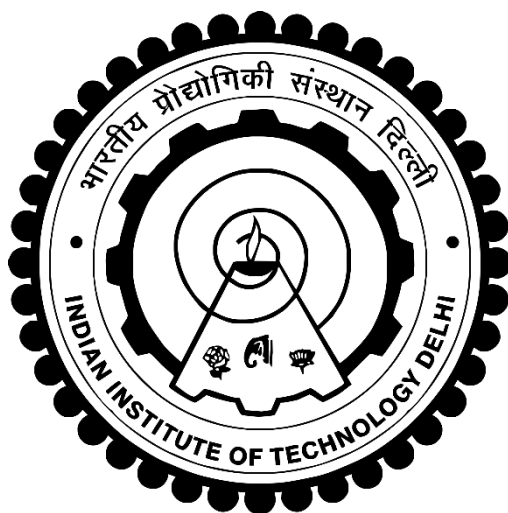


**MAPPING DOUBLE DUTY ACTIONS TO TARGET THE DUAL BURDEN OF
MALNUTRITION**

NAMRATA TYAGI



CENTRE FOR RURAL DEVELOPMENT & TECHNOLOGY

INDIAN INSTITUTE OF TECHNOLOGY DELHI

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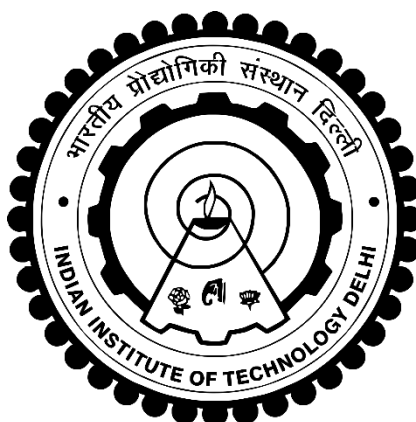
Centre for Rural Development and Technology

Submitted

In fulfilment of the requirements of the degree of

Doctor of Philosophy

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In the loving memory of my beloved father, whose unwavering support and profound belief in my abilities provided the foundation of my academic pursuits. This thesis is dedicated to him as a token of gratitude and a testament to the values of kindness and empathy he instilled in me.

CERTIFICATE

This is to certify that the thesis entitled “**MAPPING DOUBLE DUTY ACTIONS TO TARGET THE DUAL BURDEN OF MALNUTRITION**,” being submitted by **Ms. Namrata Tyagi** 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. She has worked under my guidance and supervision and has fulfilled the requirements for submission of this thesis. To the best of my knowledge, the results contained in this thesis have not been submitted in part or whole to any other university or institute for the award of any degree or diploma.

Professor Vijayaraghavan M Chariar

Professor

Centre for Rural Development & Technology

Indian Institute of Technology Delhi

New Delhi- 110016,

India.

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ABSTRACT

The dual burden of malnutrition (DBM), defined as the co-existence of undernutrition and overnutrition, is an escalating global health concern, particularly in low- and middle-income countries (LMICs). Its rising prevalence, driven by dietary transitions and changing food environments, leads to significant health and economic losses (e.g., increased mortality, morbidities, and disability-adjusted life years (DALYs) that strain healthcare systems. More than one in three individuals suffers from DBM in LMICs, and with the rising prevalence, the present healthcare system is not conducive enough to solve the crisis. Considering these limitations and challenges, preventive approaches underscore the way to address them. This study aimed to develop a novel, cost-effective, and efficient preventive approach, rather than a corrective one, to address DBM, especially in low-resource settings. This study focused on designing a framework for an efficient integrated DBM monitoring system as a preventive approach to solve the issue. The selection of adolescent females as the study group also revolved around the preventive approach to target the DBM, as the adolescent females transitioning to be future mothers, if they gained access to the planned interventions for them, would ultimately hinder the intergenerational cycle of DBM, thus targeting the root of the problem. Hence, the major DBM risk factor assessment and anthropometrics were carried out for adolescent girls to design an integrated DBM monitoring system as a preventive approach and devise solutions to address the issue.

Monitoring major risk factors of DBM discussed in this study paves the way for developing an efficient integrated surveillance system targeting DBM as a preventive measure that can help policy-making or program planning as an effective intervention to target this issue. This study aimed to assess the distribution of Body Mass Index (BMI) for age z score (BAZ)

defined nutritional-status categories among adolescent girls, examine significant DBM-related risk factors, and use stakeholder analysis to design an evidence-based framework for an integrated DBM monitoring system. This study also aimed to evaluate Mid-Upper Arm Circumference (MUAC) as an alternative low-cost screening tool in these settings by assessing its diagnostic accuracy and establishing cut-offs for identifying underweight and overweight adolescent girls.

A cross-sectional study was conducted in selected areas of Chhattisgarh and Uttar Pradesh to collect data on risk factors of DBM using a semi-structured questionnaire and anthropometrics (height, weight, and MUAC measurements), along with stakeholder analysis to assess bottlenecks and mitigation factors to target the issue. The World Health Organization (WHO) Anthroplus software was used to convert the height and weight data into BAZ scores to classify the adolescent females into thinness/severe thinness, normal, overweight, and obese categories based on BAZ scores. The regional distribution of these BAZ-defined categories was used to describe the co-existence of undernutrition and overnutrition at the population level. Stepwise regression, Random Forest (RF) analysis, and point-biserial correlation were then used to examine the association between BAZ as the dependent variable and selected demographic, environmental, dietary, and NCD-related risk factors as independent variables. Further analysis was conducted to ascertain the diagnostic accuracy of MUAC using sensitivity, specificity, area under the curve (AUC), and the Youden Index, and to establish cut-offs corresponding to underweight and overweight categories. The association between BAZ and MUAC was assessed using Pearson's correlation analysis. The Youden Index was used to find the cut-off value of MUAC for underweight and overweight individuals with respect to the BAZ score. For developing the

framework, in-depth interviews and focus group discussions were conducted using a semi-structured questionnaire for different stakeholders, i.e., district administration senior officials, Collector and District Magistrate, Anganwadi workers, doctors, block coordinators, researchers, teachers, parents, locals, and adolescents to identify DBM risk factors, designing attributes and mitigation factors.

The Dietary Diversity Score (DDS) variable was found to be the most important for the overall BAZ score at p -value <0.01 . Among the variables examined, DDS, processed food, fast food, health-promoting food, inactive hours, toilet facility, hand hygiene, protected water, kitchen garden, and livestock were positively correlated with BAZ score, and physical activity (mild), and diarrhea were negatively correlated with BAZ at p -value <0.01 . The correlation between BAZ and MUAC was found to be 0.78, $p < 0.01$. The overall sensitivity, specificity, and AUC of MUAC were observed as 0.89, 0.94, and 0.92, respectively. These findings indicate that MUAC has good diagnostic performance as a low-cost alternative to BAZ-based anthropometric assessment in resource-constrained settings. Accordingly, MUAC may serve as a practical screening alternative to BAZ-based anthropometric assessment among adolescent girls, and MUAC-based classification may support population-level DBM surveillance. The strong correlation between MUAC and BAZ supports the utility of MUAC as a field-friendly substitute for height- and weight-based assessment, thereby reducing technical and financial burden. Similarly, the strong importance of DDS in the Random Forest analysis and its positive association with BAZ indicate that dietary diversity is an important predictor of nutritional status. The framework designed from the analysis of multi-sectoral stakeholders resulted in an evidence-based, simple, user-centric, adaptable, and holistic integrated DBM monitoring system. The

resulting framework was evidence-based, user-centred, adaptable, and structured around inputs, processes, outputs, outcomes, and a feedback loop for continuous improvement. This study identified a cost-effective and efficient screening tool to support population-level DBM monitoring, and stakeholder analysis contributed to the development of a novel integrated DBM monitoring framework. This evidence-driven approach may support preventive action against DBM, reduce health-system burden, and strengthen population-level monitoring in resource-constrained settings.

सार

कुपोषण का द्वैध भार (डीबीएम), जिसे अल्पपोषण और अतिपोषण के सह-अस्तित्व के रूप में परिभाषित किया जाता है, विशेष रूप से निम्न एवं मध्यम आय वाले देशों (एलएमआईसी) में तीव्र गति से बढ़ती हुई एक वैश्विक स्वास्थ्य-चिंता है। इसकी बढ़ती व्यापकता, जो आहार संबंधी संक्रमणों और बदलते खाद्य परिवेशों से प्रेरित है, उल्लेखनीय स्वास्थ्य एवं आर्थिक हानियों का कारण बनती है; जैसे मृत्यु-दर, रुग्णताओं तथा डिसएबिलिटी-अजस्टेड लाइफ इयर्स (डीएएलवाईज़) में वृद्धि, जो स्वास्थ्य-प्रणालियों पर अतिरिक्त दबाव डालती है। एलएमआईसी में प्रत्येक तीन व्यक्तियों में से एक से अधिक व्यक्ति डीबीएम से प्रभावित है, और इसकी बढ़ती व्यापकता के साथ वर्तमान स्वास्थ्य-प्रणाली इस संकट के समाधान के लिए पर्याप्त रूप से अनुकूल नहीं है। इन सीमाओं और चुनौतियों को ध्यान में रखते हुए, निवारक उपागम इनके समाधान का मार्ग प्रशस्त करते हैं। इस अध्ययन का उद्देश्य, विशेष रूप से सीमित संसाधनों वाली परिस्थितियों में, डीबीएम के समाधान हेतु सुधारात्मक के बजाय एक नवीन, लागत-प्रभावी तथा दक्ष निवारक उपागम विकसित करना था। यह अध्ययन इस समस्या के समाधान के लिए निवारक उपागम के रूप में एक दक्ष एकीकृत डीबीएम निगरानी प्रणाली की रूपरेखा तैयार करने पर केंद्रित था। अध्ययन-समूह के रूप में किशोरियों का चयन भी डीबीएम को लक्षित करने वाले निवारक उपागम पर आधारित था, क्योंकि भविष्य की माताएँ बनने की ओर अग्रसर किशोरियाँ, यदि उनके लिए नियोजित हस्तक्षेपों तक पहुँच प्राप्त कर लें, तो अंततः डीबीएम के पीढ़ी-दर-पीढ़ी संचरित चक्र को अवरुद्ध कर सकती हैं, और इस प्रकार समस्या की जड़ को लक्षित किया जा सकता है। अतः, निवारक उपागम के रूप में एक एकीकृत डीबीएम निगरानी प्रणाली की रूपरेखा

तैयार करने तथा इस समस्या के समाधान विकसित करने हेतु किशोरियों में डीबीएम के प्रमुख जोखिम कारकों का आकलन तथा शरीरमितीय मापन किए गए।

इस अध्ययन में विवेचित डीबीएम के प्रमुख जोखिम कारकों की निगरानी, डीबीएम को निवारक उपाय के रूप में लक्षित करने वाली एक दक्ष एकीकृत निगरानी तंत्र के विकास का मार्ग प्रशस्त करती है, जो इस समस्या को लक्षित करने हेतु एक प्रभावी हस्तक्षेप के रूप में नीति-निर्माण अथवा कार्यक्रम-योजना में सहायक हो सकता है। इस अध्ययन का उद्देश्य किशोरियों में आयु के अनुसार बॉडी मास इंडेक्स (बीएमआई) z score (बीएजेड) द्वारा परिभाषित पोषण-स्थिति श्रेणियों के वितरण का आकलन करना, डीबीएम से संबंधित महत्वपूर्ण जोखिम कारकों की जाँच करना, तथा एक साक्ष्य-आधारित एकीकृत डीबीएम निगरानी प्रणाली की रूपरेखा तैयार करने के लिए हितधारक विश्लेषण का उपयोग करना था। इस अध्ययन का उद्देश्य इन परिस्थितियों में मिड-अपर आर्म सरकम्फरेंस (एमयूएसी) का एक वैकल्पिक कम-लागत स्क्रीनिंग उपकरण के रूप में मूल्यांकन करना भी था, जिसके लिए इसकी निदानात्मक शुद्धता का आकलन किया गया तथा कम-वजन और अधिक-वजन वाली किशोरियों की पहचान हेतु कट-ऑफ मान स्थापित किए गए।

डीबीएम के जोखिम कारकों से संबंधित आँकड़े एकत्र करने के लिए छत्तीसगढ़ और उत्तर प्रदेश के चयनित क्षेत्रों में एक क्रॉस-सेक्शनल अध्ययन किया गया, जिसमें अर्ध-संरचित प्रश्नावली तथा शरीरमितीय मापनों (ऊँचाई, वजन और एमयूएसी मापन) का उपयोग किया गया; साथ ही इस समस्या को लक्षित करने हेतु अवरोधों और शमन कारकों का आकलन करने के लिए हितधारक विश्लेषण भी किया गया। विश्व स्वास्थ्य संगठन (डब्ल्यूएचओ) के एन्थ्रोप्लस सॉफ्टवेयर का उपयोग ऊँचाई और वजन के आँकड़ों को बीएजेड स्कोर में रूपांतरित करने के लिए किया गया, ताकि किशोरियों को बीएजेड स्कोर के आधार पर कृशता/गंभीर कृशता, सामान्य, अधिक-वजन और मोटापाग्रस्त श्रेणियों में वर्गीकृत

किया जा सके। इन बीएजेड-परिभाषित श्रेणियों के क्षेत्रीय वितरण का उपयोग जनसंख्या-स्तर पर अल्पपोषण और अतिपोषण के सह-अस्तित्व का वर्णन करने के लिए किया गया। इसके पश्चात, बीएजेड को आश्रित चर तथा चयनित जनसांख्यिकीय, पर्यावरणीय, आहार-संबंधी तथा गैर-संचारी रोगों से संबंधित जोखिम कारकों को स्वतंत्र चरों के रूप में लेकर उनके मध्य संबंध की जाँच हेतु क्रमिक प्रतिगमन, रैंडम फॉरेस्ट (आरएफ) विश्लेषण तथा बिंदु-द्विश्रेणी सहसंबंध का उपयोग किया गया। आगे का विश्लेषण एमयूएसी की निदानात्मक शुद्धता का निर्धारण करने के लिए संवेदनशीलता, विशिष्टता, एरिया अंडर द कर्व (एयूसी) तथा यूडेन इंडेक्स का उपयोग करते हुए किया गया, और कम-वजन तथा अधिक-वजन श्रेणियों के अनुरूप कट-ऑफ मान स्थापित किए गए। बीएजेड और एमयूएसी के मध्य संबंध का आकलन पियरसन सहसंबंध विश्लेषण द्वारा किया गया। बीएजेड स्कोर के संदर्भ में कम-वजन और अधिक-वजन वाले व्यक्तियों के लिए एमयूएसी का कट-ऑफ मान ज्ञात करने हेतु यूडेन इंडेक्स का उपयोग किया गया। रूपरेखा के विकास हेतु विभिन्न हितधारकों, अर्थात् जिला प्रशासन के वरिष्ठ अधिकारियों, कलेक्टर एवं जिला मजिस्ट्रेट, आंगनवाड़ी कार्यकर्ताओं, चिकित्सकों, ब्लॉक समन्वयकों, शोधकर्ताओं, शिक्षकों, अभिभावकों, स्थानीय निवासियों तथा किशोरों के साथ अर्ध-संरचित प्रश्नावली का उपयोग करते हुए गहन साक्षात्कार और फोकस ग्रुप चर्चाएँ की गईं, ताकि डीबीएम के जोखिम कारकों, रूपरेखा-निर्माण संबंधी विशेषताओं तथा शमन कारकों की पहचान की जा सके।

डाइटरी डाइवर्सिटी स्कोर (डीडीएस) चर, समग्र बीएजेड स्कोर के लिए $p\text{-value} < 0.01$ पर सर्वाधिक महत्वपूर्ण पाया गया। परीक्षण किए गए चरों में डीडीएस, प्रसंस्कृत खाद्य, फास्ट फूड, स्वास्थ्यवर्धक खाद्य, शारीरिक गतिविधि, निष्क्रिय समय, शौचालय सुविधा, हाथों की स्वच्छता, सुरक्षित जल, रसोई बगीचा तथा पशुधन का बीएजेड स्कोर के साथ धनात्मक सहसंबंध पाया गया, जबकि शारीरिक गतिविधि (हल्की) और अतिसार का बीएजेड के साथ $p\text{-value} < 0.01$ पर ऋणात्मक सहसंबंध पाया

गया। बीएजेड और एमयूएसी के मध्य सहसंबंध 0.78 पाया गया, $p < 0.01$ । एमयूएसी की समग्र संवेदनशीलता, विशिष्टता और एयूसी क्रमशः 0.89, 0.94 और 0.92 पाई गई। ये निष्कर्ष संकेत करते हैं कि सीमित संसाधनों वाली परिस्थितियों में बीएजेड-आधारित शरीरमितीय आकलन के कम-लागत विकल्प के रूप में एमयूएसी का निदानात्मक प्रदर्शन अच्छा है। तदनुसार, किशोरियों में बीएजेड-आधारित शरीरमितीय आकलन के व्यावहारिक स्क्रीनिंग विकल्प के रूप में एमयूएसी उपयोगी हो सकता है, और एमयूएसी-आधारित वर्गीकरण जनसंख्या-स्तरीय डीबीएम निगरानी का समर्थन कर सकता है। एमयूएसी और बीएजेड के मध्य प्रबल सहसंबंध, ऊँचाई और वजन-आधारित आकलन के स्थान पर एमयूएसी की क्षेत्र-अनुकूल विकल्प के रूप में उपयोगिता का समर्थन करता है, जिससे तकनीकी और वित्तीय बोझ कम होता है। इसी प्रकार, रैंडम फॉरेस्ट विश्लेषण में डीडीएस का प्रबल महत्त्व तथा बीएजेड के साथ उसका धनात्मक संबंध यह इंगित करता है कि आहार-विविधता, डीबीएम की व्यापकता का प्रत्यक्ष माप होने के बजाय, पोषण-स्थिति का एक महत्वपूर्ण पूर्वानुमानक है। बहु-क्षेत्रीय हितधारकों के विश्लेषण से विकसित रूपरेखा के परिणामस्वरूप एक साक्ष्य-आधारित, सरल, उपयोगकर्ता-केंद्रित, अनुकूलनीय तथा समग्र एकीकृत डीबीएम निगरानी प्रणाली प्राप्त हुई। परिणामी रूपरेखा साक्ष्य-आधारित, उपयोगकर्ता-केंद्रित, अनुकूलनीय थी तथा इसे आगत, प्रक्रियाएँ, निर्गत, परिणाम और निरंतर सुधार के लिए एक प्रतिपुष्टि-चक्र के इर्द-गिर्द संरचित किया गया था। इस अध्ययन ने जनसंख्या-स्तरीय डीबीएम निगरानी के समर्थन हेतु एक लागत-प्रभावी और दक्ष स्क्रीनिंग उपकरण की पहचान की, तथा हितधारक विश्लेषण ने एक नवीन एकीकृत डीबीएम निगरानी रूपरेखा के विकास में योगदान दिया। यह साक्ष्य-आधारित उपागम डीबीएम के विरुद्ध निवारक कार्रवाई का समर्थन कर सकता है, स्वास्थ्य-प्रणाली पर बोझ को कम कर सकता है, तथा सीमित संसाधनों वाली परिस्थितियों में जनसंख्या-स्तरीय निगरानी को सुदृढ़ कर सकता है।

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List of Abbreviations

Abbreviation	Full Form
AOR	Adjusted Odds Ratio
AUC	Area Under the Curve
AWC	Anganwadi Centre
AWW	Anganwadi Worker
BAZ	Body Mass Index (BMI) for age Z score
BMI	Body Mass Index
CAB	Anthropometric and Bio-Chemical
CDC	Centers for Disease Control and Prevention
CI	Confidence Interval
CNNS	Comprehensive National Nutrition Survey
DALYs	Disability Adjusted Life Years
DBM	Dual Burden of Malnutrition
DDAs	Double Duty Actions
DDS	Dietary Diversity Score
DHS	Demographic and Health Surveys
DLHS	District Level Household Survey
FAO	Food and Agriculture Organization
FFQ	Food Frequency Questionnaire
FP	False Positives
FPR	False Positive Rate
GHO	Global Health Observatory
HICs	High-Income Countries
LMICs	Low and Middle-Income Countries
MDG	Mean Decrease Gini

MET	Metabolic Equivalent of Task
MICS	Multiple Indicator Cluster Surveys
MoHFW	Ministry of Health and Family Welfare
MUAC	Mid Upper Arm Circumference
NCDs	Non-Communicable diseases
NFHS	National Family Health Survey
NNMB	National Nutrition Monitoring Bureau
OR	Odds Ratio
RFs	Risk Factors
RO	Reverse Osmosis
ROC	Receiver Operating Characteristic
RSoC	Rapid Survey on Children
RUF	Ready-to-Use Food
SD	Standard Deviation
SDG	Sustainable Development Goals
SES	Socio-economic Status
SOFI	The State of Food Security and Nutrition
SSB	Sugar-sweetened Beverages
TP	True Positives
TPR	True Positive Rate
UN	United Nations
UNICEF	United Nations Children's Fund
UPF	Ultra Processed Foods
WASH	Water, Sanitation, and Hygiene
WHO	World Health Organization