

**MONITORING AND ASSESSING THE RISKS OF
EMERGING CONTAMINANTS IN THE RIVER GANGA
– A COMPREHENSIVE STUDY**

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DEPARTMENT OF BIOCHEMICAL ENGINEERING AND BIOTECHNOLOGY

INDIAN INSTITUTE OF TECHNOLOGY DELHI

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– A COMPREHENSIVE STUDY**

by

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DEPARTMENT OF BIOCHEMICAL ENGINEERING AND BIOTECHNOLOGY

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Certificate

This is to certify that the thesis entitled “**Monitoring and assessing the risks of emerging contaminants in the river Ganga – a comprehensive study**” being submitted by **Mr. Deepak Kumar Prasad** 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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Abstract

River Ganga is considered holy by the people of India and it supports a population of more than 440 million people. A significant source of emerging contaminants (ECs) entering the river is sewage, industrial waste, and agricultural runoff. The present study was conducted for monitoring and assessing the risks of ECs including antibiotic resistant bacteria (ARB), antibiotic resistant genes (ARGs), pharmaceutical and personal care products (PPCPs) and heavy metals in the water and sediment samples at 16 sites of the river Ganga. The estimation of abundance and identification of ARB present in water and sediments samples of the sixteen sites of the river Ganga were conducted. Six different antibiotics were used for estimating the abundance of ARB. A diverse phylogenetic group of ARB was obtained at all the sites, comprising 54 genera, including 13 opportunistic pathogenic genera, except G1 and G2. Further, the bacterial community analysis of sediment samples showed the presence of potentially waterborne pathogenic genera and species throughout the entire stretch of the river except for the sites G1 and G2. It also indicates that the bacterial core community remains the same, but their abundance varies among the sites. In this study, 20 clinically significant ARGs and 15 PPCPs and endocrine disrupting compounds (EDCs) were also estimated. Risk assessment was carried out for the exposure of heavy metals, ARB and PPCPs.

Pollution indices such as geo-accumulation (I_{geo}), enrichment factor (EF) and potential ecological risk index (RI) were used to assess the contamination level of the river at various sites. The human health risk was also evaluated for each heavy metal in terms of non-carcinogenic and carcinogenic risks. The I_{geo} indicates the extremely polluted condition at site G8 due to chromium and cadmium. Similarly, EF is also higher at site G8 for chromium and cadmium. RI indicates that the G8 and G16 were in the category of

high and considerable risk in winter. However, in summer RI for the site G8 and G9 were in the category of considerable risk. Chromium was accounted for most of the total non-carcinogenic risk in both adults and children. The carcinogenic risks for all the metals were in the negligible to an acceptable range for water exposure in adults and children. However, sediment exposure poses a moderate risk threat for children due to chromium at site G8. Quantitative microbial risk assessment (QMRA) was used to estimate the probability of infection due to ARB present in various sites. QMRA suggests that the abundance of *Pseudomonas aeruginosa*, *Enterococcus fecalis* and *Klebsiella pneumonia* in the water samples and *Enterococcus fecalis*, in the sediment samples can cause infection to person due to the exposure of water and sediment. Ecological and human health risk assessment was also estimated for PPCPs. Based on ecological risk assessment, triclocarban and diclofenac pose a higher risk for an aquatic organism (fish) in the river water column, whereas triclosan and metformin show moderate to high risk in the sediment column. However, negligible risk of PPCPs was observed for humans except for 17 α -ethynylestradiol, which can pose a moderate risk to children.

This study shows the widespread distribution of ECs and associated risk due to these ECs, throughout the river Ganga. The ECs are more abundant at the human impacted sites, indicating that the different anthropogenic activities increase the level of ECs in the river Ganga. There is a considerable variation in the concentration of heavy metals, ARB, ARGs, PPCPs and EDCs in water and sediment samples among all the sites. This variation may be due to the change in the volume of sewage and industrial waste being discharged to the river at different locations. The information gathered in this study can be used to indicate and recommend some important actions and policy suggestions for the protection of the river and the health of its users.

सार

गंगा नदी को भारत के लोगों द्वारा पवित्र माना जाता है और यह 440 मिलियन से अधिक लोगों की आबादी का सहारा है। नदी में प्रवेश करने वाले उभरते संदूषकों (ECs) का एक महत्वपूर्ण स्रोत सीवेज, औद्योगिक अपशिष्ट और कृषि अपवाह है। वर्तमान अध्ययन गंगा नदी के 16 स्थलों पर पानी और तलछट के नमूनों में उभरते हुए दूषित पदार्थों एंटीबायोटिक प्रतिरोधी बैक्टीरिया (ARB), एंटीबायोटिक प्रतिरोधी जीन (ARGs), फार्मास्युटिकल और व्यक्तिगत देखभाल उत्पादों (PPCPs) और भारी धातुओं के जोखिमों की निगरानी और आकलन के लिए आयोजित किया गया था। गंगा नदी के सोलह स्थलों के पानी और तलछट के नमूनों में एंटीबायोटिक प्रतिरोधी बैक्टीरिया (एआरबी) की प्रचुरता और पहचान का आकलन किया गया। एंटीबायोटिक प्रतिरोधी बैक्टीरिया की प्रचुरता का अनुमान लगाने के लिए छह अलग-अलग एंटीबायोटिक दवाओं का उपयोग किया गया था। G1 और G2 को छोड़कर, 13 अवसरवादी रोगजनक जेनेरा सहित 54 जेनेरा सहित, सभी साइटों पर ARB का एक विविध फ़ाइलोजेनेटिक समूह प्राप्त किया गया था। इसके अलावा, तलछट के नमूनों के जीवाणु समुदाय विश्लेषण ने G1 और G2 को छोड़कर नदी के पूरे खंड में संभावित जलजनित रोगजनक जेनेरा और प्रजातियाँ की उपस्थिति को दिखाया। यह यह भी इंगित करता है कि जीवाणु कोर समुदाय समान रहता है, लेकिन उनकी बहुतायत साइटों के बीच भिन्न होती है। इस अध्ययन में 20 चिकित्सकीय रूप से महत्वपूर्ण एआरजी और 15 पीपीसीपी और ईडीसी का भी अनुमान लगाया गया था। भारी धातुओं, एआरबी और पीपीसीपी के जोखिम के लिए जोखिम मूल्यांकन किया गया था।

विभिन्न स्थलों पर नदी के प्रदूषण के स्तर का आकलन करने के लिए भू-संचय (I_{geo}), संवर्धन कारक (EF) और संभावित पारिस्थितिक जोखिम सूचकांक (RI) जैसे प्रदूषण सूचकांकों का उपयोग किया गया था। गैर-कार्सिनोजेनिक और कार्सिनोजेनिक जोखिमों के संदर्भ में प्रत्येक भारी धातु के लिए मानव स्वास्थ्य जोखिम का भी मूल्यांकन किया गया था। I_{geo} साइट G8 में क्रोमियम और कैडमियम के कारण अत्यधिक प्रदूषित स्थिति को इंगित करता है। इसी तरह, क्रोमियम और कैडमियम के लिए साइट G8 पर EF भी अधिक है। RI इंगित करता है कि G8 और G16 सर्दियों में उच्च और काफी जोखिम की श्रेणी में थे। हालांकि, गर्मियों में

साइट G8 और G9 के लिए RI काफी जोखिम की श्रेणी में थे। क्रोमियम वयस्कों और बच्चों दोनों में कुल गैर-कार्सिनोजेनिक जोखिम के बहुमत के लिए जिम्मेदार था। सभी धातुओं के लिए कार्सिनोजेनिक जोखिम वयस्कों और बच्चों में पानी के जोखिम के लिए बहुत कम से स्वीकार्य सीमा में थे। हालाँकि, साइट G8 पर क्रोमियम के कारण तलछट का जोखिम बच्चों के लिए एक मध्यम जोखिम है। विभिन्न साइटों में मौजूद एआरबी के कारण संक्रमण की संभावना का अनुमान लगाने के लिए मात्रात्मक माइक्रोबियल जोखिम मूल्यांकन (QMRA) का उपयोग किया गया था। क्यूएमआरए का सुझाव है कि पानी के नमूनों में स्यूडोमोनास एरुगिनोसा, एंटरोकोकस फेकैलिस और क्लेबसिएला निमोनिया और तलछट के नमूनों में एंटरोकोकस फेकैलिस की प्रचुरता पानी और तलछट के संपर्क में आने के कारण किसी व्यक्ति को संक्रमण का कारण बन सकती है। पीपीसीपी के लिए पारिस्थितिक और मानव स्वास्थ्य जोखिम मूल्यांकन का भी अनुमान लगाया गया था। पारिस्थितिक जोखिम मूल्यांकन के आधार पर, ट्राइक्लोकार्बन और डाइक्लोफेनाक नदी के पानी के स्तंभ में एक जलीय जीव (मछली) के लिए एक उच्च जोखिम पैदा करते हैं, जबकि ट्राइक्लोसन और मेटफॉर्मिन तलछट स्तंभ में मध्यम से उच्च जोखिम दिखाते हैं। हालांकि, 17 α -एथिनिलेस्ट्राडियोल को छोड़कर मनुष्यों के लिए पीपीसीपी का नगण्य जोखिम देखा गया, जो बच्चों के लिए मध्यम जोखिम पैदा कर सकता है।

इस अध्ययन के परिणाम गंगा नदी में ईसी के व्यापक वितरण और इन ईसी के कारण जुड़े जोखिम को दर्शाता है। मानव प्रभावित स्थलों पर ईसी अधिक प्रचुर मात्रा में हैं, यह दर्शाता है कि विभिन्न मानवजनित गतिविधियां गंगा नदी में ईसी को बढ़ाती हैं। सभी स्थलों के बीच पानी और तलछट के नमूनों में भारी धातुओं, एआरबी, एआरजी, पीपीसीपी और ईडीसी की सांद्रता में काफी भिन्नता है। यह भिन्नता विभिन्न नमूना स्थानों पर नदी में जोड़े जा रहे सीवेज और औद्योगिक कचरे की मात्रा में परिवर्तन के कारण हो सकती है। इस अध्ययन में एकत्रित जानकारी का उपयोग नदी की सुरक्षा और इसके उपयोगकर्ता के स्वास्थ्य के लिए कुछ महत्वपूर्ण कार्यों और नीतिगत सुझावों को इंगित करने और अनुशांसा करने के लिए किया जा सकता है।

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Nomenclature

AF	Assessment factor
AMO	Amoxicillin
AMR	Antimicrobial resistance
AR	Antibiotic resistance
ARB	Antibiotic resistant bacteria
ARGs	Antibiotic resistance genes
BIS	Bureau of Indian standards
<i>bla</i>	β -lactamase
BOD	Biochemical oxygen demand
CDDEP	Centre for disease dynamics, economy and policy
CDI	Chronic daily intake
CFU	Colony forming unit
CIP	Ciprofloxacin
CLSI	Clinical and laboratory standards institute
COD	Chemical oxygen demand
CPCB	Central pollution control board
CR	Carcinogenic risk
DDDs	Define daily doses
DO	Dissolved oxygen
EC	Electrical conductivity
ECs	Emerging contaminants
EDCs	Endocrine disrupting compounds
EF	Enrichment factor
<i>erm</i>	Erythromycin ribosome methylase
ERY	Erythromycin
ESBL	Extended spectrum β -lactam
EUCAST	European committee on antimicrobial susceptibility testing
FC	Fecal coliform
HGT	Horizontal gene transfer
HI	Hazard index
HICs	High-income countries

HQ	Hazard quotient
Igeo	Geo-accumulation index
<i>int1</i>	Class 1 integron
<i>int2</i>	Class 2 integron
<i>int3</i>	Class 3 integron
KPC	<i>Klebsiella pneumoniae</i> carbapenem
LMICs	Low-middle income countries
MEC	Measured environmental concentration
MGEs	Mobile genetic elements
MIC	Minimum inhibitory concentration
MLD	Millions of litres per day
PNEC	Predictive no-effect concentration
PPCPs	Pharmaceutical and personal care products
QMRA	Quantitative microbial risk assessment
<i>qnr</i>	Quinolone resistance
qPCR	Quantitative polymerase chain reaction
RI	Potential ecological risk index
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