

**COMPREHENSIVE ENVIRONMENTAL FLOW ASSESSMENT OF
GANGA RIVER BASIN: INTEGRATING ECOLOGICAL CONCERNS
WITHIN HYDROLOGIC AND HYDRAULIC FRAMEWORK.**

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by

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CERTIFICATE

This is to certify that the thesis, entitled “*Comprehensive Environmental Flow Assessment of Ganga River Basin: Integrating Ecological Concerns within Hydrologic and Hydraulic Framework*”, being submitted by Ms. Nale Jyoti Punjahari to the Indian Institute of Technology, Delhi for the award of Doctor of Philosophy, is a record of bonafide research work carried out by her under our joint supervision. The thesis work, in our opinion has reached the standard, fulfilling the requirements for the said degree. Further, we certify that this submission is Ms. Jyoti’s own work and that, to the best of our knowledge and belief, it contains no material previously published or written by another person which to a substantial extent has been accepted for the award of any other degree or diploma of any University or Institute, except where due acknowledgment has been made in the text.

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ABSTRACT

Worldwide, the concept of Environmental flows (e-flows) has inspired a global mass movement. This phenomenon may essentially be a direct consequence of frequent reports that persistently highlight the seemingly adverse impacts of flow regulatory and abstraction oriented interventions in river basins. Though interest in e-flows is comparatively recent for researchers and investigators from across various traditional domains of science, there has indeed been a rapid progress in terms of the scope and ramifications of the concept of e-flows both in terms of its various definitions and associated terminologies as well as the required assessment methods.

This thesis has explored the concept of e-flows and its accommodation as part of the de jure water resources management policy infrastructure in case of the Ganga River Basin, arguably amongst the largest river system in terms of annual flow volume globally. The enormity of the scale of the hydrological dynamics and its interface with socio-economic and cultural dynamics across the entire domain of Ganga Basin is indeed peerless and bestows upon it the status of being an iconic and, in some sense, a unifying cultural and religious symbol for Indians across the world. This Ph. D. research seeks to respond to the widespread yearning in India for a sound and comprehensive e-flow assessment of Ganga River Basin that scores high in terms of science and objectivity besides achieving a synergy across the entire spectrum of the various entities that compete for Ganga waters.

Present research follows an interdisciplinary and hierarchical approach involving comparison of (a) Hydrologic, (b) Hydraulic and (c) Habitat Analysis methods in order to arrive at e-flows assessment for the Ganga system. In acknowledgement of the scale of spatial and temporal heterogeneity, the basin has been spatially divided into 24 sub-systems based on their similarities and diversities. For total of 141 hydrological observation sites in these sub-systems, three different periods of river flow control and regulations, ranging from earliest plausible and corresponding to minimal scale of anthropogenic interventions to the currently prevailing status, have been identified as i) unregulated flow scenario, ii) intermediate flow scenario and iii) present flow scenario.

Hydrology driven e-flow assessment based on the unregulated flow scenario and intermediate flow scenario using a) Tennant Approach, b) Tessman Approach, c) Variable Monthly Flow Approach and d) Range of Variability Approach demonstrated that these approaches fail to suggest reasonable e-flow scenarios, especially for all rainfed tributaries of Ganga, where

seasonal variations in flows are predominant. Other reason for non-suitability of these approaches is the flavour of intrinsic hydrology and ecology of the region for which these were developed that is incongruous with the reality of the Ganga Basin.

For habitat analysis approach of e-flow assessment, knowledge about five indigenous species (Golden Mahseer, Snow Trout, Gangetic Dolphin, Gharial and Hilsa) is assembled to organise the preferences of their three life stages for various hydrodynamic transport characteristics of the river. These ecological preferences are coupled with hydraulic prospects of various flow ranges at various habitat sites in Ganga Basin to establish flow versus habitat relationships for target species. Finally, spatio-temporal diversity that underscores Ganga basin's hydrological framework is linked with the ecological consequences of various flow regimes at 13 sites to suggest the most desirable and achievable e-flow regimes for these sites.

An important outcome of the study is in the form of e-flow regimes, corresponding to classes A, B, C and D respectively representing 80, 60, 40 and 20% retention of habitat available under unregulated flow regimes (reference habitat) and also the comparison of the current (altered) status of Ganga flows with the former on a monthly scale to present its current ecological health. Due to the underlying nonlinear nature of the relationships between flow and various habitat attributes such as flow depths, velocities and wetted areas, the research emphasizes that a given percent reduction in habitat retention from its reference state, is not proportional to a similar order of reduction in flows from the unregulated state and vice versa. The study shows that Gharial habitats remain essentially intact with retention of 60% of reference habitat for much of the year at all sites (with exceptions over a limited duration of a month at study sites in Chambal and Sone River) whereas the habitats of Golden Mahseer and Snow trout show a significant level of compromise. This is especially so at Uttarkashi site where habitats are reduced by more than 60% of reference habitat. The Gangetic Dolphin habitat in Rapti and Burhi Gandak seems to be well maintained whereas the study reveals that its habitat at some of the other sites examined in this research does indeed fall below threshold of class C, suggesting retention of less than 40% habitat under current levels of regulation and withdrawal. Overall, the study also suggests that, at almost all sites and for all target species, the currently prevailing flow regimes, when assessed on a monthly basis, are generally seen to possess potential to support e-flow scenario class 'C' and, thus, leading to the inference that there does exist an innate capacity in the system to provide sustenance for at least 40 % of the habitats under currently prevailing hydro-anthropogenic conditions.

As a consolidated output of the research, e-flow suggestions have been derived based on application of a diverse set of broad approaches suggested in available literature and these are presented together with an accompanying judgement regarding their feasibility in terms of (i) acceptability by the various stakeholders, (ii) their potential for successful adaptation as policy imperatives, and (iii) ease of implementation. The study suggests that habitat analysis approach of e-flow assessment, if adopted as a basis for e-flow assessment initiatives in India, has the potential to yield robust solutions with better prospects of long term acceptance and sustainability.

Key words: E-flow Assessment, Ganga River Basin, Hydrologic Method, Hydraulic Rating Method, Habitat Analysis Method, Golden Mahseer, Snow Trout, Gangetic Dolphin, Gharial, Hilsa

संक्षेप

दुनिया भर में, एनवायर्नमेंटल फ्लो (ई-फ्लो) की संकल्पना ने वैश्विक जन आंदोलन को प्रेरित किया है। यह संकल्पना अनिवार्य रूप से उन लगातार संदेशोंका प्रत्यक्ष परिणाम हो सकती है जो नदी घाटी में प्रवाह नियमन और निष्कर्षोन्मुख हस्तक्षेप के प्रतिकूल प्रभावों पर लगातार रौशनी डाल रही हैं। हालांकि, विभिन्न पारंपरिक ज्ञान-विज्ञान के क्षेत्रों के शोधकर्ताओं और जांचकर्ताओं की ई-फ्लो में दिलचस्पी हाल ही में शुरू हुई है, इस के क्षेत्रमें और उसकी उपशाखाओं के विकसन एवं विभिन्न परिभाषाओं और संबंधित शब्दावली के साथ-साथ आकलन विधियों के संदर्भ में वास्तव में तेजी से प्रगति हुई है।

इस शोध प्रबंध ने ऐसे गंगा नदी बेसिन के मामले में जल संसाधन प्रबंधन नीति के बुनियादी ढांचे के हिस्से के रूप में इ-फ्लो और इसकी आवास की अवधारणा की खोज की है, जो सम्भाव्यतः विश्व स्तर पर वार्षिक प्रवाह मात्रा के मामले में सबसे बड़ी नदियों में से एक है। हाइड्रोलॉजिकल गतिशीलता के पैमाने की व्यापकता और उसके पूरे गंगा बेसिन के सामाजिक-आर्थिक और सांस्कृतिक गतिशीलता के साथ के संबंध, वास्तव में अद्वितीय है और और यह गंगा बेसिन को प्रतिष्ठा प्रदान करते, जिसके कारण गंगा नदी दुनिया भर के भारतीयों के लिए सांस्कृतिक और धार्मिक प्रतीक है। यह गवेषणा गंगा नदी बेसिन के व्यापक ई-प्रवाह मूल्यांकन के लिए भारत में व्यापक उत्सुकता का जवाब देना चाहती है। यह मूल्यांकन गंगा जल के लिए प्रतिस्पर्धा करने वाले विभिन्न हितधारकों के बीच तालमेल की तलाश में समग्र होने के अलावा वैज्ञानिकता और निष्पक्षता के संदर्भ में अच्छी तरह से प्रदर्शन करती है।

वर्तमान शोध गंगा नदी बेसिन के लिए ई-फ्लो मूल्यांकन पर पहुंचने के लिए (ए) हाइड्रोलिक, (बी) हाइड्रोलिक और (सी) हैबिटैट एनालिसिस विधियों की तुलना का एक अंतःविषय और पदानुक्रमित दृष्टिकोण अपनाता है। स्थानिक एवं कालिक विषमता के पैमाने की स्वीकृति में, बेसिन को उनकी समानता और विविधता के आधार पर स्थानिक रूप से 24 उप-घाटियों में विभाजित किया गया है। इन उप-प्रणालियों में कुल १४१ नदी प्रवाह अवलोकन स्थलों के लिए, नदी प्रवाह नियंत्रण और विनियम की श्रृंखला, जो वर्तमान में प्रचलित स्थिति से लेकर सबसे पुरानी और न्यूनतम मानववंशीय हस्तक्षेप से संबंधित है, उसकी पहचान की गई है, । इसके अनुसार सम्पूर्ण जलप्रवाह जानकारी को निचे बताये हुए तीन अवधियों में बाटा गया है, १) अनियंत्रित प्रवाह (उनरेगुलेटेड फ्लो सिनेरियो), २) मध्यवर्ती प्रवाह (इंटरमीडिएट फ्लो सिनेरियो) और ३) वर्तमानमें प्रचलित प्रवाह (प्रेजेंट फ्लो सिनेरियो)।

हाइड्रोलॉजी संचालित ई-फ्लो मूल्यांकन अनियंत्रित प्रवाह और मध्यवर्ती प्रवाह के आधार पर चार तरीको से किया गया है, अ) टेनेंट दृष्टिकोण, ब)टेस्मान दृष्टिकोण, क) परिवर्तनीय मासिक जलप्रवाह दृष्टिकोण

और ड) परिवर्तनीयता की सांख्यिकीय सीमा दृष्टिकोण। इनके नतीजों से यह साबित होता है की यह तमाम दृष्टिकोण उचित ई-फ्लो परिदृश्यों का सुझाव देने में विफल रहते हैं। इन विधियोंकी गैर उपयुक्तता का एक कारन यह भी है की जहां वे विकसित हुई है उस जगह की आंतरिक हाइड्रोलॉजिक और पारिस्थितिकी से वे प्रभावित है, जो गंगा बेसिन की वास्तविकता के साथ असंगत है।

ई -फ्लो आकलन की हेबिटेट एनालिसिस विधि के हेतु, नदी के विभिन्न हाइड्रोलॉजिक परिवहन विशेषताओं के लिए पांच स्वदेशी प्रजातियोंके .गोल्डन महासीर, स्नो ट्राउट, गंगेय डॉल्फिन, घड़ियाल और हिलसा. तीन जीवन चरणों की प्राथमिकताओं का आकलन करने के लिए, उन प्रजातियोंके बारे में ज्ञान इकट्ठा किया गया है। इन नियोजित प्रजातियोंके अनुरूप, प्रवाह बनाम हेबिटेट सम्बन्ध प्रस्थापित करने के लिए, उनकी पारिस्थितिकी प्राथमिकताएँ, गंगा बेसिन में स्थित उनके विभिन्न हेबिटेट स्थलोंकी विभिन्न प्रवाह श्रृंखलाओं की हाइड्रोलिक संभावनाओं के साथ जोड़ी गयी है। अंततः स्थानिक एवं कालिक विविधता, जो गंगा बेसिनके हाइड्रोलिक ढाँचेको अधोरेखित करती है, वो १३ हेबिटेट स्थलोंकी विभिन्न प्रवाह श्रृंखलाओं के पारिस्थितिकी परिणामोंके साथ जोड़ी गयी है और उस आधारपर, उन स्थानोंके लिए सबसे वांछनीय और प्राप्त करने योग्य ई -फ्लो प्रणाली प्रस्तावित की गयी है।

अध्ययन का प्रमुख परिणाम ई -फ्लो प्रणाली के रूप में है, जो ए, बी, सी और डी इन चार कक्षाओंमें बनाई गयी है और अनियमित प्रवाह के तहत उपलब्ध हेबिटेट का क्रमशः ८०, ६०, ४० और २० % प्रतिधारण दर्शाती हैं। इसके अतिरिक्त, गंगाके वर्तमान पारिस्थितिकीय स्वास्थ्य को पेश करने के लिए, मासिक पैमाने पर की गयी. वर्तमान .बदली गई. और पूर्व स्थिति की तुलना भी अध्ययन का प्रमुख परिणाम है। यह अध्ययन रेखांकित करता है की, प्रवाह और विभिन्न हेबिटेट लक्षण जैसे कि प्रवाह की गहराई, वेग और गीले क्षेत्र आदि के बीच अंतर्निहित संबंध विषम होने की वजह से, अनियमित प्रवाह के तहत उपलब्ध हेबिटेट के संदर्भ में हुए हेबिटेट प्रतिधारण में विहित प्रतिशत कमी, प्रवाह में होने वाली समान मात्रा की कमीसे आनुपातिक नहीं है और अन्यथा भी नहीं है। अध्ययन से पता चलता है कि, सभी स्थलोंपर, साल के अधिकांश के लिए, अनियमित प्रवाह के तहत उपलब्ध हेबिटेट के ६० % प्रतिधारण के साथ, घड़ियाल हेबिटेट तत्त्वः बरकरार रहता है .चंबल और सोन नदी में स्थित अध्ययन स्थलों पर एक महीने की सीमित अवधि के अपवाद के साथ. तथा गोल्डन महासीर और स्नो ट्राउट हेबिटेट में विशेष मात्रा से कमी आइ है। यह प्रमुखतः उत्तरकाशीमे हुआ है जहां हेबिटेटमे ६० % से ज्यादा कटौती हुई है। राप्ती तथा बूढ़ी गण्डक मे गंगेय डॉल्फिन का हेबिटेट अच्छी तरह से बनाए रखा गया प्रतीत होता है जबकि इस शोध में परिक्षण किए गए कुछ और स्थलोंपर यह हेबिटेट वास्तव में कक्षा सी की दहलीज नीचे गिरता है, और यह लक्षित करता है कि, विनियमन और

निकास के मौजूदा स्तर के तहत, अनियमित प्रवाह के तहत उपलब्ध हेबिटेट के संदर्भ में ४०% से कम हेबिटेट प्रतिधारित है। व्यापक रूप में, अध्ययन से यह भी पता चलता है कि, लगभग सभी स्थलों पर और सभी लक्षित प्रजातियों के लिए, मासिक पैमाने पर आकलन की गयी वर्तमान में प्रचलित प्रवाह प्रणाली, आमतौर पर, कक्षा सी की इ-फ्लो प्रणाली को समर्थन करने की क्षमता रखती हुई नजर आती है और, इसके परिणामस्वरूप, यह अनुमान लगाया जा सकता है की, वर्तमान में प्रचलित हाइड्रो-मानववंशीय स्थितियों के तहत, इस प्रणाली में, कम से कम ५ हेबिटेट प्रदान करने की एक सहज क्षमता मौजूद है।

शोध के एक समेकित उत्पादन के रूप में, उपलब्ध साहित्य में सुझाये गए विविध समूहके व्यापक दृष्टिकोनोंके आवेदनसे, ई-फ्लो सुझाव व्युत्पन्न किए गए हैं और यह सुझाव (i) विभिन्न हितधारकों द्वारा उनकी स्वीकार्यता, (ii) नीति अनिवार्यताके रूपमें सफल अनुकूलन की क्षमता, और .iii) कार्यान्वयन में आसानी, के संदर्भ में उनकी व्यवहार्यता के बारे में निर्णय के साथ प्रस्तुत किए गए हैं* अध्ययन से पता चलता है कि, यदि भारत में ई -फ्लो मूल्यांकन की हेबिटेट एनालिसिस विधिको अपनाया जाये, तो यह विधि ऐसे मजबूत समाधान पैदा करने की क्षमता रखती है जिनकी दीर्घकालिक स्वीकृति और स्थायित्व की बेहतर संभावना हो।

मुख्य शब्द:

इ-फ्लो आकलन, गंगा नदी बेसिन, हाइड्रोलोजिक विधि, हाइड्रोलिक रेटिंग विधि, हेबिटेट एनालिसिस विधि, गोल्डन महासीर, स्रो ट्राउट, गंगेय डॉल्फिन, घड़ियाल, हिलसा

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ABBREVIATIONS

1D:	one-dimensional
2D:	two-dimensional
ASTER:	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BCM:	billion cubic metres
CASiMiR:	Computer Aided Simulation Model for Instream Flow Requirements
cumec:	cubic meter per second
CWC:	Central Water Commission
DEM:	Digital Elevation Model
DO:	dissolved oxygen
DRM:	Desktop Reserve Model
DWAF:	Department of Water Affairs and Forestry
EFA:	Environmental Flow Assessment
e-flows:	environmental flows
GAP:	Ganga Action Plan
GEFC:	Global Environmental Flow Calculator
GoI:	Government of India
GRBMP:	Ganga River Basin Management Plan
HEC-RAS:	Hydrologic Engineering Centre's River Analysis System
HEFR:	Hydrology-based Environmental Flow Regime
HEP:	Hydro-Electric Project
HO:	Hydrological Observation
HSC:	Habitat Suitability Criteria
IFG:	Instream Flow Group
IFIM:	Instream Flow Incremental Methodology

IHA:	Indicators of hydrologic Alterations
IWMI:	International Water Management Institute
IUCN:	International Union for conservation of Nature
km:	Kilometers
m:	meters
MAF:	Mean Annual Flow
mld:	Million Litres per Day
MMF:	Mean Monthly Flow
MSR:	Mean Seasonal Runoff
NMCG:	National Mission for Clean Ganga
NRCP:	National River Conservation Plan
PFC:	Perfluorinated Compound
PHABSIM:	Physical Habitat Simulation
RSS:	River System Simulator
RVA:	Range of Variability Approach
sq. km.:	Square Kilometres
sq. m.:	Square Meters
SRTM:	Shuttle Radar Topographic Mission
SWAT:	Soil and Water Assessment Tool
SZF:	Stage of Zero Flow
TMCM:	Thousand Million Cubic Meter
VMF:	Variable Monthly Flow
WEAP:	Water Evaluation and Planning
WSP:	Water Surface Profile
WUA:	Weighted Usable Area