

**EFFICIENCY COMPARISON OF CONVENTIONAL  
WASTEWATER TREATMENT SYSTEMS IN REMOVING  
EMERGING POLLUTANTS**

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**NEW DELHI – 110016, INDIA**

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WASTEWATER TREATMENT SYSTEMS IN REMOVING  
EMERGING POLLUTANTS**

by

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Submitted

in fulfillment of the requirements of the degree of **Doctor of Philosophy**

to the



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**NEW DELHI – 110016, INDIA**

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*DEDICATED*  
*TO MY*  
*BELOVED FATHER*

# Certificate

This is to certify that the thesis entitled “**Efficiency comparison of conventional wastewater treatment systems in removing emerging pollutants**” being submitted by **Mr. Rishabh Shukla** is worthy of consideration for the award of the degree of Doctor of Philosophy. The thesis has been prepared by him under my supervision and guidance in conformity with the rules and regulations of Indian Institute of Technology Delhi and is a record of the original bonafide research work. The results presented in this thesis have not been submitted in part or full to any other universities or institutes for the award of any other degree or diploma.

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Rishabh Shukla

# Abstract

Wastewater is among the most important reservoirs of emerging pollutants (EPs) such as pharmaceutical and personal care products (PPCPs), antibiotic resistant bacteria (ARB) and associated antibiotic resistance genes (ARGs) in urban environments. Due to the limited capability of existing sewage treatment plants (STPs) in removing EPs, the occurrence of these pollutants in the aquatic environment has become a global problem.

The present study aims to estimate the abundances of ARB, ARGs and PPCPs in the different treatment stages of STPs. Water and sludge samples were collected from the STPs and they were analyzed to estimate the abundance of coliform, ARB against the antibiotics such as, amoxicillin, ciprofloxacin, erythromycin, ESBL (Extended spectrum  $\beta$ -lactam), *Klebsiella pneumoniae* carbapenemase (KPC), meropenem and tetracycline. Also, the abundance of 20 clinically significant ARGs from each group of antibiotics, 3 mobile genetic elements (MGEs), a gene for faecal indicator BtH and 17 different PPCPs were estimated in the collected samples. All the targeted EPs were detected in the raw sewage, in the treated effluent and in the sludge, samples collected from STPs. The abundance of EPs in treated effluent and sludge indicates the inability of existing STPs in removing EPs. However, a slight reduction in the absolute abundance of ARB and ARGs was observed in the treated wastewater, whereas the relative abundance of most of the ARGs and MGEs was increased during the wastewater treatment. The strong positive correlation between MGEs and most of the ARGs, thereby indicating the dominant role of integrons genes in the proliferation of antimicrobial resistance (AMR) in the environment.

The treatment studies with activated sludge process (ASP), hybrid anaerobic reactor (HAR) and modified trickling filter (MTF) showed that MTF was superior to ASP and HAR in

removing both conventional and EPs. The diverse microbial community inside the MTF improves the overall efficiency of the system in removing conventional and EPs from urban sewage. Biodegradation was the key factor controlling the removal of most of the PPCPs during MTF operation. Moreover, among the tertiary treatment systems (UV and ozone), ozonation provides better removal of targeted EPs due to the strong oxidation potential. Though the combination of MTF and ozone provides significant reduction in the abundance of EPs but none of the tertiary systems was capable in the complete elimination of ARGs and PPCPs. Therefore, alternate advanced and effective treatment technology needs to be developed and evaluated for the complete removal of EPs.

# सार

शहरी वातावरण में अपशिष्ट जल उभरते प्रदूषकों (ईपी) जैसे फार्मास्युटिकल और व्यक्तिगत देखभाल उत्पादों (पीपीसीपी), एंटीबायोटिक प्रतिरोधी बैक्टीरिया (एबीआर) और संबद्ध एंटीबायोटिक प्रतिरोध जीन (एआरजी) के सबसे महत्वपूर्ण जलाशयों में से एक है। ईपी को हटाने में मौजूदा सीवेज उपचार संयंत्रों (एसटीपी) की सीमित क्षमता के कारण जलीय पर्यावरण में इन प्रदूषकों की घटना एक वैश्विक समस्या बन गई है।

वर्तमान अध्ययन का उद्देश्य एसटीपी के विभिन्न उपचार चरणों में एआरबी, एआरजी और पीपीसीपी की प्रचुरता का अनुमान लगाना है। एसटीपी से पानी और कीचड़ के नमूने एकत्र किए गए थे और उनका विश्लेषण एंटीबायोटिक दवाओं जैसे एमोक्सिसिलिन, सिप्रोफ्लोक्सासिन, एरिथ्रोमाइसिन, ईएसबीएल (विस्तारित स्पेक्ट्रम  $\beta$ -लैक्टम), क्लेबसिएला निमोनिया कार्बापेनमेस (केपीसी) , मेरोपेनेम और टेट्रासाइक्लिन के खिलाफ, एआरबी और कोलीफॉर्म की प्रचुरता का अनुमान लगाने के लिए किया गया था। इसके अलावा, 20 चिकित्सकीय रूप से महत्वपूर्ण एआरजी, 3 मोबाइल आनुवंशिक तत्वों (एमजीई), मल संकेतक बीटीएच के लिए एक जीन और 17 अलग-अलग पीपीसीपी की प्रचुरता का अनुमान एकत्र किए गए नमूनों में लगाया गया था।

सभी लक्षित ईपी कच्चे सीवेज में, उपचारित बहिःस्राव में और एसटीपी से एकत्र किए गए कीचड़ के नमूनों में पाए गए। उपचारित बहिःस्राव और कीचड़ में ईपी की प्रचुरता ईपी को हटाने में मौजूदा एसटीपी की अक्षमता को इंगित करती है। हालांकि, उपचारित अपशिष्ट जल में एआरबी और एआरजी की पूर्ण बहुतायत में मामूली कमी देखी गई, जबकि अधिकांश एआरजी और एमजीई की सापेक्ष बहुतायत अपशिष्ट जल उपचार के दौरान वृद्धि हुई थी। एमजीई और अधिकांश एआरजी के बीच मजबूत

सकारात्मक सहसंबंध, जिससे पर्यावरण में रोगाणुरोधी प्रतिरोध (एएमआर) के प्रसार में पूर्णांक जीन की प्रमुख भूमिका का संकेत मिलता है।

सक्रिय कीचड़ प्रक्रिया (एएसपी), हाइब्रिड एनारोबिक रिएक्टर (एचएआर) और संशोधित ट्रिकलिंग फिल्टर (एमटीएफ) के साथ उपचार अध्ययनों से पता चला है कि एमटीएफ पारंपरिक और ईपी दोनों को हटाने में एएसपी और एचएआर से बेहतर था। एमटीएफ के अंदर विविध माइक्रोबियल समुदाय शहरी सीवेज से पारंपरिक और ईपी को हटाने में प्रणाली की समग्र दक्षता में सुधार करता है। एमटीएफ ऑपरेशन के दौरान अधिकांश पीपीसीपी को हटाने को नियंत्रित करने वाला प्रमुख कारक बायोडिग्रेडेशन था। इसके अलावा, तृतीयक उपचार प्रणालियों (यूवी और ओजोन) के बीच, ओजोनेशन मजबूत ऑक्सीकरण क्षमता के कारण लक्षित ईपी को बेहतर ढंग से हटाता है। यद्यपि एमटीएफ और ओजोन का संयोजन ईपी की प्रचुरता में महत्वपूर्ण कमी प्रदान करता है लेकिन कोई भी तृतीयक प्रणाली एआरजी और पीपीसीपी के पूर्ण उन्मूलन में सक्षम नहीं थी। इसलिए, ईपी को पूरी तरह से हटाने के लिए वैकल्पिक उन्नत और प्रभावी उपचार प्रौद्योगिकी को विकसित और मूल्यांकन करने की आवश्यकता है।

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# Nomenclature

AMO	Amoxicillin
AMR	Antimicrobial Resistance
ARB	Antibiotic Resistant Bacteria
ARGs	Antibiotic Resistance Genes
ASP	Activated Sludge Process
<i>bla</i>	$\beta$ -lactamase gene
BOD	Biochemical Oxygen Demand
CEP	Chemical Emerging Pollutants
CFU	Colony Forming Unit
CIP	Ciprofloxacin
CLSI	Clinical and Laboratory Standards Institute
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
DO	Dissolved Oxygen
EC	Electrical Conductivity
EDCs	Endocrine Disrupting Compounds
EPs	Emerging Pollutants
<i>erm</i>	Erythromycin Ribosome Methylase
ERY	Erythromycin
ESBL	Extended Spectrum $\beta$ -lactam
EUCAST	European Committee on Antimicrobial Susceptibility Testing
FC	Fecal Coliforms
FST	Final Settling Tank
HAR	Hybrid Anaerobic Reactor
HGT	Horizontal Gene Transfer
HRT	Hydraulic Retention Time
<i>int1</i>	Class 1 integron
<i>int2</i>	Class 2 integron
<i>int3</i>	Class 3 integron
KPC	<i>Klebsiella pneumoniae</i> carbapenem

MEP	Microbial Emerging Pollutants
MERO	Meropenem
MGEs	Mobile Genetic Elements
MLD	Millions of Litres per Day
MTF	Modified Trickling Filter
PPCPs	Pharmaceutical and Personal Care Products
PST	Primary Settling Tank
<i>qnr</i>	Quinolone resistance
qPCR	Quantitative Polymerase Chain Reaction
RAS	Return Activated Sludge
SRT	Sludge Retention Time
STP	Sewage treatment plant
TC	Total Coliforms
TDS	Total Dissolved Solids
TET	Tetracycline
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation
WWTPs	Wastewater Treatment Plants