STORM WATER DRAINAGE DESIGN-
CHANGING TRENDS IN RAINFALL INTENSITY
WITH CLIMATE CHANGE IN INDIA

VIJAI KUMAR CHAURASIA

DEPARTMENT OF APPLIED MECHANICS
INDIAN INSTITUTE OF TECHNOLOGY DELHI
JULY 2019

STORM WATER DRAINAGE DESIGN-
CHANGING TRENDS IN RAINFALL INTENSITY WITH CLIMATE CHANGE IN INDIA

by

VIJAI KUMAR CHAURASIA

DEPARTMENT OF APPLIED MECHANICS

Submitted
in fulfilment of the requirements of the degree of Doctor of Philosophy
to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

JULY 2019

CERTIFICATE

*This is to certify that the thesis titled "**Storm Water Drainage Design-Changing Trends in Rainfall Intensity with Climate Change in India**" being submitted by **Mr. Vijai Kumar Chaurasia** to the **Indian Institute of Technology Delhi**, for the award of the degree of **Doctor of Philosophy** in Department of Applied Mechanics is a bonafide research work carried out by him under our supervision and guidance. The research work presented in this thesis has not been submitted in parts or in full to any other University or Institute for the award of any degree or diploma.*

***Sanjeev Sanghi**, Ph.D.*
Professor
Dept. of Applied Mechanics,
Indian Institute of Technology Delhi
New Delhi-110016, India

***Atul Kumar Mittal,** Ph.D.*
Professor
Dept. of Civil Engineering,
Indian Institute of Technology Delhi
New Delhi-110016, India

Date:

Place: New Delhi

ACKNOWLEDGEMENTS

I wish to offer my gratitude to everyone for helping me in this long journey of obtaining Ph.D. This thesis is the result of persistent hard work of over seven years, whereby, I have been taught, supported and motivated by many people, which enabled me to accomplish this mammoth task. I would like to offer my sincere thanks to everyone who directly or indirectly contributed in completion of this thesis.

The research topic grew out of series of discussions with my two supervisors Professor Sanjeev Sanghi and Professor Atul Kumar Mittal. Through their deep knowledge and rich experience they made me understand this topic to a greater depth. They also made me aware of the social cause behind this study.

Professor Sanjeev Sanghi is a person with vast knowledge, incomparable insights and humanity. I feel very lucky in having him as my supervisor. His encouraging words and unwavering support always motivated me during the turbulent phases of my research. With his rich experience and enormous patience, he helped me in tying up all the loose ends of my research. With immense pleasure, I wish to express my heartfelt gratitude and indebtness to Professor Sanjeev Sanghi.

Words fail me to express my gratitude to Prof. Atul Kumar Mittal for his support and encouragement to go for my Ph.D in spite of my heavy work load in office. His in-depth knowledgeable and research abilities can make anyone envy of him. He is the epitome in his field of research and teaching. His abilities to minutely observe and understand the problem is beyond comparison. He is a

person of extremely high values, ethics and conviction. Thank you sir, I am deeply beholden to you.

I am also extremely obliged to my Student Research Committee chairman Prof. Srinivas V. Veeravalli for encouraging me in my research work and helping in improving the quality of my thesis by virtue of his vast experience. Special thanks to Professor Anupam Dewan, Applied Mechanics and Associate Prof. K. N. Jha, Civil Engineering, for their guidance. Thanks also to all the faculty members of the Departmental Research Committee and Applied Mechanics Department for providing me the valuable inputs in my research.

I am grateful to the understanding and wishes sustained in Ministry by my superiors particularly Shri D.S. Mishra, Secretary (HUA) and Shri V.K. Jindal Joint Secretary (SBM-Urban) who kept me motivated. The support extended by my colleagues namely Dr. S. Saktheeswaran and Mr. Vibhor Sood, in valuable reviews and proof reading of Thesis, in addition to their heavy office work load, is deeply appreciated.

I owe my utmost gratitude to my wife Vibha, sons Suarabh and Gaurav and other family members for kept me inspiring to complete my research and, in turn, giving me full freedom to concentrate on my research even during their share of time. It is the sacrifice of my wife and, also the children, who, even during the prime time of their studies, spared me to concentrate on my research, which really made it possible. Above all, thanks to '**All Mighty God**' for giving me strength and ability to work hard. It is He, who showed me the right path in the moment of darkness.

(Vijai Kumar Chaurasia)

ABSTRACT

Majority of urban storm drainage systems are designed on the basis of Rational Method (Q= kCIA), in as much as 90% cases across the globe, in spite of having several limitations. Stationarity of rainfall statistical parameters is one such important fundamental assumption made in the hydraulic design of storm sewers/drains while using Rational Method. Climate change, particularly the rise in atmospheric temperature, is primarily responsible for intensifying the Earth Hydrologic Cycle, leading to high intensity short duration precipitations, which cannot be ignored anymore in the design of storm water drainage (SWD) systems. Storm water drainage infrastructure is designed for about 30 years in India, based on analysis of past rainfall precipitation intensity data of about 25 years or so, without giving due consideration to the changing trends of rainfall precipitation intensity caused due to climate change.

The research study presents a detailed analysis of trends of rainfall precipitation intensity in eleven cities across India. Based on analysis, Bengaluru, Patna and Lucknow showed increasing trend @ 2 % per annum, Bhubaneshwar and Mohanbari @ 1% per annum, and rest decreasing/no chang ing trends. Accordingly, the Rational Method (Q=KCIA) needs suitable modification in the present era of climate change. In its modified form, the intensity of precipitation I, need to be replaced by $I_{C,}$ which stands for - intensity of precipitation accounting for changing trend in precipitation over design period of storm water infrastructure.

The results of rainfall data analysis of Lucknow Self-Recording Rain Gauge (SRRG) station is applied over a micro storm drainage catchment in Lucknow. On application of results of increasing rainfall precipitation intensity trend for “once in a year recurrence of flooding for 60 min time of concentration”, over Kukrail micro

drainage catchment of Lucknow; out of the existing 75 drains, 15 drains i.e. (20 % of total drains) are found falling short of revised design capacity. In order to overcome the problem of frequent flooding of existing drains and to tackle excess storm runoff due to climate change, a ready to use percolation pits design table has been developed, in accordance with soil classification and its permeability. This can be used in design of percolation pits along the drains to achieve the designed level of performance. The table has been (theoretically) applied on a stretch of existing drain of size 1.5m x 2 m of 79 m length in Lucknow and observed that there is necessity for providing three numbers of 3 m x 3m percolation pits to avoid its premature remodelling.

सार

विभीन्न सीमाओं (कमियों) के बावजूद, आज भी विश्व की 90 प्रतिशत से अधिक शहरी वर्षा जल निकास प्रणालियों का डिजाइन, रेशनल मेथड के आधार पर तैयार किया जाता है| रेशनल मेथड का प्रयोग करते हुए – वर्षाजल सीवरों/ नालियों के हाइड्रोलिक डिजाइन में – वर्षा के सांख्यिकीय अवयवों की स्थिरता को एक महत्वपूर्ण मूलभूत अवधारणा माना गया है| जलवायु परिवर्तन – विशेष रूप से वायुमंडलीय तापमान में वृद्धि ही मुख्य रूप से 'पुथ्वी जलीय चक्र' को तीव्र करने के लिए जिम्मेदार है और इसके फलस्वरूप ही उच्च तीव्रता वाली लघु अवाधि की वर्षा की संख्याओं में लगातार वृद्धि हो रही है, जिसे रेशनल मेथड के आधार पर डिजाइन की जाने वाली वर्षा जल निकासी (SWD) प्रणाली में अब और अनदेखा नहीं किया जा सकता है| यहाँ यह विदित हो कि वर्तमान में वर्षा जल निकास अवसंरचना की डिजाइन लगभग 30 वर्षों के लिए किया जाता है जो कि पिछले 25 वर्षों या अधिक के वर्षा की तीव्रता के डाटा के विश्लेषण के आधार पर तैयार किया जाता है| यहाँ यह बताना महत्वपूर्ण है कि इन वर्तमान डिजाइनों में जलवायु परिवर्तन के कारण वर्षा की तीव्र हुई गति (उच्च तीव्रता वाली लघु अवधि की वर्षा) को पर्याप्त ध्यान नहीं दिया जाता है जिसके कारण ज्यादातर शहरी क्षेत्रों में बाढ़ की घटनाओं में वृद्धि पाया गया है| यह शोध अध्ययन भारत के 11 शहरों में वर्षा की तीव्रता में होने वाले बदलाव का एक विश्लेशण और भविष्यवाणी प्रस्तुत करता है|

लखनऊ सेल्फ-रिकार्डिंग रेन गेज (SSRG) स्टेशन के वर्षा डाटा का विस्तार से विश्लेषण किया गया है और इसके परिणामतः भविष्य के वर्षा की तीव्रता की अनुमानित प्रवृत्ति को प्रस्तुत किया गया है| लखनऊ के कुकरैल ड्रेनेज एरिया में "60 मिनट अवधि और वर्ष में एक बार बाढ़ की पुनरावृत्ति" की वस्तुस्थिति के लिए – वर्षा की बढ़ती तीव्रता की प्रवृत्ति के परिणामों के अनुप्रयोग पर क्षेत्र में स्थित मौजूदा 75 नालियों में से 15 नालियों (अर्थात कुल नालियों का 20 प्रतिशत) संशोधित डिजाइन क्षमता

से कम पायी गई है| यह अध्ययन वर्षा जल निकासी प्रणालियों के डिजाइन में बारिश की बदली तीव्रता की प्रवृत्ति को शामिल करने की आवश्यकता को स्थापित करता है ताकि पूर्व-परिपक्व रिमॉडलिंग या डिजाइन में निर्धारित बाढ़ से ज्यादा संख्या में आने वाले बार-बार के बाढ़ से बचा जा सके| इन मौजूदा नालियों के क्षेत्र में आने वाली एक के बाद एक बाढ़ की समस्या को दूर करने और उच्च तीव्रता वाले वर्षा से एकत्रित वर्षाजल के प्रवाह से निपटने के लिए – नालियों के आकार में बदलाव किये बिना क्षेत्र में पाए जाने वाले मिट्टी के वर्गीकरण, इसकी पारगम्यता और नालियों के बगल में गड्ढे बनाकर वर्षा जल को भूजल रिचार्ज के उद्देश्य से विभिन्न आकार और क्षमता के गड्ढों के लिए सुगम डिजाइन तैयार करने में उपयोग हेतू – एक मैट्रिक्स तैयार किया गया है| मैट्रिक्स को लखनऊ में 79 मीटर लम्बाई के 1.5 मीटर x 2 मीटर आकार की मौजूदा नाली पर (सैद्धांतिक रूप से) लागू किया गया और पाया गया कि नाली के डिजाइन अवधि के पूर्व रिमॉडलिंग से बचने के लिए 3 मीटर x 3 मीटर आकार के तीन परकोलेशन पिट (गड्ढे) बनाना आवश्यक है|

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

Symbol	Meaning
C	Run-off coeffiecient
I	intensity of rainfall
A	Area in Hectare
Q	Discharge
tc	Time of Concentration
mm	Millimeter
^{o}C	Degree Celsius
K	coefficient for percentage of runoff resulting from a rainstorm
F_{ct}	Infiltration capacity at some time t
k	infiltration rate constant
F_c	a final or equilibrium capacity
F_0	the initial infiltration capacity at the beginning of storm
km^2	Square Kilometer
$	US Dollar
%	Percentage

ACRONYMS

Abbreviation	Meaning
AMC	Antecedent Moisture Conditions
CCRA	Climate Change Risk Assessment Report
CGWB	Central Ground Water Board
CMIP	Coupled Model Intercomparison Project,
CN	Curve Number
COC	Corporation of Chennai
CPHEEO	Central Public Health & Environmental Engineering Organization
CRED	Centre for Research on the Epidemiology of Disasters
CRU	climate research unit
DNA	Daily News Analysis
EM- DAT	CRED's Emergency Events Database
GCMs	General Circulation Models
GDP	Gross Domestic Product
GHG	Green House Gas
GISS	Goddard Institute for Space Studies
HSG	Hydrological soil groups
HSG	Hydrological soil groups
IDF	Intensity-Duration-Frequency
IEA	International Energy Agency
IMD	India Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
IRC	Indian Roads Congress
LID	Low Impact Development
MHM	Million Hectare Meter
MSL	Mean Sea Level
NASA	National Aeronautics and Space Administration
NCDC	National Climatic Data Center
NDMA	National Disaster Management Authority
NIUA	National Institute of Urban Affairs

NMSH	National Mission on Sustainable Habitats
ppm	parts per million
PRECIS	Providing Regional Climates for Impacts Studies
RCP	Representative Concentration Pathways
RWH	Rain water harvesting
SEA	South East Asia
SIO	Scripps Institution of Oceanography
SRRG	Self-Recording Rain Gauge
SST	Sea Surface Temperature
SuDS	Sustainable Urban Drainage systems
SWD	storm water drain
TERI	Energy and Resources Institute
UBC	University of British Columbia
UHI	Urban Heat Island
ULB	Urban Local Body
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USEPA	United States Environmental Protection Agency
WSUD	Water Sensitive Urban Design
YAP	Yamuna Action Plan