Groundwater Contamination Crisis and Engineering Measures for Mitigation

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1. Abstract

Introduction: In the New Providence the groundwater table is on average, 5 feet below the surface throughout the island. As such, groundwater is highly susceptible to contamination due to surface runoff, percolation and infiltration.

Method of Contamination: Areas populated by shantytowns, backyard mechanics and car wash facilities are the major sources of runoff contamination throughout the island of New Providence, particularly in highly urbanized areas. Similarly backyard mechanics and carwash facilities allow automotive fluids to runoff with the potential to be infiltrated into the soil system. Shantytown residences have limited access to public utilities, and many residents use groundwater as the main source of potable water. In addition residents of general population also use groundwater as a source of potable water.

Implications: As the groundwater resource becomes more contaminated, New Providence will undergo a major social, economic and health catastrophe. The cost of water supply may rise and for the common resident, paying for water may become an economic burden. Illnesses stemming from the pollutants may result in the need for increased medical services, higher death rates, possible panic and heightened cultural tension between local residents and shantytown residents.

Value of Paper: Policies that guard against contamination of the natural resources for the protection of life will need to be introduced and a need for awareness and citizens to actively participate in reducing contaminant loading by means of land use changes and management strategies. In an effort to mitigate the foreseen circumstances this review also looks at preventative, remediation and predictive methods.

2. Introduction

2.1. Contaminant Sources

According to joint studies by WHO/UNISEF (2008) seven percent of the population across Latin America and the Caribbean do not have access to proper drinking water sources and thirty-six million people in Latin America and the Caribbean still practice open defecation (WHO/UNISEF, 2012). Water is a human right and should be afforded to all and facilities made available to protect the water resources. Over ninety-five percent of the fresh water resource globally is from groundwater (WHO, 2006). Effects of some contaminants can lead to many health concerns ranging from severe diarrhea to infections of contagious diseases, and in some cases, death. Wastes emanating from open defecation, leaky and non-existing sewer systems, improperly disposed household wastes, runoff from unapproved building materials, heavy metals, surfactants, oils and other automobile toxins have a great potential to influence the quality of groundwater in New Providence.

Across the globe nutrient inputs have been a major priority (UN WWAP, 2009). Poor sewer systems, or the lack there of, can present various strains of harmful bacteria, increase nutrients and surfactants that are harmful to humans when ingested in relatively high doses. Many studies suggests that highly dense urban areas are more likely to cause contamination to groundwater resources (Balogun et. al., 2012; Copeland et. al., 2009; Ewodo et. al., 2009). Wastes from sewer systems input nitrates and nitrites into the environment. Many nitrogen compounds are natural in nature but excess nitrogen can come from human waste, chemical leachate and fertilizers. Also, in urbanized areas, livestock fertilizer applications, improper disposal of wastes and wastewater. As with many developing countries, small scale agricultural production, whether livestock or vegetative, is customary in many shantytowns in the Bahamas. The use of fertilizers in the area allows for various levels of fertilizer and nutrient runoff. Interaction between nitrogen and phosphorus can further degrade water quality causing eutrophic conditions. Copeland et al., (2009) investigates shantytowns' impact on groundwater in Brazil and found high levels of pathogens which are linked to diarrheal diseases in humans. WHO estimated about 1,584,000 people die a year globally due to diarrheal diseases stemming from poor water quality worldwide (WHO, 2004b).

Land use and urbanization disrupts the natural makeup of a location and can cause changes to water quality. Some of the groundwater recharge is due to storm water runoff from the overland areas (Lohse & Gallo, 2010). Areas saturated with contaminants can eventually percolate to the groundwater resource. Sharp (2010) discusses the changes in land use that can impact groundwater. The author looks at the land topography, changes to water table elevations, vegetation, temperatures and pumping effects. For an urban Arizona arid area, Lohse & Gallo (2010) found that while groundwater recharge improved due to increase runoff, water quality has been compromised and the quality diminished.

Due to an abundance of water in our oceans, rivers and lakes, water resources is in many cases overlooked. But it is the quality of the water which can limit the availability of the resource for human

consumption. There are detrimental effects associated with human consumption of poor quality water. Some authors classify water as the main and most crucial element to human life (Beall, 1981, Chaplin, 2001). Many countries have experienced water shortages due to contamination. In India 85% of the drinking water comes from groundwater Wyrwoll (2012) reports that the water crises in India is due mainly to drought and poor water quality. Seventy percent of China's drinking water is attributed to groundwater, yet China is also experiencing a water crisis (Qui, 2010). Nebraska has experience a water crisis due to pesticides found in groundwater (Aiken, 1993). In Trinidad & Tobago the groundwater threats are mostly due to sewage and agricultural chemicals (WRA, 2001). An online magazine of the Inter-American Development bank (Drosdoff, 2014) states that Barbados has a water shortage forcing them to pump desalinated water into the groundwater system to avoid scarcity.

2.2. Source of Contaminants in the Bahamas

Non-point source loading impacting groundwater resources is a global concern. It is evident that groundwater resources can be contaminated by surface runoff leaching and percolating to the water table. In New Providence over 80% of the groundwater is within five feet of the surface. In this instance all surface flows has the potential to be impacted by overland contamination and over use of the resource (BEST, 2002). Urban runoff can contain many contaminants ranging from chemicals to microbial constituents. These constituents can reach groundwater resources through storm water runoff, leaching and from surface waters. Urbanization and poor land management are the main overriding issue.

There are a number of back yard auto mechanic and body work shops that are not regulated. Backyard mechanics refer to mechanic shops that are unregulated and are not necessarily zoned for practice. These mechanics unintentionally allow the surface exposure of oils and other automobile fluids. Benzene, toluene, xylene and ethylbenzene (BTEX) compounds, as a result of oil and gasoline, contain cancer causing agents which can lead to premature deaths in adults and children alike. Heavy metals which include Lead (Pb), Manganese (Mn), Copper (Cu), Nickel (Ni), Chromium (Cr) are found in car fluids and are also very toxic and harmful to health and developmental growth (Bhatia, 2006). These metals may accumulate in the tissues of humans and impact the neurologic damage and can also result heart diseases. Even after control measures are put in place contamination can still be prevalent at the study site. Ipeaiyeda & Dawodu (2008) found that even over time substantial amounts of PB and Hg were still persistent within the soil profile. Similar heavy metals and pollutants are observed for car wash areas. Nwachukwu et al., (2010) reports high levels of heavy metal concentrations with in the soil profile of areas in Nigeria. Car washes also can put a burden on water resources. Sablayrolles et al., (2010) investigated the concentration of various runoff constituents from car washes. The authors described high

levels of contaminants, so much so that the water quality of one of the sites was described as being similar to contamination levels found in wastewater. It is also possible for car washing runoff to increase sediment transport while also allowing contaminants to travel with the sediments (Bakacs et al., 2013; Sablayrolles et al., 2010).In the Bahamas contamination of groundwater can occur due to various reasons. In other parts of the world studies have found significant amounts of contaminants including heavy metals coming from mechanic shops (Onianwa et al, 2003; Adelekan & Abegunde, 2011) that did not meet required WHO water quality standard.

In addition to contamination due to runoff, and the leaching of improper disposal of wastes, it is likely that diminished groundwater quality is also a result of over consumption of the groundwater resources. The USACE has noted that point source pollution has been identified as a threat to water quality supply, and has highlighted the residents of shantytown as one source (USACE, 2004). Crompton & Savioli (1993) and McMichael (2000) of The World Health Organization reports the many common human intestinal parasites, infections and suggest that poor conditions as seen in Shantytowns can promote the increase of such pathogens. There are approximately 37 Shantytowns across New Providence as stated by the then Minister of State for Immigration, Mr. Branville McCartney, in an article by BahamasB2B (2009). In many of the Shantytown areas, adequate water facilities are not in place and it is customary for residence of these informal settlements to pump water from groundwater resources for everyday use. This adds to the strain already being placed in the groundwater resources having reached its maximum potential in New Providence (USACE, 2004). In the case of New Providence, salt water intrusion to groundwater resources is a possible cause of events when resources are overused (BEST, 2006) since in it is likely that these pumps are placed where the fresh water lenses are thin (USACE, 2004). Bowleg (a College of the Bahamas Lecture, October, 2011) estimates that 3.5 million gallon per day (MGD) of water is pumped from the groundwater resources from New Providence to be used as potable water with a maximum available daily volume of 9.63 MGD. Makeshift septic systems can become a major problem for water quality. In many of the shantytowns improper septic systems and waste management poses a concern. Many authors show that leaky septic systems are the culprit for poor groundwater quality. Robertson et al. (1991) show that two septic systems are the major sources of contamination to the aquifer. The authors used tracer testing to determine this finding.

Leaky septic systems may contribute largely to the groundwater contamination. In the Bahamas only about 15% of the residences are connected to the public sewer system (UNEP, 1998). The majority of the island disposes of wastes through decentralized waste systems. Nutrients such as nitrates can be emitted from leaky tanks and percolate to the groundwater resource. Wallace & Lowe (1998) show the impact of nitrate loading to groundwater quality using a mass-balance relationship. For the study in Egypt, Abdel-Lah & Shamrukh (2001) found bacteria leachate in the groundwater through monitoring methods. In

some instances the extraction well is located in close proximity to the septic tank. Adetunji & Odetokun found that it is likely that leaky septic tanks in short distance away from wells can lead to contamination.

This study looks at the potential water resource contamination crises in the Bahamas and the catastrophic events that may occur as a result. Additionally a review for management, remediation and prevention is being considered.

3. Potential Impacts

3.1. Environmental & Health

It is difficult to quantitatively derive the health and environmental impacts of groundwater that has been contaminated. Various studies indicate that contaminated water is the responsible source of the spread of diseases and has caused illnesses and death throughout. Ingestion of relatively high doses of various heavy metals and nutrients by humans can cause a wide range of health risks ranging from headaches to cancers and in some cases leading to death. The most common illness are as a result of fecal coliforms and nitrates found in groundwater. Wallender et al, (2013) found in their study that about 57% of outbreaks associated with contaminated water were due to bacteria emanating from human wastes.

Private self-supplied potable water is not regulated in the Bahamas and therefore risks of impairment to human health is greater. For households using groundwater as the main source of potable water, the risks of being exposed to pollutants are very high. One major effect of nitrogen to humans is respiratory illnesses. As a safety standard the WHO recommends a maximum limit for nitrite (NO_3^-) in groundwater as 50mg/L. The USEPA's maximum contamination loading (MCL) for nitrate and nitrite in groundwater is 10mg/L and 1 mg/L respectively, although some studies suggest that nitrate levels lower than 3mg/L in wells can be considered contaminated. It has first been determined (Comly 1945) that any value nitrite greater than 10 mg/L ingested by an infant has great potential to decrease oxygen levels thereby causing methemoglobinemia also known as "blue baby syndrome". In adults nitrite levels can result in thyroid problems, birth defects and cancers (UNEP, 2010). MCL's for bacteria established by the USEPA includes total coliforms with a goal MCL of zero (0) coliforms present and current standards "No more than 5.0% samples total coliform-positive (TC-positive) in a month (for water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month). While cases of the blue baby syndrome has been seen around the world, diarrheal diseases are more common in human from consumption of contaminated water. The diarrheal impacts may range from mild to fatal depending on the amount of contaminated water consumed.

There are many infectious diseases and illnesses that are spread as a result of contaminated groundwater used for drinking and can therefore have morbid effect on humans. Typhoid and diarrhea,

caused by ingesting water contaminated with microorganisms, are an illness that can lead to high fevers, headaches and loss of appetite. Another common water disease is known as malaria that is as a result of mosquitos populating in standing water. It is possible for the groundwater in the Bahamas to be contaminated by the aforementioned. In an existing shantytown in New Providence an open well was discovered (figure 1). The well contained refuse which can harbor mosquitos. This well was located 8 feet from the backdoor of a shantytown home. While the residents may not directly consume water from this well orifice, water is pump from a well in the proximity. There are effects from chemical constituents that runoff and are leached to the groundwater resource. Oils, and car fluids and all other BTEX compounds can cause developmental problems, liver, kidney and nervous system failures when consumed at certain levels.

Figure 1 A well located approximately 8 feet from the back door of a shantytown resident.

Impacts to the welfare of Bahamians and persons residing in the Bahamas will be major if nothing is done to prevent the water crisis. While health care services are efficient in the Bahamas the impact of increase illnesses and the spreading there of will increase the burden on an already overburdened health care services. Undocumented residents will need to be treated which will also contribute not just to the health care burden but also to the economic resources. The Vice President of the Caribbean Water and Wastewater Association, Mr. Jason Johnson states that any water crisis will now also become a health, safety and even a national security concern (Coto, 2013).

3.2. Social and Economic

The cost of life is immeasurable and the comfort of one's health is priceless. Social costs of contaminated water are usually very difficult to quantify and define. When there is not a preparedness plan for groundwater contamination, in times of crisis funds from various sectors will have to be reallocated for clean up since water is very essential. There is also a high price associated with remediating the contaminated groundwater resource. This cost is based on the level of contamination and the physical characteristics surrounding the source (Vangronsveld et al., 2009).

High risk and high level contamination of groundwater could lead to the devaluation of property. Public perception and misinformation has much to do with this in many cases according to IAAO, (2001). In other instances, especially in commercial real estate, groundwater pollution can impact the value of the land on a large scale.

Residents, whether for financial reasons or due to ignorance, may continue the use of groundwater even after it has been deemed contaminated. This can influence the spread of diseases and propogate illnesses in a community. It is important that during a water crisis the message for safety is communicated effectively for all social sectors to comprehend. Nsiah-Kumi (2008) discusses the importance of risk and crisis communication. In the Bahamas the majority of shantytown residents consume well water directly from the well. These residents are mainly of foreign decent to which English language is not the first spoken language, considering the official language of the Bahamas is English. Should the water supply be deemed polluted and restricted from direct consumption the language barrier should be considered for effective and clear communication.

The presence of contaminated water can force some residence into public water facilities with can impact their financial position. Based on data by the Bahamas Department of Statistics (2013) the average household size in the Bahamas is 3.4 persons. Since there is little data regarding local consumption, United States Geographical Survey (USGS) data is used. USGS estimates the average person uses about 80 -100 gallons per day. Since most people are away from the home for at least 8 hours per day or 1/3 of the day the water use at home will be estimated at about 2/3 of 90 gallons which is 60 gallons of water used within the home. The water rate as implemented by the Water and Sewerage Corporation (Bahamas), based on current water charges, is estimated at $12 per 1000 gallons, with a minimum charges quarterly of $36 to include 3000 gallons. Consequently if groundwater becomes polluted the average person that is reliant on groundwater as the main source of potable water will incur an additional $73.44 on household costs. For some, especially those residing in shantytowns, this increase in household costs can become a burden.

A higher demand in water will induce a rise in the cost of water thereby making it less affordable. The greater demand may also require infrastructural changes and increase in productivity resulting in higher cost for even preexisting public water supply consumers. Contaminated groundwater will require

proper treatment which is not commonly required for most groundwater systems. Countries like Austria, Denmark, and Hungry rely on groundwater for over 95% of the country's drinking water supplies (WHO). Fifteen percent of the water distributed by the public utilities water supplier in the Bahamas is attributed to groundwater resources of New Providence.

4. Remediation Management Strategies

It is extremely difficult to remediate groundwater once it has been polluted at very high levels (Hesano, 2006). There are many cases which indicate a direct link between the water quality and water quantity (Tilman et al., 2002; Scanlon et al., 2007). Contaminated water resources impacts water quantity in that less water is available naturally for consumption, which therefore leaves the government with the burden of producing potable water for the people. It is all these factors that give rise to concerns and consequently research work in this areas is vital. The United Nations Environmental Policy (UNEP) proposed several interventions for the protection of water resources. UNEP recommends that data collection and water quality monitoring are vital on every level from the watershed scale to international (UNEO, 2011).

In places where contaminants are expected, the use of phytoremediation and buffers can be employed. Phytoremediation is the use of plants to absorb the excess nutrients from the surrounding area. These plants may hold on to the contaminants so that they are not allowed to flow through the environment. Vangronsveld et al, (2009) assessment show that phytoremediation can be a successful and inexpensive method for reducing contaminants in groundwater. Constructed wetlands have also been used as a phytoremediation method (Sikora et al., 1998). There are various phytoremediation techniques that can be used to remove contaminants from groundwater resources. These include phytoextraction, phytodegradation and phytostabilization. Many studies show effective uses of phytoremediation: Arsenic contaminated groundwater (Natarajan et al., 2011); heavy metals (Hoffman et al., 2004, Chigbo & Batty, 2013, Mashadi et al., 2013, Muhammad et al., 2013); Oils, gases & BTEX compounds (Baruah et al., 2013); Waste waters and microbial pollutants (Bouali et al, 2012, Soleimani, 2012).

There are many native varieties of plant species in the Bahamas that have the potential to be used for phytoremediation. Correll & Correll (1982) suggests there are 45 species of ferns many of which are native to the Bahamas. Several studies suggests that ferns are effective in reducing the arsenic loading (Lu, 2009). Other native plant known as Bahamas Senna is of the Caesalpiniaceae family which is known for the high uptake of heavy metals and oils (Pinzon et al., 2010, Diaz-Martinez, 2013). Lokhande et al. (2012) & Manousaki & Kalogerakis (2012) show that Sesuvium Portulacastrum commonly known as the sea pickle is effective for removing some metals contamination form water.

Pump and treat method has been one of the most conventional method for treating contaminated groundwater (IAEA, 1999, US-EPA, 1996). This method involves the extraction of the contaminated water for treatment. The treated water is then pumped back into the ground and this process is continued. Many have found success with this process. Hoffman (1993)

Tosco et al. (2010) show that pump and treat method was successfully used to treat contaminated water that was contained by a hydraulic barrier. USEPA (2001) show that many groundwater cleanup projects used pump and treat systems.

Various other methods are used for removal of contaminants in groundwater. Physical barriers can also be used. Some of these include slurry walls and sheet piling used to contain the contamination site. These include: Iron for the sorption of constituents like arsenic or other volatile organic compounds either chemically (Cundy et al., 2008) or by an iron barrier (O'Hannesin & Gillham, 1998). Some very unconventional approaches have also been used to treat groundwater contamination. Savannah River National Laboratory saved approximately 27 million dollars by using vegetable oil to treat the chlorinated solvents (Savannah River National Laboratory).

5. Preventative Management Strategies

The Bahamas is making strides toward a more sustainable environment. The water corporation has implemented a reused water plant and has plans to expand reuse water system. This will reduce the reliance on groundwater. In more recent times the government of the Bahamas has acknowledged the potential risks of shantytowns and are now in the process of taking steps toward remediation. It is important to implement prevention strategies to mitigate the potential risks of epidemic due to groundwater contamination (Gubler, 1998).

Policy making and implementations must be a major goal as a first step in controlling and preventing possible contamination. These policies should include proper zoning for auto mechanic shops and carwash facilities, waste disposal and sanitation. It is clear that water resource management is a global issue. Ongoing monitoring of the groundwater resources should be implemented. Monitoring can include collecting observed samples, prediction modeling, and tracer applications. All auto mechanics must be required to practice proper disposal of wastes and manage chemical spills in accordance with proper environmental regulations and enforcement is key. There must be measures in place to limit the number of auto mechanic and car wash facilities in the local communal areas. Subdivision zoning, waste management and septic disposal can also mitigate risks of groundwater contamination. In many instances garbage is left in open fields in proximity to the homes. Due to lack of formal sewer or septic systems many of the residents resort to outdoor toilet use. It is in these areas where much of the residents use

groundwater as their main source of potable water. Malone (1990) and Yanggen & Webendorfer (1991) acknowledges the importance of best management practices for land use and urges that governments consider implementing policies to ensure protection of groundwater resources. Gubler (1998) discusses the need for policy changes in addition to social and economic changes for the protection of natural resources.

Land use changes and urban/regional planning can assist with improving the quality of groundwater (Carmon et al., 1997). There is an inherent relationship between the quality of groundwater and the land use practices (Lerner & Harris, 2009). As the land is modified for urban living contaminants become more likely available for storm water wash off thereby increasing the risk of groundwater contamination. Management of the land to protect groundwater from contamination due to human activity is vital to sustainability. El-Niqa & Al-Shayeb (2009) shows that land use zoning system used in Jorden to prevent groundwater contamination through human activities to be an effective management method. Some studies suggest educating the public of their role in the prevention of groundwater contamination will bring awareness thereby instituting change within the community. Hancock et al, 2004 recognizes the importance of education as a gateway to a more sustainable groundwater resource. The authors suggest maintaining a database with information regarding characteristics of the well including the hydrological, geological and ecological features. This will lead to a better understanding of the mater movement, nutrient dynamics and microbial distribution. It is by knowing these things that water resource managers can provide the adequate management strategy to prevent a water crises.

Monitoring and data collection should be induced to provide insight of the characteristics of the site in order to determine changes and to produce an accurate model of the site (IAEA, 1999). Regular monitoring and predictive models can be used to forecast ground water quality events and provide foresight to future contamination so that preventative measures can be implemented to avoid contamination. Navulur & Engel (1998) used models to assess the groundwater contamination due to nonpoint sources. In Jordan all wells, whether legal or illegal, are monitored by the government and a fee is assessed based on the drawdown (El-Niqa & Al-Shayeb, 2009). Hancock et al. (2004) urges that success of groundwater sustainability lies with “high quality research” and constant liaisons with other water quality professionals.

Engineering solutions such as introducing vegetative buffers can also be used to retain certain contamination especially nutrients to reduce the amount of runoff overland. Buffers also allow time for other contaminants to settled and be reduced by the environment naturally. The buffers act to reduce the flow of runoff and can intercept the flow while the vegetation absorbs or degrades the contaminants. Spruill & Galeone (2000) & Spruill (2000) show how the effectiveness of riparian buffers in reduction

nutrient contaminants to groundwater. Many authors used buffers as a management method (Mercado, 1984; Osborne & Kovacic, 1993, Gopalakrishnan et al., 2012).

6. Conclusion

Groundwater quality decline in the Bahamas has the potential to cause a crisis in the country since many still depend on groundwater as the main source of potable water. The Bahamas has yet to take an in depth look at the impacts of various source of contamination on the water quality and the effects on the social and economic well-being of the Bahamian society. This is a major cause for concern since water supply in the Bahamas is limited. Increased monitoring and preventative method should be employed to address the safety of potable water in the Bahamas. It is clear that healthy groundwater resources are important to the social, economic, environmental and wellbeing for the population of the Bahamas. Proper plans and management strategies should be in place to avoid any crisis that can arise as a result of contaminated water if used for consumption. Effective communication and education is key to notifying the public of potential health risks, and remediation methods should be implemented with preventative measures to avoid future contamination. Discontinued direct use of groundwater to the public, for some this is not economically feasible since they rely on groundwater. Proper plans and management strategies should be in place to avoid any crisis that can arise as a result of contaminated groundwater.

The best method for maintaining groundwater resources is preventing the water from all forms pollution. Groundwater contamination in the Bahamas can have very detrimental impacts on the population. The response to water contamination must be immediate and effective since groundwater is consumed by many throughout New Providence. A careful water balance should be maintained for the groundwater system to remain healthy.

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