agricultural drainage and sewage from Giza Governorate, is one of the main wastewater discharges to the Rosetta Nile. The highest TBCs (28×10^8 and 40.1×10^8 cfu ml^{-1} at 22°C and 37°C) are found at this point. Bacteria increased more downstream (5×10^5–15×10^7 and 8×10^5–17×10^7 cfu ml^{-1}, at 22°C and 37°C) than upstream of the discharge (2×10^4–16×10^5 cfu ml^{-1} at 22°C and 3×10^4–21×10^5 cfu ml^{-1} at 37°C). One important factor in Nile water is suspended matter, due to bacterial adherence to particles. Thus, there is a negative correlation ($r = -0.84$) between TBCs and transparency. The ratio of 22°C: 37°C counts ranges between 0.2 and 12.83 (Sabae, 1999).

10.2 Bacterial Indicators of Sewage Pollution

TC density at Kafr El-Zayat district fluctuated between 10^2 and 10^4 MPN-index 100 ml^{-1}, except at industries which discharge wastewater continuously, and where average density increased to $10^5 \times 100$ ml^{-1} (El-Abagy & Kamel, 1992). During summer 1994–spring 1996 TC was 1.3×10^2–1.6×10^4 MPN 100 ml^{-1} at the beginning of Rosetta Branch (annual average 5.5×10^3 MPN 100 ml^{-1}). FC was 11–3.3×10^3 MPN 100 ml^{-1}, with annual average 7.6×10^2 MPN 100 ml^{-1}; FS was 40–1.2×10^3 MPN 100 ml^{-1} (annual average 3.2×10^2 MPN 100 ml^{-1}) (El-Taweel, 1998). Rosetta Branch is polluted at the discharge of El-Rahawey Drain, where MPN of TC, FC and FS reach 90×10^6, 25×10^5 and 45×10^4 100 ml^{-1} (Sabae, 1999). The drain discharges ca 28×10^4 m^3 day^{-1}, of which 193×10^2 m^3 to Rosetta Nile. Water opposite Rashid city is higher in TC, FC and FS than near the sea. During February 2001, FC ranged from 1.7×10^2 100 ml^{-1} (upstream of Edfina Barrage, 1,156.5 km from AHD) to 1.3×10^3 100 ml^{-1} at Kafr El-Zayat (1,075 km from AHD). The highest counts were at Kafr El-Zayat, after which the water complied with WHO Guidelines for irrigation (Ezzat et al., 2002). In Rosetta as in Damietta, a trend occurs whereby water quality deteriorates downstream to reach its worst condition ca 120 km downstream.

10.3 Pathogenic Bacteria

Pseudomonas aeruginosa was not detected in Rashid estuary, suggesting sensitivity of these bacteria to high salinity (23.48–30.08&permile;) (Mostafa et al., 2001).

11 Conclusions

Microbial information provides evidence for pollution levels that create health risks at specific locations where pathogens as well as viruses reach unsafe levels for use in drinking, irrigation and fisheries. Human contact degrades water quality; people use the Nile for swimming, bathing, and washing, all of which may cause bacteriological pollution. Lake Victoria is also used for bathing, washing clothes, and watering livestock, and is similarly contaminated with human and animal wastes. A 1997 cholera outbreak in rural Western Kenya implicated water from Lake Victoria as a possible cause.

The counts of bacteria and pathogens in drains are even higher. Untreated human waste in these drains reaches dangerous levels. The bacterial indicators of pollution depend on the quality and quantity of waste discharged. Self-purification and competition for nutrients play a role in determining the value of such bacterial indicators.

The major sources of pollution of the White and Blue Niles are:

1. Urban centers adjacent to the Nile (e.g. Khartoum). The following adversely affect the quality of water: inputs from industry (sugar factories which dispose highly enriched organic waste), agricultural and domestic sewage sources, and drinking water for a growing population.
2. Some recently established hotels dispose sewage directly into the Nile.
3. Recreational sites on the banks of the Blue and White Niles threaten the microbial quality of Nile water.
4. Burri power station on the Blue Nile uses water for cooling and releases exhaust oil and cooling water to the Nile.
5. Raw domestic and industrial sewage in rainy season finds access to the river. With the increasing population of Khartoum, the Nile should receive only treated sewage.

The water quality of Lake Nasser is good. However, some settlements around the lake and upstream do not take precautions about water pollution. Therefore, protection of water quality should not be restricted to the river downstream of the Aswan High Dam. SRB can be a nuisance and may release H_2S under conditions present in the bottom of Lake Nasser during the hot season. Fishing in the lake ensures a gradual decrease in the organic and inorganic load leading to a lower microbiological oxygen consumption and better aeration. Enteroviruses were isolated with a frequency of 60% and positive results were unexpectedly high along 300 km of river in the south of Egypt.

The microbial load in Nile water along Egypt is due to:

1. The River having become a sink of domestic waste: 98.5% of the Egyptian population in the valley and delta lives on 1.3% of the area of the country.
2. An increasing number of boats and floating houses discharging to the river.

The major source points of pollution in Upper Egypt are nine drains, viz. Khour El-Sail Aswan, Main Draw, El-Berba, Kom Ombo, Houd El-Sebaia, Mataana, El-Ballas, Bany Shaker, and Etsa; as well as sugar factories, oil and soap factories in Sohag and a touristic galleon parking.

The water quality index (WQI) resulting from two monitoring campaigns conducted during winter (February 2000) and summer (September 2000) proved that about 71% of the sampling sites during winter show good quality of water, while the remaining sites offer a medium quality water. WQI during summer shows that only 43% of the sampling sites has good water quality; the rest is medium.

In Greater Cairo, the major source points of pollution are six drains: Ghamaza El-Kobra, El-Tebbin, Khour El-Sail Badrashin, El-Hawamdia sugar, Khour El-Sail Maasera, and Kotsica starch in addition to El-Hawamdia sugar factory

Damietta Branch is adversely affected by Talkha fertilizers and High Serw power station. The WQI for Damietta Branch during 2000 shows that during winter, water enters the branch with good quality, deteriorates downstream, then regains a medium condition. The low flow during winter, in addition to wastes from different pollution sources along the branch explain these changes.

Major source points of pollution of Rosetta Branch are five drains: El-Rahawy Drain in the south, Sobol Drain, El-Tahrrer Drain, Zawiet El-Bahr Drain and Tala Drain, in addition to industry at Kafr El-Zayat.

- The same trend of WQI occurs along the Rosetta Branch where the water reaches its worst condition 120 km downstream. The branch receives pollutants from five drains: El-Rahawy, Sobol, El-Tahreer, Zaweit El-Bahr and Tala, as well as from industrial effluents. The extremely low flow during winter, in addition to wastes from different sources explains the changes in WQI along its course.
- In spite of the high dilution factor and the high self-purification capacity of the Nile, the impact of discharges on microbial quality of the water is significant, especially during low flow years.

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