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TECHNICAL PAPER

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The Importance of Pathogenic Organisms in Sewage and Sewage Sludge

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ABSTRACT

Deficient sanitation poses a serious threat to human and animal health, involving complex relationships between environments, animals, refuse, food, pathogens, parasites, and man. However, by sanitizing and stabilizing the organic matter of sewage sludge, agriculture can utilize it to maintain soil, water, and air quality. As ingredients in soil amendments, such bioresidues are a source of nutrients for plants. Stabilization and sanitation of sewage sludge safely couple its recycling and disposal. This coupling becomes increasingly important as economic and environmental constraints make strategies for waste disposal more difficult to apply. The occurrence of viruses, bacteria, yeasts, fungi, and zooparasites in sewage sludge is reviewed in this article, and consequential epidemiologic concerns that arise from sewage sludge recycling is also addressed.

IMPLICATIONS

This review article focuses on the risks associated with improper sanitation of sewage sludge, which is widely used as soil conditioner and can carry a number of infectious diseases. The most updated knowledge about the presence of pathogenic organisms in sewage and sewage sludge is reviewed, and could be of interest to soil scientists, farmers, sewage treatment plant managers, and epidemiologists. The information contained in this review could also assist law- and policy-makers in updating laws and regulations in order to ensure a legal and regulatory framework aimed at ensuring the microbiological quality of sewage sludge (composted or not) and preventing the dissemination of infectious disease among workers, farmers, and consumers.

INTRODUCTION

Scientists, governments, and the general public share an increasing awareness of environmental problems that arise from the production of organic wastes in industrialized countries. In these countries, since the 1970s, legislators have acknowledged researchers' demands by promulgating laws intended to protect water bodies from the disposal of pollutants and organic wastes. An early example of this approach comes from the United States, which since 1972 has required, through the Federal Water Pollution Control Act, a secondary treatment of sewage by municipalities. In 1976, Italy enacted Law No. 319 (Rules for the Protection of Water from Pollution) and, on January 1992, enacted the decree requiring the same. In 1986, the European Communities (EC) enacted Directive No. 278/CEE, stipulating that all the EC countries implement rules for water protection. These regulations have increased the production of sewage sludge, which has become one of the most important sources of organic wastes. Animal farming and urban activities produce a comparably high amount of organic wastes.

Krauss and Page[1] estimated that the United States produces 5.3 Mg/year of sewage sludge, of which 16% is incinerated, 38% is landfilled, 36% is spread on soil, and 10% is handled in other ways. Haapapuro et al.[2] reported that farm animals in the United States produce 1.6×10^3 Mg of waste each year. For the European Union, L'Hermite and Ott[3] estimated sludge production to be 1.5×10^7 Mg. These figures are consistent with those estimated by Kofoed,[4] who calculated sewage sludge production per capita in the industrialized countries at 800 kg/year (95% water), equivalent to 25–40 kg/year of dry matter, with slight differences between countries. According to Goldberg-Federico et al.,[5] sludge produced from animal farming (1.4 × 10^6 Mg/year in Italy alone, on a wet weight basis) should be added to this large amount of organic matter.

Whether disposed of or recycled, this enormous quantity of organic waste represents an immense environmental challenge. Because sewage sludge is contaminated by pathogenic organisms, and often contains organic and inorganic pollutants, several ecosystems are highly polluted because of past and continued waste disposal practices. Farmers are worried about the possible diffusion of infections caused by organic refuse, which can seriously threaten workers as well as livestock grazing on soil amended with sewage sludge.[6] In addition, sludge can cause microbial contamination of surface and groundwater through run-off from contaminated land.[7] This paper reviews the presence of pathogenic organisms in sewage sludge, which is the most relevant risk associated with utilization of such organic refuse.

SEWAGE SLUDGE COMPOSITION AND CHARACTERISTICS

Sewage sludge is the byproduct of the treatment of municipal wastewater to remove pollutants. It mainly derives from sedimentation of the organic matter of wastewater, which settles down in basins specifically designed for sewage treatment. The organic fraction of the sewage sludge has such a complex composition that Boyle[8] defined it as a “chaotic mixture,” because of the abundance and diversity of its components and the presence of xenobiotic compounds. The organic matter in sewage sludge is chiefly composed of human excreta, modified by nonbiological and biological stabilization treatments. Organic matter in sewage sludge is easily fermentable and must undergo stabilization processes before any kind of utilization is considered. The stabilization procedures can be summed up as follows: (1) drying (air and/or heat); (2) chemical treatments; (3) aerobic stabilization (liquid state); (4) anaerobic stabilization (with biogas production); and (5) composting (solid state).

The efficacy of different sewage sludge treatments in reducing amounts of pathogens varies widely. Drying reduces the viability of most pathogens as water activity decreases below a critical level. Pathogens having appropriate survival strategies (bacterial spores, cysts, etc.) can easily survive the treatment and return to vegetative status when the environmental parameters become favorable.[9] In addition, because drying does not properly stabilize waste organic matter, a recontamination can occur when the material is rewet, inadvertently or on purpose, and its water content can reach a value of ~15%.[9,10] It has also been demonstrated that *Salmonella* can survive in wastewater sludge whose water content is less than 10%.[10]

The sanitation performance of a physical and chemical stabilization procedure depends on the pathogen composition of the stabilizing sludge and the chemical and physical modifications that the composition imposes on the sludge. Table 1 compares the effectiveness of different treatments on pathogen reduction. The efficacy of a biological treatment relies on several factors, such as temperature, redox potential, competition between pathogens and mineralizing microflora, and the susceptibility of stabilized organic matter to sustain pathogen growth.[11] The time/temperature ratio appears to be the key feature in the aerobic and anaerobic sanitation procedures, while in the composting process, both the temperature and antagonistic organisms cooperate in the pathogen inactivation.[10] Nevertheless, it is worth noting that, in laboratory experiments, when temperatures were less than 45 °C, the time required for virus inactivation was higher in raw than in digested sewage sludge. At temperatures greater than 45 °C, the inactivation time was quite similar for both raw and digested sewage sludge. For example, a temperature of 60 °C seems to be effective for inactivating viruses after 20 min of exposure, while a 2-hr treatment at 50 °C prevents the embrionation of the *Ascaris lumbricoides* eggs.[12]

The aerobic and anaerobic stabilization processes give a still fluid product, without any substantial volume reduction, characterized by poorly stabilized organic matter[13] and fairly variable performances in pathogen reduction.[10,14] In contrast, composting reduces the volume of processed sewage sludge and gives a storable solid product that is hygienically safe. Table 2 compares the effectiveness in pathogen reduction of such treatments. Disposal of the sewage sludge in an improper manner can enhance the oro-fecal transmission of diseases, regardless of the hygienic standards of the concerned countries. In addition, disposing of poorly sanitized sludge can increase the microbial contamination of surface water, either via direct contamination or through the run-off from lands amended with organic refuse.

SOURCES OF PATHOGENS

The type of pathogens most commonly found in sewage sludge and its derivatives (compost, dried sludge, stabilized sludge, anaerobically digested sludge, etc.) depends on the state of public health, as well as on the presence of hospitals, tanneries, meat-processing factories, and abattoirs in the same area.[15] Despite the high hygienic standards of developed countries, the degree of pathogen prevalence is usually significant. Foodborne pathogens are among the most important cause of sewage contamination in developed countries. As reported by Scott,[16] in

Table 1. Pathogen-reduction performance of nonbiological treatments of sludge.[9,14]

Type of Treatment	Sanitation Factor	Sanitizing Effect on				Product Stability
		Viruses	Bacteria	Spore	Parasite Eggs	
Pasteurization	Heat, 30 min at 70 °C	Moderate	Good	Poor	Good	Poor
Irradiation	Ionizing radiation, 300 rad	Poor	Good	Poor	Moderate/good	Moderate
Lime treatment						
Slaked lime	High pH	Moderate/good	Good	—	Moderate	Good, if pH remains >10
Quick lime	High pH, 80 °C	Good	Good	—	Good	Good, if pH remains >10

European countries, a rather high number of outbreaks of foodborne diseases occurs in single households, and a high proportion of them remain undiagnosed and unreported. Public health authorities all over the world highlight that only a small percentage (10–20%) of all outbreaks of food and waterborne illnesses are actually reported, and hence the incidences of these diseases are likely to be much higher than statistical studies indicate. The World Health Organization has estimated that only 10% of European outbreaks are reported.[17]

Domestic pets can also serve as reservoirs of zoonotic and enteropathogenic bacteria (mainly *Campilobacter jejuni* and *Salmonella* spp.). Pasquale et al.[18] described an outbreak of *Aeromonas hydrophila* in pet turtles, and D'Aoust and Lior[19] and D'Aoust et al.[20] found pet turtles to be important reservoirs of *Salmonella* spp. and a threat to public health. Woodward et al.,[21] who carried out a survey on exotic pets in Canada, reported several *Salmonella* serotypes associated with iguana, turtle and turtle water, frog, lizard, snake, chameleon, and hedgehog. In addition to foodborne and pet-carried pathogens, rotaviruses, which can easily survive in the environment, were found to be an additional cause of gastroenteritis in communities and institutions.[22]

Considering the widespread diffusion of undiagnosed and unreported infectious diseases occurring in single households, it is very likely that infected persons supply sewage systems with oro-fecal pathogens. Barker and Bloomfield[23] found that *Salmonella enteritidis* survived up to 4 weeks in biofilms in a domestic toilet following household salmonellosis. *Salmonella* spp. were isolated, by the same authors, from below the waterline of a toilet bowl up to 50 days after experimental seeding. Such findings highlight the importance of household episodes of gastroenteritis in long-lasting enrichment of sewage by pathogenic microorganisms.

Sewage contamination can also be inferred from the prevalence of infectious diseases in wastewater treatment workers. Sadik et al.[24] found that wastewater treatment workers were at high risk of contracting infectious diseases. This study, carried out on 242 employees of different wastewater treatment plants, found an increase in the incidence of gastroenteritis and gastrointestinal symptoms among such workers. In addition, Rylander,[25] investigating the occupational risk in a Swedish wastewater treatment plant, found that the amount of airborne endotoxin was between 3.8 and 32.2 ng/m^3. These endotoxin concentrations, which exceeded the Swedish recommended guidelines, significantly affected workers and caused nose irritation, tiredness, and diarrhea.

The large occurrence of zooparasites in sewage and their low minimal infective doses are likely to represent a health risk for workers exposed to sewage. Examining 126 wastewater workers in Paris, Schlosser et al.[26] found a mean intestinal zooparasite carriage of 11.8%. They found four zooparasites: *Trichiurus* sp., *Giardia lamblia*, *Entamoeba coli*, and *Endolimax nanus.*

Water- and Foodborne Diseases as Sources of Sewage Contamination

To understand the importance of foodborne disease outbreaks in developed countries, their impact on public health needs to be addressed. Such diseases have an economic impact on individuals, industries, and public agencies. Recent cost estimates for all food- and waterborne

Table 2. Pathogen-reduction performance of various biological treatments of sludge.[9]

Type of Process	Sanitizing Effect on		
	Viruses	Bacteria	Parasite Eggs
Anaerobic digestion			
Mesophilic (30–35 °C)	Poor	Poor	Poor
Thermophilic (50–55 °C)	Moderate/good	Moderate/good	Moderate
Aerobic digestion			
Mesophilic (up to 20 °C)	Poor	Poor	Poor
Termophilic (50–55 °C)	Good	Good	Good
Composting (50–60 °C)	—	Good	Good

illnesses in the United States range from 7700 to 23,000 million U.S. dollars.[27] In the United States in 1990, more than 50% of the recorded food- and waterborne outbreaks could not be attributed to any particular agent, due to poor record keeping or the inability to cultivate or identify the etiological agent.[28] These findings have been recently updated by Mead et al.,[29] who estimated that infectious diseases caused by unknown agents are ~80% of all those reported in the United States.

Levine et al.[30] reported 25,743 cases of waterborne disease outbreaks, which occurred in 24 states of the United States and Puerto Rico from 1986 to 1988. Bean and Griffin[31] and Todd[27] compiled an overview of foodborne disease outbreaks in the United States (from 1973 to 1987) and in Canada (from 1975 to 1984), respectively. They found that 120,540 and 28,827 reported cases were caused by microbiological and parasitic food poisoning in the United States and Canada, respectively. All these reports have been recently reviewed by Mead et al.,[29] who, upon analyzing data from multiple surveillance systems in the United States, found that foodborne illnesses cause ~76 million cases of disease and 5000 deaths each year. Of these cases, only 325,000 patients with foodborne illnesses were treated in hospitals. This data underlines the high incidence of household-treated infections and their consequences on pathogen loading of sewage and sewage sludge. These findings were confirmed by the FoodNet Working Group,[32] which has 16.1 million persons under observation in the United States (~6% of the population). In 1997, 2205 cases of salmonellosis, 1237 cases of shigellosis, 468 cases of cryptosporidiosis, 340 cases of *E. coli* O157:H7 infections, 139 cases of yersiniosis, 77 cases of listeriosis, 51 *Vibrio* infections, and 49 cases of cyclosporiasis were reported.

Stolle and Sperner,[33] reviewing the available data on the viral foodborne illnesses in the European Union, found that hepatitis A and small round structured viruses were the most common viral pathogens associated with contaminated food. Hepatitis E virus foodborne contamination is seldom effectively proved in European countries. The same authors pointed out that the unreported foodborne viral infections must be significantly higher than reported ones. Very recently, Bofill-Mas et al.[34] reported the isolation of polyoma viruses JC and BK in urban sewage in Spain. These authors used such findings to document epidemiologic patterns of JC and BK viruses in a human population. JC virus has been associated with a fatal demyelinating disease that occurs as a complication in AIDS patients, whereas BK virus has been associated with infection of the urinary tract.

Besides the pathogens of past concern (e.g., *Bacillus cereus, Clostridium botulinum, Clostridium perfringens, Salmonella typhi, Shigella, Staphylococcus aureus*), Tauxe[35] reported a list of new or emerging pathogens that have been recognized in the last 20 years as being predominantly foodborne. They are the Norwalk-like viruses; the bacteria *C. jejuni, Campylobacter fetus* ssp. *fetus, Escherichia coli* O157:H7, *E. coli* O111:NM, *E. coli* O104:H21, *Listeria monocytogenes, S. enteritidis, Salmonella typhimurium* DT 104, *Vibrio cholerae* O1, *Vibrio vulnificus, Vibrio parahaemolyticus, Yersinia enterocolitica*; and the alga *Nitzschia pungens* (causative agent of the amnesiac shellfish poisoning). *Campylobacter coli* and *Arcobacter* spp.,[36,37] *V. cholerae* O139,[38] and *Aeromonas* spp. should also be added to the list of emerging bacterial pathogens.

Cryptosporidium, a protozoan of emerging concern as a causative agent of waterborne diseases,[39] is frequently isolated from wastewater treatment plants[22] and commonly found in surface water. *Cryptosporidium* has become an important pathogen in drinking water, and is associated with a high risk of disease, particularly for immunocompromised persons. From 1984 to 1992 in the United States, 12 waterborne outbreaks of cryptosporidiosis have been reported.[39]

Scott[16] observed that in the European countries, a rather high number of outbreaks of foodborne diseases occurred in single households. *Salmonella* spp. and *C. jejuni* were the most frequently reported bacteria responsible for household-associated foodborne illnesses. Scott also reported that in the Netherlands and France, the estimated number of gastroenteritis cases per year was as high as 2.5 million. In Europe, from 1989 to 1991, 157,245 cases of bacterial foodborne illnesses were reported (including *Salmonella* spp.), with 99,245 cases of gastroenteritis being attributed to *C. jejuni*. In the same years, *Salmonella* spp. was responsible for 2378 outbreaks associated with household food contamination, and *C. jejuni*, 1064 outbreaks. In addition, Notermans and Hoogenboom-Verdegaal[40] estimated that, each year, *Salmonella* and *Campylobacter* spp. caused, respectively, ~12,000 and 25,000 cases of acute enteritis per million inhabitants.

THE OCCURRENCE OF PATHOGENS IN WASTEWATER AND SEWAGE SLUDGE

Sewage contamination by pathogenic microorganisms has been thoroughly studied, so scientific literature on this topic is ample. By comparison, the contamination of sewage sludge has received much less attention. Even though the presence of pathogens in sewage sludge can be inferred by sewage contamination, it should be noted that sewage sludge undergoes several physical and chemical treatments (air or oxygen supply, pasteurization, air-drying, addition of chemicals, etc.), which can reduce, with highly variable efficiency, the viability and/or the concentration of pathogens. The following sections focus on the occurrence of pathogens in wastewater and sewage sludge.

Viruses

In marine and freshwater ecosystems, suspended organic matter and/or clay minerals can, very efficiently, absorb viruses,[41,42] allowing them to withstand harsh environmental conditions. More than 100 different types of viruses excreted by humans[43] may be absorbed on sludge organic matter and thereby protected from inactivation.[44,45] In addition to human viruses, animal viruses present from birds, dogs, and cats may reach sewage systems and then contaminate wastewater, to the detriment of human health. Human strains of the influenza virus can persist for years in pigs, as a possible reservoir of this disease.[46] Human influenza viruses can also live in domestic and migratory birds.[47-50]

Virus concentrations in sewage sludge have been estimated to be 10^3 cytopathogenic units (CU) per kg (w.w.), and almost 100% of the sludge samples contained enteric viruses.[44] These results have been confirmed by Gantzer et al.,[51] who found up to 22.5 CU of infectious enteroviruses per 1 L of treated wastewater. Soares et al.[52] found 3.29×10^4 and 1.61×10^3 enteric viruses per kg of digested and undigested sewage sludge, respectively.

Among viruses of human concern found in sewage and in sewage sludge, the occurrence and prevalence of hepatitis A virus (HAV) has been quite extensively studied. Sobsey et al.[48] found that HAV was able to survive for at least 3 months in the environment of sewage treatment plants. More recently, Cadilhac and Roudot-Thoraval[53] found that 39% of samples from a waste disposal system were positive for HAV, and that occupational exposure to sewage increased the risk of infection from 15 to 30%. De Serre and Laliberté[54] confirmed those results and proposed that HAV should be considered an occupational hazard for sewage workers. These authors found a causal relationship between a small community outbreak and the infection of three workers employed in the water treatment plant that treated the wastewater of the infected community. Vonstille et al.[55] reported an HAV epidemic (39 cases) in Florida that occurred after overflowing sewage contaminated seawater. Despite such results, Trout et al.[56] did not find occupational risk factors for HAV to be statistically significant among wastewater workers in Cincinnati.

Other viruses that occur in sewage sludge include the hepatitis E virus, found and characterized in sewage in Barcelona, Spain, where hepatitis E was not endemic.[57] Also, Van Der Avoort et al.[58] recently isolated epidemic poliovirus type 3 from sewage in the Netherlands. The isolation of poliovirus was consequent to an outbreak of poliomyelitis in an unvaccinated community. Sewage was recognized as a carrier, spreading the epidemic. Earlier, Ansari et al.[59] reported the presence of the human immunodeficiency virus type 1 nucleic acid in wastewater. Unfortunately, there is a lack of epidemiologic documentation of the transmission of these viruses to humans through agricultural utilization of sewage sludge.[43] For a list of viruses commonly found in sewage sludge, see Table 3.

Bacteria

Bacterial pathogens in sewage sludge contribute significantly to health problems, locally and globally. Table 4 gives the concentrations of indicator and pathogenic bacteria in sewage sludge. Following are details about several of these pathogens.

Salmonella spp. These are the most widespread bacterial pathogens of significant global public health concern that are likely to cause an important sewage sludge contamination. About 25,000 cases of salmonellosis were reported annually in the United Kingdom for the period of 1988–1990.[60] The author noted that, because of the failure to report all the cases, the actual number of people who

Table 3. Viruses excreted by humans that can be isolated from sewage sludge.[34,43,57,126,127]

Virus	Diseases or Symptoms Caused
Enteroviruses	
Polio virus	Poliomyelitis, meningitis, fever
Coxackievirus A	Herpangina, respiratory disease, meningitis, fever
Coxackievirus B	Myocarditis, congenital heart anomalies, respiratory disease, pleurodynia, rash, fever
Echovirus	Meningitis, respiratory disease, diarrhea, encephalitis, acute hemorrhagic conjunctivitis, fever
New Enteroviruses	
Adenovirus	Respiratory disease, eye infection
Parvovirus	Meningitis, encephalitis, respiratory disease, acute hemorrhagic conjunctivitis, fever
Reovirus	Not clearly established
Hepatitis A virus	Infectious hepatitis
Hepatitis C virus	Infectious hepatitis
Hepatitis E virus	Infectious hepatitis
Rotavirus	Vomiting and diarrhea
Astrovirus	Not established
Calicivirus	Vomiting and diarrhea
Coronavirus	Common cold
Norwalk agent and other small round viruses	Vomiting and diarrhea
Adeno-associated viruses	Not clearly established, but associated with respiratory disease in children
Polyomaviruses	
JC	Progressive multifocal leukoencephalopathy
BK	Infections of the urinary tract

Table 4. Bacteriological characteristics of sewage sludge.

		Coppola and Manfredi[129]	Strauch[130]	De Bertoldi et al.[105]	
	Raw Sludge[a]	Liquid Sludge[a] Aerobically Digested	Liquid Sludge[a] Anaerobically Digested	Raw Sludge[b]	Raw Sludge[a]
Total Coliforms	10^4–10^9	10^5–10^6	10^4–10^5	1.1×10^9	
Fecal Coliforms	10^4–10^8	10^5–10^6	10^3–10^4	1.9×10^5	
Escherichia coli					10^7
Fecal Streptococci	10^5–10^8	10^5–10^6	10^3–10^4		
***Salmonella* spp.**	10^3–10^6	0–10	10–10^2	2.9×10^2	10^5
***Shigella* spp.**					10^7
Pseudomonas aeruginosa				3.3×10^3	
***Klebsiella* spp.**					10^7
***Yersinia* spp.**					10^6
***Brucella* spp.**	0–10^3	0	0		
***Staphylococcus* spp. (coagulase-positive)**	10^2–10^5	0–10	0		
Oxidase-Positive Strains					10^4
Anaerobic Sulfate-Reducers	10^4–10^7	10^5–10^7	10^4–10^5		

[a]Bacteria/g dry matter; [b]Average geometric mean of bacteria/g dry matter.

suffered from *Salmonella* spp. food poisoning alone may have been as high as 250,000 in 1991. Strauch[43] reported on the severity of the *Salmonella* spp. infections in the Federal Republic of Germany in 1977, when the economic losses caused by human and livestock salmonellosis reached ~59 million and 73 million U.S. dollars, respectively. Tauxe[61] estimated that in 1988, the number of *Salmonella* spp. infections in the United States was between 840,000 and 4,000,000. This estimate is based on 43,785 reported cases of salmonellosis, which represented from 1/20 to 1/100 of the actual cases.[62] Similar findings were reported by Todd,[27] who estimated that between 1975 and 1984 in Canada, with a population of ~10% of that in the United States, 15,817 persons became ill following the consumption of foods contaminated with *Salmonella* spp. In southern California, Kinde et al.[63] found *Salmonella enteritidis* phage type 4 in treated waters coming from a sewage treatment plant.

In an interesting survey[64] on *S. enteritidis* antibiotic resistance in *Salmonella* outbreaks in southern Italy from 1990 to 1998, the authors found that, of the 44 drug-resistant strains, 23 strains were resistant to 1 antibiotic, 3 to 2 antibiotics, 10 to 3 antibiotics, 2 to 4 antibiotics, 1 to 5 antibiotics, 3 to 7 antibiotics, and 3 to 8 antibiotics. These figures emphasize the high level of hygienic danger associated with land disposal of sewage sludge without a proper sanitation procedure. In Switzerland, Hess and Breer[6] found an epidemiologic causal relationship between the disposal of municipal sewage sludge on grazing land and salmonellosis in cattle herds. The infected dairy cows could be responsible for further transmission of salmonellosis to humans. In this way, the infection, coming from ill persons, returns to the population again via sewage sludge and dairy cows.

Findlay[65] reported that in a soil treated with raw slurry, no salmonellae were found 2 weeks after the organic amendment, but *Salmonella dublin* was found in the same soil 5 months later. These findings highlight that *Salmonella* spp. can last for a long time in contaminated soil and can multiply in such an environment. Morse and Duncan[66] listed the survival rates of *Salmonella* spp. in the environment as follows:

Tap water	87 days
Pond water	115 days
Pasture soil	120 days
Garden soil	280 days
Avian feces	28 months
Dried bovine manure	more than 30 months

E. coli. Hoeller et al.[67] for the first time isolated enterohemorrhagic *E. coli* from municipal sewage in Germany. Such a report highlights that, besides the main infection routes (person-to-person contact, consumption of raw milk and undercooked meat), environmental contamination by sewage can play an important role in the diffusion of such a pathogen. Shiga toxin-producing *E. coli* is increasingly recognized as an emerging pathogen in both developed and developing countries,[68] where it is associated with hemolytic uremic syndrome and hemorrhagic colitis. Muniesa and Jofre[69] recently found, in 15 sewage sludge samples from Europe, South Africa, and New Zealand, phages infecting *E. coli* O157:H7, which carries Shiga toxin gene Sxt 2. This finding points out the danger of spreading Sxt 2 genes in different enterobacteria strains. Although the occurrence of the Sxt 2 gene in wastewater is presumably common in developing countries, Muniessa and Jofre[69] demonstrated that these genes are also widely distributed in Europe.

Aeromonas spp. Table 5 lists bacterial pathogens that can be expected in sewage sludge; the list, based on data reported by Strauch,[43] has been updated to take into consideration other bacterial pathogens contaminating sludge. Motile *Aeromonas*, for instance, have been added to the list on the grounds of their occurrence in the environment and human populations.[70-72] For example, Poffe and Op de Beek,[73] studying a wastewater treatment plant in Belgium, reported an efficiency of removal of *A. hydrophila* from wastewater greater than 99%. *A. hydrophila* was found to be concentrated in primary sludge (10^7 cfu/g w.w.), whereas partially dried sludge and trickling-filtered sludge contained more than 10^6 cfu/g (w.w.) of this bacterium. In agreement with these findings, Stecchini and Domenis[74] reported a high concentration of mesophilic *Aeromonas* (1.75×10^8 cfu/mL) in the influent of an urban wastewater treatment plant in Italy. These authors also reported a low efficiency of removal of *Aeromonas* spp., with an effluent concentration of these bacteria as high as 6.04×10^6 cfu/mL. It is also notable that Gray et al.[75] found mesophilic *Aeromonas* spp. in farm animals and in the surrounding environment.

V. cholerae and the Related Vibrio Species. The World Health Organization[76] reviewed the information on the epidemiology of diarrheic diseases caused by *V. cholerae* and the related *Vibrio* species and found that, despite the high hygienic standards of the industrialized countries, *V. cholerae* and related species still infect a significant number of persons. The *V. cholerae* serotypes O1 and O139 and non-O1 can cause a large array of illnesses, ranging from a mild disease to fatal cholera.[38] One-third of the 35 *Vibrio* spp. are pathogenic to humans and animals.[77,78] The physiological characteristics of these bacteria allow them to live in aquatic ecosystems (drinking, fresh, and sea water) and to contaminate water, sediment, and seafood.[77-81] *Vibrio* spp., including *V. cholerae*, are therefore commonly found in sewage sludge.

The consumption of seafood can cause outbreaks or single-case infections, with subsequent sewage contamination. A number of reports enumerate the occurrences of *V. cholerae* and other *Vibrio* spp. in oysters and other seafood all over the world.[77,81,82] In Mediterranean countries, the most utilized fecal decontamination procedure for edible mussels requires the washing of mussels in tanks continuously supplied by filtered and/or UV-irradiated seawater. The well-known susceptibility of enteric bacteria to the chemical composition of the seawater enables adequate mussel purification. In contrast, seafood infection by pathogenic *Vibrionaceae* overrides the possibility of decontamination through the normal procedure because of the aforementioned physiological characteristics of these bacteria.[83] Although the impact of the difficulties in sanitizing contaminated shellfish on public health is still under investigation, it is likely responsible for a wide circulation of these pathogens among the population, with inevitable sewage and sewage sludge contamination.

Table 5. Bacterial pathogens that have been isolated from sewage sludge.[43,63,67,73,128]

Primary Pathogens	Opportunistic Pathogens
Motile *Aeromonas*	*Citrobacter* spp.
Arcobacter spp.	*Enterobacter* spp.
Bacillus anthracis	*Escherichia coli*
Brucella spp.	*Klebsiella* spp.
Campylobacter coli	*Proteus* spp.
Campylobacter fetus ssp. *fetus*	*Providencia* spp.
Campylobacter jejuni	*Serratia* spp.
Clostridium botulinum	
Clostridium perfringens	
Escherichia coli O111:NM	
Escherichia coli O157:H7	
Escherichia coli O184:H21	
Leptospira spp.	
Listeria monocytogenes	
Mycobacterium spp.	
Pseudomonas aeruginosa	
Salmonella spp.	
Shigella spp.	
Staphylococcus (coagulase positive strains)	
Streptococcus (beta-hemolyticus strains)	
Vibrio cholerae	
Vibrio parahaemolyticus	
Vibrio vulnificus	
Yersinia enterocolitica	

L. monocytogenes. Strauch[43] included, in the list of pathogens commonly found in sewage sludge, *L. monocytogenes*, the bacterial etiologic agent of listeriosis, a rather rare illness with a 30% death rate.[84] In agreement with these findings, De Luca et al.[37] confirmed sewage sludge contamination by *L. monocytogenes* by examining five different types of sludge (primary raw, activated, thickened, digested, and dewatered) in an Italian sewage treatment plant. *L. monocytogenes* was found in all sludge types, in concentrations ranging from 2743 to 6 MPN/g d.m.

This bacterium, recently associated with food-borne outbreaks, is considered a pathogen of new concern.[85,86] Foodborne incidents increased the cases of human infection, roused the scientific community and governments to a state of alarm, and caused huge economic losses to the food industry, mainly the dairy industry. The *L. monocytogenes* contamination of raw milk in Italy, Spain, United States, Finland, Canada, United Kingdom, Ireland, Netherlands, France, and Germany ranged from 0 to 45% of the samples examined, whereas the contamination of dairy products in Italy, United Kingdom, Canada, France, Netherlands, France, and Germany was between 0 and 10%.[87] A review of the 1988–1989 European literature revealed that 23% of the meat and meat products examined, 4% of the milk and dairy products, 3% of the vegetables, and 12% of the fish and crustaceans were contaminated by *L. monocytogenes.*[88] Jay,[89] examining reports from 1971 to 1994, found that *L. monocytogenes* was present in 16% of meat products, with highly variable concentrations (from <100/g to 1.9 × 10^5/g). Meng and Doyle[90] reported that recent studies on the prevalence of *L. monocytogenes* in humans indicated that from 2 to 6% of individuals are carriers, whereas the percentage of carriers among farm animals ranged from 10 to 50%. Besides being isolated from humans and farm animals, Fenlon[91] (in 1985) isolated *L. monocytogenes* within such reservoirs of the agricultural environment as silage and wild birds, and, a few years later, also within the farm environment, Skovgaard and Morgen[92] found that 62% of animal feed samples, 51% of cow feces, and 33% of poultry feces were positive for *L. monocytogenes.*

The World Health Organization pointed out the importance of sewage sludge in the dissemination of *L. monocytogenes* in the environment.[17] The results reported in that study were corroborated by Dijkstra[93] and Watkins and Sleath,[94] who found *L. monocytogenes* in contaminated surface water, sewage, and sewage sludge. De Luca et al.[95] found *L. monocytogenes* in the sewage sludge of a treatment plant in Italy and showed that the occurrence of *L. monocytogenes* was correlated with the season, being more abundant in spring and autumn. They also found *L. monocytogenes* resistant to biological oxidation of sludge but sensitive to anaerobic conditions.

Campylobacter ssp. A common etiological agent of gastroenteritis in developed countries, *C. jejuni* is commonly found in surface water and sewage. The enrichment of surface water from *Campylobacter* spp. can be caused by water run-off from farmland,[98] particularly when poorly sanitized sludge is used as an organic amendment. *Campylobacter* spp. was commonly isolated from sewage sampled from sewage treatment plants, with *C. jejuni* being ~80% of those *Campylobacter* isolates.[96] Stampi et al.[36] found that the *C. jejuni* and *C. coli* present in sewage were extremely sensitive to the treatment undergone by the sludge in a sewage treatment plant. Oxygen activation of sludge reduced *Campylobacter* spp. by 99.63%, and the subsequent tertiary treatment with 2 ppm of chlorine dioxide reduced these bacteria to an undetectable level. These authors found *Campylobacter* only in sludge of the primary sedimentation tanks, and always absent from the secondary activated sludge, in a treatment plant in Italy. Waage et al.[97] isolated *C. jejuni* and *C. coli* from sewage in northern Europe (Norway).

Arcobacter butzleri. Recent findings[38] demonstrated the presence of *A. butzleri* in an Italian sewage treatment plant and in all types of sewage sludge (primary, activated, thickened, and anaerobically digested). The concentration of *A. butzleri* in sludge peaked in April, May, June, and September, following the same seasonal distribution observed by De Luca et al.[37] for *L. monocytogenes.* Finally, with regard to resistance capacities of pathogenic bacteria, which need to be taken into account for sewage sludge, it is worth noting that some of the bacteria that colonize the human intestinal tract can acquire antibiotic resistance genes. Among them are *E. coli* and *Enterobacter fecium*.[99] The spread of antibiotic-resistant bacterial strains from animals to humans is well documented for *S. typhimurium*.[99] The large use of antibiotics in animal husbandry for promotion of growth, for prophylaxis, and for therapy, and in hospitals for prophylaxis and therapy, causes the enrichment of antibiotics in the environment and produces a selective pressure on bacteria.

The appearance of multiresistant strains of pathogenic bacteria is an issue of particular concern in developed countries. *S. typhimurium* phage type DT 104 C was found to harbor multiple resistances, including decreased susceptibility to ciprofloxacin.[100] Aarestrup et al.[101] found an increased antibiotic resistance among pathogenic and indicator bacteria isolated from pigs, cattle, and broilers in Denmark. In general, these authors most frequently observed antibiotic resistance among isolates from pigs. Recently, Coque et al.[102] isolated vancomicin-resistant enterococci from nosocomial, community, and animal sources. The human health impact of these antibiotic-resistant bacteria, which are likely to be found in sewage and sewage sludge, is not yet well understood.

Yeast and Fungi

Pathogenic yeast and fungi are likely to be of secondary importance in contamination of humans through sewage sludge. Such organisms can cause a fairly wide range of diseases, from allergies to serious systemic infections.[103] Some fungi can also produce mycotoxins when they grow on specific foodstuffs and foods. *Aspergillus fumigatus*, a medically important fungal opportunist and respiratory allergen, is always present in sewage sludge and heavily contaminates the atmosphere of composting plants.[104] The most important pathogenic yeast and fungi, mostly found in sewage sludge, are reported in Table 6.

A. fumigatus, which is always present in the atmosphere during the composting of sewage sludge, represents up to 75% of airborne microflora of composting plants.[104] Milner et al.[104] point out that it is impossible to eliminate the health risk represented by *A. fumigatus* because this fungus utilizes cellulose as a source of carbon, and cellulose-rich materials are often utilized as bulking agents in sludge composting. *A. fumigatus* is always present in composting sludge, especially during the thermophilic phase.[105] Boutin et al.[106] found similar results in a municipal solid waste composting plant and reported the presence of the following fungi genera: *Monilia* spp. (*Candida* spp. in the current taxonomy), *Penicillium* spp., and *Mucor* spp. Most of the species belonging to these genera are potentially pathogenic for immunocompromised patients, whereas *Aspergillus* spp. is a well-known agent of allergic diseases.

Zooparasites

The Europeans, from the 14th to the 19th centuries, spread a fairly wide range of diseases all over the world, during their exploratory voyages and military colonization campaigns, which caused rather serious health problems for the extra-European populations. Today, the high number of travellers, immigrants, refugees, and resettled persons coming from the developing countries are reversing this flow. It is extremely likely that zooparasites are the most important pathogenic agents currently imported into industrialized countries.

Cryptosporidium parvum oocysts are frequently isolated both from wastewater and treated effluent of sewage treatment plants.[39] Chauret et al.[107] described the occurrence of *Cryptosporidium* oocysts and *Giardia* cysts during wastewater treatment. All the samples taken in the sewage inlet were positive for both of these protozoa, and the water treatment reduced the *Cryptosporidium* oocysts and *Giardia* cysts by 2.96 and 1.40 $\log_{10}$, respectively, whereas anaerobic sludge digestion resulted in no reduction. The higher concentrations found in mixed sludge (thickened activated sludge mixed with raw sludge in a 1:3 ratio) were 3810 *Cryptosporidium* oocysts per 100 g and 11,800 *Giardia* cysts per 100 g.

Table 6. Pathogenic yeast and fungi that have been isolated from sewage sludge.[7,106]

Yeast	Fungi
Candida albicans	*Aspergillus* spp.
Candida guillermondii	*Geotricum candidum*
Candida krusei	*Epidermophyton* spp.
Candida tropicalis	*Phialophora richardsii*
Cryptococcus neoformans	*Trycophitum* spp.
Trichosporon	

It is relevant to mention that Withemore and Robertson[108] found that *Cryptosporidium* oocysts can survive in sludge-amended soil for at least 30 days. Run-off from agricultural lands is one of the most important routes of surface water contamination, because cattle are suspected to be reservoirs of this protozoan.[39] The risk of surface water contamination is much enhanced by soil amendment with improperly sanitized sewage sludge. *Cyclospora cayetanensis* has been isolated from wastewater by Sturbaum et al.,[109] who detected oocysts in an oxidation lagoon of a wastewater treatment plant. They confirmed that fecal-contaminated water might act as a vehicle for transmission of *C. cayetanensis* infections.

The health concern arising from the presence of zooparasites in sewage sludge is probably underestimated, despite increased interest in parasitology. Recently, Dowd et al.[110] found the microsporidia *Enterocytozoon intestinalis*, a causative agent of gastrointestinal diseases in humans, in wastewater and sewage sludge in a sewage treatment plant in the United States. Earlier, Havelaar et al.[14] emphasized the quantitative importance of sewage contamination by the eggs of zooparasites. They reviewed the works of Liebman,[111] Boersema et al.,[112] and Piekarski and Pelster,[113] which suggest that, in the sewage treatment plant of a middle-sized European city, the input of *A. lumbricoides* eggs and other parasitic helminths could easily reach several billions a day. Johnson et al.[114] found a long survival time for eggs of *Ascaris suum* in sludge after mesophilic digestion and lagoon storage. These eggs can successfully infect suitable hosts after 29 weeks, and perhaps a portion of the egg population can survive for more than 6 months in stockpiled biosolids from digested sludge. Other authors have reported a survival time for *Ascaris* eggs in lagooned, digested, and composted sludge of 33 months to 4–6 years.[115,116] Cai et al.[117] found that *Ascaris* eggs survived for several months in sewage-irrigated or sludge-manured soils.

As stated by Strauch,[43] the epidemiology of zooparasites is more complex than that of viruses and bacteria. Zooparasites may have more than one intermediate host and more than one larval stage, each characterized by a different degree of sensitivity to environmental conditions. The zooparasites of major concern are *Taenia saginata*, *A. lumbricoides*, *A. suum*, and *Toxocara canis*.[14]

Table 7. Parasites that have been isolated from sewage and sewage sludge.[43,109,110]

Protozoa	Cestodes	Nematodes
Cyclospora cayetanensis	*Diphyllobothrium latum*	*Ancylostoma duodenale*
Cryptosporidium parvum	*Echinococcus granulosus*	*Ascaris lumbricoides*
Encephalitozoon intestinalis	*Hymenolepsis nana*	*Necator americanus*
Entamoeba histolytica	*Taenia saginata*	*Toxocara canis*
Giardia lamblia	*Taenia solium*	*Toxocara catii*
Sarcocystis spp.		*Trichiurus trichiura*
Toxoplasma gondii		
Vittaforma corneae		

Table 7 lists the zooparasites that are to be expected in sewage sludge. As stated before, some "exotic" zooparasites should also be included in the list, as suggested by the work of Crotti et al.,[118] who examined 542 African students living in Perugia, Italy. Apart from several other zooparasites listed in Table 7, they also found a high incidence of *Necator americanus* and *Hymenolepis nana* in asymptomatic subjects. Finally, Ilsoe et al.[119] investigated the transmission route of *T. saginata* eggs from human feces to cattle in Denmark. The most frequent source of infection in animals in permanent pasture was the illegal use of sewage sludge from septic tanks as organic amendment on pasture soil.

CONCLUSIONS

Sewage sludge harbors a large variety of pathogens able to cause or spread a high number of transmissible diseases to both humans and animals. Nevertheless, the utilization of sludge is consistent with the worldwide effort to reduce environmental pollution and to recycle the organic fraction of wastes in soil. The conflict arising from harmful sludge characteristics and its usefulness for agricultural and land reclamation can be settled by sanitation treatments.

A significant scientific problem arises from the need to obtain a hygienic safe product before any kind of use. The microbiological tests that should be carried out in order to ascertain the effectiveness of the sanitation procedures of sludge are still grounds for discussion. More than a methodological problem, we are facing a theoretical question: Which (micro)organisms should be utilized as markers to indicate the success of the sanitation treatment or to indicate that the product is hygienically safe and can be safely utilized for agricultural purposes *sensu lato*?

The classical indicator bacteria (fecal coliforms and streptococci), as well as *Salmonella* isolated from sanitized organic materials issued from sewage treatment plants, have proved to be deficient indicators for ascertaining the real hygienic risk concealed in such products. Most of the pathogens of new concern are unrelated to the classical bacterial indicators, as underlined by Krovacek et al.,[120] who stressed the ineffectiveness of fecal coliforms currently utilized to define water hygienic quality and proposed *Aeromonas* spp. as a new indicator organism. Also, Rose[39] reported the lack of correlation between the concentration of coliform bacteria in water and the presence of enteric protozoa.

Technical limitations for detection and isolation procedures can be considered the main difficulties in monitoring sludge pathogens. In addition, pathogenic bacteria introduced into a hostile environment may become viable but not culturable[121] without losing their virulence factors. Note also that sludge may contain several xenobiotic compounds, and composted sludge could facilitate inhospitalities between pathogenic bacteria. To overcome the limitations of isolation and detection procedures, Straub et al.[7] proposed in 1993 that polymerase chain reaction (PCR) technologies could be useful tools in detecting viruses and pathogens in the environment, including in soil amended with sewage sludge. The PCR-based methods have proved to be able to detect viruses, bacteria, and zooparasites in environmental samples in sewage sludge and compost, even when they were present at very low concentrations.

Because of the complexity of matrices in which microorganisms must be detected, a number of problems associated with the sensitivity and specificity of PCR-based identification procedures, when applied to environmental microbiology, have been encountered. Inhibitory substances present in wastewater, sewage sludge, and composts could directly or indirectly interfere with PCR amplification techniques.[59] Yet another complication is that PCR can still recognize or detect the DNA of the organisms that have been killed during technological processes, thus yielding false positive results.[122] Nevertheless, Droffner and Brinton,[123] measuring the survival of *E. coli* and *Salmonella* populations in composts using DNA probes, found that *S. typhimurium* Q survived for at least 5 days at greater than 60 °C during wastewater sludge composting. Such findings stress the usefulness of molecular techniques in detecting bacterial pathogens in complex matrices, and also the need for a deeper knowledge, from an epidemiological standpoint, of their survival in harsh environmental conditions.

In addition to this, keep in mind that stabilized organic matter can still become a pathogen attraction when stored before using. In order to avoid recontamination by pathogenic organisms, the U.S. Environmental Protection Agency[124] took into account the importance of limiting the attraction exerted on pathogen vectors by stabilized organic wastes. A good example of the hygienic danger represented by pathogen vectors has recently been given by Olsen and Hammack,[125] who isolated *S. enteritidis*, *Salmonella infantis*, and *Salmonella heidelberg* from two different species of flies (*Musca domestica* and *Hydrotaea aenescens*), and *Salmonella mdandaka* from a mealworm (*Alphitobius diaperinus*). Other domesticated and wild animals, which often carry human pathogens, can contaminate improperly sanitized organic wastes.

The scientific debate stemming from difficulties in assessing the performance of organic waste sanitization and stabilization procedures, and difficulties in describing their pathogen attraction characteristics, is far from being settled. This incertitude in setting adequate standards for controlling the health risk of waste is mirrored by inadequate legislation that provides unsatisfactory rules and procedures for reducing or eliminating potential health risks latent in poorly sanitized and/or stabilized organic waste matter. The further development of molecular techniques seems to be a promising avenue for solving the technical analytical problems that hinder comprehension of survival mechanisms that allow pathogens to withstand harsh environmental conditions in wastes. In addition, such techniques could help in clarifying epidemiologic issues that underpin the occurrence of pathogens in waste, wastewater, and stabilized organic waste materials.

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REFERENCES

1. Krauss, G.D.; Page, A.L. Wastewater, Sludge and Food Crops; *Biocycle* **1997**, *February*, 74-82.
2. Haapapuro, E.R.; Barnard, N.D.; Simon, M. Review—Animal Waste used as Livestock Feed: Dangers to Human Health; *Prevent. Med.* **1997**, *25*, 599-602.
3. L'Hermite, P.; Ott, H. Processing and Use of Sewage Sludge: A European R&D Picture. In *Biological Reclamation and Land Utilization of Urban Wastes;* Zucconi, F., De Bertoldi, M., Coppola, S., Eds.; Proceedings of an International Symposium, Naples, Italy, October 11–14, 1983; pp 111-120.
4. Kofoed, A. Optimum Use of Sludge in Agriculture. In *Utilization of Sewage Sludge on Land: Rates of Application and Long-Term Effect of Metals;* Berglund, S., Davis, R.D., L'Hermite, P., Eds.; D. Riedel: Boston, MA, 1983; pp 2-21.
5. Goldberg-Federico, L.; Rossi, N.; Spallacci, P. Agricultural Use of Organic Wastes (Livestock Slurries, Sewage Sludges, Composts): The Situation in Italy; *Chimica Oggi* **1989**, *7*, 29-32.
6. Hess, E.; Breer, C. Salmonellen Epidemiologie und Grundlanddungung mit Klärschlamm; *Azbl. Bakt. Hyg.* 1 Orig. B **1975**, *161*, 54-60.
7. Straub, T.M.; Pepper, I.L.; Gerba, C.P. Hazards from Pathogenic Microorganisms in Land-Disposed Sewage-Sludge; *Rev. Environ. Contam. Toxicol.* **1993**, *132*, 55-91.
8. Boyle, M. Biodegradation of Land-Applied Sludge; *J. Environ. Qual.* **1990**, *19*, 640-644.
9. Dumontet, S.; Dinel, H.; Baloda, S. Pathogen Reduction in Sewage Sludge by Composting and Other Biological Treatments: A Review; *Biol. Hort. Agric.* **1999**, *16* (4), 409-430.
10. Yeager, J.G.; Ward, R.L. Effects of Moisture Content on Long-Term Survival of Bacteria in Wastewater Sludge; *Appl. Environ. Microbiol.* **1981**, *41*, 1117-1122.
11. Stentiford, E.I. Recent Development in Composting. In *Compost: Production, Quality and Use*; De Bertoldi, M., Ferranti, M.P., L'Hermite, P., Zucconi, F., Eds.; Elsevier Applied Science: New York, 1986; pp 52-60.
12. Finstein, M.S.; Wey-Ru Lin, K.; Fischler, G.E. Sludge Composting and Utilization: Review of the Literature on the Temperature Inactivation of Pathogens. In *New Jersey Agricultural Experiment Station Int. Report*; The State University of New Jersey: New Brunswick, NJ, 1982.
13. Higgins, A.J.; Kaplovsky, A.J.; Hunter, J.V. Organic Composition of Aerobic, Anaerobic and Composted-Stabilized Sludge; *J.—Water Pollut. Control Fed.* **1982**, *54*, 466-472.
14. Havelaar, A.H.; Oosterom, H.; Notermans, S.; van Knapen, F. Hygienic Aspects of the Application of Sewage Sludge to Land. In *Biological Reclamation and Land Utilisation of Urban Wastes;* Zucconi, F., De Bertoldi, M., Coppola, S., Eds.; Proceedings of an International Symposium, Naples, Italy, October 11–14, 1983; pp 167-200.
15. Bruce, A.M.; Davis, R.D. Utilization of Sewage Sludge in Agriculture. Maximizing Benefits and Minimizing Risks. In *Biological Reclamation and Land Utilization of Urban Wastes;* Zucconi, F., De Bertoldi, M., Coppola, S., Eds.; Proceedings of an International Symposium, Naples, Italy, October 11–14, 1983; pp 102-111.
16. Scott, E. Foodborne Disease and Other Hygiene Issues in the Home; *J. Appl. Bact.* **1996**, *80*, 5-9.
17. *The Risk to Health of Microbes in Sewage Sludge Applied to Land*; Euro Reports and Studies No. 54; World Health Organization: Geneva, 1981.
18. Pasquale, V.; Baloda, S.B.; Dumontet, S.; Krovacek, K. An Outbreak of *Aeromonas hydrophila* Infection in Turtles (*Pseudemis scripta*); *Appl. Environ. Microbiol.* **1994**, *60*, 1678-1680.
19. D'Aoust, J.Y.; Lior, H. Pet Turtle Regulations and Abatement of Human Salmonellosis; *Can. J. Public Health* **1978**, *69*, 107-108.
20. D'Aoust, J.Y.; Daley, E.; Croizer, M.; Sewell, A.M. Pet Turtles: A Continuing International Threat to Public Health; *Am. J. Epidemiol.* **1990**, *132*, 233-238.
21. Woodward, D.L.; Khakhria, R.; Johnson, W.M. Human Salmonellosis Associated with Exotic Pets; *J. Clin. Microbiol.* **1997**, *35*, 2786-2790.
22. Koopmans, M.P.G.; van Aspen, I. Epidemiology of Rotavirus in The Netherlands; *Acta Pediatr.* Suppl. **1999**, *88*, 31-37.
23. Barker, J.; Bloomfield, S.F. Survival of Salmonella in Bathrooms and Toilets in Domestic Homes Following Salmonellosis; *J. Appl. Microbiol.* **2000**, *89*, 137-144.
24. Sadik, A.K.; Tammy, A.; Bisesi, M.S.; Schaub, E.A. Prevalence of Infectious Diseases and Associated Symptoms in Wastewater Treatment Workers; *Am. J. Ind. Med.* **1998**, *33*, 571-577.
25. Rylander, R. Health Effects among Workers in Sewage Treatment Plants; *Occup. Environ. Med.* **1999**, *56*, 354-357.
26. Schlosser, O.; Grall, D.; Laurenceau, M.N. Intestinal Parasite Carriage in Workers Exposed to Sewage; *Eur. J. Epidemiol.* **1999**, *15*, 261-265.
27. Todd, E.C.D. Foodborne Disease in Canada—A 10-Year Summary from 1975 to 1984; *J. Food Prot.* **1992**, *55*, 123-132.
28. Potter, M.E. The Changing Face of Foodborne Disease; *J. Am. Vet. Med. Assoc.* **1992**, *201*, 250-253.
29. Mead, P.; Slutsker, L.; Dietz, V.; McCaig, L.F.; Bresee, J.S.; Shapiro, C.; Griffin, P.M.; Tauxe, R.V. Food-Related Illness and Death in the United States; *Emerg. Infect. Dis.* **1999**, *5*, 607-625.
30. Levine, W.C.; Stephenson, W.T.; Craun, G.F. Waterborne Disease Outbreaks, 1986–1988; *J. Food Prot.* **1991**, *54*, 71-78.
31. Bean, N.H.; Griffin, P.M. Foodborne Disease Outbreaks in the United States, 1973–1987: Pathogens, Vehicles, and Trends; *J. Food Prot.* **1990**, *53*, 804-817.
32. Wallace, D.J.; Van Gilder, T.; Shallow, S.; Fiorentino, T.; Segler, S.D.; Smith, K.E.; Shiferaw, B.; Etzel, R.; Garthright, W.E.; Angulo, F.J. Incidence of Foodborne Illnesses Reported by the Foodborne Diseases Active Surveillance Network (FoodNet)–1997; FoodNet Working Group; *J. Food Prot.* **2000**, *63*, 807-809.
33. Stolle, A.; Sperner, B. Viral Infections Transmitted by Food of Animal Origin: The Present Situation in the European Union; *Arch. Virol. Suppl.* **1997**, *13*, 219-228.
34. Bofill-Mas, S.; Pina, S.; Girones, R. Documenting the Epidemiology of Polyoma Viruses in Human Population by Studying their Presence in Urban Sewage; *Appl. Environ. Microbiol.* **2000**, *66*, 238-245.
35. Tauxe, R.V. Emerging Foodborne Diseases: An Evolving Public Health Challenge; *Emer. Infect. Dis.* **1997**, *3*, 425-434.
36. Stampi, S.; De Luca, G.; Varoli, O.; Zanetti, F. Occurrence, Removal and Seasonal Variation of Thermophilic Capylobacters and *Arcobacter* in Sewage Sludge; *Zentralbl. Hyg. Umweltmed.* **1999**, *202*, 19-27.
37. De Luca, G.; Zanetti, F.; Fateh-Moghadm, P.; Stampi, S. Occurrence of *Listeria monocytogenes* in Sewage Sludge; *Zentralbl. Hyg. Umweltmed.* **1998**, *20*, 269-277.
38. Bhattacharya, M.K.; Dutta, D.; Bhattacharya, S.K.; Deb, A.; Mukhopadhyay, A.K.; Nair, G.B.; Shimada, T.; Takeda, Y.; Chowdhury, A.; Mahalanabis, D. Association of a Disease Approximating Cholera Caused by *Vibrio cholerae* of Serogroups Other than O1 and O139; *Epidemiol. Infect.* **1998**, *120*, 1-5.
39. Rose, B.J. Environmental Ecology of *Cryptosporidium* and Public Health Implications; *Ann. Rev. Public Health* **1997**, *18*, 135-161.

40. Notermans, S.; Hoogenboom-Verdegaal, A. Existing and Emerging Diseases; *Int. J. Food Microbiol.* **1992**, *15*, 197-205.
41. Gantzer, C.; Quignon, F.; Schwartzbrod, L. Poliovirus-1 Adsorption onto and Desorption from Raw and Digested Sewage Sludge; *Appl. Environ. Microbiol.* **1994**, *15*, 271-278.
42. Metcalf, T.G.; Rao, V.C.; Melnick, J.L. Soil-Associated Viruses in a Polluted Estuary; *Monogr. Virol.* **1984**, *15*, 97-110.
43. Strauch, D. Survival of Pathogenic Microorganisms and Parasites in Excreta, Manure and Sewage Sludge; *Rev. Sci. Tech. Off. Int. Epiz.* **1991**, *10*, 813-846.
44. Schwartzbrod, L.; Mignotte, B. Virus Entérique et Boues Résiduaires Urbaines; *Bull. Soc. Fr. Microbiol.* **1986**, *11*, 11-16.
45. Chauret, C.; Springthorpe, S.; Sattar, S. Fate of *Cryptosporidium* Oocysts, *Giardia* Cysts, and Microbial Indicators during Wastewater Treatment and Anaerobic Sludge Digestion; *Can. J. Microbiol.* **1999**, *45*, 257-262.
46. Hannoun, C.; Gourreau, J.M. Surveillance de la Grippe chez les Porcs Sains; *Comp. Immun. Microbiol. Infect. Dis.* **1981**, *3*, 133-136.
47. Markwell, D.D.; Shortridge, K.F. Possible Waterborne Transmission and Maintenance of Influenza Viruses in Domestic Ducks; *Appl. Environ. Microbiol.* **1982**, *43*, 110-116.
48. Sobsey, M.D.; Shields, P.A.; Hauchman, F.S.; Davis, L.; Rullman, V.A.; Bosch, A. Survival of Hepatitis A Virus in Environmental Samples. In *Viral Hepatitis and Liver Diseases*; Liss, A.R., Ed.; Academic Press: New York, 1988; pp 121-124.
49. Slemon, R.D.; Shieldcastle, M.C.; Heyman, L.D.; Bednarik, K.E.; Senne, D.A. Type A Influenza Viruses in Waterfowl in Ohio and Implications for Domestic Turkeys; *Avian Dis.* **1991**, *35*, 165-173.
50. Suss, J.; Schafer, J.; Sinnecker, H.; Webster, R.G. Influenza Virus Subtypes in Aquatic Birds of Eastern Germany; *Arch. Virol.* **1994**, *135*, 101-114.
51. Gantzer, C.; Maul, A.; Audic, J.M.; Schwartzbrod, L. Detection of Infectious Enteroviruses, Enteroviruses Genomes, Somatic Coliphages, and *Bacteriodes fragilis* Phages in Treated Wastewater; *Appl. Environ. Microbiol.* **1998**, *64*, 4307-4311.
52. Soares, A.C.; Straub, T.M.; Pepper, I.L.; Gerba, C.P. Effect of Anaerobic Digestion on the Occurrence of Enteroviruses and *Giardia* Cysts in Sewage Sludge; *J. Environ. Sci. Health* **1994**, *A29*, 1887-1897.
53. Cadilhac, P.; Roudot-Thoraval, F. Seroprevalence of Hepatitis A Virus Infection among Sewage Workers in the Parisian Area, France; *Europ. J. Epidem*. **1996**, *12*, 237-240.
54. De Serre, G.; Laliberté, D. Hepatitis A among Workers from a Wastewater Treatment Plant during a Small Community Outbreak; *Occup. Environ. Med.* **1997**, *54*, 60-62.
55. Vonstille, W.T.; Stille, W.T.; Sharer, R.C. Hepatitis A Epidemics from Utility Sewage in Ocoee, FL; *Arch. Environ. Health* **1993**, *48*, 120-124.
56. Trout, D.; Mueller, C.; Venczel, L.; Krake, A. Evaluation of Occupational Transmission of Hepatitis A Virus among Wastewater Workers; *J. Occup. Environ. Med.* **2000**, *42*, 83-87.
57. Pina, S.; Jofre, J.; Emerson, S.U.; Purcell, R.H.; Girones, R. Characterization of a Strain of Infectious Hepatitis E Virus Isolated from Sewage in an Area Where Hepatitis Is Not Endemic; *Appl. Environ. Microbiol.* **1998**, *64*, 4485-4488.
58. Van Der Avoort, H.G.A.M.; Reimerink, J.H.J.; Mulders, A.R.M.N.; Van Loos, A.M. Isolation of Epidemic Poliovirus from Sewage Sludge during the 1992–93 Type 3 Outbreak in the Netherlands; *Epidemiol. Infect.* **1995**, *114*, 481-491.
59. Ansari, S.A.; Farrah, S.R.; Chaudhry, G.R. Presence of Human Immunodeficiency Virus Nucleic Acid in Wastewater and Their Detection by Polymerase Chain Reaction; *Appl. Environ. Microbiol.* **1992**, *58*, 3984-3990.
60. Lacey, L.W. *Salmonella enteritidis* in Eggs: A Novel Problem. In *I Problemi della Moderna Biologia: Ecologia Microbica, Analitica di Laboratorio, Biotecnologia*; Grimme, H., Landi, E., Dumontet, S., Eds.; Atti IV Convegno Internazionale, Ordine Nazionale dei Biologi: Sorrento, Italy, 1991; pp 391-402
61. Tauxe, R.V. *Salmonella*: A Postmodern Pathogen; *J. Food Prot.* **1991**, *54*, 563-568.
62. Chalker, R.B.; Blaser, M.J. A Review of Human Salmonellosis: III. Magnitude of Salmonella Infection in the United States; *Rev. Infect. Dis.* **1988**, *10*, 111-124.
63. Kinde, H.; Read, D.H.; Ardans, A.; Breitmeyer, R.E.; Willoughby, D.; Little, H.E.; Kerr, D.; Gireesh, R.; Nagaraja, K.V. Sewage Effluent: Likely Source of *Salmonella enteriditis* Phage Type 4 Infection in a Commercial Chicken Layer Flock in Southern California; *Avian Dis.* **1996**, *40*, 672-676.
64. Nastasi, A.; Mammina, C.; Cannova, L. Antimicrobial Resistance in *Salmonella enteritidis*, Southern Italy, 1990–1998; *Emerg. Inf. Dis.* **2000**, *6*, 401-403.
65. Findlay, C.R. The Survival of *Salmonella dublin* in Cattle Slurry; *Vet. Rec.* **1971**, *89*, 224-227.
66. Morse, E.V.; Duncan, M.A. Salmonellosis: An Environmental Health Problem; *J. Am. Vet. Med. Assoc.* **1974**, *165*, 1015-1019.
67. Hoeller, C.; Koschinsky, S.; Witthuhn, D. Isolation of Enterohemorrhagic *Escherichia coli* from Municipal Sewage; *Lancet* **1999**, *353*, 2039.
68. Nataro, J.P.; Kaper, J.B. Diarrheagenic *Escherichia coli; Clin. Microb. Rev.* **1998**, *11*, 142-201.
69. Muniesa, M.; Jofre, J. Occurrence of Phages Infecting *Escherichia coli* O157:H7 Carrying the Stx 2 Gene in Sewage from Different Countries; *FEMS Microbiol. Lett.* **2000**, *183*, 197-200.
70. Krovacek, K.; Farris, A.; Baloda, S.B.; Linderberg, B.; Peterz, M.; Mansson, I. Isolation and Virulence Profiles of *Aeromonas* spp. from Different Municipal Drinking Water Supplies in Sweden; *Food Microbiol.* **1992**, *9*, 215-222.
71. Krovacek, K.; Pasquale, V.; Baloda, S.B.; Soprano, V.; Conte, M.; Dumontet, S. Comparison of Putative Virulence Factors in *Aeromonas hydrophila* Strains Isolated from Marine Environment and Human Diarrheal Cases in Southern Italy; *Appl. Environ. Microbiol.* **1994**, *60*, 1379-1382.
72. Sanyal, S.C.; Singh, S.J.; Sen, P.C. Enteropathogenicity of *Aeromonas hydrophila* and *Plesiomonas shigelloides*; *J. Med. Microbiol.* **1975**, *8*, 195-198.
73. Poffe, R.; Op de Beek, E. Enumeration of *Aeromonas hydrophila* from Domestic Wastewater Treatment Plants and Surface Waters; *J. Appl. Bacteriol.* **1991**, *71*, 366-370.
74. Stecchini, M.L.; Domenis, C. Incidence of *Aeromonas* Species in Influent and Effluent of Urban Wastewater Purification Plants; *Lett. Appl. Microbiol.* **1994**, *19*, 237-239.
75. Gray, S.J.; Stickler, D.J.; Bryant, T.N. The Incidence of Virulence Factors in Mesophilic *Aeromonas* Species Isolated from Farm Animals and Their Environments; *Epidemiol. Infect.* **1990**, *105*, 277-294.
76. Cholera and Other Vibrio-Associated Diarrheas. In *Bull. World Health Org.*; World Health Organization: Geneva, 1980; p 58.
77. Sakazaki, R.; Shimada, T. *Vibrio* Species as Causative Agents of Foodborne Infection. In *Developments in Food Microbiology*; Robinson, R.K., Ed.; Elsevier Appl. Sci.: New York, 1982; pp 123-151.
78. Dodin, A.; Dosso, M. Ecologie des Vibrions Pathogènes. In *Proc. of Deuxième Colloque International de Bacteriologie Marine*; CNRS: Brest, France, 1984; pp 12-16.
79. Watkins, W.D.; Cabelli, V.J. Effect of Faecal Pollution on *Vibrio parahaemolyticus* Densities in an Estuarine Environment; *Appl. Environ. Microbiol.* **1985**, *49*, 1307-1313.
80. Venkateswaran, K.; Takai, T.; Navarro, I.M.; Hashimoto, H.; Siebeling, R.J. Ecology of *Vibrio cholerae* Non O1 and *Salmonella* spp. and Role of Zooplankton in Their Seasonal Distribution in Fukuyama Coastal Waters, Japan; *Appl. Environ. Microbiol.* **1989**, *55*, 1591-1598.
81. Kaysner, C.A.; Abeyta, C.; Stott, R.F.; Krane, M.H.; Wekel, M.M. Enumeration of *Vibrio* Species, Including *Vibrio cholerae*, from Samples of an Oyster-Growing Area, Grays Harbor, Washington; *J. Food Prot.* **1990**, *53*, 300-311.
82. Rippey, S.R. Infectious Diseases Associated with Molluscan Shellfish Consumption; *Clin. Microbiol. Rev.* **1994**, *7*, 419-425.
83. Richards, G.P. Microbial Purification of Shellfish: A Review of Depuration and Relaying; *J. Food Prot.* **1988**, *51*, 218-251.
84. Nieman, R.E.; Lorber, B. Listeriosis in Adults: A Changing Pattern—Report of Eight Cases and Review of Literature, 1968–1978; *Rev. Infect. Dis.* **1980**, *2*, 207-227.
85. El-Gazar, F.E.; Marth, E.H. *Listeria monocytogenes* and Listeriosis Related to Milk, Milk Products and Dairy Ingredients: A Review; *Milchwissenschaft* **1991**, *46*, 14-19.
86. Schlech, W.F., III. Foodborne Listeriosis; *Clin. Infect. Dis.* **2000**, *31*, 770-775.
87. Carminati, D. *Listeria monocytogenes* e Prodotti Lattiero-Caseari. In *I Problemi della Moderna Biologia: Ecologia Microbica, Analitica di Laboratorio, Biotecnologia*; Grimme, H., Landi, E., Dumontet, S., Eds.; Atti IV Convegno Internazionale, Ordine Nazionale dei Biologi: Sorrento, Italy, 1991; pp 423-440.
88. Rocourt, J.; Jacquet, C. *Listeria* et Listériose Humaine: 10 Années après la Première Demonstration d'une Épidémie Humaine d'Origine Alimentaire; *Biologi Italiani* **1992**, *4*, 11-17.
89. Jay, J.M. Prevalence of *Listeria* spp. in Meat and Poultry Products; *Food Control* **1996**, *74*, 209-214.
90. Meng, J.; Doyle, M.P. Emerging and Evolving Microbial Foodborne Pathogens; *Bull. Inst. Pasteur* **1998**, *96*, 151-164.
91. Fenlon, D.R. Wild Birds and Silage as Reservoirs of *Listeria* in Agricultural Environments; *J. Appl. Bacteriol.* **1985**, *59*, 537-543.
92. Skovgaard, N.; Morgen, C.A. Detection of *Listeria* spp. in Feces from Animals, in Feed and in Raw Food of Animal Origin; *Int. J. Food. Microbiol.* **1988**, *6*, 299-242.
93. Dijkstra, R.G. The Occurrence of *Listeria monocytogenes* in Surface Water of Canals and Lakes, in Ditch of One Big Polder and in the Effluents and Canals of a Sewage Treatment Plant; *Zbl. Bakt. Hyg.* **1982**, *B 176*, 202-205.
94. Watkins, J.; Sleath, K.P. Isolation and Enumeration of *Listeria monocytogenes* from Sewage, Sewage Sludge and River Water; *J. Appl. Bacteriol.* **1981**, *50*, 1-9.
95. De Luca, G.; Zanetti, F.; Fateh-Moghadm, P.; Stampi, S. Occurrence of *Listeria monocytogenes* in Sewage Sludge; *Zbl. Hyg. Umweltmed* **1999**, *201*, 269-277.

96. Koenraad, P.M.F.J.; Ayling, R.; Hazeleger, F.M.; Newell, D.G. The Speciation and Subtyping of *Campylobacter* Isolates from Sewage Plants and Wastewater from a Connected Poultry Abattoir Using Molecular Techniques; *Epidemiol. Infect.* **1995**, *115*, 485-494.
97. Waage, A.S.; Vardund, T.; Lund, V.; Kapperud, G. Detection of Small Numbers of *Campylobacter jejuni* and *Campylobacter coli* Cells in Environmental Water, Sewage, and Food Samples by a Semi-Nested PCR Assay; *Appl. Environ. Microbiol.* **1999**, *65*, 1636-1643.
98. Jones, K.; Betaieb, M.; Telfoerd, D.M. Correlation between Environmental Monitoring of Thermophilic Campylobacters in Sewage Effluent and the Incidence of *Campylobacter* Infection in the Community; *J. Appl. Bacteriol.* **1990**, *69*, 235-240.
99. Witte, W. Ecological Impact of Antibiotic Use in Animals on Different Complex Microflora Environments; *Int. J. Antimicrob. Agents* **2000**, *14*, 321-325.
100. Thrlfall, E.J.; Ward, L.R.; Frost, J.A.; Willshaw, G.A. Spread of Resistance from Food Animals to Man—The UK Experience; *Acta Vet. Scand. Suppl.* **2000**, *93*, 63-68.
101. Aarestrup, F.M.; Bager, F.; Jensen, N.E.; Madsen, M.; Meyling, A.; Wegener, H.C. Resistance to Antimicrobial Agents Used for Animal Therapy in Pathogenic, Zoonotic and Indicator Bacteria Isolated from Different Food Animals in Denmark: A Baseline Study for the Danish Integrated Antimicrobial Resistance Monitoring Programme (DANMAP); *APMIS* **1998**, *106*, 745-770.
102. Coque, T.M.; Tomayko, J.F.; Ricke, S.C.; Okkyisen, P.C.; Murray, B. Vancomycin-Resistant Enterococci from Nosocomial, Community and Animal Sources in the United States; *Antimicrob. Agents Chemother.* **1996**, *40*, 2605-2609.
103. Bodey, G.P.; Vartibvarian, S. Aspergillosis; *Eur. J. Clin. Microbiol. Infect. Dis.* **1989**, *8*, 413-437.
104. Milner, P.D.; Marsh, P.B.; Snowden, R.B.; Parr, J.F. Occurrence of *Aspergillus fumigatus* during Composting of Sewage Sludge; *Appl. Environ. Microbiol.* **1977**, *34*, 765-772.
105. De Bertoldi, M.; Coppola, S.; Spinosa, L. Health Implications in Sewage Sludge Composting. In *Disinfection of Sewage Sludge: Technical, Economic and Microbiological Aspects*; Bruce, A.M., Havelaar, A.H., L'Hermite, P., Eds.; Commission of the European Communities, D. Reidel: Dordrecht, Germany, 1983; pp 165-178.
106. Boutin, P.; Torre, M.; Moline, J. Bacterial and Fungal Atmospheric Contamination at Refuse Composting Plants: A Preliminary Study. In *Compost: Production, Quality and Use;* De Bertoldi, M., Ferranti, M.P., L'Hermite, P., Zucconi, F., Eds.; Elsevier Appl. Science: New York, 1986; pp 266-275.
107. Chauret, C.; Springthorpe, S.; Sattar, S. Fate of *Cryptosporidium* Oocysts, *Giardia* Cysts, and Microbial Indicators during Wastewater Treatment and Anaerobic Sludge Digestion; *Can. J. Microbiol.* **1999**, *45*, 257-262.
108. Whithemore, T.N.; Robertson, L.J. The Effect of Sewage Sludge Treatment on Oocysts of *Cryptosporidium parvum*; *J. Appl. Bacteriol.* **1995**, *78*, 34-38.
109. Sturbaum, G.D.; Ortega, Y.R.; Gilman, R.H.; Sterling, C.R.; Cabrera, L.; Klein, D.A. Detection of *Cyclospora cayetanensis* in Wastewater; *Appl. Environ. Microbiol.* **1998**, *64*, 2284-2286.
110. Dowd, S.E.; Gerba, C.P.; Pepper, I.L. Confirmation of the Human-Pathogenic Microsporidia *Enterocytozoon bieneusi, Enterocytozoon intestinalis,* and *Vittaforma corneae* in Water; *Appl. Environ. Microbiol.* **1998**, *64*, 3332-3335.
111. Liebman, H. Die Moglichkeiteder Verbreitung von Zooparasiten des Menschen und der Haustiere durch die Landwirtschaftlike, Abwasserverwertung, 1953. In Havelaar, A.H.; Oosterom, H.; Notermans, S.; van Knapen, F. Hygienic Aspects of the Application of Sewage Sludge to Land. In *Biological Reclamation and Land Utilisation of Urban Wastes*; Zucconi, F., De Bertoldi, M., Coppola, S., Eds.; Proceedings Int. Conference, Naples, Italy, 1983; pp 167-200.
112. Boersema, J.H.; Straver, B.; Franchimont, J.H.; Ruitemberg, E.J. Eerste Ervaringen met een Isolatiemethode van Eieren van Parasitaire Wormen uit Uitgeigist Rioolslijk. 1974. In Havelaar, A.H.; Oosterom, H.; Notermans, S.; van Knapen, F. Hygienic Aspects of the Application of Sewage Sludge to Land. In *Biological Reclamation and Land Utilisation of Urban Wastes*; Zucconi, F., De Bertoldi, M., Coppola, S., Eds.; Proceedings Int. Conference, Naples, Italy, 1983; pp 167-200.
113. Pierkarski, G.; Pelster, B. Parasitologische Aspekte zur Klarschlammdeponie. 1980. In Havelaar, A.H.; Oosterom, H.; Notermans, S.; van Knapen, F. Hygienic Aspects of the Application of Sewage Sludge to Land. In *Biological Reclamation and Land Utilisation of Urban Wastes*; Zucconi, F., De Bertoldi, M., Coppola, S., Eds.; Proceedings Int. Conference, Naples, Italy, 1983; pp 167-200.
114. Johnson, P.W.; Dixon, R.; Ross, A.D. An In-Vitro Test for Assessing the Viability of *Ascaris suum* Eggs Exposed to Various Sewage Treatment Processes; *Int. J. Parasitol.* **1998**, *28*, 627-633.
115. O'Donnell, C.J.; Meyer, K.B.; Jones, J.V. Survival of Parasite Eggs upon Storage in Sludge; *Appl. Environ. Microbiol.* **1984**, *48*, 618-625.
116. Gaspard, P.; Wiart, J.; Schwartzbrod, J. Parasitological Contamination of Urban Sludge for Agricultural Purposes; *Waste Manage. Res.* **1997**, *15*, 429-436.
117. Cai, S.W.; Zhou, S.Y.; Wang, J.Q.; Li, S.Y.; Zhu, X.L.; Wang, J.J.; Xue, J.R. A Bacteriological and Helminthological Investigation of a Sewage-Irrigated Area in a Beijing Suburb; *Biomed. Environ. Sci.* **1988**, *1*, 332-338.
118. Crotti, D.; Chiacchella, A.; Geranio, N. Incidenza di Parassitosi in Studenti di Colore in Perugia; *Biologi Italiani* **1990**, *3*, 41-44.
119. Ilsoe, B.; Kyvsgaard, N.C.; Nansen, P.; Heriksen, S.A. Bovine Cysticercosis in Denmark: A Study of Possible Causes of Infection in Farm Animals with Heavily Infected Animals; *Acta Vet. Scan.* **1991**, *31*, 159-168.
120. Krovacek, K.; Farris, A.; Mansson, I. Enterotoxigenic and Drug Sensitivity of *Aeromonas hydrophila* Isolated from Well Water in Sweden: A Case Study; *Int. J. Food Microbiol.* **1989**, *8*, 149-154.
121. Roszak, D.B.; Calwell, R.R. Survival Strategies of Bacteria in the Environment; *Appl. Environ. Microbiol.* **1987**, *52*, 531-538.
122. Baloda, S.B.; Krovacek, K. Use of Polymerase Chain Reaction (PCR) Technology in the Detection of Foodborne Pathogens: An Overview. In *Proceedings of International Congress on "Quality of Veterinary Services for the 21st Century"*; Kuala Lumpur, 1994; pp 123-126.
123. Droffner, M.L.; Brinton, W.F. Survival of *E.coli* and *Salmonella* Populations in Aerobic Thermophilic Composts as Measured with DNA Gene Probes; *Zentralbl. Hyg. Umweltmed.* **1995**, *197*, 387-397.
124. *EPA Standards for the Use and Disposal of Sewage Sludge*; 40 CFR Part 503; U.S. Environmental Protection Agency, Business Publish. Inc.: Silver Spring, MD, 1992.
125. Olsen, A.R.; Hammack, T.S. Isolation of *Salmonella* spp. from the Housefly, *Musca domestica* L., and the Dump Fly, *Hydrotaea aenescens* (Wiedemann) (diptera muscidae), at Caged-Layer Houses; *J. Food. Prot.* **2000**, *63*, 958-960.
126. *Report of WHO Scientific Group of Human Viruses in Water, Wastewater and Soil*; Technical Report Series No. 639; World Health Organization: Geneva, 1979.
127. Brautbar, N.; Navizadeh, N. Sewer Workers: Occupational Risk for Hepatitis C—Report of Two Cases and Review of Literature; *Arch. Environ. Health* **1999**, *54*, 328-330.
128. Stampi, S.; Varoli, O.; Zanetti, F.; De Luca, G. *Acrobacter cryaerophilus* and Thermophilic Campylobacters in a Sewage Treatment Plant in Italy: Two Secondary Treatments Compared; *Epidem. Infect.* **1993**, *110*, 633-639.
129. Coppola, S.; Manfredi, C. Risanamento Igienico dei Fanghi Risultanti dalla Depurazione delle Acque Reflue; *Nuovi Annali di Igiene e Microbiologia*, XXXIV; **1983**, *3*, 223-239.
130. Strauch, D. Microbiological Specification of Disinfected Sludge. In *Compost: Production, Quality and Use*; De Bertoldi, M., Ferranti, M.P., L'Hermite, P., Zucconi, F., Eds.; Elsevier Appl. Science: New York, 1986; pp 21-229.

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