MODELING SEWER OVERFLOW OF KARBALA CITY WITH LARGE FLOATING POPULATION

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This work I dedicate to:

My beloved father and my beloved mother

My faithful wife and my sons, Ali, Murtadah, Mohammed, Baqer, Fatimahalzahrah

My brothers and sisters

My homeland Iraq

For always standing by my side through ups and downs without even a slightest sigh

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ABSTRACT

The sewer systems of many historical or religious cities are not well associated with present needs. Sudden influx of huge floating population during sacred or festival periods places tremendous pressure on utility services including the sewer system in such cities. Sewer overflow, inundation of roads, environmental degradation, and consequent epidemics are very common during such gatherings. Modeling of sewer quantity and quality with varying population is, therefore, very important for cities with a large floating population in order to mitigate the problem. The major objective of this study is to develop a model to assess the impacts of floating population on sewer systems during pilgrimage, in order to proffer necessary mitigation measures. The Karbala city of Iraq was chosen as a case study in the present research. Statistical and physically based models such as Storm Water Management Model (SWMM), Multiple Linear Regression (MLR), Structural Equation Model (SEM) and Artificial Neural Network (ANN) were used for this purpose. The model outputs were analyzed to assess possible changes in sewer discharge and quality in the context of increasing population. Different adaptation measures were also assessed and suitable adaptation measures were identified for mitigating the impacts. The results showed that sewer flow in Karbala city typically increased in the range of 0.009492-0.0144 m^3/s for every population rise of one thousand, measured at 95% confidence interval. On the other hand, the concentrations of total suspended solid (TSS) and Biochemical Oxygen Demand (BOD_5) increased by 26-46 mg/L and 9-19 mg/L, respectively at 95% confidence interval, for every 1mm increase in rainfall. BOD_5 was also found to increase by 4-17 mg/L for every ten thousand increase in population. The temporal and spatial modeling of sewer overflow shows that it mostly happens during prayer times and in the upstream area, as the sewer system in the region is incapable of carry in a huge inflow of sewer during those periods. The assessment of different technical measures revealed that pipe-jacking system is the most suitable approach in Karbala city for reducing sewer overflow by up to 70%, if properly installed and managed.

ABSTRAK

Sistem pembentung di kebanyakan bandar bersejarah dan keagamaan adalah tidak memenuhi keperluan semasa. Peningkatan kemasukan secara tiba-tiba jemaah secara besar semasa tempoh suci atau perayaan memberi tekanan yang besar kepada sistem utiliti termasuk sistem pembentung di bandar-bandar tersebut. Limpahan pembentung, banjir jalanraya, pencemaran alam sekitar dan wabak penyakit adalah sangat biasa semasa tempoh perhimpunan tersebut. Pemodelan kuantiti dan kualiti pembentung dengan populasi berbeza adalah sangat penting untuk bandar-bandar dengan kemasukan populasi terapung yang besar sebagai langkah untuk mengurangkan masalah tersebut. Objektif utama kajian ini adalah untuk membangunkan sebuah model untuk menilai kesan jemaah kepada sistem pembentung semasa mengerjakan Haji, dalam usaha untuk mencadangkan langkah-langkah pengurangan yang perlu. Bandar Karbala Iraq telah dipilih sebagai kajian kes dalam kajian ini. Model statistikal dan berasaskan fizikal seperti Model Pengurusan Air Banjir (SWMM), Regrasi Linear Berganda (MLR), Model Persamaan Struktur (SEM) dan Rangkaian Neural Buatan (ANN) telah digunakan untuk tujuan kajian ini. Output model dianalisa untuk menilai kemungkinan perubahan pelepasan pembentung dan kualiti dalam konteks populasi yang semakin meningkat. Langkah-langkah penyesuaian yang berbeza juga dinilai dan langkah-langkah penyesuaian sesuai telah dikenalpasti untuk mengurangkan kesan. Hasil kajian menunjukkan bahawa aliran pembentung di bandar Karbala biasanya meningkat dalam julat 0.009492-0.0144 m^3/s untuk setiap kenaikan satu ribu penduduk, diukur pada selang keyakinan 95%. Sebaliknya, kepekatan jumlah pepejal terampai (TSS) dan Keperluan Oksigen Biokimia (BOD_5) meningkat sebanyak 26-46 mg/L dan 9-19 mg/L, masing-masing pada selang keyakinan 95%, bagi setiap peningkatan 1 mm dalam hujan. BOD_5 juga didapati meningkat sebanyak 4-17 mg/L bagi setiap peningkatan sepuluh ribu penduduk. Pemodelan ruang dan masa pembentung limpahan menunjukkan bahawa ia kebanyakannya berlaku pada waktu solat dan di kawasan hulu sungai, kerana sistem pembentung di rantau ini tidak mampu membawa aliran masuk pembentung yang besar semasa tempoh-tempoh tersebut. Penilaian terhadap langkah-langkah teknikal yang berbeza menunjukkan bahawa sistem paip-pemicu adalah pendekatan yang paling sesuai di bandar Karbala untuk mengurangkan limpahan pembentung sehingga 70%, jika dipasang dan diuruskan dengan betul.

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LIST OF ABBREVIATIONS

EPA	-	Environmental Protection Agency
SSO	-	Sewerage Sanitary Overflows
NPS	-	Non-Point Source
DEM	-	Digital Elevation Model
BOD_5	-	Biochemical Oxygen Demand (Five days)
TSS	-	Total Suspended Solids
SWMM5	-	Storm Water Management Model
ANN	-	Artificial Neural Network
MLR	-	Mulite- Linear Regression
BMPs	-	Best management practices
RDII	-	Rainfall Dependent Inflow and Infiltration
DO	-	Dissolved oxygen
SEM	-	Structural Equation Modeling
MLP	-	Multilayer perceptron
GIS	-	Geographical Information System
DWF	-	Dry Weather Flow
Qav.	-	Average Sewer Discharge
Q max.	-	Maximum Sewer Discharge of Pump Station
P	-	Floating Population
R	-	Rainfall
D	-	Distance of Manhole from City Center

SSL	-	Suggested Sewer Line
PJS	-	Pipe-Jacking System
MM	-	Measurement Model
CR	-	Composite Reliability
AVE	-	Average Variance Extracted

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Sewage is defined as a combination of liquid wastes (a) conducted away from residences, commercial buildings and industrial establishments; (b) admitted to or find its way into ground, surface, and storm water sewers (Steel et al., 1985; Metcalf and Eddy, 1981; Virtueller and Der, 2009). Depending on the type of sewage, sewer systems are classified as sanitary, storm or combined. Sanitary sewers carry sanitary sewage produced by the community and industrial waste water. On the other hand, storm sewer carries the surface runoff generated by storms. Storm water often enters sewer networks through poor joints, around manhole covers and other deficiencies (Steel et al., 1985; Metcalf and Eddy, 1981; EPA, 1997). Combined sewers carry all types of sewage in the same conduits (Metcalf and Eddy, 1981). The important goal of sewer networks is the protection of citizens from the diminution of pollution to receiving waters (Hvitved et al., 2013).

Sewer systems are considered as one of the most important components of urban infrastructures (Hahn et al., 2002; Niemczynowicz, 1999; Pitt and Clark, 2008). Sewer networks are usually constructed after considering the peak sewer flows, which are calculated, based on population, per-capita consumption, trade effluent flows and an allowance for infiltration (Atkins, 2011). However, sewage systems are still not properly developed in many cities across the world (Burian et al., 2002; Moore, 2010). Therefore, sudden influx of floating population often causes the failure of sewer systems in such cities. Increasing rainfall intensity due to climate change also becomes a major challenge for sewer systems. These problems are particularly challenging in festival cities where sudden influx of huge populations often cause huge pressure on existing utility services. Increasing population (temporary or permanent) always leads to increase in dry weather flow, thus increases average sewer discharge based on the Manning equation (Obaid et al., 2014). The sewer systems of many historical or religious cities across the world are not well associated with present day needs. Therefore, an extreme increase in temporary visitors to urban areas during major events like festivals or pilgrimages causes severe impacts on infrastructure, particularly sewer systems. Sanitary sewer overflows (SSO), inundation of roads with sewer and related sanitary and health issues during the pilgrimage period have become a growing concern in such cities in recent years (Obaid et al., 2014).

Rainfall during pilgrimage or festivals often deteriorates the situation. Sudden rainfall after a long dry spell also causes a high level of pollution of storm waters. Rainfall increases runoff volumes and peaks (Burns et al., 2005) and increases the non-point source (NPS) pollution in the runoff (Ying and Sansalone, 2010a; Ying and Sansalone, 2010b). A number of studies in recent years have showed that rainfall causes overflow of sewage systems, regardless of intensity and amount. Therefore, the water quality of receiving water bodies severely deteriorates, particularly during or after rainfall events (Butler and Davies, 2000; Llopart et al., 2014; Freni et al., 2011). Climate change induced-change in rainfall patterns can potentially increase the discharge amount and affect the operation of a sewer system (Abdellatif et al., 2015). It has been reported that nearly 50% of the total pollution in receiving waters is due to sewer overflow (Llopart et al., 2014) and therefore, it is a major challenge in sewer system management. Sewer systems of many cities date back over 100 years. Even recent sewer systems can fail due to huge influx of waste. The sewer networks are constructed beneath the earth. Therefore, signs of degradation and capacity limitations cannot be understood unless there is a major failure. Therefore, impact assessment of population and rainfall on sewer system is very urgent, in order to mitigate sewer failure and avoid environmental hazard.

This chapter presents the background of the problem related to sewer disposal for cities which experience huge temporary floating population. It illustrates sewer problems during festive occasions in countries like China, India, Saudi-Arabia, Italy, etc. and related environmental problems. It also includes the problem statement, objectives, significance and scope of the study.

1.2 Background of the Problem

Sewer management in a city with floating population is a major problem for urban scientists, drainage engineers and policy makers. The problem is challenging for the historic cities, where floating population rises few folds during pilgrimage. Floating population is a terminology used to describe a group of people who reside in a given population for a certain amount of time and for various reasons, but are not generally considered part of the official census count (Sisci and Xiang, 2003). Pilgrimage is a form of travelling to visit places, which is a common custom of most communities. Most of such travelling are motivated by religious desires or tourist's purpose (Gladstone, 2005; Rinschede, 1992; Sharpley and Sundaram, 2005). Pilgrimage tourism seems to be a new academic concept, but is certainly not a new phenomenon (Timothy and Olsen, 2006). Pilgrimage, whether motivated by religious needs or tourist's purpose, is experiencing increasing trend across the world. This includes pilgrimage motivation, pilgrimage activities and tourism influence on pilgrimage (Vijayanand, 2012). A number of studies reported that pilgrimage travel to places have significantly increased in recent decades with improvement in transport infrastructure and accessibility to transport systems (Obaid et al., 2014; Shinde, 2012; Goodkind and West, 2002).

There are many festival cities in the world such as, Moeran (Japan), Mexico Passariello, India (Ichaporia), Sri Lanka west (Kernper), the Central U.S.A (Albers and Williams) and the Caribbean (Lett) (Graburn, 1983). Besides, there are many pilgrimage cities across the world, such as, Mecca, Karbala, Vatican (Italy), and many cities of India. Millions of pilgrims visit shrines in India like Varanasi, Rishikesh, Hardwar, Azmir, Bhubaneswar, Gangotri and Gangasagar, etc. every year. According to Vijayanand (2012), there are nearly 51 festival places (Shakti peethas) in India which are visited by millions of tourists throughout the year. A large number of pilgrims visit the temple of Lord Vitthal all year round, but the number of pilgrims increases drastically during special occasions such as fortnightly full moon days (Ekadashi) (Patange et al., 2013).The Roman Catholic shrines in Lourdes, France received 4,608,000 visitors who came mostly in the short pilgrimage season between April and October (Rinschede, 1986; Eade, 1992). Olympic cities are also examples of cities with a large floating population. The Olympic Games attracted millions of tourists to Olympic cities (Florida et al., 2004; Peiser and Reilly, 2004; Streets et al., 2007; Traversi et al., 2008). For example, the Winter Olympic Games in Italy attracted almost 2 million spectators during the games period (Traversi et al., 2008) in the cities of Torino, Pavia and Verona. The Guca Trumpet Festival is held annually in Guca village Dragacevo region in western Serbia. The 2-10 days festival attracts up to 600,000 visitors in number (Tadic et al., 2010). Ambaji Temple in India attracts one crore (10 million) pilgrim's annually and approximately 10,000 pilgrims daily. More than three million pilgrims visit the city of Mecca during the pilgrimage period (Al-Haj). For two days, about 5 million people gather every year in the BiswaEstima (religious gathering) on the bank of Turag River, near the small city of Tangi in Bangladesh (Bisho, 2015). There are many such cities across the world that experience floating population.

The floating population in festival or religious cities has been an issue since ancient times. The ancient Olympic Games that used to hold once in four years were both religious and athletic festivals. It used to attract huge crowds from all over Greece and beyond in a small Olympic city. The city of Mecca is a place of pilgrimage from ancient time. People across the globe used to visit the city during pilgrimage. Therefore, the problem induced by huge floating population is well known from ancient times. With the development of people's well-being and demand for better services, the environmental issues faced during festival or pilgrimage periods have started to generate concern. This has become a major concern in recent years as the total number of population during the peak of festival or pilgrim periods increases in almost all festival or pilgrimage cities across the world. This increase is due to population growth, enhanced ability to move, and more economical ability.

As the world’s population continues to increase, and the economy continues to develop, it can be expected that the number of visitors to festival cities during festive periods will continue to grow. The devotees in BiswaEstima in Bangladesh have increased from a few thousands in the early 1980s to about 5 million in recent years. Similarly, the number of pilgrimage tourists is increasing rapidly in most of the pilgrimage centers of India. For example, a small festival town (Alandi) in India used to experience a population of 17,565 in 1981, but increased by 10,249 in 1991. The growth rate was much higher (71.34 %) between 1991 and 2001 (Patange et al., 2013). In Karbala city, the number of pilgrims increased from 10 million in 2009 to 20 million in 2014 (Jafria, 2013; Alkafeel Global Network, 2014). The city of Mecca experienced an increase of pilgrims by 1 million in the last five years. One of the Indian cities, Pandharpur, had 70000 visitors in 1991 but increased to 100000 visitors in 2001 (Patange et al., 2013).

Drastic population increase during pilgrimage or festival period put tremendous pressure on utility services of the city. Huge influx of population during the pilgrimage period also causes many environmental problems in pilgrimage cities. Nevertheless, studies related to anthropogenic environmental problems in pilgrimage cities are still very limited (Shackley, 2001; Tanner and Mitchell, 2002). Massive wastes, particularly the sewers generated by the huge amount of population for a short period are very complex and difficult to handle and thus causes severe environmental threats. A large increase in population causes a high rise in average sewer flow. The biggest bathing days in 2013 in the Ganges River near the Indian city of Allahabad during the holiest day of the festival (KumbhMela) caused an average influx of around two million persons in a day. This caused heavy pollution of the Ganges River in India (Hindustan Times, 2013). The condition of Ambaji Town of Gujarat, which attracts one crore (10 million) pilgrims is deteriorating due to inadequate infrastructure and poor pilgrim facilities; resulting in poor quality of life for residents and pilgrims (GSP, 2009; Soni and Thomas, 2013). Sudden influx of pilgrims in the city of Mecca affects urban services and often disrupts the urban system. The city faces a number of environmental and other urban problems during the pilgrimage period.

The growth of floating population influences the expansion of a city (Ascoura, 2013). Urban areas are characterized by dynamic changes in terms of population structure and land use. Changes in population, living standards of the population, increased per capita water demand, etc., in combination with changes in land-use cause tremendous change in both quantity and quality of sewage discharge. The sewer infrastructure needs to be upgraded from time to time to deal with these dynamics. Inadequate sewage system, improper design and the deterioration of sewer systems over the years make the sewer system incapable of handling the changing dynamics. Furthermore, climate change may intensify rainfall and shorten the flood return period in the future, which may aggravate the situation (Jorgensen et al., 2006). The problem is much severe in historic cities. Usually, huge numbers of people visit pilgrim cities during festive periods and thus, increase the total population of the city by many folds. This huge floating population places enormous pressure on the sewer system of the city. Many of the open areas become sites for defecation by pilgrims. The network of sewer pipes becomes predominantly choked (FoV, 1998).

The massive wastes generated by the huge population for a short period, are very complex and difficult to handle and this causes severe threats to the environment. Usually, the sewer systems of pilgrim cities are very old and cited in historical locations and therefore, very difficult to modify. Furthermore, it is not possible to build huge sewer systems for the huge population visiting the city only for a particular event in a year. These make solving the sewer problem of pilgrim cities much more complex.

Sewage overflows, inundation of roads with sewer, and related sanitary and health issues during the pilgrimage period have become a growing concern in festival cities in recent years. It is well established that population pressures, land-use conversion and its resulting pollution consequences appear to be the major diffuse pollution problem today (Novotny, 2003; Jabbar, 2011). Urban sewer systems are designed to provide safety and comfort for urban citizens. The role of urban sewer system is much more important in rapidly growing cities. Adaptation measures including redesigning, restructuring, sewer management, etc., are required to mitigate the growing pressure on urban sewer systems in cities.

Sewer overflow during intense rainy season is a major problem in many urban areas across the world. It has been reported that a total of 4,709 properties are at risk of sewer flooding at least once in every ten years in England and Wales (Ofwat, 2011). The flooded area in the Can Tho city of Vietnam increased by up to 50% during similar rainfall events (Tran Van Tu, 2010). Intense rainfall events have also been projected to increase in most parts of the world. Increased urban concentration, urban population and rainfall intensity will certainly increase the incidence of sewer overflow, especially in developing countries, if proper adaptation measures are not undertaken. The problem will be many fold and severe in religious or festival cities where a sudden influx of a huge population puts huge pressure on the existing sewage system. Especially in old religious or pilgrimage cities located in developing countries, sewer overflow and consequent environmental degradation and related public health issues are the most significant urban problem. It has been projected that urban population will reach 60% of the world’s population by 2030

(UN, 2005). Intense rainfall events have also been projected to increase in most parts of the world. Research in this regard is very essential as the problem becomes more intricate.

1.3 Statement of the Problem

Sewer management in cities with floating population is a major problem for urban scientists, drainage engineers and policy makers. The problem is challenging for historic festival cities where the floating population rises hundred times during pilgrimage. The problem gradually increases with population growth, improved facilities for public mobility and increased rainfall induced by climate change. As the sewage problem is the major cause of environmental pollution and epidemics during pilgrimage, proffering solution to this problem is extremely important for environmental safety, public health protection and people’s comfort. Quantitative estimation of population and rainfall elasticity of both sewer quantity and quality can help to assess how the growing population and changing precipitation pattern will change sewer flow, which in turn can be used for planning, development and management of urban sewer system in the context of environmental change.

1.4 Objectives of the Study

The objectives of the study are as follows:

1. To develop a sewer discharge model to estimate the sensitivity of sewer flow to population.
2. To predict future changes in sewer discharge due to the changes in population and climate.
3. To develop a model for prediction of spatial and temporal susceptibility of sewer overflow.
4. To develop a wastewater quality model in order to assess the sensitivity of sewage quality to population and rainfall.
5. To explore technical measures to mitigate sewer flooding in historic cities which experience high floating population.

1.5 The Significance of the Study

Huge discharge through a sewer system during the pilgrimage period causes sewer overflow, which in turn creates significant problems in terms of environment, public health and psychology. The novelty of this study is to create a model to predict sewer overflow and waste water quality for a sewer system. The model could be applied at any location in the world having similar problems. Furthermore, this study evaluated the maintenance performance of sewage quality, and it is expected to assess the impacts of population and rainfall on urban waste water quality.

Another major importance of the research is that it identifies technical solutions to the problem of a city's sewer system, whose population increases many folds in certain months. The model developed in the research will be able to predict the unknown situation induced by floating population influx and climate change which the city has never faced. Therefore, it will be possible to understand future changes in sewer situations due to population growth and adopt necessary measures to mitigate the impacts.

1.6 Scope of the study

The scopes of the study are as follows:

a) The study was conducted in the Karbala city center of Iraq, a place where millions of people gather for pilgrimage in the festival months.
b) The study was based on the available data on population, climate, sewer discharge, wastewater quality (the concentrations of BOD5 and TSS), and extent of sewer and storm networks in the study area.
c) The maximum sewage flow for the area was considered during the period when maximum rainfall coincides with maximum number of pilgrims.
d) Land-use of the study area was mapped from LANDSAT data to identify the residential areas.
e) Information from the Directorate of the Municipality of Karbala was used to demarcate commercial, industrial and public spaces.
f) The pollution information provided by the Directorate of Population Census was used for the study.

g) Data on average daily consumption of water per person was collected from the Directorate of Water Supply in Karbala.

h) Storm Water Management model (SWMM5) and Geographic Information System (GIS) was used to calculate the amplitude of discharge during peak rainfall and maximum pilgrim numbers.

i) The ratio of sewer deficit to sewer network of the city was used to identify measures required to solve the sewer problem.

j) Only technical solutions in the context of increasing pilgrims to avoid sewage overflow and environmental pollution were considered.

1.7 Research Questions and Hypotheses

This study aims to answer the following questions. How to simulate sewer overflow and sewer water quality in urban areas that experience sudden influx of population? What mechanisms can be used in a model to analyze sewer systems during pilgrimage periods and rainy season? What are the technical measures that can be used to mitigate sewer flooding in the historical area?

The hypotheses of this research are as follows:

i. Sewer overflow in the Karbala city center is highly sensitive to population and rainfall in the area.

ii. Future changes in sewer discharge in Karbala will follow the line of chaning floating population.

iii. Spatial and temporal extents of sewer overflow depends on number of floating population and rainfall amount.

iv. Sewage quality depends on number of floating population and amount of rainfall.

v. Technical measures like pipe-jacking system can reduce sewer overflow significantly.

The results and discussion from simple equations of sewer discharge and sewage quality can be verified by comparing with those obtained using a physically-based model of sewer overflow in order to prove that the equations are capable of being a reliable alternative to the physics-based model.

1.8 Outline of the Study

The research work for this study consists of two parts. The first part is to construct models to estimate, modify and examine sewer overflow with a floating population while the second part consists of the experiments to mitigate the problem in festival and historic cities. This thesis consists of five chapters and appendices.

i. Chapter 1 shows the background of sewer overflow in old and historic cities during pilgrimage days and rainy seasons. The objectives and scope of the study are also mentioned in this Chapter.
ii. Chapter 2 illustrates previous studies in the world and the methods which had been taken to mitigate sewer overflow.
iii. Chapter 3 describes detailed discussion of the method used for data collection, analysis and model development in the study.
iv. Chapter 4 presents the analysis and results obtained by using the methods illustrated in Chapter 3. It also discusses the results obtained from the model application to mitigate sewer overflow and sewage quality with a floating population and rainy seasons. It shows the technical measurements that are adapted to mitigate sewer overflow.
v. Finally, the conclusions derived from the study together with recommendations for future work are presented in Chapter 5.

1.9 Summary

The research proposal is formulated in this chapter. It highlights the problem statements, objectives of the study, the importance of the research and research questions. From the background analysis of the situation, it can be summarized that sewer management in a city with floating population is a great concern for environmental safety, public health protection and people’s comfort in different countries across the world. The concern gradually increases with population growth, improved facilities for public mobility, and increased rainfall induced by climate change. A review of related studies is given in the next chapter.

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