https://doi.org/10.20965/jdr.2016.p0732

Paper:

A Case Study on the Health Risks Related to Flood Disasters in South Africa

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[Received April 22, 2016; accepted June 28, 2016]

Floods occurred in the Ndlambe Local Municipality in South Africa in October 2012. During various stages of the post-disaster recovery, bacterial concentrations were measured in water and soil samples from the flood zone. All drinking water concentrations of *E. coli* were below 1–3 colony forming units per 100 millilitres (CFUs/100 mL). The flood waters contained between 46500 to more than 100000 CFUs/100 mL of *E. coli*. The concentrations of *Salmonella* spp. in the flood waters varied from 5000 to 250000 CFUs/100 mL. The presumptive *Vibrio* spp. concentrations in flood waters ranged from 1000 to over 150000 CFUs/100 mL. The soil concentrations for *E. coli* ranged from 1 to above 330 colony-forming units per 1 g of soil dry weight (CFUs/g). The soil concentrations of *Salmonella* spp. varied from below 1 to 22 CFUs/g. The estimated airborne fungal concentrations ranged from 16820 to 28540 colony-forming units per 1 cubic meter. An outbreak of an infectious disease was recorded among the volunteers who assisted with the post-disaster recovery. The likely bacterial causative agents included strains of *Aeromonas* spp. and *Vibrio cholerae*. Any human contact with either the contaminated flood waters or of flooded dwellings should only occur, if the individuals in questions are equipped with the full-body personal protective gear. Non-governmental stakeholders performed majority of the post-disaster recovery operations, as the local government could only cover 11% of the required costs. Applying sanitation funds to disaster recovery and increased use of the low-cost flood defence products in high risk areas could provide a solution for the future.

Keywords: *Aeromonas* spp., *Vibrio* spp., *Escherichia coli*, flood disaster management, fungal air contamination

1. Introduction

Flood waters can become faecally contaminated through contact with various faecal pollution sources, e.g. flooding of municipal sewer systems [1]. Flood water interaction with such sources can compromise microbial water quality of flood waters. Ten Veldhuis et al. [1] measured the indicator microorganism concentrations in water samples from flooded municipal sewers. The measured concentrations were comparable to those reported for raw sewage [1]. The flood water concentrations of *Escherichia coli* (designated as *E. coli* in further text), *Campylobacter* spp. and *Salmonella* spp. were reported to be higher during flooding than during the post-flooding conditions [2]. Hurricanes and the related flooding have been reported to lead to significant fungal contamination of human dwellings [3]. Exposure to molds inside flood zones can lead to asthma, rhinitis and other respiratory disorders [4]. Data from other reports on flood disasters indicate that the human population can be at significant risk from viral gastroenteritis during the clean-up stages of the flood disaster management cycle [5]. Survival of pathogens and the infectious doses are significantly affected by temperature, volume of rainfall and other local factors [6]. Therefore the exact nature of the microbial risk from flood waters must be known and quantified in a given geographical location. Local risk evaluation is of critical importance for efficient disaster management and public health planning in a given jurisdiction.

The annual probability of flooding has been reported to be equal to 83.3% in South Africa as summarised by Zuma et al. [7]. On 20th October 2012, a “cut-off low pressure system” hit the Eastern Cape Province of South Africa [8], which resulted in heavy rainfall and flooding [9]. Various parts of Port Alfred in the Ndlambe Local Municipality were submerged under 2 m of flood water [8, 9]. The total disaster damages were estimated at approximately 82 million USD [8, 9]. One of the most damaged areas of the city was the Medolino Caravan Park and Resort (designated as Medolino in further text) [10]. This five-star resort was flooded and became inundated with 2 to 3 meter deep layer of flood water and sewage from burst municipal sewers. The entire geographical area of the resort was flooded. A public health assessment and risk evaluation was conducted inside the flood zone. This included assessment of the microbial water quality on the municipal drinking water supply and the flood water; and enumeration of bacteria in soils from the flood zone. An attempt was made to identify bacterial pathogens which might have caused the outbreak of an infectious disease during the post-disaster recovery in the flood zone. Results from these microbial analyses and their implications for flood disaster management in South Africa are described in this study.

2. Materials and Methods

2.1. Chemicals and Consumables

The following consumables were purchased from Merck Pty. (Ltd.; Cape Town/Johannesburg, South Africa): TCBS, agar, m-FC agar, XLD agar, tetrathionate broth powder, KOH, R2A agar, potato dextrose agar, NaCl, components of the one-quarter-strength Ringer solution and Kovacs indole reagent. The following consumables and chemicals were purchased from Spellbound Labs (Port Elizabeth, South Africa): nitril gloves, sterile cotton swabs or throat swabs, 40 ml sterile urine jars, automatic pipette tips and 90 mm sterile Petri dishes. Ethanol was purchased from Chemstores (Rhodes University, Grahamstown, South Africa). The API 20E system kits were purchased from BioMerieux South Africa (Pty.) Ltd. (Midrand, South Africa). Personal protective gear, including face masks, gumboots and nitril gloves (Spellbound Labs, Port Elizabeth, South Africa) were worn by the authors during sampling in the flood zone. The first sampling took place immediately after the owners of Medolino finished pumping out the majority of the sewage and flood waters from the resort on November 19, 2012. The second sampling took place in the post-flooding conditions on January 15, 2013. Water samples were collected by filling the 40 ml sterile urine jars to the brim with the respective water sample as described previously [11]. Overall water sample collection, transport into the laboratory and the incubation (equipment) followed the procedures of Luyt et al. [11].

2.2. Bacterial Enumerations

The *E. coli* concentrations were enumerated as blue colonies on the m-FC agar using the membrane filtration technique and after confirmation with positive indole test at 44.5 ± 0.2°C [12]. For membrane filtration, 40 to 80 ml of the respective water sample was used. The heterotrophic plate count (HPC) was measured by spread-plating 200 μl of the respective sample on R2A agar. These plates were then incubated at 25-27°C for 5 days. Concentrations of the heterotrophic plate count bacteria are designated as the HPC concentrations in further text. On November 19, 2012, three municipal potable water samples were collected from taps located inside the Medolino flood zone. The measured concentrations of indicator microorganisms in these samples are shown in **Table 1**. In **Table 1**, samples designated Municipal sample 1 and Municipal sample 2 were collected from the municipal drinking water taps located inside the Medolino tourist chalets. Both chalets were flooded in October 2012. Municipal sample 3 was collected from a flooded private house located inside the Medolino flood zone. One control sample from the municipal drinking water supply was collected from a private house which was located outside of the Medolino flood zone. The measured indicator microorganisms from this sample are designated as Municipal control sample in **Table 1**.

The sampling on January 15, 2013 was conducted on the same four drinking water sites inside and outside of the original flood zone. The measured concentrations of indicator microorganisms from this sampling are shown in **Table 2**. On both sampling occasions, a sample was collected from the area which was flooded and where sewage contamination from burst municipal sewage collection pipe was detected. The enumerated microbial concentrations are reported as the flood water sample results in **Tables 1** and **2**. Concentrations of *E. coli* were measured using the same method as with the municipal potable water samples, but the spread-plating technique and not membrane filtration was used. Besides *E. coli*, concentrations of *Salmonella* spp. in the municipal drinking water and the flood waters were measured using the selective XLD agar and the enrichment steps in the tetrathionate broth.

For the *Salmonella* spp. enumeration, 20 mL of the sterile tetrathionate broth was poured aseptically into a sterile 40 mL urine jar. Then 1 mL of the given water sample was spiked into the sterile tetrathionate broth. This operation was repeated in duplicate for all flood water samples. After the spike, the tetrathionate broth aliquots were incubated at 37°C for 24 hours. The individual urine jars were hand-shaken periodically during the incubation period. This enrichment step was aimed at lowering the detection limit of the enumeration of *Salmonella* spp. After the enrichment step, 1 mL of the enriched flood water samples was subjected to decimal dilution in physiological saline and spread-plated onto the XLD-agar plates. All plates were then incubated at 37°C for 24 hours. The *Salmonella* spp. colonies were counted as red colonies or the black-centre colonies. All samples were analysed in duplicate.

Throughout the study, an active exchange of information took place between the authors, the Medolino owners, local councilor and municipal officials about the disaster management of the flood zone. The aim was to maximise the efficiency of the post-disaster recovery in the area. During these interactions, it came to fore that an infectious disease outbreak occurred among 7 volunteers, who assisted in the post-disaster recovery operation at Medolino. After participating in the Medolino cleanup, the volunteers all suffered from symptoms such as bloody stool, diarrhoea, vomiting and general weakness. No personal information about any of the infected individuals was collected and no formal interviews with any human subjects took place. Therefore no ethical approval was required for carrying out this study or any of its parts. The authors suspected that strains of *Vibrio* spp. and *Salmonella* spp., or related strains might be the causative agents of this infectious disease outbreak. Thus all samples of the municipal drinking water, the flood waters and soils from the flood zone were tested for the presence of *Vibrio* spp. This was done through decimal dilution and

Table 1. Microbial water quality of domestic taps linked to municipal supply in the Medolino flood zone during the sampling on 19th November 2012.

Sampling site	*E. coli* (cells/100 mL)[a]	HPC (CFUs/mL)[b]	Risk evaluation[c]
Municipall control	<3	>1500	Low risk of faecal contamination of the municipal tap water from flooding, but chlorination of the pipes should be done urgently to eliminate microbial re-growth inside the potable water distribution system.
Municipal sample 1	<3	>1500	Low risk of faecal contamination of the municipal tap water from flooding, but chlorination of the pipes should be done urgently to eliminate microbial re-growth inside the potable water distribution system.
Municipal sample 2	<3	>1500	Low risk of faecal contamination of the municipal tap water from flooding, but chlorination of the pipes should be done urgently to eliminate microbial re-growth inside the potable water distribution system.
Municipal sample 3	<3	>1500	Low risk of faecal contamination of the municipal tap water from flooding, but chlorination of the pipes should be done urgently to eliminate microbial re-growth inside the potable water distribution system.
Flood water sample	>100000	Not determined	High risk of waterborne disease upon human contact with this flood water, i.e. any contact of the population with the river water should be avoided and the clean-up personnel should wear the full-body protective gear.

[a] Reported as the colony forming units in 100 mL of sample.
[b] Reported as colony forming units in 1 mL of sample after growth at 25-27 °C for 5 days.
[c] Evaluated based on the 1996 South African water quality guidelines for domestic use [15].

Table 2. Microbial water quality of domestic taps linked to municipal supply in the Medolino flood zone during the sampling on January 15, 2013.

Sampling site	*E. coli* (cells/100 mL)[a]	HPC (CFUs/mL)[b]	Risk evaluation[c]
Municipal control	<1	>1500	Low risk of faecal contamination of the municipal tap water from flooding, but chlorination of the pipes should be done urgently to eliminate microbial re-growth inside the potable water distribution system.
Municipal sample 1	<1	>1500	Low risk of faecal contamination of the municipal tap water from flooding, but chlorination of the pipes should be done urgently to eliminate microbial re-growth inside the potable water distribution system.
Municipal sample 2	<1	>1500	Low risk of faecal contamination of the municipal tap water from flooding, but chlorination of the pipes should be done urgently to eliminate microbial re-growth inside the potable water distribution system.
Municipal sample 3	<1	>1500	Low risk of faecal contamination of the municipal tap water from flooding, but chlorination of the pipes should be done urgently to eliminate microbial re-growth inside the potable water distribution system.
Flood water sample	46500	Not determined	High risk of waterborne disease upon human contact with this flood water, i.e. any contact of the population with the river water should be avoided and the clean-up personnel should wear the full-body protective gear.

[a] Reported as the colony forming units in 100 ml of sample.
[b] Reported as colony forming units in 1 mL of sample after growth at 25-27 °C for 5 days.
[c] Evaluated based on the 1996 South African water quality guidelines for domestic use [15].

spread-plated on TCBS agar. The inoculated plates were incubated at 37°C for 24 hours and the results were evaluated as according to the supplier's instructions. Stable TCBS bacterial isolates were also subjected to the morphological and physiological identification using the API 20E kits.

For the extraction of *Vibrio* spp., *Salmonella* spp. and *E. coli* from soil samples, the method for extraction of bacteria from mulch were adapted [13]. The selection of the bacterial species to enumerate was based on the endemic species in the area of the flood zone and general knowledge about causative agents of bacterial infectious diseases in South Africa. The same agar media and enrichment steps as with the water samples were then used to enumerate the respective bacteria in the 1/4 Ringer solution extracts of soils. Only spread-plating was applied. Visual examination of the flooded buildings revealed that residual mud walls and flooded items. These were sampled for qualitative detection of *E. coli*, *Salmonella* spp., *Vibrio spp*. and fungi. The mud samples were collected by dipping the sterile cotton swabs into the mud and removing a subsample of the material. The samples were then placed on ice and transported into the laboratory. In the laboratory, the cotton swabs were used to streak the sampled mud directly onto the selective media. The same media were used as mentioned for the detection of bacterial species as described for the water samples. Fungi were detected on the potato-dextrose agar.

2.3. Assessment of Fungal Contamination Inside Flooded Dwellings

In the post-disaster recovery phase of the Medolino flood disaster management, heavy fungal contamination could be visible inside the chalets and houses inside the flood zone. A semi-quantitative assessment of the airborne fungal concentrations was performed using the settle-plate technique on the potato-dextrose agar [14]. Exactly 2 rooms in a private house were sampled by using three settle plates per room. The airborne fungal concentrations are reported as fungal colony-forming units per cubic meter of indoor air. The airborne fungal concentrations were estimated to provide a quick assessment of the respiratory public health risk to volunteers and municipal personnel during the post-disaster recovery in Medolino.

3. Results and Discussion

3.1. Drinking Water Microbial Quality

All drinking water concentrations of *E. coli* were below 3 colony-forming units per 100 millilitres (designated as CFUs/100 mL in further text) on November 19, 2012 (see **Table 1** for details). This was the case regardless of whether the samples were taken inside or outside of the Medolino flood zone. The *E. coli* concentrations in the municipal drinking water samples taken on January 15, 2013 were below 1 CFUs/100 mL (see **Table 2** for details). Concentration of *E. coli* is the standard indicator of faecal contamination of drinking water. The measured concentrations from Port Alfred indicate that the flooding did not compromise the municipal potable water infrastructure or the potable microbial water quality. This is based on the lack of faecal contamination detected inside and outside Medolino flood zone. Lack of faecal contamination is supported by the measured *E. coli* concentrations which were below the detection limit of the membrane filtration technique used. At the same time, the municipal drinking water samples were negative for *Salmonella* spp. and *Vibrio* spp.

The HPC concentrations were higher than 1500 colony-forming units per millilitre (designated as CFUs/mL in further text) in all samples of the municipal drinking water. This is clearly visible from the data measured in the Municipal samples 1–3 in **Tables 1** and **2**; and the Municipal control in **Table 1**. These HPC concentrations indicate that a treatment breakdown occurred between the water treatment plant and the end points of use [15]. The breakdown was unrelated to the flooding as it affected municipal water samples taken from inside and outside of the Medolino flood zone. Municipal officials and councilors were contacted by the authors. The authors suggested that an urgent chlorination of the section of the municipal potable water supply grid be carried out.

3.2. Bacterial Concentrations in the Flood Zone

The *E. coli* concentration in the flood waters sampled on November 19, 2012 was higher than 100000 CFUs/100 mL. On the same sampling occasion, the concentrations of *Salmonella* spp. in the flood waters were higher than 150000 CFUs/100 mL. Enumerations on the TCBS agar indicate that the presumptive concentration of *Vibrio* spp. ranged from 6500 to over 150000 CFUs/100 mL. The flood water concentration of *E. coli* decreased to 46500 CFUs/100 mL in the sample taken on January 15, 2013. These *E. coli* concentrations indicate high levels of faecal/sewage contamination of the flood waters [15]. Therefore data in **Tables 1** and **2** clearly indicate that any human contact with the sampled flood waters should be avoided [15]. On the other hand, the alternative would be that the full-body personal protective gear should be worn by anyone who enters the flood zone.

The flood water samples taken on January 15, 2013 contained the concentrations of *Salmonella* spp. from 50000 to 250000 CFUs/100 mL. On the same sampling date, the flood water samples contained 1000 to 16500 CFUs/100 mL of presumptive *Vibrio* spp. The samples of the mud material from the walls of the flooded houses in Medolino were positive for fungi. This confirmed the presence of fungal contamination of the flooded dwellings. The airborne fungal concentrations were estimated to range from 16820 to 28540 CFUs/m^3. This indicates high probability of the adverse respiratory health effects on the human population inside the affected flood zone [4, 14]. In the aftermath of Hurricanes Katrina and Rita in 2005, concentrations of *E. coli* in the flood water ranged from 140 to 4600 CFUs/100 mL [16]. In

Malaysia, the concentrations of *E. coli* in flood waters were reported to be equal to 67100 CFUs/100 mL [17]. At the same time, the concentrations of *Salmonella* spp. ranged from 2500 to 23300 CFUs/100 mL [17]. Between 1.2 and 35000 CFUs/100 mL of flood waters was reported for the presumptive *Vibrio* spp. in water samples from Lake Pontchartrain in Louisiana [18]. Thus the flood water bacterial concentrations from this study are comparable to or higher than the literature values.

The soil concentrations of *E. coli* ranged from 33 to more than 330 colony-forming units per gram of soil dry weight (designated as CFUs/g in further text) during the initial sampling on November 19, 2012. The soil concentrations of *Salmonella* spp. on the same sampling date was below 1 CFU/g. The XLD agar was, however, overgrown with yellow and pink colonies, which would indicate the presence of *Pseudomonas aeruginosa* and coliform bacteria. *Pseudomonas aeruginosa* is a common soil bacterium and so its presence in the flooded soil samples is not surprising. Same applies to the presence of coliform bacteria in soils. The presumptive soil concentrations of *Vibrio* spp. were below 1 CFU/g on November 19, 2012. Fifty percent of the mud streaks from the two flooded tourist chalets at Medolino were positive for *Salmonella* spp. on November 19, 2012. Re-sampling on January 15, 2013 indicated that the *E. coli* concentration in the previously flooded soils ranged from 1 to 3 CFUs/g. The soil concentrations of *Salmonella* spp. ranged from 4 to 22 CFUs/g. Only a single colony was observed on the TCBS agar, but the quantitation limit of the method was not reached.

Schaupp [19] reported that the soil concentrations of *E. coli* in the flood zones in Accra, Ghana ranged from 48000 to 850000 CFUs/g. Casteel et al. [20] reported that the soil concentrations of *E. coli* ranged from 4 to 400 CFUs/g. Therefore the soil concentrations of *E. coli* measured in this study are comparable to or lower than the literature values. Alam and Zafar [21] measured the concentration of *Salmonella* spp. and reported a value of 45 CFUs/g. Soil samples were taken in an estuary with no major flooding [21]. Therefore the soil concentrations of *Salmonella* spp. at Medolino did not seem to be significantly affected by the flooding. Lack of the quantifiable number of the presumptive *Vibrio* spp. strains in soils samples from the flood zone indicates that the *Vibrio* spp. bacteria likely died off the fastest from all the enumerated bacteria.

3.3. Bacterial Identification

The API 20E system and the ABIS software[1] were used to further identify the causative agent of the outbreak of infectious disease that was reported during the post-disaster recovery at Medolino. Identification was performed on three stable bacterial isolates which were isolated on the TCBS agar from the flood zone. These are designated as strain 2 (a soil isolate) and strains 5 and 12 (the flood water isolates). The following characteristics were recorded for the three presumptive *Vibrio* spp. strains. Strain 2 had the following characteristics: growth as yellow colonies on the TCBS agar, positive for growth on nutrient agar, positive for the string test indicating Gram-negative bacteria, growth in 0% NaCl – positive, growth in 1% NaCl – positive, oxidase test – positive, nitrate test – positive, the myo-inositol test – negative, the Arginine dihydrolase – positive, Lysine decarboxylase – positive and Ornithine decarboxylase – negative. These morphological characteristics and were analysed using the ABIS system. The results indicated that strain 2 could *Vibrio proteolyticus*, *Vibrio cholerae*, *Vibrio aestuarianus* and *Vibrio anguillarum*. The identification percentage of accuracy from the forced-mode ABIS system ranged from 77–88%.

Strain 5 which was isolated from flood water had the following morphological characteristics: growth as yellow colonies on the TCBS agar, positive growth on nutrient agar. The bacterium was Gram-negative as indicated by the positive string test. This strain was also positive for growth on 0% NaCl and 1% NaCl. Additionally, the following biochemical characteristics were recorded: Oxidase test – positive, Nitrate test – negative, Myo-inositol – negative, Arginine dihydrolase – positive, Lysine decarboxylase – negative and Ornithine decarboxylase – positive. Analysis of the strain's characteristics using the ABIS system indicated that the strain could be one of the following: *Vibrio porteresiae*, *Vibrio cholerae* and *Vibrio anguillarum*. The identification accuracy of the forced mode determination ranged from 66 to 77%.

Finally, the flood water isolated strain 12 flood water grew in the form of yellow to blue-green colonies on the TCBS agar. It was positive for growth on nutrient agar and Gram-negative based on the positive string test. Additionally, the following biochemical characteristics were recorded: growth in 0% NaCl – positive, growth in 1% NaCl – positive, Oxidase test – negative, Nitrate test – positive, Myo-inositol – negative, Arginine dihydrolase – positive, Lysine decarboxylase – negative and Ornithine decarboxylase – positive. These morphological and biochemical characteristics could be no matched to any *Vibrio* spp. strain. The literature data and the clinical symptoms reported by the volunteers are used below to try to identify the potential bacterial causative agent of the infectious disease outbreak at Medolino.

Vibrio aesturianus is a marine bacterium and solely a mollusk pathogen as documented for *Crassostrea gigas* [22]. Thus is unlikely that *Vibrio aesturianus* was the causative agent of the Medolino infectious disease outbreak. *Vibrio anguillarum* is a well-documented fish pathogen that does not cause human infections [23]. Therefore it is also unlikely that this bacterium was the causative agent of the Medolino outbreak in 2012. Similar conclusion can be drawn about *Vibrio porteresiae* which is usually isolated from wild-rice and mangroves, but it is not a human pathogen [24]. *Vibrio proteolyticus* is a non-pathogenic species, but it has similar enzyme characteristics as the pathogenic *Vibrio vulnificus* [25].

Vibrio vulnificus injected into the bodies of laboratory rats has been shown to increase the vascular permeability

1. available at: http://www.tgw1916.net/bacteria_logare.html

the dorsal skin due to the secretion of histamine in mast cells [25, 26]. In other studies, *Vibrio vulnificus* has been reported to cause "sepsis, severe cellulitis with rapid development to ecchymoses and bullae" [27]. This occurs after exposure of open wounds to warm seawater with high concentrations of *Vibrio vulnificus*. The route of exposure could provide an explanation for the Medolino outbreak, but the clinical symptoms do not match those reported for the infected volunteers from the Medolino post-disaster recovery clean-up. Thus *Vibrio proteolyticus* or *Vibrio vulnificus* were not the causative agents of the Medolino outbreak.

Vibrio cholerae is a well-known human pathogen with its strains causing diarrhoeal diseases [28]. Common clinical symptoms of human infections by this pathogen include "watery diarrhoea, vomiting and leg cramps" [28]. However, some patients do not exhibit any clinical symptoms [28]. Sewage contamination at Medolino was widespread and the contact of volunteers might have resulted in contracting cholera. On the other hand, not all clinical symptoms that were reported by the infected volunteers are explained by the *Vibrio cholerae* infection. Thus it was probably not the only causative agent of the Medolino outbreak in 2012, but could have contributed to it. Strains belonging to *Pseudomonas* spp. and *Aeromonas* spp. have been reported to grow as blue-green colonies on the TCBS agar [29]. Thus strain 12 might have been such a strain. *Aeromonas hydrophila* has been reported to cause human cases of diarrhoea and the symptoms include bloody stool [30]. This bacterium is commonly found in aquatic and marine environments [30]. Therefore it could have been one of the causative agents of the Medolino outbreak in 2012.

Results from this study indicate that major microbial contamination of water resources and risk to human and environmental health was observed at Medolino after the October 2012 floods. There was clear presence of the local government officials at the site of the floods throughout the duration of this study. The local government officials also seem to possess majority of the necessary skills to deal with the flood disaster management. The only exception seemed to be the lack of a water testing laboratory in the Ndlambe jurisdiction and the lack of full awareness of the potential impacts of flood waters on public health of the population. This was based on the lack of full-body protective gear when the officials entered the flood zone. However, financial shortages were identified as the main cause of the inadequate local government response to the flood damages and post disaster recovery at Medolino. Thus the main costs and action in the post-disaster recovery, e.g. funding of sewage and flood water pumping operations, and the clean-up at the site had to be performed by Medolino owners and community volunteers.

3.4. Analysis of the Results and Context of Flood Disaster Management in the Study Area

The Ndlambe Local Municipality spent 30400 USD from its own budgetary resources to deal with the immediate aftermath of these floods in the entire Port Alfred area [31]. Local government was, however, unable to cope with the full impact of the floods due to budgetary constraints. This is best demonstrated by the Ndlambe own recovery cost estimates which led to the request for immediate assistance from the National Government in the amount of 2.46 million USD [31]. The post-disaster recovery costs were then estimated by local government to reach a total of 6.22 million USD [31]. The Ndlambe local government again applied for external funding from the national government to cover these costs [31].

The indicator microorganism concentrations measured in the flood waters from Medolino were likely caused by the breakdown of the municipal pumps, designated to remove the sewage and flood waters from the Medolino area. This conclusion is supported by the fact that the Ndlambe Municipality spent only 6400 USD on the pumping operation, when the two new pumps were requested in the emergency relief assistance from the National Government [31]. The total cost of immediate disaster response equal the cost of purchase of two new pumps for removal of flood waters and sewage from the Medolino area and this was estimated at 60000 USD. Since the internal financial resources of the Ndlambe Municipality accounted for only 11% of the required costs, the majority of the after-flood pumping was funded by the Medolino owners. The example of the flood response by Ndlambe local government is not unique and happens commonly in South Africa.

Documents from the South African Parliament's Portfolio Committee on Water and Sanitation indicate that the national government was concerned about the overall water quality in South Africa since 2012 [32]. The main problems were identified by the committee to include the following issues: acid mine drainage, shortage of technical skills in the water sector, and the stakeholder awareness about overall water quality in the water sector [32]. Partially in response to these concerns, the South African National Government adopted an approach which entailed focusing outcome and strategic lines, functional lines and management and governance lines [32]. In the focus area of outcome and startegy, it focused on putting into practice an Equity Policy which placed drinking water at the center of integrated development in South Africa [32]. The improvement of functional lines included improving and stretching water resources and implementing the use of water efficiently. Management and governance involved the success of effective water governance and developmental water management, entrenching sustainable business principles and engaging private and water use sectors [32].

Clean drinking water is critical for the maintenance of human health [33]. It has often been observed that rivers in South Africa are seriously affected by illegal water use, by over abstraction and by pollution. Both eco-viability and human use of water resources are compromised. The National Department of Water affairs and Forestry, agreed on increasing the number of monitoring stations along South African rivers. This initiative was due to the death of eight people in the Eastern Cape Province in South Africa after drinking polluted river water. A mechanism of monitoring microbial levels established so as to prevent further unnecessary deaths. Due to the importance of water to human health, most municipalities in South Africa municipalities began to tighten up their monitoring programmes to make sure that they comply with national norms and standards for microbial water quality. Even though the main focus was on drinking water quality, the Department of Water affairs and Forestry has instigated assessments on waste-water treatment works to ensure compliance with effluent quality standards [33]. Such legislative and governmental strategies must be widened to put the flood disaster management at the heart of government policies. Principle of cooperative governance and the integration of disaster management response mechanisms should take place among all the levels of government. This is supported by the findings from this study on the effect that local floods can have on microbial water quality.

A mindset shift is needed at the local government level which puts disaster management and spending on it at the center of the functioning of municipalities. This should be mainly focused in the geographical areas that are at high risk from flooding. Use of low-cost flood defence technologies should be stimulated and awareness about them should be raised among the local government officials. Financial shortages in disaster management funding could be addressed, in the context of floods in South Africa by the use of sanitation funding mechanisms [34]. Such funds could be used, e.g. for purchase of pumping equipment for the removal of flood waters and sewage from flood zones such as Medolino.

The present study shows that (flood) waters can have significant and detrimental effects on human health and environment. It also affects business continuity as the Medolino resort only resumed operations three and a half years after the 2012 floods. The communities and local government which are located in the flood-prone regions must ensure that drinking water is free of pathogenic microorganisms. Regular monitoring of microbial water quality and inspection of the infrastructure are of critical importance for the public health (disaster) management and preparedness in the flood-prone regions. Results of the current study indicate that the microbial monitoring was not conducted in the flood zone without the authors' involvement. This was a combination of the following factors: financial constrains of the Ndlambe Municipal Budget, the lack of a water-testing laboratory in Ndlambe Local Municipality and the lack of awareness of the public health implications of floods among the local government officials. This will have to be addressed through improved on-the-job training and workshops of local government officials responsible for disaster management. In this context, collaboration with academic institutions which offer disaster management education and conduct research in the area is critical.

Such institutions include Stenden South Africa which is located in close proximity to the Medolino site [35]. It offers the Bachelor of Business Administration in Disaster Management as an "honours level qualification" [35]. The first three years are dedicated to a combination of lectures, workshops and practical training in disaster management theory and application [35]. The fourth year is then run as on-the-job training where the students get placed in industry and work as health and safety officers, disaster managers, etc. [35]. The Stenden South Africa faculty members also run workshops with local government officials and provide consulting services upon need/request. This institution and the Bachelor of Business Administration in Disaster Management were only starting around the time of the October 2012 floods. Thus the staff could not provide advice or assistance at the time of the flood management and post-disaster recovery. However, the experiences of the Medolino owners, the local government official and the authors of this article could be used to make the future disaster management professionals aware of the destructive nature of a local disaster. This is of critical importance as the majority of disasters worldwide are local in nature and will likely form a major part of the professional dealings of the Bachelor of Business Administration in Disaster Management students after graduation.

The oldest academic centre conducting research in disaster management in South Africa is the African Centre for Disaster Risk Studies (ACDS) [36]. It is located at the North-West University's Potchefstroom Campus and it was founded in 2002 [36]. The centre conducts research activity on the issues of social transformation, disaster management, local governance and other subjects [36]. These activities form the critical part of the teaching component which is focused on Masters and PhD projects [36]. Since 2014, the centre also offers the Postgraduate diploma in Disaster Risk Studies which could be ideal for education of the local government officials [37]. The centre has strong links to the National Disaster Management Centre which coordinates disaster management at the national level for the entire geographical territory of South Africa. A part of this collaboration is the publication of the SCOPUS-indexed Journal of Disaster Risk Studies [38]. It is run as a golden-open access publication with no article processing charges for authors [38]. It is internationally peer-reviewed and publishes theoretical and practical papers on disaster management and risk reduction. As such it provides a good resource for the local government officials to keep up to date with the latest developments in research and practice of disaster management in South Africa and internationally. Awareness about this resource and others from ACDS should be raised and among the disaster management stakeholders in South Africa.

Another academic centre offering disaster management education is the Department of Geography and Environmental Studies at the University of Stellenbosch [39]. In 2011, Research Alliance for Disaster Risk Reduction (RADAR) was launched by this Department as an Africa-wide platform for conducting research and multilateral scientific collaborations in disaster management and risk reduction [39]. In addition the Department offers the Bachelor of Arts in Disaster Risk Science and Masters of Philosophy in Disaster Risk Science and Development [38]. This centre has active in establishing disaster management links across the African continent. This makes RADAR an ideal platform for implementation wide-ranging disaster management initiatives. These would provide a mechanism of interaction and exchange of information between local government, academics and disaster management practitioners in South Africa. Addressing specific disaster management challenges at the local government level could be addressed efficiently using platform like this. More about this is described in one of the upcoming chapters.

The causative agent of the outbreak of the infectious disease was narrowed down to *Vibrio cholerae* or *Aeromonas* spp. *(hydrophila)*. *Vibrio cholerae* is endemic to South Africa and outbreaks of cholera are common occurrence. The Public health officials and the healthcare personnel are aware of this disease. The Standard Treatment Guidelines contain protocols and drugs regimens aimed at management and curing of this infectious disease. However, the same can't be said about the other possible causative agent of the 2012 Medolino outbreak. To the best of the authors' knowledge, this is the first report of strains belonging to *Aeromonas* spp. as possible causative agents of an infectious disease in South Africa. The government documents such as the Standard Treatment Guidelines do not contain any information about how to treat infections due to *Aeromonas* spp. Therefore this study has provided new insights into the nature of public health hazards related to flood disasters in South Africa. More awareness must be raised among healthcare professionals and more research must be conducted into the die off rates and the environmental survival of infectious strains belonging to *Aeromonas* spp.

This study has reinforced the body of knowledge on adverse health effects of water contamination resulting from environmental disasters. The group has also captured that some natural and complex environmental disasters have the potential to increase the burden of diseases on the South African population. They can also potentially contribute to increasing the mortality and morbidity due to communicable diseases in the country. The authors of this study have attempted to provide recommendations for planning and preparing to prevent communicable diseases after flood disasters, as these will relate on population movement and displacement throughout South Africa. Moreover, population, poor waste management, lack of shelter and economic hardship may cause a dramatic increase in the rates of communicable diseases after disasters.

Reinforcement of health-surveillance systems in South Africa and proper management of information on specific diseases are critical in moving forward with the prevention of health-related outcomes of natural disasters in South Africa. More baseline information must be collected on the risk from various pathogens during flood disasters in South Africa. Due to limited funding, the current study was not focused on the identification and enumeration of viral pathogens in the flood zone. However, future research on this topic should be encouraged. The current study identified major limitations in the disaster management in the flooded Area of Ndlambe Local Municipality. These limitations include the lack of emergency medical and flood management supplies at the local government level to mitigate that impacts of flooding, limited and drawn out diagnosis of the causative agent of the flooding-related infectious disease outbreak; and the related streamlining of medical referrals for any necessary treatment. Body of knowledge about the pathogen that should be considered relevant in such cases has been widened by the present study. Contingency support and planning by local, provincial and national governments should be paramount and the private sector and academics must play a central/advisory role to help design efficient programmes in this context. They must also continue to drive education, provide training and share latest research findings with disaster management practitioners and communities around South Africa. The multi-stakeholders platforms should be used for efficient exchange of information in this regard.

4. Conclusion

Urban flood risk and the impact of flood events are expected to increase as urban development in flood prone areas continues and intensity of some rainfall events is increasing as a result of climate change. Aging urban drainage infrastructure already limits the drainage capacity in existing urban areas. Damage resulting from flooding is also exacerbated by water and sewage pipe burst which leads to potential impact of surrounding areas. Knowledge of water quality changes to possible microbial contamination during flooding is critical as such occurrences do not only carry potential property damage but also has serious human health implications. This paper therefore provides critical insight to bacterial related risks associated with flooding and this will enable better resource management and infrastructure planning. The possible bacterial causative agents included the following bacteria: *Vibrio cholerae* and a strain belonging to genus *Aeromonas* spp. Non-governmental stakeholders performed majority of the post-disaster recovery operations, as the local government could only cover 11% of the required costs. Solutions could be found by applying sanitation funds to disaster recovery and increased use of the low-cost flood defence products in areas at high risk from flooding.

Acknowledgements

The authors would like to thank the staff and owners of the Medolino for providing access to the sampling sites. The authors are also grateful to the local municipality and the owners for providing the background information about the extent of the damage during the 2012 floods in Port Alfred.

References:

[1] J. A. Ten Veldhuis, F. H. Clemens, G. Sterk, and B. R. Berends, "Microbial risks associated with exposure to pathogens in contaminated urban flood water," Water Research, Vol.44, No.9, pp. 2910-2918, 2010.

[2] E. E. Yard, M. W. Murphy, C. Schneeberger, J. Narayanan, E. Hoo, A. Freiman, L. Lewis, and V. R. Hill, "Microbial and chemical contamination during and after flooding in the Ohio River–Kentucky, 2011," J. Of Environmental Science And Health, Part A: Toxic/Hazardous Substances and Environmental Engineering, Vol.49, No.11, pp. 1236-1243, 2014.

[3] M. A. Riggs, C. Y. Rao, C. M. Brown, D. Van Sickle, K. J. Cummings, K. H. Dunn, J. A. Deddens, J. Ferdinands, D. Callahan, R. L. Moolenaar, and L. E. Pinkerton, "Resident cleanup activities, characteristics of flood-damaged homes and airborne microbial concentrations in New Orleans, Louisiana, October 2005," Environmental Research, Vol.106, No.3, pp. 401-409, 2008.

[4] M. Brandt, C. Brown, J. Burkhart, N. Burton, J. Cox-Ganser, S. Damon, H. Falk, S. Fridkin, P. Garbe, M. McGeehin, J. Morgan, E. Page, C. Rao, S. Redd, T. Sinks, D. Trout, K. Wallingford, D. Warnock, and D. Weissman, "Mold Prevention Strategies and Possible Health Effects in the Aftermath of Hurricanes and Major Floods," 2006, available at: http://www.cdc.gov/mmwr/preview /mmwrhtml/rr5508a1.htm [accessed July 14, 2015]

[5] L. Fewtrell, D. Kay, J. Watkins, C. Davies, and C. Francis, "The microbiology of urban UK floodwaters and a quantitative microbial risk assessment of flooding and gastrointestinal illness," J. of Flood Risk Management, Vol.4, No.2, pp. 77-87, 2011.

[6] C. D. Luyt, S. M. M. Khamanga, R. Tandlich, W. J. Muller, "Survival of Bifidobacteria and their usefulness in Faecal Source Tracking," Liquid Waste Recovery, Vol.1, No.1, pp. 1-11, 2015.

[7] B. M. Zuma, C. D. Luyt, T. G. Chirenda, and R. Tandlich, "Flood disaster management in South Africa: legislative framework and current challenges," published in the peer-reviewed proceedings from the 2012 Int. Conf. on Applied Life Sciences (ICALS2012) Konu, Turkey, September 10-12, 2012, pp. 127-132 (ISBN 978-953-51-0725-5), 2012.

[8] E. R. Poolman, "A probabilistic impact-focused early warning system for flash floods in support of disaster management in South Africa," Ph.D. thesis, University of Pretoria, Pretoria, South Africa, p. 86, 2014.

[9] National Sea Rescue Institute of South Africa, "Port Alfred – River Flooding: Update: Port Alfred. Sunday, 21st October, 2014: NSRI Continue Throughout Weekend to Assist in Flooding," 2012, available at: http://www.nsri.org.za/2012/10/port-alfred-river-flooding/ [accessed July 2, 2015]

[10] "Port Alfred Medolino Holiday Resort – description," 2008, available at: http://www.petfriendly.co.za/index.php?option=com_content&view=article&id=253:port-alfred-medolino-holiday-resort&catid =96:eastern-cape&Itemid=170 [accessed July 2, 2015]

[11] C. D. Luyt, W. J. Muller, and R. Tandlich, "Low-cost tools for microbial quality assessment of drinking water in South Africa," HealthMed, Vol.5, No.6, Supplement Vol.1, pp. 1868-1877, 2011.

[12] C. D. Luyt, W. J. Muller, and R. Tandlich, "Calibration of bifidobacterial indicators for microbial water quality monitoring in South Africa," Published in the peer-reviewed proceedings from the 13th SGEM Geo Conf. on Water Resources, Forest, Marine and Ocean Ecosystems, Albena, Bulgaria, June 16-22, 2013, pp. 47-54, DOI:10.5593/SGEM2013/BC3/S12.006 (ISSN 1314-2704, ISBN 978-619-7105-02-5), 2013.

[13] K. Whittington-Jones, R. Tandlich, B. M. Zuma, S. Hoossein, and M. H. Villet, "Performance of the pilot-scale mulch tower system in treatment of greywater from a low-cost housing development in the Buffalo City, South Africa (extended version), Int. Water Technology J., Vol.1, No.2, Paper 7, 2011.

[14] H. K. Dillon, J. D. Miller, W. G. Sorenson, J. Douwes, and R. Jacobs, "Review of methods applicable to the assessment of mold exposure in children. Environmental Health Perspectives," Vol.107 (Supplement 3), pp. 473-480, 1999.

[15] Department of Water Affairs and Forestry (DWAF, 1996) South African Water Quality Guidelines, Vol.1 (Domestic Water Use), Pretoria, South Africa, 1996, available at: http://www.kowiecatchmentcampaign.org.za/kcc%20materials/DWAdomestic guidelines.pdf [accessed July 3, 2015]

[16] C. D. Sinigalliano, M. L. Gidley, T. Shibata, D. Whitman, T. H. Dixon, E. Laws, A. Hou, D. Bachoon, L. Brand, L. Amaral-Zettler, R. J. Gast, G. F. Steward, O. D. Nigro, R. Fujioka, W. Q. Betancourt, G. Vithanage, J. Matthews, L. E. Fleming, and H. M. Solo-Gabriele, "Impacts of Hurricanes Katrina and Rita on the microbial landscape of the New Orleans ara," Proc. of the National Acadeny of Sciences, Vol.104, No.21, pp. 9029-9034, 2007.

[17] Z. D. Mohamed Basri, Z. Otghman, and M. Ab. Wahid, "Detection of pathogenic bacteria in flood water," ISFRAM 2014 proceedings, Springer, pp. 185-193, 2015.

[18] O. D. Nigro, A. Hou, G. Vithanage, R. S. Fujioka, and G. F. Steward, "Temporal and spatial variability in culturable pathogenic *Vibrio* spp. in Lake Pontchartrain following Hurricanes Katrina and Rita," Applied and Environmental Microbiology, Vol.77, No.15, pp. 5384-5393, 2011.

[19] A. N. Schaupp, "The Flooding of Urban Communities in Accra, Ghana: Assessing Population at Risk, Behavioral Response, and Fecal Contamination," MSc thesis, Rollins School of Public Health, Enory University, Atlanta, GA, USA, 2013, available at: https://etd.library.emory.edu/view/record/pid/emory:d95d6 [accessed July 3, 2015]

[20] M. J. Casteel, M. D. Sobsey, and J. P. Mueller, "Fecal contamination of agricultural soils before and after hurricaneassociated flooding in North Carolina," J. of Environmental Science and Health Part A 41, pp. 173-184, 2006.

[21] Md. Wahidul Alam and M. Zafar, "Occurrences of *Salmonella* spp. in water and soil sample of the Karnali river estuary," Microbes and Health, Vol.1, No.2, pp. 41-45, 2012.

[22] M. H. Aboubaker, J. Sabrié , M. Huet, and M. Koken, "Establishment of stable GFP-tagged *Vibrio aestuarianus* strains for the analysis of bacterial infection-dynamics in the Pacific oyster, *Crassostrea gigas*," Veterinary Microbiology, Vol.164, pp. 392-398, 2013.

[23] I. Frans, C. W. Michiels, P. Bossier, K. A. Willems, B. Lievens, and H. Rediers, "*Vibrio anguillarum* as a fish pathogen: virulence factors, diagnosis and prevention," J. of Fish Diseases, Vol.34, No.9, pp. 643-61, 2011.

[24] N. Rameshkumar, Y. Fukui, T. Sawabe, and S. Nair, "*Vibrio porteresiae* sp. nov., a diazotrophic bacterium isolated from a mangrove-associated wild rice (*Porteresia coarctata Tateoka*)," Int. J. of Systematic and Evolutionary Microbiology, Vol.58, No.7, pp. 1608-15, 2008.

[25] S. Miyoshi, "Extracellular proteolytic enzymes produced by human pathogenic vibrio species," Frontiers of Microbiology Vol.4, p. 339, 2013.

[26] S. Miyoshi, K. Sugiyama, Y. Suzuki, H. Furuta, N. Miyoshi, and S. Shinoda, "Enhancement of vascular permeability due to histamine-releasing effect of Vibrio vulnificus protease," FEMS Microbiology Letters, Vol.40, pp. 95-98, 1987.

[27] M. H. Bross, K. Soch, R. Morales, and R. B. Mitchell, "*Vibrio vulnificus* Infection: Diagnosis and Treatment," American Family Physician, Vol.76, No.4, pp. 539-544, 2007.

[28] Minnesota Department of Health, "Causes and Symptoms of Cholera," 2015, available at: http://www.health.state.mn.us/divs/ idepc/diseases/cholera/basics .html [accessed July 30, 2015]

[29] TCBS Agar., 2015, available at: https://www.sigmaaldrich.com /content/dam/sigma-aldrich/docs/Fluka/Datasheet/86348dat.pdf [accessed July 30 2015]

[30] Public Health Agency of Canada, "*Aeromonas hydrophila* – pathogen safety data sheet – infectious substances," 2012, available at: http://www.phac-aspc.gc.ca/lab-bio/res/psds-ftss/aeromonas-hydrophila-eng.php [accessed July 30, 2015]

[31] Ndlambe Local Municipality, "Request for National Contribution to alleviate the effects of a disaster (emergency relief), Port Alfred, Eastern Cape, South Africa, December 2012.

[32] National Water Resource Strategy of South Africa, Briefing by Department of Water Affairs to the South African Parliamentary Portfolio Committee on Water and Sanitation, Parlkiament of South Africa, Cape Town, Meeting Minutes from September 11, 2012, 2012, available at: https://pmg.org.za/committee-meeting/14836/ [accessed July 14, 2015]

[33] Hansard: Appropriation Bill : Debate on Budget Vote No.34 – Water Affairs and Forestry, Report to the South African Parliamentary Portfolio Committee on Water Affairs and Forestry, Parlkiament of South Africa, Cape Town, Meeting Minutes from June 23, 2009, 2009, available at: https://pmg.org.za/hansard/18016/ [accessed on July 14, 2015]

[34] S. Hoossein, K. Whittington-Jones, and R. Tandlich, "Sanitation policy and prevention of environmental contamination in South Africa," Environmental Engineering and Management J., Vol.13, No.6, pp. 1335-1340, 2014.

[35] Stenden South Africa, avilable at: http://www.stenden.ac.za /index.php/school-of-disaster- management/program [accessed August 6, 2015]

[36] African Centre for Disaster Studies, available at: http://acds.co.za /index.php?page=about [accessed August 6, 2015]

[37] African Centre for Disaster Studies, available at: http://acds.co.za/ [accessed August 6, 2015]

[38] Journal of Disaster Risk Studies, available at: http://www.jamba.org.za/index.php/jamba [accessed July 31, 2016]

[39] Stellenbosch University, Research Alliance for Disaster Risk Reduction, available at: http://www.riskreductionafrica.org/partners-and-programmes/stellenbosch-university-stellenbosch-south-africa/ [accessed April 20, 2016]

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