Visualising the spatial distribution of diarrheal disease using the geographical information system: a WASH perspective

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Abstract: The main water resource in the Gaza Strip is facing a serious challenge in terms of quantity and quality posing significant health threats on Gaza population. According to the statistics, diarrhoea among children was reported and reached the alerting thresholds several times last years. The aim of the study is to visualise the spatial distribution of diarrhoea, based on an established geo-statistical database. The distribution of diarrheal disease at districts and municipal levels were presented and visualised. In addition, discussion and recommendations for improved water, sanitation and hygiene (WASH) services for risk mitigation were included. The study served as a pilot for an integrated GIS-based water quality and public health monitoring program and showed that GIS can be a very helpful tool to visualise the prevalence of one of the water-borne diseases for better decision-making and proper WASH intervention.

Keywords: diarrhoea; geographical information system; GIS; public health; WASH; Gaza Strip.

1 Introduction

Diarrhoea is a symptom of an infection in the intestinal tract, which can be caused by bacteria, virus or parasites. The infection can be spread through contaminated drinking-water/food, poor sanitation or from person-to-person as a result of poor hygiene (WHO, 2013).

Microorganisms from human or animal excreta is the main source of microbiological contamination, which reaches humans through contaminated water from wastewater, landfills, or wastewater treatment stations, causing serious health problems (Abudaya et al., 2013).
Worldwide, diarrhoea is considered one of the major leading causes of morbidity and mortality among children, though it can be prevented and treated (WHO, 2013; CDC, 2013; Liu et al., 2012). It is estimated that 95% of diarrhoea cases can be prevented through environmental interventions, amongst them increasing the availability of safe drinking water (Bartram and Gordon, 2008). In the Gaza Strip, diarrheal diseases were the highest self-reported diseases among its residents and one of the major causes of morbidity among children.

Palestine is among the Middle Eastern countries that intensively experience water and sanitation problems, which are exacerbated due to the conflict with Israel (Özerol, 2013). As part of the occupied Palestinian territories, Gaza Strip comprises a narrow zone of land along the Mediterranean Sea with a surface area of about 365 km². The Gaza Strip is composed of five districts; the North, Gaza, Deir Al-Balham, Khan Younis and Rafah district wherein water and sanitation services are provided through 25 municipalities. The imposed siege and the repeated Israeli wars over the Gaza Strip have severely impeded the rehabilitation and the development of the water and sanitation sector.

According to the Palestinian Water Authority (PWA), only 4% of the supplied domestic water in 2014 is matching the WHO guideline limits for drinking water, while the remaining portion is out of limit for Chloride and Nitrate. The contamination of the main aquifer is associated with the shortage in water supply and the uncontrolled discharged of untreated or partially treated wastewater, which are seriously affected by the existing political and economic situation.

Visualisation of the diseases’ spatial distribution has been a cornerstone in epidemiology and public health practice since 1850s when John Snow determined the source of cholera outbreak. Nowadays, WHO, CDC and numerous other public health organisations are using GIS to investigate and respond to global epidemics. This study is aiming to visualise the spatial distribution of diarrhoea among children below three years old using the geographical information system (GIS), which gave insights into areas, where diarrheal disease is more prevalent (Esri, 2011).

## 2 Conceptual framework

### 2.1 Factors associated with diarrheal incidence

94% of diarrheal burden is attributable to the environment, including risks associated with unsafe water, lack of sanitation and poor hygiene. Moreover, it is estimated that the majority of diarrheal cases can be prevented through environmental interventions, amongst them water, sanitation, and hygiene (WASH) activities including increasing the availability of safe drinking water, improved sanitation services and proper hygienic practices (George, 2008). The interventions aiming to reduce the faecal oral transmission of pathogens.

Figure 1 presents the main WASH interventions that contribute to the reduction in diarrheal incidence.
Improved water services involve the improvement in water quality, water safety planning, household water treatment and safe storage while the improving sanitation services includes connection to piped sewerage system, efficient treatment of wastewater, and safe disposal of wastewater.

Hygienic interventions such as health promotion, raising awareness campaigns and promoting hand washing with water and soap are effective if the context was considered particularly in overcrowded and highly populated areas. In addition, the projected population growth during the upcoming years will increase the demanded for WASH services.

Visualising the special distribution of diarrheal disease using the GIS can be useful for monitoring the impact of improved water supply, sanitation, and hygienic practices on diarrheal incidence as one of the waterborne diseases.

3 Materials and methods

A literature review of the available studies and reports was conducted to identify the source and the type of required statistics for this study. The study was carried out, as a pilot for a more comprehensive GIS baseline study on water quality and public health, using the available statistics registered by each health facilities in the Gaza Strip for one year (2013).
In 2013, 65,296 diarrheal cases among children ‘less than three years old’ were reported to the epidemiology department with an incidence rate of 41.5%. Since the year of 2006, there was a continuous increase in the incidence of this disease (MoH, 2014). The percentage of diarrheal cases among children below three years old per the five districts in Gaza is shown in Figure 2.

The available statistics for diarrhoea among children below three years old were collected at health facility level from the main health providers in the Gaza Strip; the Ministry of Health (MoH) and the UNRWA health facilities. Excel tables were created for the number of cases registered per health facility, the population density, the sewage network coverage, and water quality statistics.

The maps were generated using a reference GIS base-map for the Gaza Strip including the districts and the municipalities provided by the PWA databank unit. The spatial attributes for each health facility and the collected statistics were organised and imported to GIS geo-database. Shape files of districts, municipalities, health facilities’ locations were used. Health facilities’ locations including 42 MoH clinics, 20 UNRWA clinic and 7 hospitals which serving the population in the Gaza Strip.

A disease map was created for diarrhoea based on the statistics registered by each health facility in 2013. The GIS maps were created and visualised for the distribution of diarrhoea per the districts and municipalities’ areas using coordinates for health facilities. The interpolated values were, number of cases among each district, municipality, percentage of sewage network coverage and district population. Summation of cases registered by health facilities per each municipality areas were visualised and colour-coded according to the included colour scheme within each map and where the red colour indicates the highest registered cases.

Kriging techniques are used to map the collected data, which have been displayed with ArcMap 10.2 software in a geographic information system (GIS) using colour-coding. The results were sited below and discussed based on the developed maps in addition to referenced maps extracted from the literature.

It is worth to mention that, during 2013, 75% of health facilities in the Gaza Strip participated in reporting and notification of communicable diseases including diarrheal disease (MoH, 2014). Therefore, underreporting is still expected and the real number is likely to exceed what has been mentioned in the study.
4 Results and discussion

4.1 Disease maps

Globally, the average of diarrhoea among children under three years of age reaches one to three episodes annually and acute diarrhoea accounts for almost ten percent of all childhood hospital admissions. In the Gaza Strip, diarrhoea is one of the most common childhood illnesses and the main cause of outpatient visits and hospitalisations. According to United Nations Relief and Works Agency (UNRWA) for Palestine Refugees in the Near East epidemiological bulletins, diarrhoea remains the major cause of infectious diseases morbidity among the refugee population. The bulletins showed an increasing trend for watery diarrhoea among children below three years old during the last years (UNRWA, 2012, 2013, 2014).

Following the methodology mentioned in the previous section, GIS maps were generated showing the distribution of diarrheal cases among children below three years old in the Gaza Strip, Palestine. The maps were generated at two scales, the first was the districts’ level and the second was the municipalities’ level, which is more detailed than the first one. The distribution of cases at districts’ level is shown in Figure 4. The five districts were colour-coded as described in the legend.

Figure 4 Distribution of diarrheal cases (children <3) per district (see online version for colours)
The highest number of cases were reported in the North district followed by the Khan Younis District and then by Deir Al Balah and Gaza. While the lowest number of cases was registered in the Rafah District. Prioritising water sanitation and hygiene (WASH) interventions to address the areas with the highest recorded cases in the North and Khan Younis Districts need to be considered.

Further presentation of the distribution of diarrheal cases at more detailed scale, the municipalities’ level, gave more insight into areas within each district with high recorded number of cases (see Figure 5). Though Rafah District has the lowest registered diarrheal cases, there was an area within the district related to Rafah Municipality with high registered cases (2,000–5,000 cases) which require more attention in term of WASH interventions.

**Figure 5** Distribution of diarrheal cases (children <3) per municipality (see online version for colours)

The GIS map in Figure 5 helps to identify the most affected and vulnerable populations such as people living in Beit Lahia, Beit Hanoun, Al Nusairat, Khan Yonis and Rafah Municipalities.
Further investigation need to be undertaken to explore the source and quality of drinking water, the adequacy of sanitation and hygiene services within the areas where diarrhoea is highly prevalent. According to literatures, diarrhoea is prevalent among people using municipal water than people using desalinated for drinking (Yassin et al., 2006).

Therefore, improving water quality and raising people’s awareness in this regard is expected to reduce the incidence of diarrhoeal cases.

4.2 Water and sanitation

Many studies around the world confirmed that, safe water, adequate sanitation together with good hygiene is fundamental to good health. Improvements in one or more of these three components can greatly reduce the rates of morbidity and the severity of water born-diseases especially among children living in developing countries (WHO, 2013; CDC, 2013; Merchant et al., 2003).

In the Gaza Strip, the main water resource, the aquifer, is facing a serious challenge in term of quantity and quality posing significant health threats on its population. In term of quantity, the daily average of water consumption per capita is 79.8 l/c/d with the lowest recorded consumption rate in Khan Younis District (73 l/c/d). The insufficient supply of water is also plagued with supply interruption lasting for several days, which has an implication on people’s water demand for hygiene practices (PWA, 2015; Roeder et al., 2010).

According to UN and PWA reports, 96% of the Gaza aquifer is mainly contaminated with Chloride or Nitrate which and considered unfit for human use as it does not match with the WHO guidelines for drinking water. Eighty-seven present of the aquifer is contaminated with Nitrate and is attributed mainly to untreated wastewater infiltration and the uncontrolled agricultural practices (the usage of fertilisers and pesticides) (PWA, 2014). Contamination of the main aquifer by wastewater infiltration and the inadequate disinfection are contributing to the existing disease burden.

The complex political, demographic, urbanisation, and socioeconomic context has in turn placed significant pressure on the environmental resources, which led to a serious deterioration in water quality and quantity (UNEP, 2009; PNIPH & NIPH, 2014; PWA, 2011). According to the UN report, the Gaza aquifer will be irreversibly damaged by 2020. The report cited the deteriorated infrastructure, health, and power as contributing factors to the worsening situation in Gaza (UN, 2011). The longstanding blockade had already created an unsustainable water and sanitation status, which is complicated by the existing conflict with Israel (OCHA, 2015).

Depending on the results of the groundwater chemical analyses carried out twice a year by both MOH and the Coastal Municipal Water Utility (CMWU) for about 200 domestic groundwater wells in Gaza Strip, the PWA has evaluated these results through preparing contour maps for Nitrate as pollution reference (see Figure 6).
Figure 6  Nitrate concentration map (see online version for colours)

Figure 7  Sewage network coverage per district (see online version for colours)
The NO\textsubscript{3} contour map showed concentrations ranging between 50 mg/l and 300 mg/l. The highest NO\textsubscript{3} concentrations were mainly reported in different residential areas of the Gaza Strip reflecting the percolation of the wastewater to the underneath aquifer through the networks, cesspits or septic tanks. Khan Younis also recorded high nitrate concentration since most of the residential area is not served by sewerage system and many areas are still served by cesspits facilities. Furthermore, the low NO\textsubscript{3} concentration was reported in the area that is not occupied by residents (the southeast part of Rafah) or characterised by low transitivity of thick unsaturated characterised (Al Nusairat area) (PWA, 2015).

About 83% of Gaza inhabitants are living in houses connected to public sewerage network (PCBS, 2015). The existing sewage network coverage in the Gaza Strip per each district is shown in Figure 7 where Khan Younis district has the lowest coverage (< 50%). The efficiency of the existing Waste Water Treatment Plants (WWTPs) is illustrated in Figure 8 where Khan Younis and Rafah WWTPs have the lowest efficiency (45%) (PWA, 2013). The functioning sewage treatment system is seriously affected by lack of power supply, making the already existing situation worse. In addition, there is an evidence of sanitation-related infections in the Gaza Strip (Ashour et al., 2009).

Figure 8  Efficiency of the existing WWTPs in the Gaza Strip (see online version for colours)
Sewage is one of the biggest reasons for groundwater contamination in the Gaza Strip. It is estimated that around 38 MCM of sewage are produced annually across Gaza’s residential areas (Ramahi, 2013). More than 400 m$^3$/day of sewage aerobic sludge and 5,000 m$^3$/year of anaerobic sludge are randomly disposed in the Gaza Strip, creating several environmental and health hazards (Nasser et al., 2009). The overloaded wastewater treatment plants and the lack of electricity to operate them, leakages from wastewater sewage to the coastal aquifer resulted in the presence of faecal coliforms, detergents and elevated nitrate concentrations (Shomar et al., 2010). Water samples collected from groundwater wells surrounding wastewater treatment ponds and sewage leakage areas showed high levels of total and faecal coliform counts (PNIPH & NIPH, 2014). Moreover, the level of contamination in the water supply networks was found to be higher than that in wells, occurring mainly in winter and summer seasons (Yassin et al., 2006).

According to reviewed studies and research, it is expected that improving the sewage system particularly for Khan Younis District, which has the lowest sewage network coverage and the less efficient WWTP, would reduce the registered cases of diarrhoea. Combined interventions including the improvement of water quality and hygienic practices would have a great impact on the public health status.

4.3 Hygiene

In 2010, the UNICEF and PHG concludes that, on average, due to poor water quality and hygiene practices, 20% of households had at least one child under the age of five who had been infected with severe diarrhoea in the four weeks prior to the survey (UNICEF, 2010). According to UNRWA for Palestine Refugees in the Near East epidemiological bulletins, diarrhoea remains the major cause of morbidity among infectious diseases in the refugee population. The bulletins showed an increasing trend for watery diarrhoea among children below three years old during the last years (UNRWA, 2012, 2013, 2014). During the Israeli military operations over Gaza Strip, an increase in the incidence of diarrhoea among children was reported (Thurstans and Sibson, 2010; UNRWA, 2015). As emergency response, hygiene kits were distributed during this period particularly within the overcrowded shelters.

About 40% of population receive water supply for 5–8 hours, once every three days (EWASH, 2015), which has impacted the availability of water for hygienic practices.

According to WHO studies, a significant proportion of diarrheal disease can be prevented through safe drinking-water, adequate sanitation and hygiene. Improved water supply reduces diarrhoea morbidity by 21%. Improved sanitation reduces diarrhoea morbidity by 37.5%. Washing hands reduces diarrheal cases by up to 35%.

4.4 Population density

The estimated population in the Gaza strip is 1.8 million which is expected to reach 3.7 million in 2035. With this population growth, a remarkable increase in the demand for WASH services is expected (PWA, 2011; UNCTAD, 2015).
In 2014, the Gaza Strip population density reached 4,986 inhabitants/km² making it one of the highest population densities in the world. The average household’s size in the Gaza Strip is 5.7 persons, and according to the PCBS, 99.9% of households are connected to water public network.

In general, diarrhoea can spread rapidly, when people in crowded conditions lack clean water for hygiene and sanitation. Accordingly, raising awareness campaigns need to target and be prioritised to serve areas that are overcrowded and highly populated.

Figure 9  Population density per district (see online version for colours)

As per the illustration in Figure 9, Gaza District has the highest population density followed by the north district. Investment in awareness raising campaigns and hygienic promotion activities particularly in the highest populated districts is expected to reduce diarrhoea burden within those areas. Improved outcomes would be expected if the campaign were conducted in parallel with interventions aiming to improve water and sanitation services.

According to the UNRWA statistics, diarrhoea among children, was reported and reached the alerting thresholds several times during the past years. Studies around the world showed that, investment in the WASH sector via ensuring safe drinking water, adequate sanitation, and proper hygiene can inhibit diarrheal disease. More in depth researches have estimated that WASH interventions can reduce diarrheal disease percentage between 30% and 60%. Therefore, it is expected that Figure 9 related to the
distribution of diarrheal cases among children could be improved through adoption of national WASH policies and strategies.

5 Conclusions

The study helped to visualise the spatial distribution of one of the main recognised water born disease, which is diarrhoea among children below three years old, and across the Gaza Strip districts and municipalities. The highest reported cases were visualised in the North district followed by the Khan Younis District. The study revealed the spatial distribution of the disease and highlighted the variation in the number of recorded cases across Gaza Districts and municipalities during the year 2013. The maps provided insights into the hotspot areas where the highest registered cases were located such as Beit Lahia, Beit Hanoun, Al Nusairat, Khan Younis, and Rafah Municipalities.

Literature has estimated that WASH interventions can reduce diarrheal disease percentage between 30% and 60% therefore, it is expected that well-designed WASH interventions accompanied by enabling and more stable political environment will contribute to the reduction of the registered diarrheal cases among children below three years old. The recommended WASH interventions are; the improvement in water supply and quality, the improvement in sanitation services and wastewater treatment efficiency, and the improvement in hygienic practices.

The authors recommended the usage of the available geo-statistical database and GIS disease maps as baseline for an integrated GIS water quality and public health monitoring program. The recommended GIS monitoring program will help in maintaining situational awareness of disease spread and tracking of outbreaks, documenting disparity and ensuring the focused allocation of resources.

Further research is needed to investigate the possible correlations between water related diseases and public health using more advanced geo-statistical analysis tools. The ongoing updating of maps will help to monitor the situation, investigate outbreaks, target interventions, and inform policy makers.

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References


