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Analysis of Sewer Chokes Using GIS: A Case Study Nairobi City Western Region

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ABSTRACT: *Nairobi city has been facing sanitation problems related to sewage outflows and sewage pipe bursts. Nairobi City Water and Sewerage Company (NCWSC), a state owned water utility, uses Operation and Maintenance Information System (OMIS) in sewer chokes analysis in order to reduce the number of chokes occurring within their jurisdiction. This study focused on spatial sewer choke analysis in Nairobi's Western Region using Geographic Information Systems (GIS) which would enable easier spatial understanding of the chokes as well as improve on visual interpretation of otherwise complicated and detailed raw data. Data on causes of chokes was collected through field surveys and interviews and the frequency of these causes determined. Hot spot analysis on the data spatially revealed the hot and cold spots in the region. GIS was found to be useful as it spatially reflected the relationship and strength of each factor to choke formation. Further, Geographic Weighted Regression (GWR) was used to spatially reveal the trends of factors that influence choke occurrences. High population density, poverty level, number of households, vandalism and water supply were the major factors that contributed to high choke volumes in the region.*

KEYWORDS: *sewer choke, hot spot, spatial analysis, GIS, Nairobi City Water and Sewerage Company*

I. INTRODUCTION

The provision of sewage services in the Third World is a major challenge. Around two-thirds of the Third World's urban population has no hygienic means of disposing of excreta (Hardoy *et al,* 1993). Rapid urbanization has presented serious challenges on the management and disposal of sewage (Chiuta *et al*, 2002; Moyo and Mtetwa, 2002). Other cities also experience this problem; the sewage system in Mzuzu in Malawi cannot cope with the growing population; human wastes are exposed at the surface (Chenje, 1996). Most sewage treatment works are old and are poorly maintained and are also overdue for rehabilitation. Sewage treatment plants in Zambia handle only 20% of sewage collected, while 80% is lost into storm drains because of leakages and blockages (Chipungu and Kunda, 1994). Nairobi City is not exceptional as its sewerage system is also characterized with frequent chokes. Nairobi City Water and Sewerage Company (NCWSC), owned by the Kenyan Government, provide sewerage services in Nairobi. However the provision of sewerage services in Nairobi has not kept pace with rapid growth of city both in population and areal extent. Moreover the existing sewer and sanitation structures are over-strained and cannot adequately serve the present situation. Upgrading the sewer infrastructure seems to be the ultimate solution, however, this process is quite expensive and may take some time. This research seeks to come up with effective ways of addressing potential sewer chokes in future before new sewer lines can eventually be constructed.The sewerage system has the potential to discharge raw sewerage in to the environment e.g. if a sewer becomes blocked, an overflow will occur often at an access point such as maintenance holes (Sinclair, 2005). NCWSC needs to manage its water sewerage assets to minimize sewerage overflows.

This company is currently utilizing the Operation and Maintenance Information System (OMIS) to analyze sewer chokes. Conventional database management software can only answer statistical questions like how many potential chokes are anticipated in future and which region has the highest choke volumes. GIS applications, in contrast can relate all this information geographically. Previous studies have used the GIS as a spatial analysis tool (Chang et al, 1997; Khaemba and Stein, 2000) and a GIS-based decision support system (Wu et al, 2001; Van Der Perk et al, 2001) for various applications. In this study, GIS complements the OMIS by allowing the user to spatially visualize data thus revealing hidden relationships, patterns and trends. For example GIS can answer queries like; which areas spatially need regular check up; which pipes have broken down, where are the manholes located; this minimizes manhole search during the unblocking process.

This study aims to analyze the sewer data collected by NCWSC by spatially correlating the sewer chokes with factors influencing their formation. This will assist NCWSC to move beyond the current practice of targeting blockage hotspots and focus on proactive maintenance activities on identifying where additional future blockages may occur.

II. STUDY AREA AND METHODOLOGY

Study Area : In its enhancement on service delivery, NCWSC has divided Nairobi City County into six regions, namely; Western, Eastern, Southern, Northern, North Eastern and Central (Fig. 1). Specifically Western region was used for the analysis this study. This was due to its heterogeneous characteristics. Kawangware is a slum area with high population and a high man hole vandalism cases, Loresho is an area for the wealthy with very low population, Highridge represents a middle class area and Westlands is a commercial centre. Further, this region was selected due to well documented historical data on causes of sewer chokes and location of pipe data.

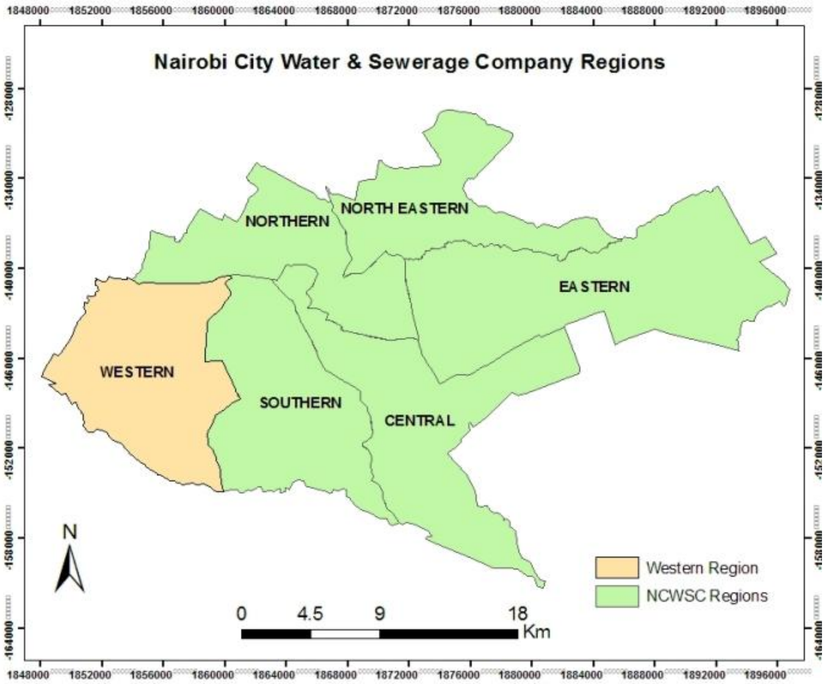

Figure 1: NCWSC study region; Western region has been used as a cases study.

Methodology : Primary, secondary and tertiary data was obtained in order to achieve the objectives of this study.Primary data were collected through the use of key informants, interviews and field observations. Face-to-face interviews were administered with the senior and junior staff of NCWSC. Observations were made through several visits to the sites, which were affected by sewer blockages. This enabled the researcher to have firsthand information on what was obtained with regard to blockages in the Western Region. GIS vector data in ArcView® shapefile format of the reticulation network was obtained from the Engineering Department of NCWSC. Demographic data was obtained from Kenya National Bureau of Statistics (KNBS). Secondary data were obtained through scrutiny of relevant official records and reports kept at the NCWSC library. This was supplemented by critical perusal of books, publications (such as newspapers and journals) on the topic under discussion. A geodatabase of the sewer reticulation network for the region was created using ArcGIS® 10 and the information captured included; pipe size, blockage records and choke causes. The geodatabase was the platform on which various analysis were done.

Analysis methods : Frequency analysis was performed to obtain the rate of recurrence of each choke cause; the Frequency (Statistics) tool in ArcToolbox was utilised in this study. Hot spot areas refer to areas that suffer frequent chokes due to similar causes on a regular basis. Hotspot analysis uses vectors to identify the locations of statistically significant hot spots and cold spots in data. The analysis of hot spot areas was important, as it showed a pattern of recurring events due to similar, if not the same, causes. Hot Spot Analysis tool was run on the point data; each point represented a location in the Western region whose historical blockage data for the year 2012 –June 2013 was readily available. A scatterplot matrix was used to determine the relationship between chokes and the factors that were found to influence the formation of blockages. Geographically

Weighted Regression (GWR) was used to analyze the spatial influence of the various factors. GWR is a local, spatial, regression method; it allowed the relationships being modeled to vary across the study area. GWR coefficients values, computed by the regression tool, reflected the relationship and strength of each factor to choke formation. The Spatial Autocorrelation tool was run on the standardized residuals in the Output Feature Class to determine if the model was well specified. This analysis was performed aggregating chokes reported within each administrative sub-location (such as Kilimani, Loresho and Kawangware) in the Western Region.

III. RESULTS AND DISCUSSION

Causes of sewer blockages: Case study of the Western Region : According to the NCWSC Western region causes of sewer blockages can be attributed to intrusion by roots, silt, rags, stones, polythene papers and fats. The findings from the analysis of historical blockage records showed that rags and grit with 32.2% and 30.2% respectively caused most of the reported blockages while intrusion by roots had the least impact (1.5%).

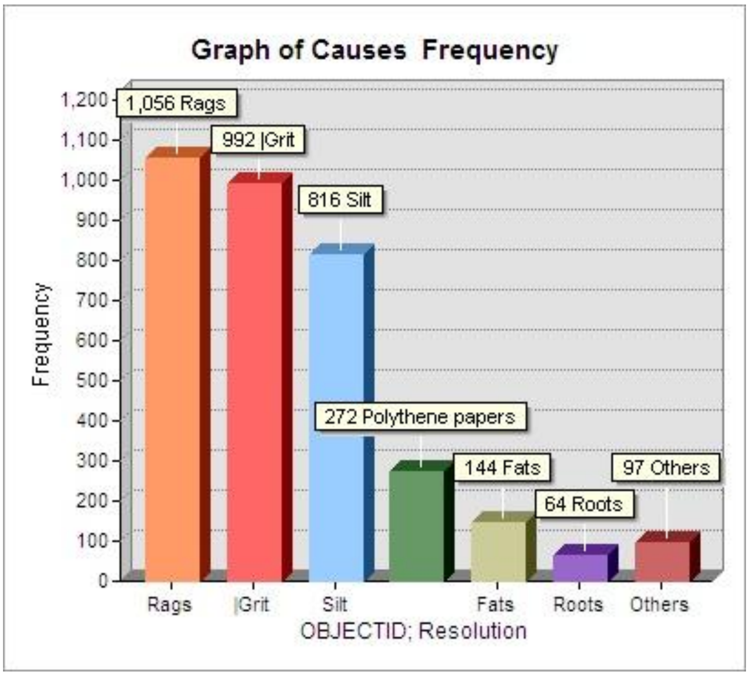

Figure 2: Causes of sewer chokes within the Western region, 2012-June 2013
Source: NCWSC

Hot spot Analysis

Hot spots and cold spots were determined by using the sewer choke frequency data; these were locations whose historical blockage information had been obtained from the NCWSC western region. Hot spot data allows for the determination of frequent hot spots. For conceptualization of spatial relationships; fixed distance band was used. It used critical distance to decide what neighbors to include and thus the scale of analysis was consistent across the study area. There was an interaction or influence among sewer chokes and their neighbors. For example sewer chokes in Kawangware had immediate neighbors such as Lavington, Westlands, Mountain View and Riruta. Another example was an area like Highridge whose neighbors were Spring Valley and Parklands. The hot spot analysis tools worked by looking at each sewer choke within the context of neighboring chokes. An area with a high choke frequency was interesting but may not have been a statistically significant hot spot; a good example was the Mall Area at Westlands. Though it had high choke frequency it was not statistically significant because it was surrounded by areas such as the Spring Valley and Brookside whose choke frequency was substantially low. To be a statistically significant hot spot, a choke had to have a high frequency value and be surrounded by other chokes with high frequency values as well. All the choke points in Kawangware had very high choke volumes surrounded by points with high choke volumes, thus this area was identified as a hot spot area. Also, some choke location in Highridge had high choke frequency surrounded by locations with high choke frequency. And the same concept was applied for low frequency values surrounded by other low values to determine cold spots.

The distance band chosen for the region was 1000 meters, this distance band was chosen because it matched the scale of analysis for this study; moreover it was adequate to delineate hot spots in the Western region which was one of the major objectives of this study. Areas with high ***z*** score values (Fig. 3) were the hot spots; they had high frequency of sewer chokes and were surrounded by other areas with high frequency of sewer chokes. These areas were Kabiria, Kawangware and Kangemi. Areas with low ***z*** score values were the cold spots; these had low frequency of sewer chokes surrounded by other areas with low frequency of sewer chokes. These areas were Loresho, Spring Valley and Kileleshwa. Areas that did not form part of statistically significant clusters were Mountain View, Muthangari and Kikuyu. Statistical significance was based on p-values and ***z***-scores that were calculated when Hot Spot Analysis was run. Findings from this region could be generalized to other areas in the city. That is other areas in the city that have similar characteristics that were influencing choke frequencies. An area like Kawangware is similar to Mathare (Eastern Region) and an area like Loresho is similar to Karen (Southern Region). Analyzing hotspot areas would be fundamental to NCWSC as the procedure would allow regulating checkups in the area to ensure smooth sewer flow in the pipeline, and it further reduces the possibility of chokes.

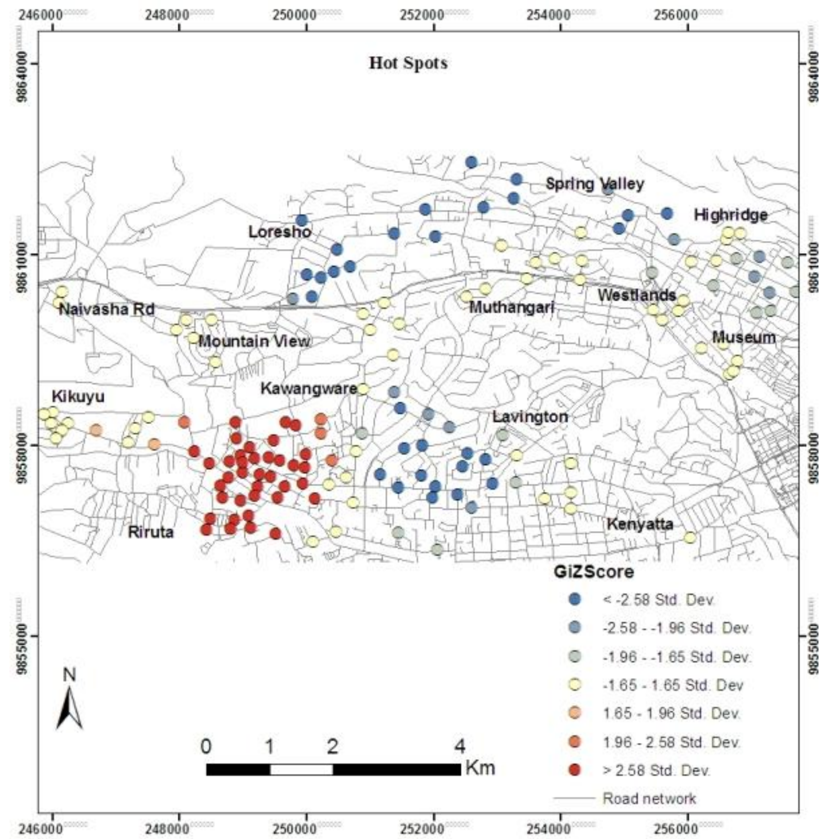

Figure 3: Hot spots and cold spots in the Western region

Inverse Distance Weighted Interpolation : To improve on visualization purposes (to provide guidance in decision making); the results were interpolated using Inverse Distance Weighted Interpolation (IDW) to a continuous surface as shown in Fig. 4. Interpolation was for visualization purposes only, otherwise, the true statistical analysis happened feature by feature. Showing both the surface and the true results of the hot spot analysis at the same time was a great way to present both the statistical results and the more approachable visualization in a defensible way.

Finding Key variables : The next question this study sought to answer was, “Why are choke volumes so high in those hot spot areas?” and “What are the factors influenced the formation of those chokes?”Factors influencing choke occurrence collected during the face to face interviews and field visits were assessed using Scatterplot Matrix Graph tool of ArcGIS (Fig. 5). Factors such as vandalism, household, population and poverty level had a positive relationship with chokes. This meant their increase led to increase of sewer chokes. Water availability was a major cause of chokes. Areas (Parklands and Spring Valley) with high water supply throughout the week had lesser choke frequencies compared to areas (Kangemi and Kawangware) where water was rationed and got water only once a week yet they had very high population. Other factors found though not shown in Fig. 5 were the diameter of the pipe and age of the pipe. Over 90% of the blockages occurred in pipes whose diameter was 225 mm and below and also very old pipes had more blockages.

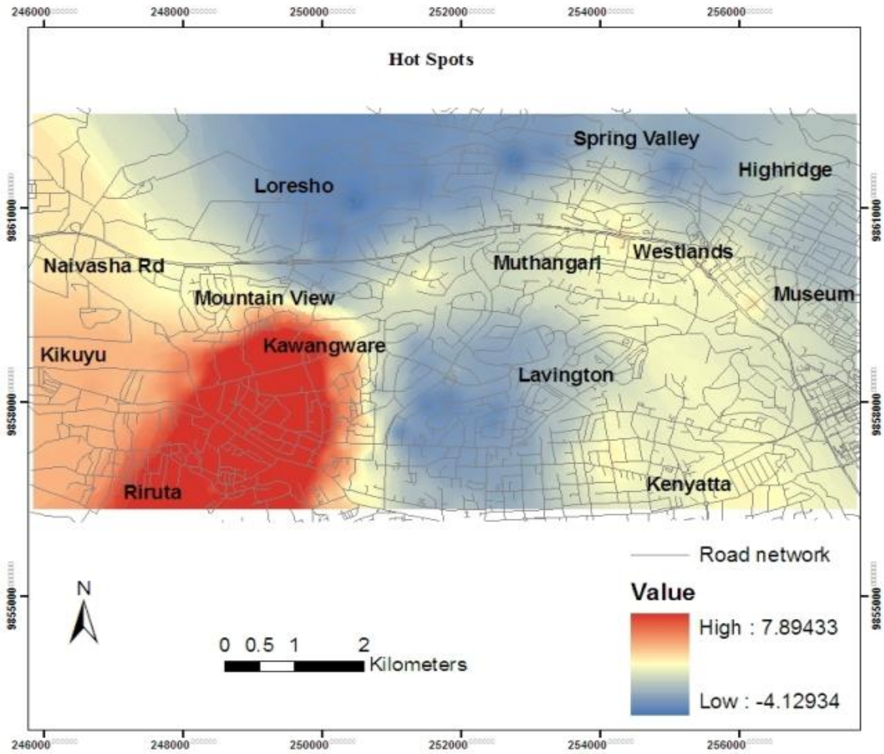

Figure 4: Hot spot analysis interpolated

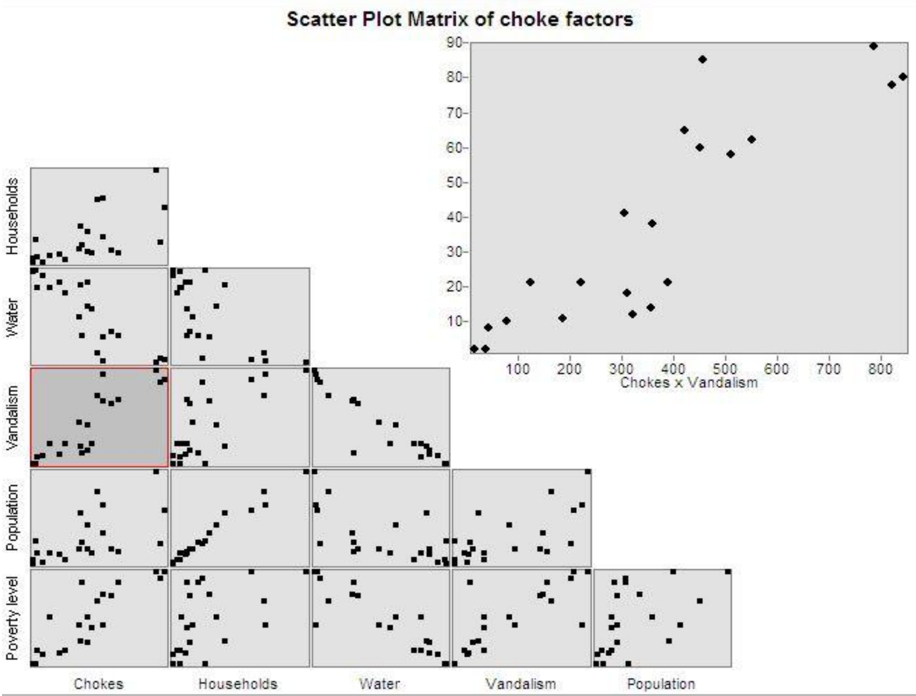

Figure 5: Scatterplot matrix investigating the relationship between chokes and factors influencing their occurrences

Geographic Weighted Regression (GWR) Analysis : Factors such as vandalism, water availability, poverty levels and number households were explored using GWR. They were used as the explanatory variables and chokes as the dependent variables. The standard residuals (Fig. 6) of the model were run in Spatial Autocorrelation tool and a random spatial pattern was found; meaning the model had been well specified.Factors that influence choke occurrences have policy implications or are associated with particular remediation strategies; these factors were analyzed using GWR to better target where those policies and projects are likely to have the biggest impact.

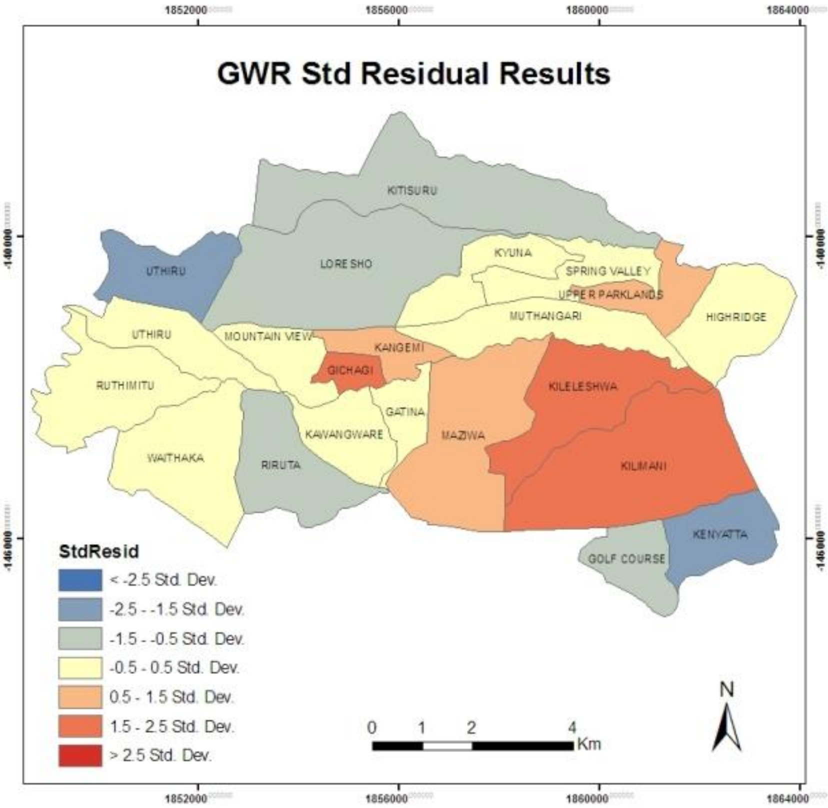

Figure 6: Output map of the standardized residuals after running the GWR

The GWR results had coefficients for all the factors influencing choke formation used in the model; these coefficients spatially indicated areas where the explanatory variable was either a strong or weak indicator of choke occurrence.

Relationship and strength of each factor to the sewer choke formation : Coefficients values, computed by the regression tool, reflected the relationship and strength of each factor to the sewer choke formation. These factors were symbolized to reveal their trend which showed that some were strong indicators of choke volumes in some locations and weak in other locations. The darkest colored areas (Fig. 7, 8 and 9) are locations in the study area where a factor had the strongest relationship with choke formation whereas the lightest colored areas are locations where a factor was the weakest relationship with the choke formation. The dark colored areas (Fig. 7) are locations in the study area where the household was a very strong predictor of choke formation. The light colored areas were locations where that variable was less important**.** When it comes to administering a remediation strategy, as shown, it is easier for NCWSC to focus on a specific area with the utilization of GIS as compared to looking at raw data from tables. For example, blockage in area like Kilimani and Loresho are caused by increase in the number of households. This is as a result of land use change from single dwelling to apartments and therefore expansion of sewer network might be one of the remediation strategies. In Fig. 8, the dark colored areas are locations in the study area where the vandalism was a very strong predictor of choke formation. The light colored areas were locations where this variable was a weak predictor of choke formation; areas like Kawangware and Kangemi with many vandalism cases, the company might opt to design new manhole covers without iron that causes them to be vandalized. Fig. 9 shows that areas such as Riruta and Uthiru are affected by the problem of water supply, for NCSWC, the most probable remediation strategy might coming up with how they can increase water supply in these areas. Also there are areas where several factors that influence sewer choke formation and therefore the company will have to develop multiple remedial strategies.

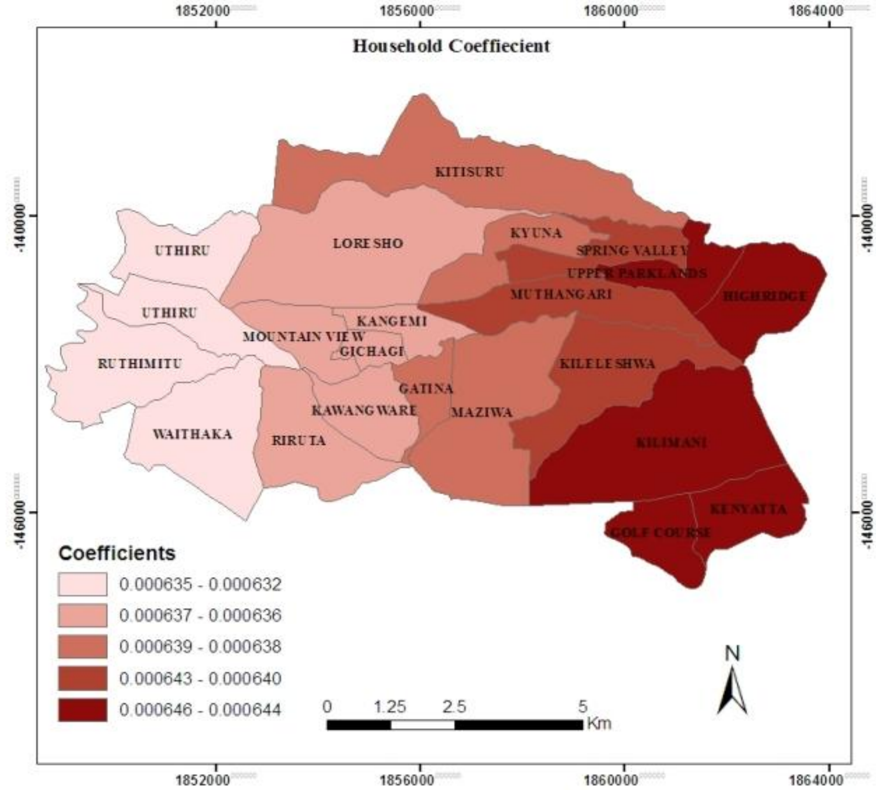

Figure 7: Spatial relationship of households to sewer choke occurrences

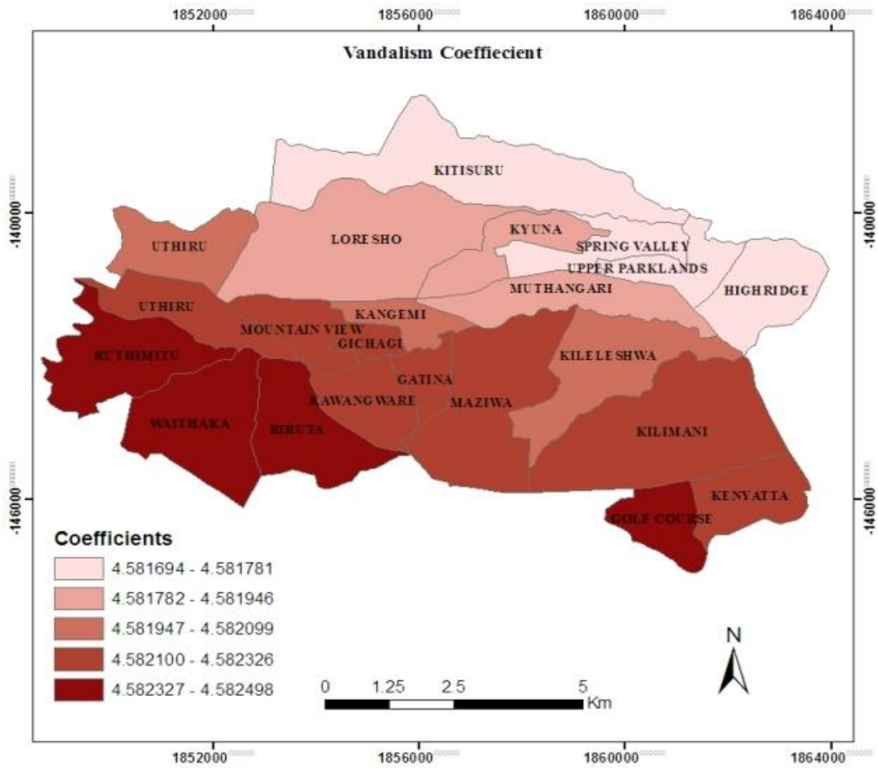

Figure 8: Spatial relationship of vandalism to sewer choke occurrences

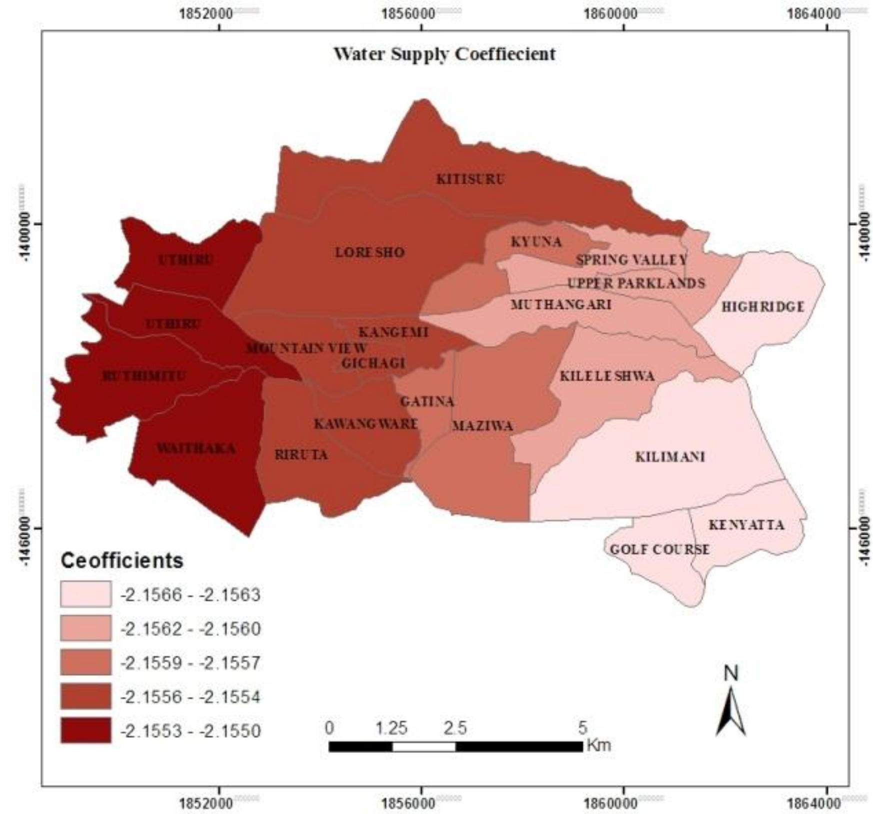

Figure 9: Spatial relationship of water supply to sewer choke occurrences

IV. CONCLUSION AND RECOMMENDATION

A hot spot analysis delineated areas of interests thus regular checkups can be made in order to reduce the chokes. This would be vital in tackling the problems at its initial stages rather than attempting to alleviate the situation after a problem has occurred. Sewer chokes were examined and spatial relationships explored using GIS, to better understand the factors behind observed spatial patterns, and to develop remediation strategies based on that understanding. Factors that influence choke formation vary across the study area and GIS spatially revealed those trends. This research will hopefully assist NCWSC in making quick and effective decisions and to move beyond the current practice of targeting blockage hotspots and focus on proactive maintenance activities on identifying where additional future blockages may occur. With the availability of standardized datasets for the whole of Nairobi region, then more rigorous analysis can be conducted. For example a data set of pipe characteristics overlaid with sewer design data and also land use change on housing types data, unfortunately this is not the case in this study.

V. ACKNOWLEDGEMENTS

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