Geospatial Analysis to Recognize the 2016-2017 Yemeni Cholera Epidemic - A Case Study of Sana'a City and Districts of Sana'a Governorate

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Abstract

The United Nations have deemed the situation in Yemen the world's worst humanitarian crisis. Yemen is currently experiencing the largest cholera epidemic in recent history. The first cases were declared in September 2016, and over 1.1 million cases and 2,300 deaths have since been reported. The research relied on information available of the number of recorded cases of cholera from hospitals and health centers in Sana'a city and Sana'a Governorate. Spatial statistical analysis is the most intriguing and remarkable aspect of GIS. In this study, Some of Spatial statistical analysis methods were used to figure out the volume of cholera outbreak in Yemen. Hot and cold spot, interpolation distance weighted (IDW), ordinary least square (OLS), and geographically weighted regression (GWR) were used. The analysis shows a high concentration of concentrations in hospitals located in Sana'a city and parts of Sana'a governorate adjacent to the capital Sana'a, especially areas in the north and west parts of the city. The large number of recorded cases of cholera is due to the contamination of rainwater with wastewater sewage in the agricultural areas adjacent to the sewage channel. During the rainfall season, this led to the flooding of agricultural areas with such water, which led to contamination of vegetables and fruits. In addition, farmers in that area use electrical generators to vacuum water from sewage channel and to irrigate crops.

Keywords: Cholera epidemic, Yemen crisis, Spatial statistical analysis

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Introduction

Cholera is an important public health problem worldwide. Toxigenic Vibrio cholera is responsible for 1.4 to 4.3 million cases with about 21,000–143,000 deaths per year *(Thandavarayan et al., 2019, p3).* Cholera is a bacterial disease caused by infection of small intestine by Vibrio cholera, characterized by a variety of diarrhea, abdominal cramp and dehydration. Most common route of infection is through contaminated water and foods *(Nishiura et al., 2017, p4).* The clinical consequences of this diarrheal disease include discharge of substantial volumes of watery stool, loss of electrolyte, rapid dehydration that may advance to hypovolemic shock and metabolic acidosis. Death rates due to cholera infection are reported to be as high as 70%, mainly due to the delay in rehydrating the patients *(Thandavarayan et al., 2019, p3).*

Since early 2015, Yemen has been in the throes of a grueling civil war, which has devastated the health system and public services, and created one of the world's worst humanitarian disasters *(Al-Mekhlafi, 2018, p1560)*. The United Nations have deemed the situation in Yemen the world's worst humanitarian crisis *(Federspiel and Ali, 2018, p2)*. By September 2016, only 46% of the 3,507 hospitals and clinics were operating7 and blockades of the Red Sea ports prevented the entry of key goods. The war and siege that started in 2015 and continue to date, have had a devastating impact on every vital sector in Yemen including health, agriculture, service, and industry *(El Bcheraoui et al., 2018, p4).*

The World Health Organization (WHO) reported having established 139 oral rehydration corners, trained 900 health workers in the management of cholera, delivered 1 million bags of IV fluids, distributed 158 cholera kits and sent 1450 cholera cots. The WHO described having treated 700,000 suspected cases of cholera *(Federspiel and Ali, 2018, p2).*

Yemen is experienced the largest cholera epidemic in recent history. The first wave disseminated cholera in the south before an explosive surge in the second wave across the south, center and north. Lasting 7 months, the first wave peaked at 2000 suspected cases weekly in December 2016 and 1663 deaths in total (Figure 1). The second wave included a rapidly increasing trend and expanding geography over 2 months, and a gradually decreasing trend over 8 months, with a massive peak of 50832 weekly suspected cases in June 2017 and 2265 deaths in total *(Spiegel, et al., 2019, p4) and (Weill et al., 2019, p231).*

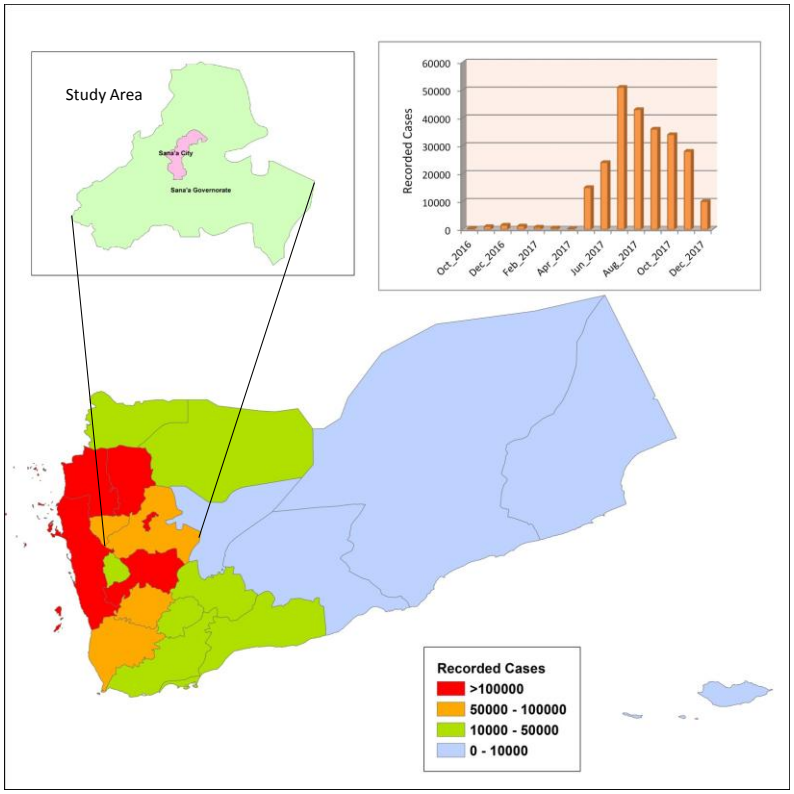
The armed conflict increases the likelihood of the emergence of epidemics (*Gayer, et al., 2007, p1627*). This is obvious during the cholera epidemic in Yemen in 2015 and 2016. The degradation of water and sanitation infrastructure

had given rise to the proliferation of mosquitos and hence cycles of large-scale malaria and dengue outbreaks. In addition, the increasing phase occurred at the onset of the rainy season and was potentially associated with a shift from household use of deep well water to contaminated surface water.

Study Area

Sana'a Governorate and Sana'a city have been chosen as the study area. Sana'a is a governorate of Yemen. However, Sana'a city is not part of the Governorate but instead forms the separate governorate. Both of Sana'a governorate and Sana'a city cover an area of around 15.000 km². Sana'a city (the capital of Yemen), Amran, Hajjah, Al-Hodaidah and Dhamar have more than 100,000 recorded cases. In addition, the number of cases ranged from 50,000 to 100,000 have been recorded in Sana'a governorates, Mahwit, Ibb and Taiz governorates, while in the governorates of Al-Jawf, Sa'ada, Rima, Al-Bayda, Al-Dhale'e, Lahj, Abyan and Aden, the number of recorded cases ranged between 10,000 to 50,000. Finally, Shabwah, Marib, Hadramout and Al-Mahra governorates have recorded less than 10,000 cases (Figure 1).

Figure 1: Recorded Cases of Cholera from Sept. 2016 to Dec. 2017



Data Limitation

Unfortunately, the research encountered considerable difficulties in acquiring the necessary data such as the number of casualties and the number of deaths in Sana'a city and Sana'a Governorate to conduct targeted analyzes focusing on each geographical area. This lack of data may leave researchers with no chance to calculate rates, causes, and variables to find out the causal-spatial relationship. Therefore, the research relied on information available of the number of recorded cases of cholera from hospitals and health centers in Sana'a city and Sana'a Governorate.

Materials and Methods

Data

The data used in the study were collected from the Infectious Diseases Department of the Yemeni Ministry of Health. The data contains detailed statistics on cholera recorded cases received by hospitals, health centers and health units in Sana'a governorate and Sana'a city. The number of these health facilities reached 391 distributed among governmental and private establishments. The number of health facilities in the city of Sana'a was 131, while in Sana'a governorate was 260. In addition, digital data were used for agricultural areas, residential neighborhoods, streets, water wells, population, valleys, and sewage channel in the study area.

GIS Methods

Disease mapping provide information on a measure of disease across a geographical space. Disease maps are able to provide us a rapid visual summary of complex geographic information. These maps may also identify subtle patterns in epidemic/health data that are sometimes missed in tabular presentations *(Elliott and Wartenberg, 2004, p 995)*. Advances in GIS technology provide very good opportunities for environmental and geographical specialist to study associations between demographic and environmental exposures and the spatial distribution patterns of diseases. According to *(Anamzui, 2012, p21)* the objectives of spatial epidemiological analysis are the description of spatial patterns identification of disease clusters, and explanation or predication of disease risk.

This study concentrates on the application of a GIS based on spatial and geo-statistical analyses to study the spatial patterns of cholera and define areas of

high risk and demographic risk factors that contribute to high rates of cholera. Spatial statistical analysis is the most intriguing and remarkable aspect of GIS. In this study, some of spatial statistical analysis methods were used to figure out the volume of cholera outbreak in Yemen:

- Cluster detection (Hot and cold spot) to examine tendency of risk.
- Interpolation Distance Weighted (IDW).
- Ordinary Least Square (OLS),
- Geographically Weighted Regression (GWR).

Result and Discussion

The study shows a variation in the number of health centers and cholera cases in the Districts of Sana'a, the capital, and its suburbs. The 26 and 7 health centers in Al-Sabeen and Al-Tahrir districts received the highest cases of cholera, with 15537 and 15127 cases respectively, with a total of 30,664 cases, representing 35% of the total number of 87,418 cases, while with 3 health centers, the Old Sana'a district was the lowest district received 131 case as shown in Figure (2) and Figure (3).

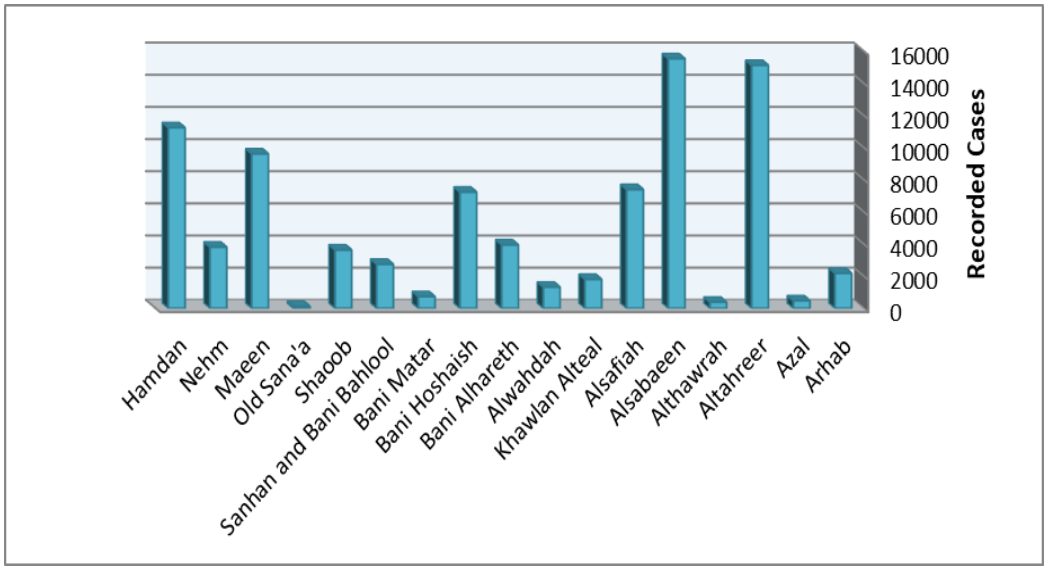


Figure 2: Recorded Cases in health centers in Districts of Sana'a, the capital, and its suburbs

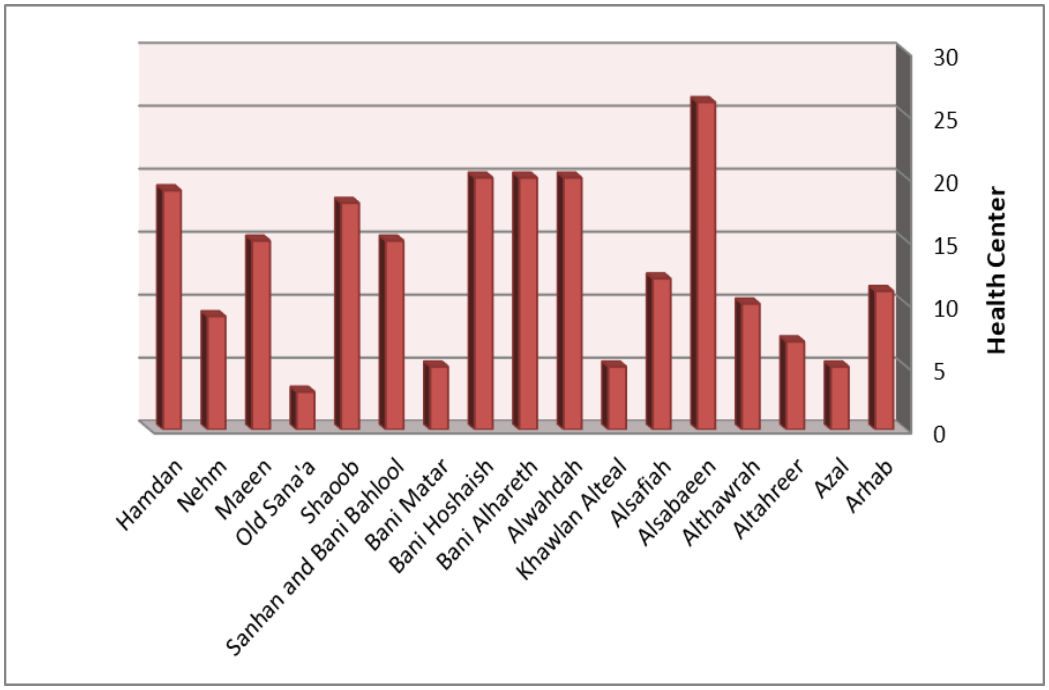


Figure 3: Number of health centers in Districts of Sana'a, the capital, and its suburbs

Figure (4) also shows the result of a density analysis (IDW) of recorded cholera cases that were treated in health centers. The analysis shows that health centers located in the city of Sana'a and its environs, especially in the northern and western parts of the city, have received large numbers of cholera cases ranging from 500 to 6000 cases. The high concentration of cholera cases indicates a high number of infected people in those areas that are considered urban areas.

The reason for that may be the contamination of rain water with sewage water in the agricultural lands adjacent to the sewage canal north of Sana'a city. The infected cases began in October 2016 after the end of the rainy season. This led to the flooding of agricultural areas with polluted water, which polluted the vegetables and fruits grown there. In addition, farmers in Bani Al-Harith district, "which is a major source supplying the markets of Sana'a city with vegetables," use generators to draw water from the sewage channels and irrigate crops.

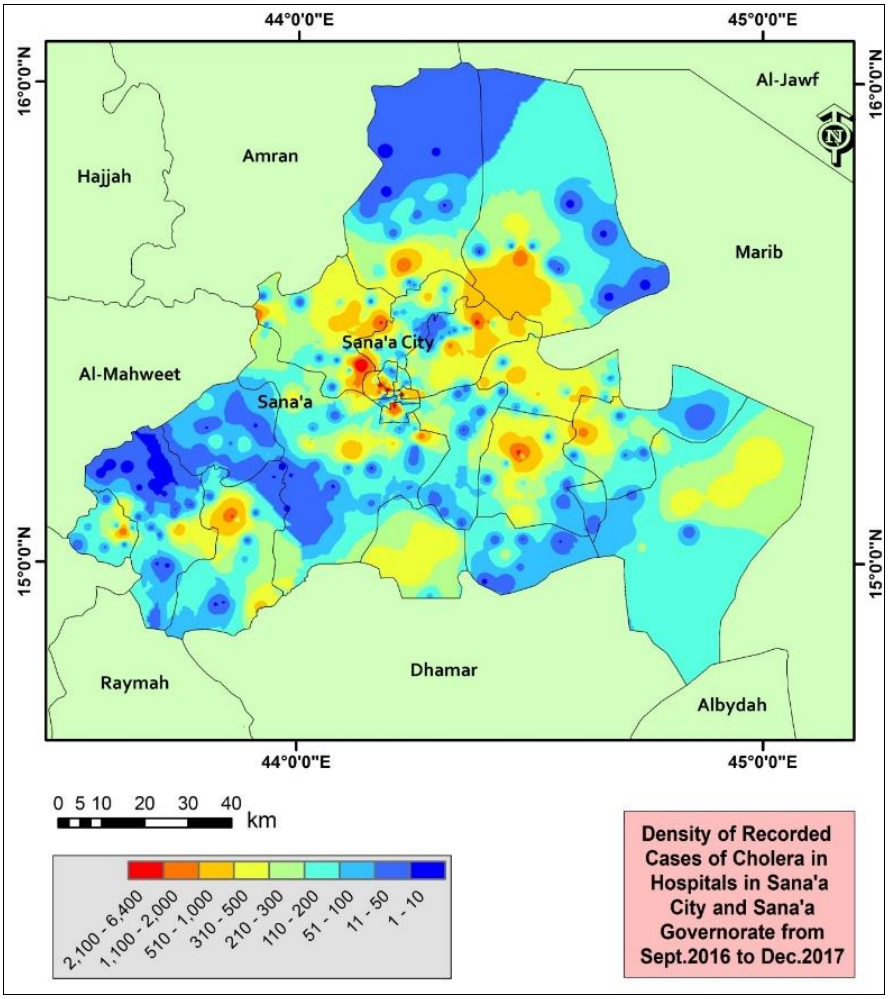


Figure 4: Density of cholera cases treated at the hospitals in the study area

Children are most vulnerable to infection, and due to low immunity, malnutrition and unhealthy living conditions, children suffer more than adults from infection and disease. The health system is collapsing and doctors are not being paid and suffers from severe shortages of basic medical supplies. Operating health facilities are under severe pressure and cannot accommodate the increasing numbers of patients. To make matters worse, the doctors have not been paid for several months. While collecting data, doctors reported that many doctors left hospitals and traveled outside Yemen in search of a better life. They also reported a lack of medicine and medical supplies so the devices were not working and in need of repair. Some hospitals have been bombed by aircraft and they are out of service.

In addition, the shortage of safe drinking water and medical supplies in hospitals in the study area increases the continuous spread of cholera and acute watery diarrhea. UNICEF is working with partners on health, water, sanitation, hygiene and communication for development to scale up the response to control the outbreak, prevent its spread, and reduce the risk of its return.

Figure (5) shows the result of the mass detection analysis. It can be seen that there is a high concentration of cholera cases in hospitals in Sana'a and the surrounding areas. Obviously, the further from the city center, the less focused she is. This analysis shows that a large number of cholera cases were recorded in areas around Sana'a city. They may have been affected by agricultural products irrigated with polluted wastewater. This has put great pressure on receiving cases of cholera in hospitals due to limited resources, which affects the incidence of deaths due to the large numbers of injured.

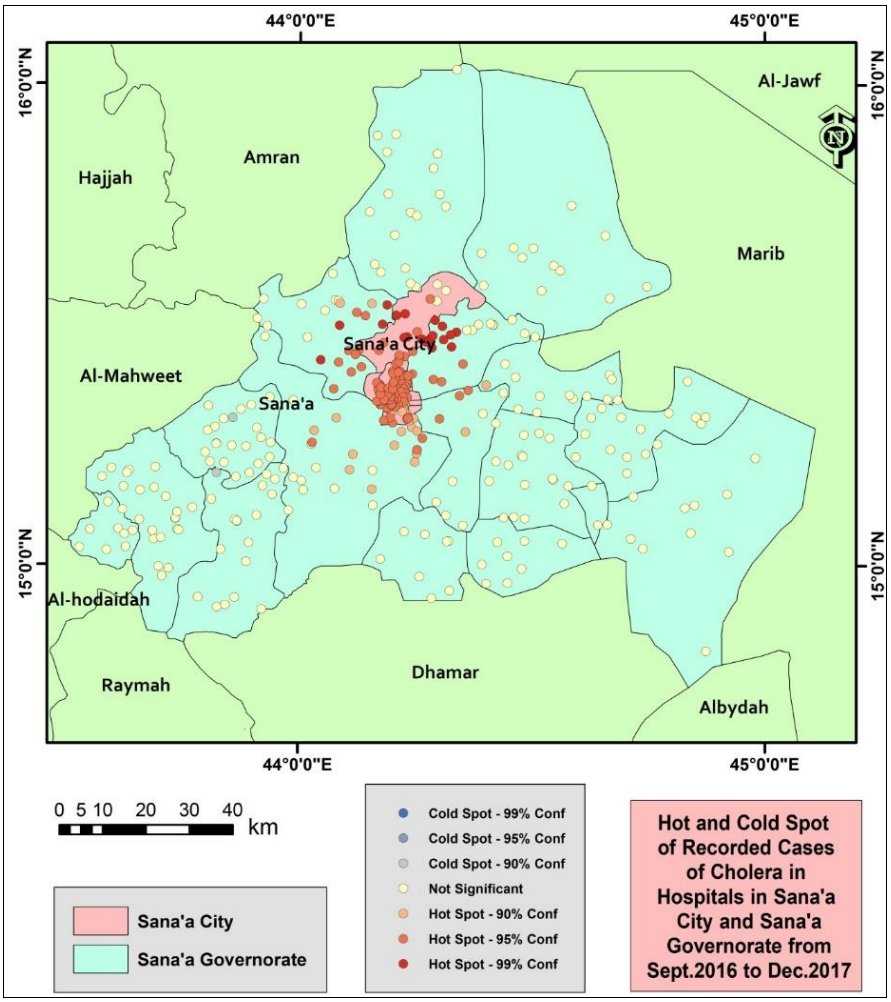


Figure 5: Result of the hot spot analysis in the study area

The spread of cholera is the worst that can happen to the population of Yemen, but it was expected due to the collapse of the health system. There are more than 600 health facilities that are no longer operational, and many facilities that are still operating are either understaffed or operating at minimal operational capacity.

Two years after Yemen faced the largest outbreak of acute watery diarrhea / cholera in the world, the most vulnerable populations, especially the marginalized and displaced, remain vulnerable to disease. Since the beginning of 2019, 300,000 suspected cholera cases and 500 disease-related deaths have been recorded in Yemen.

A field worker explained that the strategy for educating the population on how to recognize signs of cholera and how to protect themselves from this disease consists of three axes: "We sterilize water sources with chlorine, and we sterilize water tanks, to ensure the safety of the water. Providing families with sanitary items that include soap, washing powder and water containers, and finally, we go between homes and explain to families how cholera is spread and how they can protect themselves from it. "

(Figure 6) displays the population density in the city of Sana'a, which has a population of more than 3 million according to population indicators in 2018. Obviously, the population density is high in the zones of old city and Al-Tahrir zone (commercial area). The density in that areas ranging from 57,000 to 130,000 people. The population density decreases the further away from the city center and ranges from 20 to 300 people in low-density areas.

(Figure 7) illustrates the IDW analysis density of the recorded cases of cholera treated by the hospitals. This analysis shows the high concentration of concentrations in hospitals in the center and west part of Sana'a city. It is clear that many of these public and private hospitals have received cholera cases ranging from 400 to more than 6,000 case.

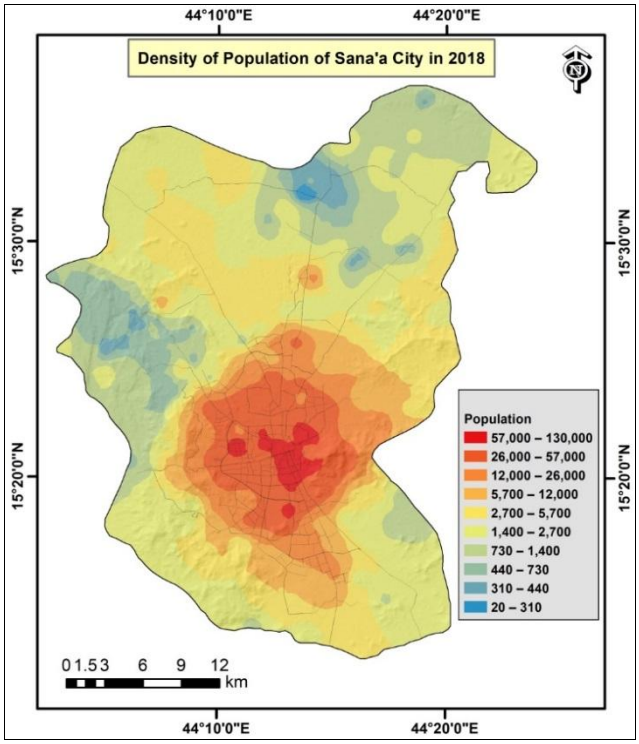


Figure 6: population density in Sana'a city

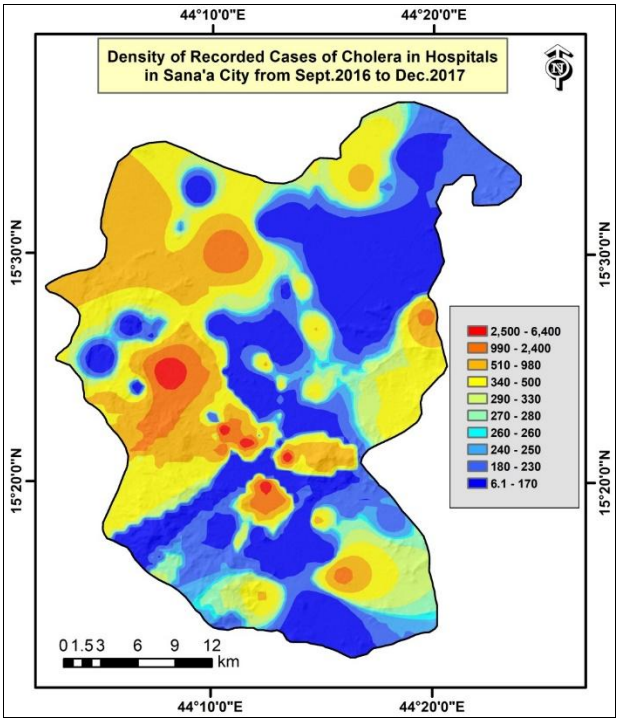


Figure 7: the recorded cases of cholera treated by the hospitals

Figure (8) shows the water wells in the Sana'a city and its environs with abound 5727 artesian wells and 758 hand surface. The reason for the existence of such a large number of wells is due to the lack of governmental supervision and legalization of the drilling of these wells. Another reason is the rapid urbanization of Sana'a at the expense of agricultural land. Al-Saylah channel is a place for torrents flow from the mountain valleys surrounding the city. The end of Al-saylah is in the north of the city located near the wastewater sewage recycling refinery.

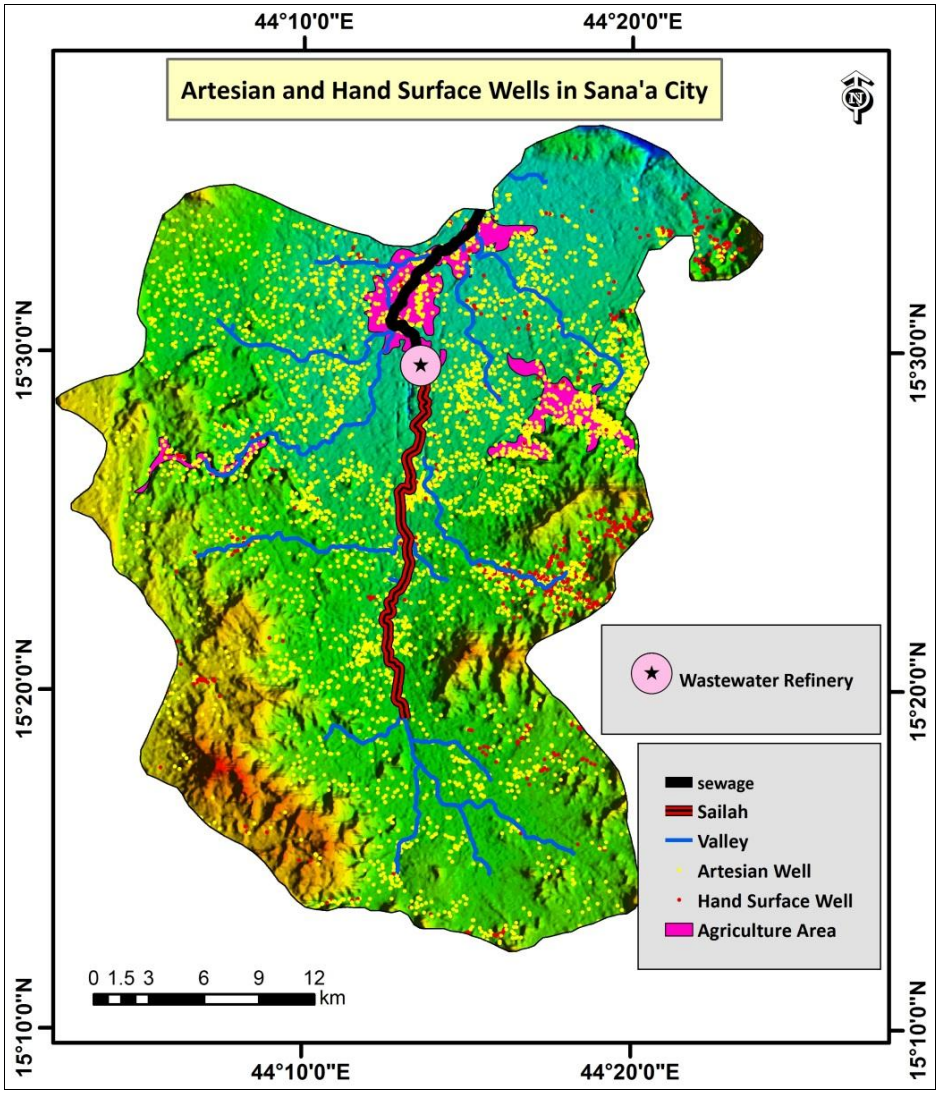
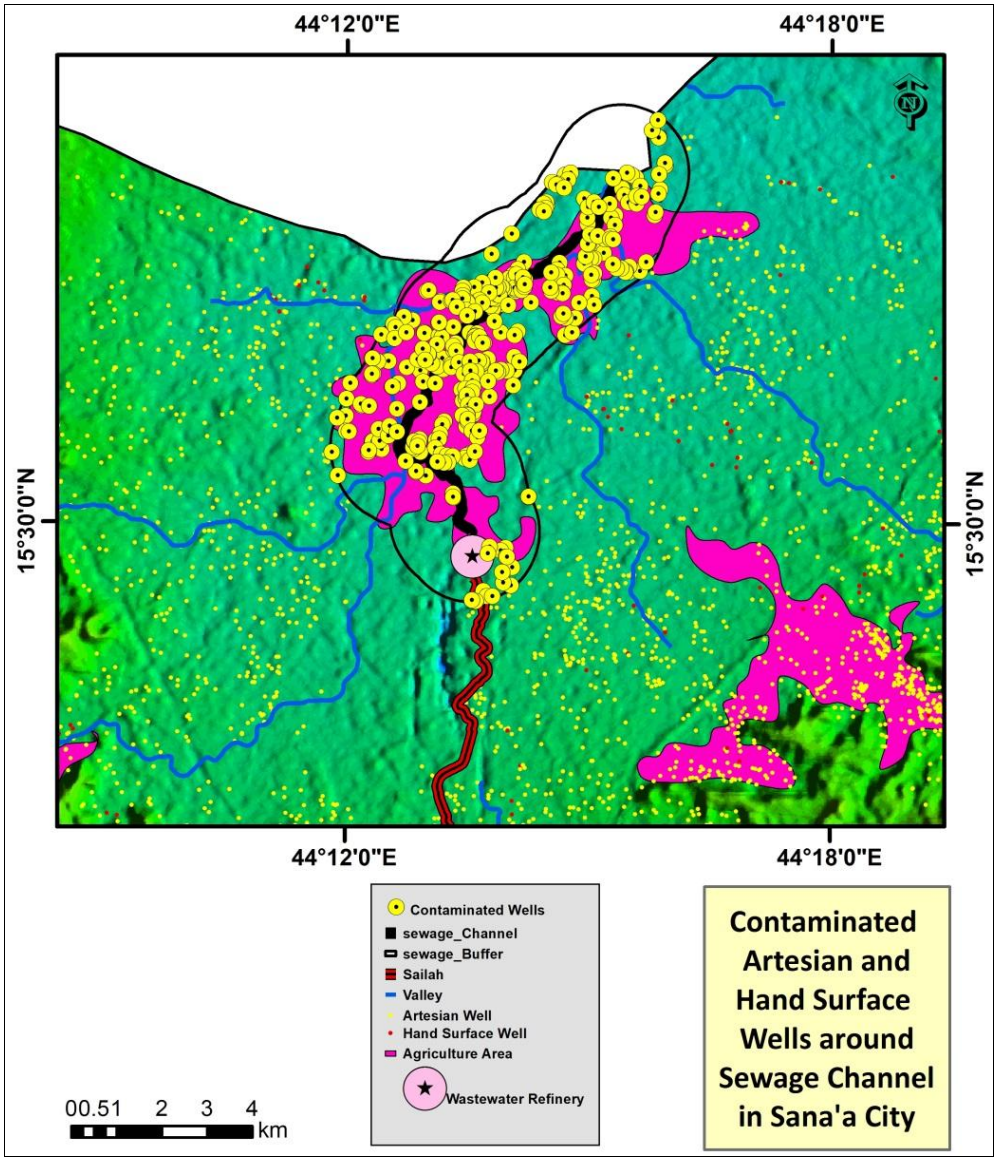


Figure 8: Water wells in the Sana'a city

The wastewater sewage recycling refinery is connected to the sewage drainage canal. This canal crosses the agricultural area north of Sana'a city, as shown in (Figure 8) and (Figure 9). There are 344 wells on both sides of the canal (Figure 9). This canal is considered as a major risk factor and a major cause of cholera outbreaks. It always mixes with rainwater during the rainfall season and that water is used by farmers to irrigate crops.



Figue 9: the contaminated wells around the wastewater sewage canal

The result of geographically weighted regression is shown in (Figure 10). The recorded cases of cholera in shospitals in Sana'a City was randolly distributed with z-score of 0.2088 and p-value of 0.8345. However, some hospitals in the center and north parts of Sana'a city had overloaded of cases with standar deviatin ranged from 0,5 to 2,5.

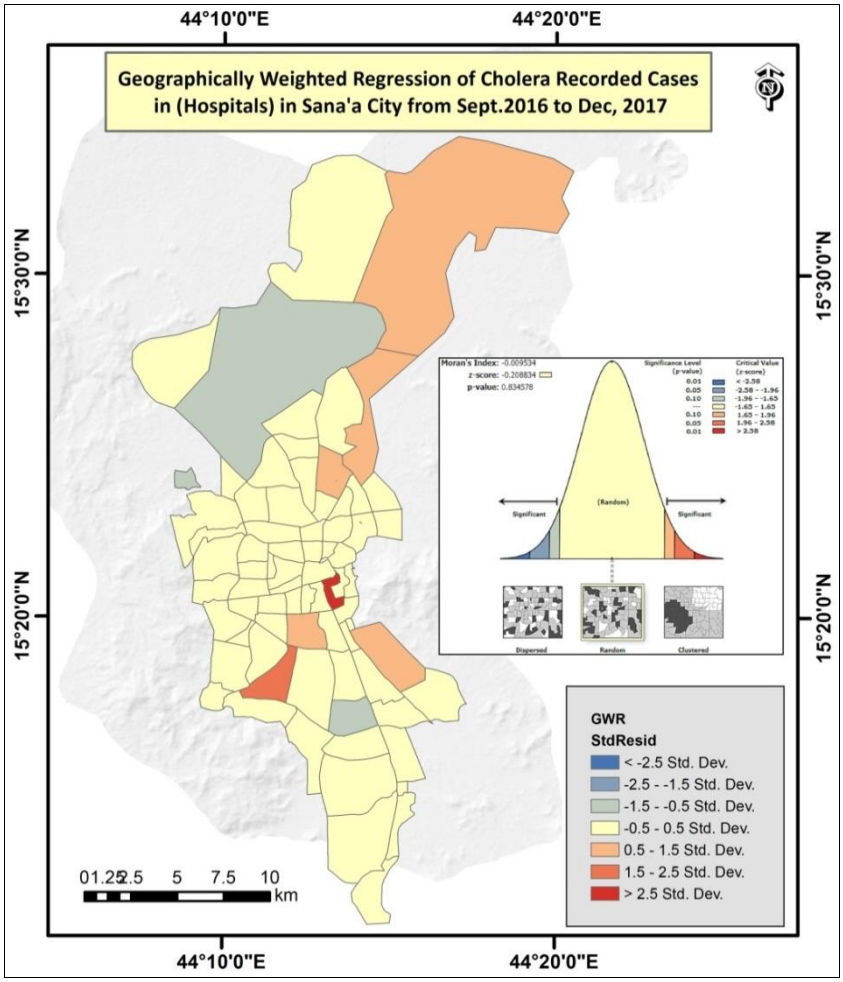


Figure 10: geographically weighted regression (GWR)

Conclusion

The cholera response in Yemen was and remains extremely complicated and challenging for a variety of reasons such as political, cultural, and environmental. The spatial statistical analysis methods display that the outbreak of cholera in the study area is caused by four main factors: firstly, collapsing of infrastructure specially the health services. Secondly, the Garbage piled up in the streets for a month, because of a protest by cleaners who demanded to raise their wages. Thirdly, the rainfall in the summer that mixed with garbage resulting in an outbreak of cholera. Finally, Mixing rain water with sewage that flooded the areas of growing vegetables and fruits in the north of Sana'a city with that water, and this created a suitable environment for the outbreak of cholera.

Recommendation

- Because of the weakened public health system, a large, explosive outbreak should be anticipated, so an early priority should be to increase the capacity to culture cholera through the establishment of peripheral laboratories.
- Evaluation of the early warning alert and response functions of the surveillance system will be useful for preparedness for potential future cholera outbreaks as quickly as possible in Yemen by using statistical and climate modeling to prioritize geographical areas.

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التحليل الجغرافي المكاني للتعرف على وباء الكوليرا في اليمن خلال الفترة من 2016 إلى 2017 - دراسة حالة لمدينة صنعاء ومناطق محافظة صنعاء

محمد أحمد مياس

أستاذ نظم المعلومات الجغرافية والاستشعار عن بعد المشارك - قسم الجغرافيا والجيوانفورماتكس – كلية الآداب والدراسات الإنسانية – جامعة صنعاء

مُلَخَّص:

عدت الأمم المتحدة الوضع في اليمن أسوأ أزمة إنسانية في العالم، ويشهد اليمن حاليا أكبر وباء الكوليرا في التاريخ الحديث، وقد تم الإعلان عن الحالات الأولى في سبتمبر 2016، وتم الإبلاغ عن أكثر من 1.1 مليون حالة إصابة و2300 حالة وفاة، وقد اعتمدت هذه الدراسة على المعلومات المتوفرة عن عدد حالات الكوليرا المسجلة من المستشفيات والمراكز الصحية في مدينة صنعاء ومحافظة صنعاء، وفي هذه الدراسة تم استخدام التحليل الإحصائي المكاني لمعرفة حجم تفشي الكوليرا في اليمن، حيث تم استخدام تحليل المناطق الساخنة، وتحليل مسافة الاستيفاء المرجحة (IDW) وتحليل الانحدار المكاني التراتبي (OLS) وتحليل الانحدار الجغرافي الموزون(GWR)، وأظهرت نتائج التحليل وجود تركزات عالية في عدد الحالات المصابة في المستشفيات الواقعة في مدينة صنعاء وأجزاء من محافظة صنعاء المجاورة للعاصمة صنعاء، وخاصة المناطق الواقعة في الأجزاء الشمالية والغربية من المدينة، كما أظهرت الدراسة إلى أن سبب وجود عدد كبير من حالات الكوليرا المسجلة في مدينة صنعاء وضواحيها يرجع إلى تلوث مياه الأمطار بمياه الصرف الصحي في المناطق الزراعية المجاورة لقناة الصرف الصحي شمال مدينة صنعاء خلال موسم الأمطار، حيث أدى ذلك إلى غمر المناطق الزراعية بمياه الصرف الصحي، مما أدى إلى تلوث منتجات الخضروات والفواكه، إضافةً إلى استخدام المزارعين في تلك المنطقة مولدات كهربائية لسحب المياه من قنوات الصرف الصحي وري المحاصيل.

الكلمات المفتاحية: وباء الكوليرا، أزمة اليمن، التحليل الإحصائي المكاني في نظم GIS