ISSN : 2349-6495(P) | 2456-1908 (O)

International Journal of Advanced Engineering Research and Science

(IJAERS)

An Open Access Peer-Reviewed International Journal

Journal DOI: 10.22161/ijaers

Issue DOI: 10.22161/ijaers.117

AI PUBLICATIONS

Vol.- 11 | Issue - 7 | Jul 2024

editor.ijaers@gmail.com | editor@ijaers.com | https://www.ijaers.com/

International Journal of Advanced Engineering Research and Science (IJAERS)

(ISSN: 2349-6495(P)| 2456-1908(O))

DOI: 10.22161/ijaers

Vol-11, Issue-7

July, 2024

Publisher

AI Publication

Email: editor.ijaers@gmail.com; editor@ijaers.com

Web: www.ijaers.com

International Editorial/ Reviewer Board

Editor in Chief

- **Dr. Swapnesh Taterh (Chief-Editor),** Amity University, Jaipur, India

Cheif Executive Editor

- **S. Suman Rajest,** Vels Institute of Science, Technology & Advanced Studies, India chief-executive-editor@ijaers.com

Associate Editors

- **Dr. Ram Karan Singh,** King Khalid University, Guraiger, Abha 62529, Saudi Arabia
- **Dr. Shuai Li,** University of Cambridge, England, Great Britain

Editorial Member

- **Behrouz Takabi,** PhD, Texas A&M University, Texas, USA
- **Dr. Gamal Abd El-Nasser Ahmed Mohamed Said,** Port Training Institute (PTI), Arab Academy For Science, Technology and Maritime Transport, Egypt
- **Dr. Hou, Cheng-I ,** Chung Hua University, Hsinchu Taiwan
- **Dr. Ebrahim Nohani,** Islamic Azad University, Dezful, IRAN.
- **Dr. Ahmadad Nabih Zaki Rashed,** Menoufia University, EGYPT
- **Dr. Rabindra Kayastha ,** Kathmandu University, Nepal
- **Dr. Dinh Tran Ngoc Huy,** Banking and Finance, HCM, Viet Nam
- **Dr. Engin NAS,** Duzce University, Turkey
- **Dr. A. Heidari,** California South University (CSU), Irvine, California, USA
- **Dr. Uma Choudhary,** Mody University, Lakshmangarh, India
- **Dr. Varun Gupta,** National Informatic Center, Delhi, India
- **Dr. Ahmed Kadhim Hussein,** University of Babylon, Republic of Iraq
- **Dr. Vibhash Yadav,** Rajkiya Engineering College, Banda. UP, India
- **Dr. M. Kannan,** SCSVMV University, Kanchipuram, Tamil Nadu, India
- **José G. Vargas-Hernández,** University of Guadalajara Periférico Norte 799 Edif. G201-7, Núcleo Universitario Los Belenes, Zapopan, Jalisco, 45100, México
- **Dr. Sambit Kumar Mishra,** Gandhi Institute for Education and Technology, Baniatangi, Bhubaneswar, India
- **DR. C. M. Velu,** Datta Kala Group of Institutions, Pune, India
- **Dr. Deependra Pandey,** Amity University, Uttar Pradesh, India
- **Dr. K Ashok Reddy,** MLR Institute of Technology, Dundigal, Hyderabad, India
- **Dr. S.R.Boselin Prabhu,** SVS College of Engineering, Coimbatore, India
- **N. Balakumar,** Tamilnadu College of Engineering, Karumathampatti, Coimbatore, India
- **R. Poorvadevi,** SCSVMV University, Enathur, Kanchipuram, Tamil Nadu, India
- **Dr. Subha Ganguly,** Arawali Veterinary College, Sikar, India
- **Dr. P. Murali Krishna Prasad,** GVP College of Engineering for Women, Visakhapatnam, Andhra Pradesh, India
- **Anshul Singhal,** Bio Instrumentation Lab, MIT, USA
- **Mr. Lusekelo Kibona,** Ruaha Catholic University, Iringa, Tanzania
- **Sina Mahdavi,** Urmia Graduate Institute, Urmia, Iran
- **Dr. N. S. Mohan,** Manipal Institute of Technology, Manipal, India
- **Dr. Zafer Omer Ozdemir,** University of Health Sciences,Haydarpasa, Uskudar, Istanbul, TURKIYE
- **Bingxu Wang,** 2721 Patrick Henry St Apt 510, Auburn Hills, Michigan, United States

Vol-11, Issue-7, July 2024
(10.22161/ijaers.117)

Detail with DOI (CrossRef)

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-7; Jul, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.117.1

Health of informale female caregivers of dependent older adults

Maria Regina Teixeira Ferreira Capelo[1], Rita Maria Baptista Lemos Silva[2], António José de Olim Marote Quintal[3], Christina César Praça Brasil[4], João André Ferreira Capelo[5], Ellen Synthia Fernandes de Oliveira[6], Raimunda Magalhães Silva[7]

[1]Centro de Línguas e Literaturas Lusófonas e Europeias, Universidade de Lisboa, Portugal
Email: m.regina.capelo@gmail.com
[2]Escola Superior de Saúde, Universidade da Madeira, Portugal
Email : ritamlbsilva@hotmail.com
[3]Serviço de Saúde da Região Autónoma da Madeira (SESARAM), Hospital Dr. Nélio Mendonça, Portugal
Email: ajdomq@gmail.com
[4]Programa de Pós-Graduação em Saúde Coletiva, Universidade de Fortaleza, Brasil
Email : cpraca@unifor.br
[5]Centro de Medicina Física e Reabilitação de Alcoitão, Portugal
Email: joao.andre.capelo@gmail.com
[6] Programa de Pós-Graduação em Saúde Coletiva, Universidade de Goiás, Brasil
Email : ellen@ufg.br
[7]Programa de Pós-Graduação em Saúde Coletiva, Universidade de Fortaleza, Brasil
Email: rmsilva@unifor.br

Received: 07 May 2024,

Receive in revised form: 12 Jun 2024,

Accepted: 22 Jun 2024,

Available online: 02 Jul 2024

Keywords*— *Caregiver´s health, frail older adult, informal caregivers.

***Abstract*—** *To describe the self-perceived health of informal female caregivers when caring for dependent older adults at home. Methods: This descriptive, exploratory, quantitative-qualitative included ten females with a mean age of 54 years residing in a Portuguese insular context. The data collection tool was a questionnaire survey with one open-ended question about feelings and a scale about symptoms. Results: Ethical and moral issues, the duty to reward those providing care, the nobility of caring, and benefits for the dependent older adults sustain positive feelings, while negative feelings concern caregivers, namely, routine changes, misunderstanding, distress, anguish for witnessing irreversible transformations of the person cared for, and harm to health. The perceived physical and psychological symptoms (in descending order per the observed means) were tiredness, physical and mental exhaustion, general fatigue, decreased strength and endurance, nervousness, irritability, anxiety and insomnia, back pain, stomach pain, and depression. Conclusions: This study did not explore the impact of the COVID-19 pandemic situation on the health of the participants but showed that caring for dependent older adults at home strongly impacts the life and health of informal caregivers. The feelings and symptoms perceived by informal caregivers can also affect the lives of dependent older adults. An accurate assessment of the event in the region is crucial to increase effective public policies aimed at informal caregivers, a group increasingly essential in an aging contemporary society.*

I. INTRODUÇÃO

Os idosos, na atualidade, representam 12% da população mundial sendo previsível a duplicação deste quantitativo até 2050[1]. Uma realidade marcante na Região Autónoma da Madeira pautada pelo crescente decréscimo do peso relativo dos jovens e de adultos em idade ativa[2]. Este território insular português, com 254 000 habitantes, apresenta 17% (N= 43 177) da população com 65 anos e mais, índice de envelhecimento de 129,50% e índice de dependência dos idosos de 24,30%[2]. A região ostenta um elevado envelhecimento demográfico, mantém acentuada taxa negativa de crescimento natural (+0,31) e um crescente número de pessoas longevas. Assim sendo, existe a probabilidade da região englobar na sua população um elevado número de idosos dependentes, que permanecem no seu domicílio, sujeitas ao apoio permanente de um cuidador.

A diversidade de tarefas efetuadas pelo cuidador informal, diariamente, traduz-se numa sobrecarga severa que o impacta negativamente, afetando a saúde, o trabalho, bem como as atividades sociais indispensáveis ao seu bem-estar[3]. Essas funções incluem a prestação de cuidados, a relação interpessoal, as expectativas face ao cuidar e a perceção de autoeficácia dos cuidados prestados[4]. Neste sentido, o cuidado integral disponibilizado à díade - idoso dependente e respetivo cuidador, demanda soluções assistenciais específicas do sistema de saúde e centradas na atenção domiciliar, facilitadoras do acesso ao auxílio interprofissional qualificado, promotor de saúde e preventivo de doenças[5,6]. Requere, também, suporte emocional e aprendizagem de processos[7] adequados, cruciais para quem cuida e para quem é cuidado.

A Organização Mundial de Saúde[8] assinala que o crescente envelhecimento da população mundial tem concorrido para o acréscimo do número de pessoas idosas com progressiva dependência funcional. No entanto, o envelhecimento humano é um processo normal, progressivo e irreversível que ocorre ao longo da vida[8,9], relacionado com o surgimento de doenças crónicas incapacitantes[10] e à decadência das capacidades físicas e mentais do indivíduo[8]. Compreende perda de autonomia e independência e restringe a capacidade de autocuidado, compromete a qualidade de vida e dá origem a relações de subordinação que interferem nos processos de interação social do idoso[11]. Neste contexto, cada vez mais, elementos da família, amigos e vizinhos, assumem o papel de cuidadores informais, prestando os cuidados ao idoso dependente na modalidade *pro bono*[12,13]. A relação entre o cuidador e a pessoa cuidada é sobretudo filial e conjugal[10,13,14], evidenciada pela desigualdade de género[6,15], pela proximidade física e emocional com o idoso, pela prestação permanente e solitária dos cuidados, sem auxílio estatal, marcada por restrições na vida pessoal, sobrecarga de trabalho, adoecimento, desemprego e escassa interação social e afetiva[6,16].

Em reconhecimento do papel do cuidador informal, nos últimos tempos, diversos países legislaram com o objetivo de atenuar as vulnerabilidades concernentes ao processo de cuidar. Neste domínio, o Reino Unido defende o aconselhamento, o registo e a capacitação do cuidador ao exigir que os hospitais sinalizem os cuidadores familiares, que são informados dos planos relacionados com a alta do paciente familiar e, consequentemente, formados para prestarem os necessários cuidados no domicílio[17]. Em 2019, também Portugal continental e as Regiões Autónomas dos Açores e da Madeira, criaram o Estatuto do Cuidador Informal que estatuem os direitos e os deveres do cuidador e da pessoa cuidada, e determinam as medidas de apoio[18-20]. Após a aplicação de um projeto piloto, a subsequente regulamentação, será publicada, indiciando que, apenas, uma exígua franja da população tem sido abrangida por tal Estatuto.

Entender o fenómeno em apreço poderá facultar informações adicionais que venham a contribuir para socorrer intervenções assistenciais direcionada para este grupo populacional. Neste sentido, o objetivo deste estudo consiste em descrever a auto perceção da saúde de cuidadores informais ao cuidarem de idosos dependentes no domicílio, inseridos na especificidade situacional de um contexto insular, sobre a própria saúde, de forma a identificar sentimentos e sintomas que avaliam como resultantes da sua atividade quotidiana.

II. MÉTODO

Design

Este estudo descritivo e de carácter exploratório procura aceder à essência dos fenómenos a partir das vivências experienciadas e relatadas pelos próprios participantes e só pode ser compreendida em situação contextual. Este recorte da pesquisa adotou uma abordagem quali-quantitativa, no seu âmbito, procurando trazer à luz dados, indicadores e tendências observáveis. A componente qualitativa socorre-se dos valores, das crenças e das representações dos participantes, enquanto a quantitativa descreve numericamente o fenómeno avaliado[21]. Crê-se que, no seu âmbito, a modalidade qualitativa e quantitativa complementa-se, conforma e patenteia a essência do fenómeno e a significação que as cuidadoras informais lhe atribuem, isto é, oferece uma visão mais holística do objeto de estudo.

Participantes

Participaram dez cuidadoras informais, todas do sexo feminino e faixa etária entre 35 a 79 anos de idade (M=

53,60; DP= 11,52). A duração da prestação de cuidados ao idoso dependente varia entre 1 ano e sete anos (1 ano-1; 2 anos – 1; 3 anos – 3; 5 anos – 3; 7 anos – 2).

O estudo empírico realizou-se numa região insular portuguesa, demograficamente envelhecida, em concreto, na Região Autónoma da Madeira. As participantes residem no litoral sul da ilha da Madeira onde se concentra a maioria da população madeirense. Na constituição da amostra não probabilística utilizou-se a estratégia metodológica *snowball sampling* ou "Bola de Neve"[2]. Esta técnica ocorre quando um participante-chave indica outros participantes que se alinham aos critérios de inclusão do estudo e viabilizam o acesso e a interpretação profícua aos conteúdos em apreciação. Por ter sido atingida a saturação dos dados, considerou-se dispensável prosseguir com a aplicação de mais questionários.

Foram eleitos os seguintes critérios de inclusão: ser o principal familiar cuidador de idoso dependente, ter idade superior a 18 anos, residir na Ilha da Madeira, Portugal e estar disponível para participar no estudo.

Procedimento

O primeiro contacto social com uma informante-chave serviu para a exposição do estudo e solicitar a sua colaboração no sentido de indicar outros cuidadores que contribuíssem para a composição da amostra. A situação pandémica do COVID-19, obrigou a população ao confinamento. Por isso, o contacto com os participantes foi efetuado por e-mail, em dezembro de 2020.

Os participantes responderam a um questionário constituído por três partes distintas: I) Perfil sociodemográficos (sexo, idade e tempo de cuidados/dependência do idoso); II) Um recorte qualitativo com a questão "Quais são os principais sentimentos que marcam a sua vida como cuidador informal?" e III) Questões referentes a sintomas que podem ser percecionados pelos cuidadores informais de idosos dependentes no processo de cuidar, tais como, "excesso de esgotamento", "fadiga geral", "dores nas costas", "dores no estômago", "esgotamento físico e mental", "diminuição das forças e da resistência", "nervosismo", "irritabilidade", "ansiedade", "insónias" e "estado depressivo", sendo respondidos numa Escala Likert de cinco pontos (0 – nenhum; 1 – pouco; 2 – moderado; 3 – bastante; 4 - elevado).

Os participantes foram convidados a subscreverem um termo de consentimento livre e esclarecido (TCLE) e a responderem ao instrumento de recolha de dados. As respostas ao questionário, bem como o TCLE consentimento livre foram devolvidas até ao final de janeiro de 2021, num mesmo envelope, devidamente fechado.

Neste processo, os procedimentos éticos foram cumpridos, designadamente, a proteção dos participantes quanto a danos físicos ou mentais, o direito à privacidade do seu comportamento, a participação integralmente voluntária e informação prévia dos objetivos do estudo[23]. O estudo teve aprovação do comitê de ética da Fundação Oswaldo Cruz, mediante o parecer n. º 1.326.631. Os dados obtidos foram tratados de forma anónima e confidencial, protegidos ao abrigo do Regulamento (EU) 2016/679 do Parlamento Europeu e do Conselho de 27 de abril de 2016[24] e a Lei n. º 58/2019 de 8 de agosto de 2019[25], que garante a sua realização de acordo com a disposição jurídica nacional.

Análise dos dados

Todos os questionários foram identificados pela letra Q seguida da numeração relativa ao número de participante (Q1 a Q10) tendo em vista a garantia do anonimato e a confidencialidade dos dados.

Socorremo-nos de técnica de análise de conteúdo para o tratamento dos dados qualitativos, extraídos do testemunho das participantes. Foram ponderadas as significações (conteúdos) ordenadas, classificadas e analisadas segundo os pressupostos da hermenêutica-dialética[26]. Foi usada uma abordagem indutiva e, aquando da codificação, ressaltou-se a frase como unidade de análise. Tendo em conta o reduzido número de participantes, não houve recurso a artefactos tecnológicos. As técnicas de análise de dados assentaram na leitura acurada de todos os testemunhos das participantes para apreensão dos sentimentos associados ao fenómeno. A validade interna incluiu a leitura compreensiva e minuciada entre investigadores que reapreciaram as respostas das participantes e, extraíram, as aceções emergentes. Neste âmbito procedeu-se à triangulação das diversas perceções e interpretações de dois investigadores para aclarar cada significado. Realizou-se uma construção interpretativa singular, envolvida na relação entre o contexto empírico particular e o olhar subjetivo do pesquisador. Por fim, os achados apreciados, perfilados com as questões de pesquisa e com o objetivo do estudo, foram confrontados com outros estudos científicos, a fim de outorgar um suporte fidedigno ao estudo. Complementarmente, a validade do constructo de investigação efetuada assentou na submissão ao olhar atento das participantes e dos coautores, do relatório que espelha o fenómeno em estudo.

A análise descritiva dos dados quantitativos, presente neste estudo, visa essencialmente relatar as caraterísticas da amostra e responder à questão de investigação alusiva aos sintomas percecionados pelas participantes[27]. Essencialmente, resume um conjunto de dados extraídos de uma amostra, para que sejam facilmente

compreendidos, tanto pelo investigador como pelo leitor[21].

O instrumento incluiu um conjunto de questões a serem respondidas numa Escala Likert. Neste seguimento, valemo-nos da média (M) como medida de tendência central, pelo facto de ser considerada a única que, no cálculo, inclui todos os *scores* de uma distribuição. Por sua vez, a distância de cada um dos *scores* em relação à média do grupo foi verificada por meio do desvio padrão (DP). Esta medida de dispersão ou de variabilidade representa a raiz quadrada da variância e tem em conta todos os valores de uma distribuição e, consequentemente, fornece indicações sobre a forma como os *scores* se distribuem em torno da média. Os dados quantitativos foram processados no software SPSS, versão 20.0. para obtenção da média e do desvio padrão de cada um dos itens quantitativos[27], relativos às questões alusivas aos sintomas percecionados e avaliados pelos participantes.

III. RESULTADOS E DISCUSSÃO

As perceções das cuidadoras informais de idosos dependentes, são apresentadas sequencialmente, surgindo em primeiro lugar a análise referente aos resultados qualitativos seguida da análise quantitativa. Logo, desde uma narrativa analítica, subjetiva, num nível de análise de conteúdo sobre os depoimentos concedidos, ressaltaram múltiplos sentimentos que marcam a vida do cuidador informal do idoso dependente. Por conseguinte, os sintomas reportados pelas cuidadoras informais de idosos dependentes emergem descritos e mensurados pelos respetivos valores médios e ilustrados pela respetiva medida de dispersão - o desvio padrão. Concomitantemente, os achados são confrontados ou contrastados com outros referenciais teóricos sobre o tema em análise.

Sentimentos que marcam a vida do cuidador informal do idoso dependente

Diversos são os sentimentos positivos e negativos vivenciados pelos participantes no desempenho do seu papel de cuidador informal de idoso dependente reportados nas narrativas das participantes. A perceção de aspetos benéficos e gratificantes de ser cuidador está no juízo formado sobre a nobreza da ação para com o idoso dependente ao assinalarem que:

> *"(...) Tem a parte positiva, que sabemos que estamos a fazer o nosso melhor e ter uma atitude muito nobre para com o idoso dependente" (Q6).*

Portanto, uma componente importante respeita ao dever de cuidar de quem já cuidou. Esta premissa constitui um valor fundamenta[14]. A satisfação pessoal, o sentimento de dever cumprido, a preocupação com o bem-estar, a tranquilidade pelo facto de o idoso estar bem cuidado e o reforço do vínculo afetivo são vivenciados pelo cuidador informal[28]. Apesar da sobrecarga que a prestação de cuidados ao idoso dependente transporta, o cuidador consegue nutrir sentimentos de solidariedade, amor e carinho por gostar de quem cuida[29], que são emocionalmente gratificantes, traduzindo-se numa perspetiva pessoal enriquecedora[4].

A pesquisa de Machado et al.[30], também expôs a presença de sentimentos frente aos problemas quotidianos do cuidador de familiares com doenças crónicas. Neste domínio, apontam perceção positiva perante sentimentos benéficos decorrentes dos cuidados e perceção negativa devido às alterações na vida laboral. Questões afetivas, éticas e morais apoiam a assunção do papel de cuidador[15], numa ambivalência entre as perceções psicológicas positivas e negativas, conforme revelam os seguintes testemunhos:

> *"Não diria negativos, pois muda a nossa rotina, mas fazemos por eles o que já fizeram por nós. E isso não creio que seja negativo, mas sim um crescimento pessoal" (Q9).*
> *"O cuidador informal experimenta sentimentos que, muitas vezes, são indescritíveis, mas o maior é o de impotência, imprevisibilidade e esgotamento/cansaço" (Q5).*

Cuidar gera um quotidiano adverso e desencadeia sofrimento no cuidador[30]. O dever de retribuir, o compromisso familiar e uma multiplicidade de sentimentos díspares invadem o quotidiano do cuidador. Os testemunhos dos participantes expressam:

> *"Cansaço, diminuição de forças e de resistência e irritabilidade" (Q1).*
> *"Tristeza profunda, stresse, ansiedade, angústia, desalento, nervosismo, culpa, sentimento de impotência" (Q4).*
> *"Impaciência, tristeza, desespero, revolta, apatia, depressão" (Q8).*
> *"Por vezes sentimos medo, solidão e tristeza e alguma insegurança" (Q6).*

Esses aspetos são intensificados com o incremento da dependência funcional do idoso como revela uma participante:

> *"É ver o desgaste dia após dia de alguém que amamos, é angustiante e um medo de perda"* (Q9).

Sentimentos de incompreensão, de não ser ouvido e constatação da ausência de suporte, indiciam desgaste e revelam a necessidade de uma rede de apoio e proteção ao cuidador informal[15], designadamente: "O não ser entendido, compreendido e muitas vezes não ser ouvido nos pedidos de socorro, porque o cuidador também fica doente, cansado, deprimido e muitas vezes precisa de ajuda também" (Q10).

Tais experiências vivenciadas ininterruptamente, prolongadas no tempo, podem causar danos na saúde do cuidador[15]. Contudo, o efeito no stresse do indivíduo decorre da avaliação subjetiva que o indivíduo elabora sobre si, a partir dos recursos pessoais, sociais, culturais e até relacionais de que dispõe[30,31]. Essas questões narradas pelos participantes sugerem a necessidade de atenção à saúde mental visando prevenir, mitigar ou recuperar as vulnerabilidades que afetam o cuidador informal no seu quotidiano.

Sintomas percecionados pelas cuidadoras informais de idosos dependentes

Os resultados assinalam que o excesso de cansaço advindo da prestação de cuidados ao idoso dependente, situa um participante no nível moderado, cinco no nível bastante e quatro no nível elevado (M= 3,30; DP= 0,68). Resultado idêntico é evidenciado para a fadiga no geral em que dois participantes indicam nível moderado, quatro bastante e quatro elevado (M= 3,20; DP= 0,79). Quanto à diminuição das forças e da resistência, observou-se quatro no nível moderado, três no nível bastante e três no nível elevado (M= 2,90; DP= 0,88).

Em relação aos sintomas físicos, associados a dores nas costas, dois não reportam sintomas, um indica nível baixo, três nível moderado, um nível bastante e quatro nível elevado (M= 2,20; DP= 1,55); e, quanto a dores no estômago, quatro não indicam sintomas, dois referem nível baixo, um nível moderado, um nível bastante e dois nível elevado (M= 1,50; DP= 1,65).

No concernente aos sintomas percecionados pelos cuidadores informais relacionados com a saúde mental, os resultados revelam esgotamento físico e mental, sendo que, dois dos participantes percecionam nível moderado, cinco indicam nível bastante e três nível elevado (M= 3,10; DP= 0,74); quanto ao nervosismo, um participante indica nível baixo, três nível moderado, cinco no nível bastante e um nível elevado (M= 2,60; DP= 0,84); no referente à irritabilidade, um indica nenhuma, dois pouca, um moderada, cinco bastante e um elevada (M= 2,50; DP= 1,08); no sintoma ansiedade, um participante indica nenhuma, três moderada, um, bastante e três elevada (M= 2,50; DP= 1,08); um participante responde que não tem insónias, um assinala o nível poucas, três o nível moderadas e um nível elevado (M= 2,50; DP= 1,35); relativamente ao estado depressivo, três participantes não percecionam, dois indicam nível baixo, um nível moderado, três nível bastante e um nível elevado (M= 1,50; DP= 1,65).

Os dados corroboram a literatura internacional, que aponta implicações negativas na saúde do cuidador pelo impacto que imprime na prestação de cuidados, na relação interpessoal, nas expectativas face ao cuidar e na perceção de autoeficácia[4]. Essas implicações na saúde podem ser: psicológicas, como ansiedade, depressão, angústia, insónia, ressentimento e despersonalização; físicas, nomeadamente cansaço e dores; sociais, como isolamento, ausência de lazer e descuido com a aparência; laborais, a exemplo da sobrecarga, desempenho ineficaz, menor apoio e insegurança relativamente ao cuidado; e, ainda, económicas, como renda prejudicada e aumento de gastos com o idoso[13]. Portanto, a vivência quotidiana tende a erodir a vida do cuidador informal[32], imprime sobrecarga e desgaste emocional, tem repercussões na qualidade de vida e, especialmente, demanda apoio e capacitação[7] condizentes com as reais necessidades deste estrato populacional.

Os resultados obtidos a partir de uma amostra reduzida, não probabilística e de achados assentes nas representações das participantes não se prestam à generalização. Por isso, as asserções extraídas neste estudo, para obterem validação externa, necessitam de replicação através de novas pesquisas individuais e respetiva aplicação em diferentes contextos sociais, geográficos e globais. No entanto, a súmula do conhecimento obtido, que versa aspetos cruciais inerentes à díade cuidador informal – idoso dependente, poderá confluir para o reconhecimento da complexidade do ato de cuidar, a valorização do papel de cuidador informal, a criação de redes de suporte e de recursos, a disponibilização de equipamentos, a construção de programas ou de tecnologias educativas tendentes à formação e à orientação do cuidador informal, a sensibilização dos jovens para a possibilidade de, no futuro, terem de assumir o papel de cuidadores informais, a inclusão de tecnologias associadas à prestação de cuidados a pessoas dependentes no currículo escolares e o aprimoramento de políticas públicas centradas no cuidado ao cuidador.

IV. CONCLUSÕES

Diversas fragilidades decorrentes da prestação de cuidados a idosos dependentes assinalam implicações negativas a nível da saúde física e psicológica das cuidadoras informais. De facto, além de percecionarem sentimentos positivos, benéficos e gratificantes, no seu dia-a-dia, vêm-se numa ambivalência, assoladas por um

extenso manancial de sentimentos negativos que, quando continuados ao longo do tempo, impactam a sua saúde.

Os cuidados primordiais ao idoso dependente compreendem o atendimento e a satisfação das necessidades básicas humanas. Desta forma, o idoso é beneficiado por cuidados mais humanizados, no próprio lar e, sobretudo, imersos numa relação de confiança e afeto.

Por outro lado, vários aspetos relacionados com a promoção da saúde do cuidador informal de idosos dependentes foram descortinados, nomeadamente, a importância do apoio domiciliário estatal, a coadjuvação, o apoio psicológico, a educação para a saúde, a educação para o cuidado e as relações de cuidado para com o idoso dependente. Também salienta as dificuldades financeiras e a conciliação da vida profissional e da vida de cuidador.

Os achados descrevem um quadro complexo de sentimentos e sintomas percecionados e reportados pelas cuidadoras informais de idosos dependentes. Os testemunhos cedidos foram baseados na experiência vivida. Estes dados apoiam a noção de que os benefícios para o idoso dependente são indubitáveis, mas, em contrapartida, denunciam que as cuidadoras poderão estar a assumir um fardo que, ao longo do tempo, produz efeitos nocivos na saúde.

Este estudo obteve achados preocupantes acerca da saúde das cuidadoras informais. Como a sua prática é pautada pela interação, os sentimentos e os sintomas percecionados pelas cuidadoras, consequentemente, afetam a pessoa cuidada. Assim sendo, os achados configuram-se importantes para a elaboração e implementação de políticas públicas tendentes à redução dos impactos da função na saúde das cuidadoras e na qualidade de vida dos idosos, principalmente em regiões demograficamente envelhecidas.

Concomitantemente, a situação pandémica do COVID-19 promoveu a descontinuidade do acesso aos cuidados de saúde. Porém, este estudo não explorou o impacto da situação pandémica do COVID-19 na saúde das participantes ou no bem-estar dos idosos dependentes, mas revelou que cuidar do idoso dependente no domicílio impacta fortemente a vida e a saúde do cuidador informal.

Esta evidência afetou as populações mais vulneráveis, entre as quais se inclui a díade cuidador informal – idoso dependente. Neste seguimento, intervenções diversas, urgentes, firmes e coordenadas, tendo em vista o bem-estar do cuidador e do idoso dependente, são indispensáveis. Ressalta-se, nesse domínio, que a aplicação do Estatuto do Cuidador Informal poderá concorrer para uma atenção especial às especificidades do envelhecimento e para a melhoria da equidade em saúde na Região Autónoma da Madeira. Recomenda-se a realização de novos estudos que permitam aferir o impacto da implementação generalizada dos normativos, recentemente publicados e regulamentados, na saúde do cuidador informal e no bem-estar do idoso dependente.

Destaca-se, também, o autocuidado do cuidador. Para tal, é de salientar a capacidade de evocar a cooperação de outras pessoas, designadamente da família alargada, de amigos ou profissionais de saúde; a capacidade de recorrer aos serviços sociais e aos serviços de saúde; de aceder a informação e a recursos, potenciando o fortalecimento das redes de apoio. Estas ações, provavelmente, diminuirão a carga associada à tarefa de cuidar do idoso dependente e, possivelmente, tornar-se-á eficaz na minoração dos sentimentos negativos e dos sintomas patogénicos que impactam a saúde das participantes e que, consequentemente, afetam o bem-estar dos idosos dependentes. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

AGRADECIMENTOS

Os autores agradecem a todas as cuidadoras informais que participara neste estudo.

REFERÊNCIAS

[1] Suzman, R., Beard, J. R., Boerma, T., & Chatterji, S. (2015). Health in an ageing world: what do we know? *Lancet*, 9967(385), 484-6. https://doi.org/10.1016/S0140-6736(14)61597-X

[2] Instituto Nacional de Estatística (Pt). (2022). *Estatísticas demográficas: 2019* [Internet]. Lisboa: IN [acesso em 10 ago. 2022]. Disponível em: https://www.ine.pt/xurl/pub/71882686

[3] Kong, Y-L., Anis-Syakira, J., Jawahir, S., Tan, Y. R., Rahman, N. H., & Tan, E.H. (2021). Factors associated with informal caregiving and its effects on health, work, and social activities of adult informal caregivers in Malasia: findings from the National Health and Morbidity Survey 2019. *BMC Public Health*, 21,1033. https://doi.org/10.1186/s12889-021-11022-1

[4] Mónico, L. S. M., Custódio, J. R., Frazão, A. A., Parreira, P., Correia, S., & Fonseca, C. (2017). A família no cuidado aos seus idosos: gestão da sobrecarga e estratégias para enfrentar as dificuldades. *RIASE*, 3(2), 908-98. http://dx.doi.org/10.24902/r.riase.2017.3(2).982

[5] Brasil, C. C. P., Silva, R. M., Bezerra, I. C., Vieira, J. E. S., Figueiredo, M. L. F., Castro, V. F., Queiroz, F. F. S. N., Capelo, M. F. T. F. (2021). Percepções de profissionais sobre o agente comunitário de saúde no cuidado ao idoso dependente. *Ciência & Saúde Coletiva*, 26(1), 109-18. https://doi.org/10.1590/1413-81232020261.31992020

[6] Ceccon, R. F., Vieira, L-J. E. S., Brasil, C. C. P., Soares, K. G., Portes, V. M., Garcia Júnior, C. A. S., Schneider, I. J. C., & Carioca, A. A. F. (2021). Envelhecimento e dependência no Brasil: características sociodemográficas e assistenciais

de idosos e cuidadores. *Ciência & Saúde Coletiva*, 26(1), 17-26. https://doi.org/10.1590/1413-81232020261.31992020

[7] Couto, A. M., Caldas, C. P., Castro, E. A. B. (2019). Cuidado domiciliar a idosos dependentes de cuidadores familiares com sobrecarga e desconforto emocional. Revista Pesquisa: Cuidado é Fundamental, 11(4), 944-50. https://ciberindex.com/c/ps/P944950

[8] World Health Organization (2015). *World Report on Ageing and Health.* Geneva: WHO Library.

[9] Galado, M. (2018). *Serpa promove a qualidade de vida dos cuidadores informais!* [dissertação]. Évora: Universidade de Évora. [acesso em 20 ago. 2022]. Disponível em: http://hdl.handle.net/10174/23529

[10] Rozin, L., Santos, A. C., Silva, J. O. M., Makuch, M. V., & Matia, G. (2017). Sobrecarga do cuidador familiar do idoso dependente. *Espaçopara a Saúde*, 18(2), 55-62. https://doi.org/10.22421/15177130-2017v18n2p55

[11] Moraes, E. M. (2012). *Atenção à saúde do idoso: aspectos conceituais.* Brasília: Organização Pan-Americana da Saúde.

[12] Cuidadoresportugal (2002). *Vila Nova de Gaia: Cuidadores Portugal* [acesso em 10 ago. 2022]. Disponível em: www.cuidadoresportugal.pt

[13] Melo, J. S., Curado, H. T. A. M., Silva, K. A., Brandão, M. L., Brandão, M. L., Simonini, N. D, et al. (2019). O estresse do cuidador de idosos dependentes. *Resu - Revista Educação em Saúde*, 7(2), 70-85.

[14] Pereira, S., & Duque, E. (2017). Cuidar de idosos dependentes: a sobrecarga dos cuidadores familiares. *Revista Kairós*, 20(1), 187-202. https://doi.org/10.23925/2176-901X.2017v20i1p187-202

[15] Sousa, S. G., Silva, R. M., Reinaldo, M. A. S., Soares, S. M., Gutierrez, D. M., & Figueiredo, M. L. F. (2021). "A gente não é de ferro": vivências de cuidadores familiares sobre o cuidado com idosos dependentes no Brasil. *Ciência & Saúde Coletiva*, 26(1), 27-36. https://doi.org/10.1590/1413-81232020261.30172020

[16] Minayo, M. C. S. (2020). Cuidar de quem cuida de idosos dependentes: por uma política necessária e urgente. Ciência & Saúde Coletiva, 26(1), 7-16. https://doi.org/10.1590/1413-81232020261.30872020

[17] The National Archives (UK) [Internet]. (2014). *London: UK Public General Acts*; [citado 2022 Jun 10]. Disponível em: https://www.legislation.gov.uk/ukpga/2014/23/contents/enacted

[18] Portugal. Lei n.º 100, de 6 de setembro de 2019. (2019). Estatuto do Cuidador Informal. *Diário da Republica Eletrónico.* Disponível em: https://data.dre.pt/eli/lei/100/2019/09/06/p/dre/pt/html

[19] Portugal. Decreto N.º 5/2019/M. (2019). Estatuto do cuidador informal da Região Autónoma da Madeira. *Diário da Republica Eletrónico.* Disponível em: https://data.dre.pt/eli/declegreg/5/2019/07/17/p/dre/pt/html

[20] Portugal. Decreto N.º 22/2019/A. (2019). Regime jurídico de apoio ao cuidador informal na Região Autónoma dos Açores. *Diário da Republica Eletrónico.* Disponível em: https://data.dre.pt/eli/declegreg/22/2019/11/05/p/dre/pt/html

[21] Fortin, M-F. (2009). *Fundamentos e etapas do processo de investigação*. Loures: Lusodidacta.

[22] Bockorni, B. R. S., & Gomes, A. F. (2021). A amostragem em snowball (bola de neve) em uma pesquisa qualitativa no campo da administração. *Revista Ciências Empresariais UNIPAR*, 22(1),105-17. https://doi.org/10.25110/receu.v22i1.8346

[23] Feldman, R. (2001). Compreender a Psicologia. New York: McGraw Hill.

[24] União Europeia (2016). Regulamento N.º 2016/679 de 27 de Abril de 2016. *Bruxelas: UE.* Disponível em: https://eur-lex.europa.eu/legal-content/PT/TXT/PDF/?uri=CELEX:32016R0679&from=PT

[25] Portugal. Lei n.º 58/2019, de 8 de agosto de 2019. (2019). Tratamento de dados pessoais. *Diário da Republica Eletrónico.* Disponível em: https://data.dre.pt/eli/lei/58/2019/08/08/p/dre/pt/html

[26] Bardin, L. (1995). *Análise de Conteúdo*. Lisboa: Edições 70.

[27] Pestana, M., Gageiro, J. (2005). *Análise dos dados para Ciências Sociais: a complementaridade do SPSS* (5a ed.). Lisboa: Edições Silabo.

[28] Cruz, D. C. M., Loureiro, H. A. M., Silva, M. A. N., & Fernandes, M. M. (2010). As vivências do cuidador informal do idoso dependente. *Revista Enfermagem Referência*, 3(2), 127-36. https://doi.org/10.12707/RIII1018

[29] Castro, L., Souza, D., Pereira, A., Santos, E., Lomeo, R., & Teixeira, H. (2016). (2016). Competências dos cuidadores informais familiares no autocuidado: autoestima e suporte social. *Investigação Qualitativa em Saúde*, 2, 1346-55. http://www.proceedings.ciaiq.org/index.php/ciaiq2016/article/view/892

[30] Machado, B. M., Dahdah, D. F., Kebbe, L. M. (2018). Cuidadores de familiares com doenças crônicas: estratégias de enfrentamento utilizadas no cotidiano. Cad. Bras. Ter. Ocup., 26(2), 299-313. https://doi.org/10.4322/2526-8910.ctoAO1188

[31] Vaz-Serra, A. (2011). O stress na vida de todos os dias. Lisboa: edição do Autor.

[32] Camargo, R. C. V. F. (2010). Implicações na saúde mental de cuidadores de idosos: uma necessidade urgente de apoio formal. SMAD, Revista Electronica Salud Mental, Alcohol, Drogas, 6(2), 231-54. https://doi.org/10.11606/issn.1806-6976.v6i2p231-254

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-7; Jul, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.117.2

Afrodite Project - Proposal of Biocompatible Nipples for Patients with Breast Cancer and Victims of Accidents

Filippi Benevenutto Ongarelli[1] , Huemerson Maceti[1,2], Júlia Reis Marques[1], Patrícia Dário Bertasso[1], Nicole Isabelle Borge Fernandes[1]

[1]Colégio Puríssimo Coração de Maria – Highschool – Rio Claro/SP - Brazil
[2]FHO - Hermínio Ometto Foundation – Araras/SP – Brazil

Received: 09 May 2024,

Receive in revised form: 15 Jun 2024,

Accepted: 24 Jun 2024,

Available online: 05 Jul 2024

***Keywords*— Nipples, Breast Cancer, 4.0 Technology.**

***Abstract*—** *Through the ages, breasts have played multiple roles, ranging from a source of nourishment to a source of pleasure and a symbol of femininity. The loss of these not only poses challenges of a physical nature but also prominent psychological disturbances, especially when associated with the context of breast cancer. In the current period, it is observed that an estimated contingent of 2.3 million individuals faced this arduous battle in the year 2020 (according to data from INCA - Instituto Nacional de Câncer), a struggle that left a myriad of physical scars and psychological traumas in its wake. Among the painful sequels, the deprivation of the areola stands out, whose reconstruction, unlike the breasts themselves, presents a notably more complex challenge. Regardless of the gender of the affected person and the circumstances that led to the deprivation of that essential part of their integrity, it is imperative that all those who experience such misfortune receive unconditional support. It was in this spirit of solidarity that a meticulously crafted silicone prosthesis was conceived, with the purpose of reproducing the lost areola(s) for those affected by this painful situation. This piece is remarkable in its total customization, adapting precisely to a wide range of models. Nevertheless, it is worth noting that its application does not require surgical procedures, thus enabling the restoration of self-confidence and the sparkle in the eyes of those who have already suffered too much. It is pertinent to emphasize that this innovative endeavor received valuable support from the facilities of the FABLAB "Espaço Maker" of Colégio Puríssimo, equipped with devices such as scanners and 3D printers. With the guidance provided by specialized literature in the areas of reverse engineering, human anatomy, psychoanalysis, art history, and humanity, a deep knowledge was obtained that constituted secure foundations for the practices adopted in this context.*

I. INTRODUCTION

The breasts are crucial parts in the feeding of a newborn, as evidenced during lactation, where mothers secrete milk to breastfeed their infants. In the past, they were not seen as anything more than part of the female body, a fact that can be observed in the sculpture of the

Venus of Willendorf, where there is a striking presence of bare breasts, which were seen as nothing more than fertility symbols. Over time, with the predominance of men in the religious and artistic realms, breasts began to be portrayed in paintings and statues as sexual objects, particularly dating back to Classicism (FAUSTINO, 2023).

However, biologically speaking, breasts are nothing more than a combination of tissues (adipose, connective, and glandular), blood vessels and lymphatics, and nerve fibers (VARELLA, 2023).

ANATOMY OF A FEMALE CHEST

(source: https://www.infoescola.com/anatomia-humana/ glandulas-mamarias/ acesso em 03/03/2023)

Nevertheless, breasts are important parts for women, as evidenced by the increase in searches for implantation and explantation (FACINA, 2023). Losing them is not easy, especially when it does not occur by choice, but due to accidents or cancer - in the latter case, breast reconstruction is provided by the SUS free of charge, but the nipple as a whole is not restored, according to data from the State Health Secretariat.

However, loss also affects men, but while women's loss is widely discussed and addressed, men's is rarely mentioned, which can cause discomfort when they wish to share their experiences.

In summary, everyone deserves support when facing the loss of their breasts, nipples, and/or areolas, after all, accidents or a cancer diagnosis can deeply impact psychological well-being, resulting in feelings of guilt, trauma, isolation, anxiety, and even depression. There are, of course, paid options available, such as tattooing, filling with hyaluronic acid, and even adhesive molds for the skin. However, none of them is completely effective, since tattooing does not restore nipple volume, something highly desired by men and women for situations such as going to the beach, wearing specific clothes. Hyaluronic acid filling can result in adverse reactions and is not a long-term solution (BIERNATH, 2023), while prefabricated molds can be inaccurate, leading to areola asymmetry. In addition, the personalized molding procedure can be uncomfortable and invasive, as it usually involves applying plaster to replicate the breast's structure, which can be aversive for many people who wish to avoid physical contact. Both tattooing and filling involve the use of needles, which can be emotional triggers for some people, given their past experiences.

In summary, although there are alternatives to deal with the loss of the areolas, many people end up not seeking these options, due to the reasons mentioned above and also due to socioeconomic factors, such as lack of resources or concerns about cancer recurrence, among others.

Keeping these needs in mind, the project seeks to create personalized prostheses for the nipple and areola through a process of scanning and 3D printing, eliminating the need for direct contact and needles, which provides greater confidence and privacy, restoring the patient's self-esteem and self-love.

II. OBJECTIVES AND PROJECT RELEVANCE

After a thorough analysis of cases, consultation with specialists, such as the Rio Claro Cancer Support Network, consideration of reports of traffic accidents in which victims had their nipples amputated, and review of various documents and works on the subject, the project for personalized areola prostheses for breast cancer patients or victims of accidents was developed. A common element to all these situations is the profound impact on the psychological state of the individuals affected.

It is worth noting that the cost of the product is quite affordable, and the necessary knowledge for its production was acquired through instructions regarding the use of scanner and 3D printer, 3D modeling, and silicone pigmentation. Furthermore, the materials used are of high quality and have remarkable durability, making the cost-benefit very attractive. Each areola costs R$ 12.00, including all necessary inputs.

This work was driven by the Pink October movement, a period of mobilization and awareness about the fight against breast cancer. Its realization is guided by humanitarian and solidarity objectives, aiming to restore smiles to the faces of those who had lost hope. The project plays a crucial role in improving people's psychological state, helping to combat problems such as depression, anxiety, trauma, and distortions in self-image, all derived from experiences of great impact. This is particularly

relevant in everyday contexts, where both women and men may feel comfortable displaying their bodies and wearing specific clothes. It is important to emphasize that the satisfaction of the project focuses on the people who can benefit from it, and not just on those who observe it.

III. PROJECT DEVELOPMENT

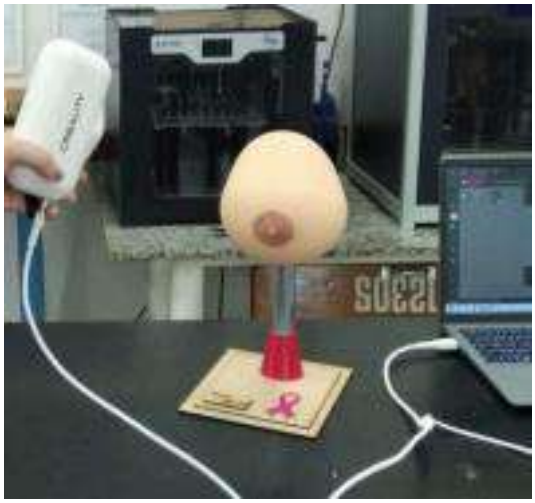
To conduct this study, the reverse engineering technique was employed to simulate the procedure that would be performed on humans. Initially, a breast model was selected from the Thingiverse database (a website with free 3D models for download). This model was then imported into the Tinkercad platform (a free electronic platform for 3D modeling), where the mold was duplicated and the areola was subsequently removed from one of the breasts, thus simulating a patient in the postoperative phase.

Breast's 3D modelling. Source: writers (2023)

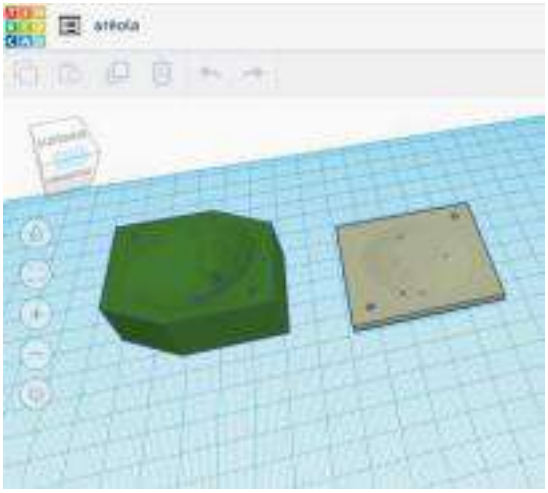
The next step involved the use of Simplify3D software (slicing software), which refined the details in preparation for the breast printing process.

Printed breasts. Source: writers (2023)

After the completion of the prints, digital scanning of the breasts was performed, simulating a patient with reconstruction of only one breast. The data obtained by the 3D scanner were processed in the Tinkercad platform, and the mold was created to be printed.



Breasts being scanned. Source: writers (2023)



3D modeling of the molds. Source: writers (2023)

The digitally developed molds were printed on the same 3D printer, but now in high definition, generating structures faithful to the originals. These molds were then treated with Kala brand mold release spray and filled with Du Latex brand industrial silicone. The predominant choice was the addition model Platsil Gel 00 silicone, which, besides being biocompatible, exhibited an appropriate texture and provided the desired result in the pigmentation process.

Mold release agent. Source: writers (2023)

First mold with industrial silicone. Source: writers (2023)

Regarding pigmentation, the initial approach involved the application of silicone with a pink coloration, a choice based on the belief that pigmentation, although successful, could blend with the colorations already present in the areolas themselves. This was evidenced when an areola originally made with orange rubber acquired a reddish hue during the micropigmentation process.

COLORATION TEST (PROFESSIONAL TATTOO ARTIST)

Three initial models, the one on the left prepared with GingiFast Elastic, the middle one with industrial silicone, and the one on the right with GingiFast Rigid.

Source: writers (2023)

Pigmentation of the molds by a specialized tattoo artist. Source: writers (2023)

It is worth noting that the coloring is done with micropigmentation materials (the needle being discarded correctly after use), as it would also be compatible with human skin, in addition to being a long-lasting process. Although humans were not involved in the experiments, the search for hypoallergenic products with good recommendations - both in terms of durability, efficiency, and cost-effectiveness - was relentless and recurrent in this project.

Contact was also maintained with oncologist Dr. André Orlando Marques (CRM 85800), who provided various guidelines throughout the project, indicating plastic surgeons, allergists, dermatologists, mastologists, and even professionals in his field, in order to demonstrate the importance of this project.

There was an exchange of emails with the Scientific Review Committee of FEBRACE, which advised against conducting tests on humans, especially in recently operated cases, opening space for the exclusive use of mannequins and 4.0 technology.

For the fixation of the areola(s), after research and testing, it is recommended to use a glue commonly used in the attachment of wigs and hair implants, specifically Bold Hold Active adhesive produced by The Hair Diagram, with 41ml available on the market for R$83.93 (authorized by ANVISA). Although this project did not involve humans in the experiments, the search for hypoallergenic products with good recommendations was relentless and recurrent in this project.

IV. RESULTS

After the production of 10 different molds, satisfactory results were obtained regarding texture and realism. The procedure proved to be economically viable since the use of technology facilitated the modeling process. Cost of R$ 12.00 per areola with its respective mold already printed. Micropigmentation provided us with a wide variety of shades capable of faithfully "copying"

the coloration of a real areola (R$ 50.00 each micropigmentation - tattoo artist).

Micro-pigmented areolas. Source: the authors (2023)

The material used in the areolas that showed the best results was Gingifast Elastic, soft, with a hardness of 40 Shore, compatible with the various techniques used to make artificial gums and with excellent aesthetic results. It is a silicone-based compound in a two-component cartridge with a cold crosslinker. It has a high elastic modulus to ease removal and reapplication on the breast. It has excellent aesthetic results due to its translucency and vascularization. It is worth noting that this material is approved by ANVISA, as its use occurs in gingival reproduction used by dentists in implantology procedures.

V. CONCLUSIONS

It is imperative to emphasize that the manifestation of a breast cancer diagnosis or the experience of a traumatic accident are events that transcend human will, and indeed, they are never easy challenges to overcome. Although, over time, it may be said that "the burden becomes more bearable," the profound psychological impact of breast mutilation cannot be underestimated, affecting both women and men. The stigma, melancholy, and distortion of self-image that arise from this loss are true obstacles that do not contribute to the success of the treatments undertaken.

Ensuring, therefore, that individuals affected by such adversities are provided with ample support, not limited to simple surgical interventions for breast reconstruction, but also enabling them to have expedited access to personalized and non-invasive techniques for areola restoration, represents a measure aimed at providing serenity and building pillars of self-confidence. This will translate into an enhanced ability to successfully face the recovery period and embrace post-treatment life with greater resilience.

It is imperative that all those who face the loss of their breasts, nipples, and areolas receive unconditional support, as experiencing a traumatic event such as an accident or a cancer diagnosis can have profound consequences for psychological well-being. Dealing with the sequelae resulting from these experiences can inflict feelings of self-criticism, trauma, withdrawal, anxiety, and even depression, impacting mental and emotional health significantly.

REFERENCES

[1] VARELLA, DRAUZIO. **Breasts.** Available on: https://drauziovarella.uol.com.br/mulher/mamas/#:~:text=As%20mamas%20s%C3%A3 o%20constitu%C3%ADdas%20por,de%20alimento%20para%20os%20beb%C3%AAs. Accessed on: 05/04/2023

[2] SOARES, NAYANE PEIXOTO. **Mammary glands**. Available on: https://www.infoescola.com/anatomia-humana/glandulas-mamarias/. Accessed on: 05/04/2023

[3] GRILLO, MARCOS. **Silicone explantation: increases demand for the procedure.** Available on: https://marcosgrillo.com.br/explante-de-sil icone-aumenta-a-procura-pelo-procedime nto/ Accessed on: 05/07/2023

[4] FACINA, GIL. **Breast cancer in men.** Available on: https://facina.com.br/copia-mamas-densa s-1 Accessed on: 05/10/2023

[5] SOLUTUDO - **The city in detail. Rioclarense Network for Cancer Combat - Carmem Prudente**. Available on: https://www.solutudo.com.br/empresas/sp /rio-claro/ongs-e-entidades-sociais/rede rioclarense-de-combate-ao-cancer-carme m-prudente-3670271 Accessed on: 05/16/2023

[6] INCA. **Cancer statistics**. Available on: https://www.gov.br/inca/pt-br/assuntos/ca ncer/numeros Accessed on: 05/16/2023

[7] **STATE DEPARTMENT OF HEALTH - Santa Catarina. Ministry of Health releases R$ 4 million for breast reconstruction surgeries in Santa Catarina.** Available on: https://www.saude.sc.gov.br/index.php/noticias-geral/13909-ministerio-da-saude-libe ra-r-4-milhoes-para-cirurgias-de-reconstrucao-mamaria-em-santa-catarina#:~:text=Toda%20mulher%20que%2C%20em%20virtude,de%20espera%20para%20o%20procedimento. Accessed on: 05/165/2023

[8] FAUSTINO, HELEN MACEDO. **University of Southern Santa Catarina - UNESC. Bachelor's degree in Visual Arts.** Accessed on: 05/22/2023.

[9] FEBRACE. **Forms and safety regulations**. Accessed on: 05/22/2023

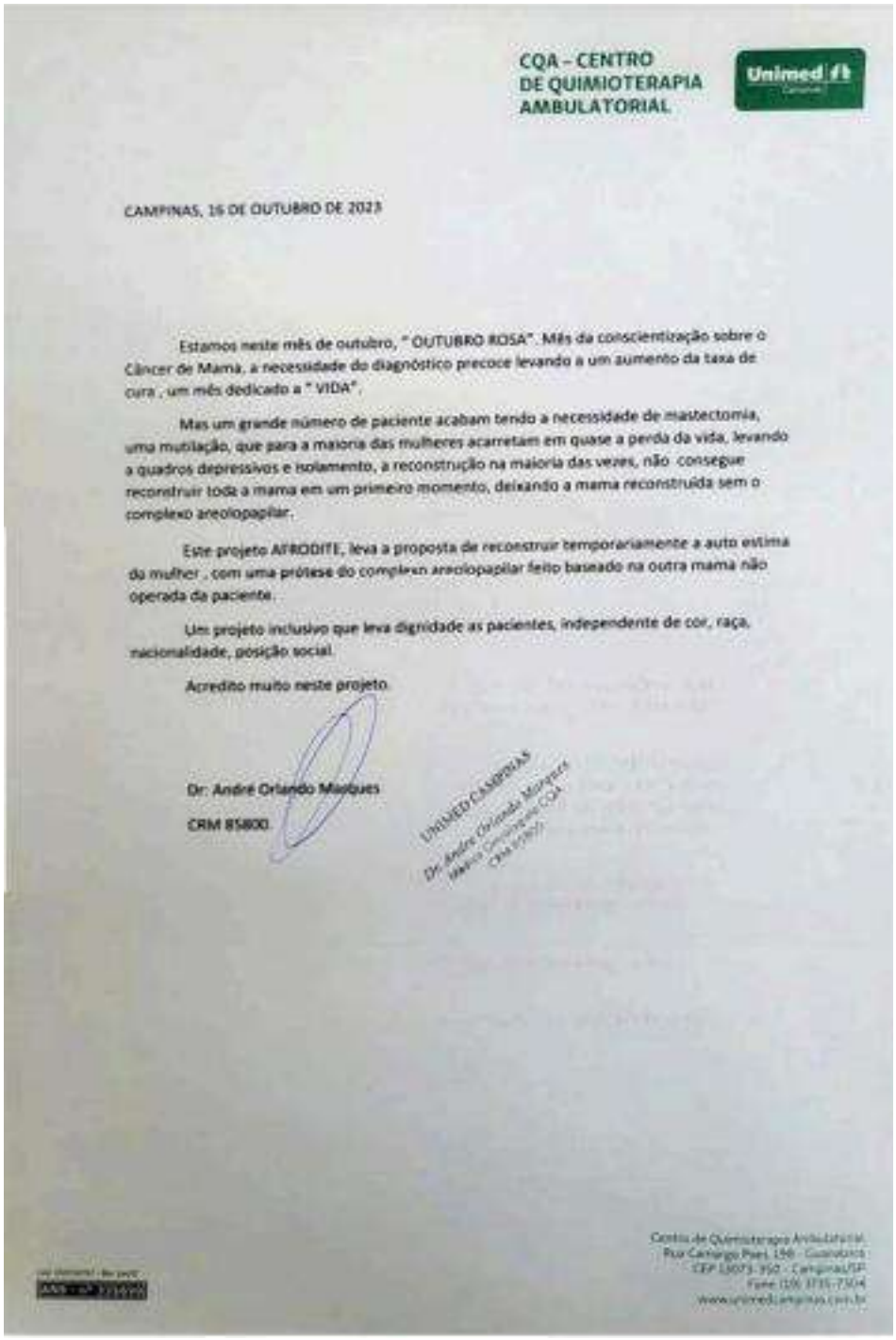
[10] BIERNATH, ANDRÉ. **Hyaluronic acid: the risks and contraindications of the product that became a hit**

against wrinkles. Available on: https://www.bbc.com/portuguese/geral-62 042982 . Accessed on: 05/27/2023 [10]

[11] LIRA, Valdemir. **Manufacturing processes using 3D printing(Technologies, equipment, study of case and 3D printer project).** Blucher; 1ª edition (april 30, 2021). Accessed on: 05/29/2023.

[12] E. Lachat *, T. Landes, P. Grussenmeyer. **PERFORMANCE INVESTIGATION OF A HANDHELD 3D SCANNER TO DEFINE GOOD PRACTICES FOR SMALL ARTEFACT 3D MODELING.** Ottawa, Canada, 2017. Available on: https://isprs-archives.copernicus.org/articl es/XLII-2-W5/427/2017/isprs-archives-XLI I-2-W5-427-2017.pdf. Accessed on: 06/01/2023.

APPENDICES



CQA – CENTRO DE QUIMIOTERAPIA AMBULATORIAL

Unimed

CAMPINAS, 16 DE OUTUBRO DE 2023

Estamos neste mês de outubro, " OUTUBRO ROSA". Mês da conscientização sobre o Câncer de Mama, a necessidade do diagnóstico precoce levando a um aumento da taxa de cura , um mês dedicado a " VIDA".

Mas um grande número de paciente acabam tendo a necessidade de mastectomia, uma mutilação, que para a maioria das mulheres acarretam em quase a perda da vida, levando a quadros depressivos e isolamento, a reconstrução na maioria das vezes, não consegue reconstruir toda a mama em um primeiro momento, deixando a mama reconstruída sem o complexo areolopapilar.

Este projeto AFRODITE, leva a proposta de reconstruir temporariamente a auto estima da mulher , com uma prótese do complexo areolopapilar feito baseado na outra mama não operada da paciente.

Um projeto inclusivo que leva dignidade as pacientes, independente de cor, raça, nacionalidade, posição social.

Acredito muito neste projeto.

Dr. André Orlando Marques

CRM 85800

UNIMED CAMPINAS
Dr. André Orlando Marques
Médico Coordenador CQA
CRM 85800

Centro de Quimioterapia Ambulatorial
Rua Camargo Paes, 198 - Guanabara
CEP 13073-350 - Campinas/SP
Fone (19) 3735-7504
www.unimedcampinas.com.br

(CAMPINAS, OCTOBER 16, 2023: We are in this month of October. "PINK OCTOBER". A month of awareness about breast cancer, the need for early diagnosis leading to an increased cure rate, a month dedicated to "LIFE". But a large

number of patients end up needing mastectomy, a mutilation, which for most women almost amounts to loss of life, leading to depressive episodes and isolation. Reconstruction, most of the time, cannot fully rebuild the breast in the first instance, leaving the reconstructed breast without the areolopapillary complex. This project, AFRODITE, proposes to temporarily rebuild women's self-esteem with a prosthesis of the areolopapillary complex based on the other non-operated breast of the patient. An inclusive project that brings dignity to patients, regardless of color, race, nationality, or social position. I believe strongly in this project.)

"Everything is precious to someone who has been deprived of everything for a long time."

Friedrich Nietzsche

ACKNOWLEDGEMENTS

Our heartfelt thanks...

- ... to our advisor, Filippi Ongarelli, for the sleepless nights listening to our various ideas about the project.
- ... to our co-advisor Huemerson Maceti, who was always so willing to support us and invest in us.
- ... to Dr. André Orlando Marques, for the tips and collaboration.
- ... to our families and friends for making time available.
- ... to the interviewees and project supporters, for being so generous in their contributions of experiences and knowledge.
- ... to each other for never giving up.
- ... to Puríssimo Coração de Maria – High School to our education process and to support us and invest in us.
- ... to Rede ICM de Educação – to support us and invest in us.

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-7; Jul, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.117.3

EcoQuad - Device for Sustainable Transport by Hybridization of Electricity and Photovoltaic Solar Energy

Filippi Benevenuto Ongarelli[1], Huemerson Maceti[1,2], Angelo Cezar Semencio Filho[1,3], Bruno de Oliveira dos Santos[1,3], Gustavo Zotin Gomes de Oliveira[1,3], Thais Mamprin[1,3], Lucas Antunes Soares Moreira[1,4]

[1]Colégio Puríssimo Coração de Maria, Rio Claro - SP
[2]FHO - Hermínio Ometto Foundation University Center - FHO
[3]3rd grade high school students
[4]1st grade high school student

Received: 05 May 2024,

Receive in revised form: 09 Jun 2024,

Accepted: 20 Jun 2024,

Available online: 05 Jul 2024

Keywords*— *Alternative transportation; Electric car; Sustainable energy, Science teaching

***Abstract*—** *Over the past decades, global warming has been widely discussed around the world. Along with the phenomenon itself, it is also discussed the fact that one of its main causes is the emission of polluting gases into the atmosphere, which in turn are produced by cars and other means of transportation. About the situation, it has become common for environmental issues to be explored and the tendency of large automobile companies to start the production of vehicles that do not use fossil fuels, in addition to seeking solutions also related to the format of these vehicles. However, such solutions have several flaws, because they are rarely accessible to the population, in addition to using different energy sources that are still harmful to the environment. Another obstacle that can be noted is the lack of interest of the population in other types of vehicles that are not common or convenient and that require some adaptability. New solutions must be created so that economic, social and ecological aspects are met. In this way, the development and execution of a personal car called EcoQuad is presented, whose purpose has an educational and political character, thus seeking to promote a new style of production based on the hybridization of electric and solar photovoltaic energy. As a scientific character, the development of this project aims to prove the ecological and efficient aspects that can be achieved together through the hybrid energy system described. Because it is a hybrid vehicle, powered by batteries and solar panels that work together, the cost benefit is superior to ordinary vehicles, because with the correct distribution of energy used from the battery bank and solar modules, vehicle maintenance will be more affordable and less frequent. For such an experiment to be possible to be executed, it is concluded the need to expand the technological nationalization, which would make the project commercially viable. The project was guided by teachers and executed by high school students from Colégio Puríssimo Coração de Maria, ICM Education Network, and was presented at the Brazilian Science and Engineering Fair*

(FEBRACE) in 2023, winning 1st place in the Engineering category and 4th place overall in the largest Science and Engineering Fair in Latin America.

I. INTRODUCTION

Urban pollution has always been a major problem in industrialized and developing countries. In recent times, the world has experienced a high concentration of air pollutants in urban regions. Linked to this, the climate phenomenon "global warming"

has become increasingly commented on in current times. It is known that the main cause of such an event is the growing emission of polluting gases, which result from the use of automobiles and other types of transportation that are developed based on the same principle of energy generation. In addition, it is understood that Brazil is experiencing a serious crisis in its economy, especially in the increase in fuel prices, as a result of the return of global economic growth and the consequent search for commodities.

From this principle it has become common to disseminate ideals that encourage the production of environmentally friendly transportation devices, both in the materials that constitute these products and in the forms of fuels used. However, these "solutions" become impractical in the current Brazilian market because the number of people capable of owning such technology does not represent the majority of the population. Linked to this, locomotion alternatives such as walking, bicycles or electric motorcycles have shown not to meet the needs and expectations of the population, culminating in the same environmentally harmful transportation mentioned above.

At the 26th UN Climate Conference, COP 26, they turned to transportation. One of the agreements reached was signed by 24 countries and a group of car manufacturers, who pledged to end the era of fossil fuel vehicles by 2040 "or earlier".

That said, new solutions need to be developed in order to meet the need for a sustainable energy source, but that fits the conventional transportation model and already appreciated by the population, so that there is a concrete adherence to the new style of locomotion.

It is understood the need for an affordable and realistic introduction of technological and sustainable evolution for a country like Brazil, in order to achieve the proposed metrics of gas emission reduction from a fully replicable technology.

II. OBJECTIVE AND PROBLEM QUESTION

Question Problem

Currently, the transportation sector uses more than 50% of petroleum products and more than 40% of all fossil energy consumed in the country. It is therefore one of the sectors that can contribute most to reducing greenhouse gas emissions and other pollutants (BARAT, 2007).

According to a study by the Institute of Applied Economic Research (IPEA), about 20% of users of public roads, especially in large cities, are responsible for occupying 80% of them. This problem is caused by several factors, among which the main ones are the following: historically the country has prioritized private transport with incentives to automakers and consumers to acquire their cars, poor conditions of use of most means of public transport such as buses and trains and the poor planning of cities regarding public roads and long distances between homes and workplaces.

According to this same IPEA study, private cars, cabs and motorcycles obtain subsidies of around R$ 20.0 billion each year, corresponding to 86.0% of all subsidies given to the transportation system by the three spheres of government. On the other hand, public transportation has annual subsidies of around R$ 3.0 billion, corresponding to 14.0%.

Since its implementation in 1986, the Program for the Control of Air Pollution from Motor Vehicles (PROCONVE) has reduced the emission of pollutants from new vehicles by about 97%, through the progressive limitation of pollutant emissions (VASCONCELLOS, 2000), through the introduction of technologies such as catalytic converters, electronic fuel injection and improvements in automotive fuels.

However, problems such as pollution, degradation, gas emissionsand mass consumption are also a reflection of development and, although they are the topic of discussions and protests, they do not generate significant commotion and repercussion on the part of the population. As a result, these problems are still present and are getting worse every day.

The search for alternatives that really work at all social levels is scarce, when in fact, it should be the way out to improve the world. Motivation comes from each individual and individual involvement is needed to recover

decades of waste and mistreatment of the environment. It is also necessary, more than the acceptance by countries and economic powers in treaties and protocols, cheap, viable projects that are within everyone's reach, to start this new model and thus represent the collective interest of the population, signaling to large companies to completely change their production styles to be based mainly on sustainability.

Objective

The main objective of this work is to prove the possibility of a new style of production in the automobile market, in order to reduce the emission of carbon dioxide and cheapen the cost of supply, since electricity is generally cheaper than fossil fuels. Thus, the development and execution of a solar-powered electric car for personal use is presented, whose objective is educational and political, thus seeking to promote the benefits of electric vehicle technology and promote a new style of production based on the hybridization of electric and solar photovoltaic energy.

It is necessary to emphasize that this vehicle was produced with the premise of having an optimal cost benefit, since the correct use of the battery bank and the proper use of the charger, autonomy will be the key point of this article. Therefore, many of the choices made regarding the materials used were made based mainly on the cost and efficiency presented. Some of these parts were already in possession, but in disuse, so even though they did not demonstrate the best cost-benefit and the most correct models to be used, they were adopted in the project.

The problem of cars overheating during prolonged disuse in open spaces such as parking lots is also understood. In the open, it is estimated that the internal temperature of a car can reach 70°C. Moreover, with the increasing rise in global temperature due to high gas emissions, this figure is only set to rise. In this way, it is intended to use these consequences of human exploitation in favor of reducing pollutants in the environment. The electric car is developed with the premise of standing in an open environment while its user works, in order to use all the energy from the sun's rays that would be wasted in just heat in the car's structure, so that it also feeds the battery used on the way from home to the workplace.

The project was developed based on a common lifestyle, in which a commute to work would be made, with the battery being charged during the night. During working hours, the car will be at rest and the energy used during the morning commute will be replenished through the solar plates, which will reach maximum efficiency during midday, as will be proven in this article.

III. DESCRIPTION OF MATERIALS AND METHODS

Structure

For the support and general structuring of the car, metal bars such as metalon (20mm x 20mm) and small iron plates (scraps) were used. The entire structure was welded and some structures were properly screwed or fitted. Since metalon is a high cost-benefit material if we take into account its high toughness, its price, and its lightness, it is one of the best applicability materials for this project. In addition, if we compare it with other materials, such as aeronautical aluminum, the price to weld it is considerably lower than the others.

Therefore, it should be remembered that this project has a demonstrative character, in which it aims to suggest a low-cost car model with reasonable performance over short distances.

The seats were bolted directly to the EcoQuad tubes, and metalon structures were developed at a lower level than the seats to house the batteries and controller.

Above the passengers, four metal bars were used to support the solar panels, which will be discussed later in this article. The latter were fixed by screws in the opposite directions of length, i.e., in the front and rear of the way they were positioned. Due to their large size, both plates served as the roof of the car, with the absence of any metal plate or material that would serve as support for the pair.

As a base for the car structure, two identical bicycles that were in disuse were used, connected through 3 hollow steel bars, with a diameter of 1 inch. Aiming at greater stability and durability, bars with a larger diameter were chosen at the bottom of the vehicle, considering that the weight forces of the passengers, the battery, the solar panels and the upper structure would be directed between the bicycles, in addition to pressing the 4 tires that make up the car.

In addition, the EcoQuad structure was designed to equally distribute the total weight supported on the three lower bars, with a substantial focus on the third bar, located at the rear, which has greater strength potential compared to the others due to its interconnection with both bike suspensions.

Regarding the tires, they are original of the bikes themselves and it is estimated that each one supports the weight of 100Kg each, filled with compressed air and with approximately 35 lbs of pressure. Since the force would be distributed among the four tires, the entire structure and its

contents could not exceed 400 kg. Below is the table indicating the objects and their respective mass values. The following information has been approximated always above its real value for a more simplified visualization.

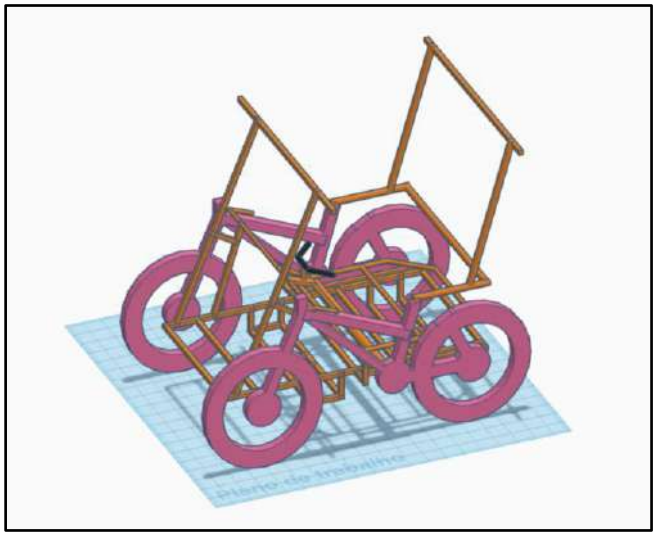


Fig.1 - Ecoquad Structure, Developed with Tinkercad

Table 1 - Objects Supported by Bicycles

Device	Quantity		Mass (kg)
Solar plate	2 pcs.		24 Kg
Battery	3 pcs.		54 Kg
Bicycle	2 pcs.		15 Kg
Engine	1 pcs.		5 Kg
Controller	1 pcs.		1 Kg
Aluminum sheets	0,42 m²		1 Kg
Metal bars	25 m		30 Kg
Occupants	2 pcs.		170 Kg
	Total Mass		**300 kg**

Battery

For the choice of battery, it was established to use the VRLA Deep Cycle Gel system, as it is more common, there is no risk of explosion, widely used in the market and relatively cheap, if compared to more modern batteries. Although the lead acid battery closely resembles a common automotive battery, the latter is not recommended for the use of photovoltaic systems. This is due to the need for prolonged electric current from the photovoltaic system. The automotive battery is designed to deliver an intense electric current for a short period, in order to be favorable for the initial torque in a car, for example. Because of this characteristic, automotive batteries are quickly discharged, and can only undergo a small level of discharge - compared to the stationary lead acid battery - in order to extend their useful life (VILLALVA, 2012). These factors make it impractical to use them in systems that require a continuous and moderate load of energy for a considerable period of time, such as the vehicle discussed in this article.

The autonomy of the prototype is directly proportional to the amount of charge accumulated by the batteries and, therefore, we opted for three imported models of 12 Volts and 70Ah each, of the Freedom brand, which will be installed on the support and connected in series with each other with the intention of extracting 36 Volts from the set. We must remember that the specifications of the engine designated for this project are: 36 Volts and 750 Watts.

The batteries were positioned on metalon supports, specifically designed for this type of use, below the level of the seats.

During the operation of this car, it is necessary to monitor the charge of the batteries, as the depth of discharge will be proportional to the autonomy of the prototype. This monitoring will be performed through a manually developed voltmeter. as will be described throughout this article, a charge controller will be used for intelligent management of battery recharging by solar photovoltaic energy. Although the controller has an auto-off function if the battery bank voltage decreases and the health of the set is impaired, this action would be done without any warning and could cause serious accidents if the car is currently being used. Because of this, a system was developed using Arduino, capable of emitting an alert sound, which intensifies as the voltage continues to decrease.

Controller

Photovoltaic systems with batteries must necessarily employ a charge controller or regulator. The charge controller is the device that makes the correct connection between the photovoltaic panel and the battery, preventing the battery from being overcharged or discharged excessively (VILLALVA, 2012).

Most controllers recharge the battery to maintain a healthy charge profile, thereby increasing battery life and maximizing utilization. More improved controllers also have maximum power point tracking (MPPT) of the PV modules, which enables increased system efficiency.

The controller used in EcoQuad is from the ***Powmr*** brand, directed to solar load and with MPPT function, presenting a maximum current of 60A and voltages of 12, 24, 36 and 48 Volts.

Maximum power point tracking (MPPT) contributes in particular to the charging of batteries using solar energy. Assuming that the car is parked in the open air but the insolation is very low, causing a voltage of 20 Volts, for example, it would not be possible to charge the 36 Volt voltage battery bank. At this point, the controller would be responsible for increasing the voltage to reach the required voltage and thus charge the batteries.

When we raise the voltage by a transformation process, there is always a decrease in the amount of electric current. Therefore, in times of lack of sunshine, the controller will ensure charging which, although it takes longer compared to times of sufficient sunshine, at least the load can be carried out.

Solar panels

A properly functioning photovoltaic energy system is composed of a set of photovoltaic modules and a set of complementary equipment, being batteries and charge controllers. These components may vary according to the methods used and the application of the PV system.

Photovoltaic modules generate electricity in direct current. Batteries store the electricity obtained from sunlight during the day, making it possible to recharge the batteries.

In the structure of the project there is a compass installed for better understanding and positioning of the same, regarding the direction of the sun's rays, seeking to improve the use of the sun's rays (geopositioning). Since the project and its use originate in Brazil, a country in the southern hemisphere, the modules have to be directed to geographic north, also known as true north, slightly divergent from the magnetic north of a common compass. This subtle repositioning provides greater efficiency in capturing solar radiation throughout the day. However, a greater inclination of photovoltaic modules to the North favors energy production in winter (when the apparent path of the Sun is facing North and lower than the zenith and the days are drier and clearer), while it hinders energy production during the summer (when the apparent path of the Sun is closer to the zenith and the days are cloudier and rainier). Therefore, it is of utmost importance that the inclination of the plates horizontally is made based on latitude, climatic aspects of the region of use and seasonal characteristics of energy consumption. For this reason, the angle of the solar plates in EcoQuad are adjustable. A rule of thumb is to tilt 5 to 25 degrees more than the local latitude, seeking to prioritize maximum energy production in the most critical month (ALVARENGA, 2006). The city of Rio Claro, in the interior of São Paulo, serves as the base for the car studies and, since it has a latitude of approximately 22ºS, we positioned the plates with an angulation of approximately 35º.

With the correct arrangement of solar modules, EcoQuad is able to absorb as much solar radiation as possible. As for its direction, the compass has the role of guiding the driver to position the car in the most correct and appropriate way possible, taking into account the physical provisions of where it is located.

For the project, two Kyocera brand boards were used, model KC125TM, which have a voltage of 18V and a power of 125W each. Although the plates described are relatively dated, their use is due to the disuse in which it was before the idealization of the project, which resulted in the reduction considered of the expected costs.

Engine

For the choice of the ideal electric motor, in a vehicle propulsion system, it is important that it has a high initial torque and can develop a final speed consistent with the characteristics defined for the vehicle, that is, when seeking to obtain a high torque, do not disregard the maximum intended speed (COSTA, 2009).

It was decided to use a permanent magnet motor for its simplicity of use and high torque capacity, in order to compensate for the choice of a stationary battery, which has low initial torque power (compared to Lithium). In addition to its high suitability for the project, this motor model is available for purchase over the internet or even in some industrial electronics junkyards. In this prototype, the working voltage is 36 Volts and the nominal power is 750 W, similar to those used in electric bicycles, widely spread in countries like China. The choice of a motor with a voltage of 36V is evident so that it could be powered by the solar plates in real time, without using the battery power itself, only when it was extremely necessary.

The motor chosen was a brushless type, whose power is 750W, its voltage is 36V and its rotation is evaluated at 500 RPM. After analyzing the EcoQuad system as a whole, it was realized that the most appropriate option would be to choose a motor suitable for bicycles, which is installed on the rim of one of the wheels. The motor also comes with accelerators, brakes and all the control system that a car needs.

Types of energy sources for the engine

When considering the prospects of today's world that insist on afflicting the environment - such as indirectly falling on the population and their quality of life - the construction of a car made mostly of unused parts, devoid of any source of fossil fuel and with a performance potential far superior to that of a conventional car, requires an energy source without any cost. If the EcoQuad were to

use its solar modules to power the battery, which in turn would carry the load to the engine, then the cycle of using environmentally harmful materials would continue. This is due to the intensive use of the battery that would store all the load and participate in the process of large discharge during the movement of the car, drastically reducing its useful life. With the intensive use of the battery bank, its replacement would have to be done frequently, which would increase the maintenance cost of the EcoQuad, making it similar and expensive as a conventional car, in addition to causing serious damage to the environment by the disposal of batteries, which is mostly done improperly.

> *Improper disposal can cause the battery to deform in its capsule, which can lead to leakage of the toxic waste that is composed inside. The liquid inside the device is a non-biodegradable and non-decomposable product that causes pollution when it is discharged into subsoil, groundwater, rivers and waterways. Dangerous for hydrology and agriculture, causing irreparable damage to the environment and crops (ALVES DOS ANJOS, 2022).*

Due to these issues, the production and development of EcoQuad not only aims to use the solar plate to charge the batteries and drive the vehicle only by the latter, but also to use the solar plates as a primary source of energy.

The production of a motorized system with real-time power supply from the solar panels is the most suitable for this project. In this case, the battery continues its purpose of powering the EcoQuad. As will be analyzed later in this section, the EcoQuad needs an initial torque of which the solar panels cannot provide such energy and power in such a short period of time. Thus, when the use of solar panels as the main source of energy is required, the battery bank will provide energy for the initial torque, removing the EcoQuad from inertia and also at times when the irradiation is not sufficient to keep the EcoQuad in constant motion, such as in tree-lined streets. Should such a situation occur, the energy source will be immediately switched to the battery through the charge controller, specifically configured to perform the interconnection between the motor and its two possible energy sources.

In summary, EcoQuad offers two types of energy. The first and most conventional is the use of a battery bank as the sole energy source. The second is through the primary use of solar panels, which will be softly assisted by the batteries.

Calculations

Although it is possible to charge the battery bank in conventional sockets, the charge will be made only through solar radiation, so that the expenses for the operation of the car keep its purpose to be as low as possible, making it more affordable. In addition, with less excessive use of the battery, its useful life is increased, leading to its longer use and later replacement, making the car even cheaper.

In addition to calculating the efficiency that the modules are able to provide, it is necessary to find out the amount of energy generated by the solar modules, so that it is possible to infer the aptitude of the plates to provide enough energy in a certain period of time, so that the EcoQuad works continuously during this period, without losing its efficiency considerably at some point. Through these same calculations it will be possible to infer the motor's ability or lack thereof to drive the EcoQuad. In order to obtain such information, the insolation method was used to determine the amount of energy produced daily by the solar modules, in which the energy produced by the mode daily in Wh (*EP)*, the daily insolation in Wh/m²/day (*ES*), the surface area of the module in m² (*AM*) and the efficiency of the module (*nM) are* used. No calculation was made specifically for the battery due to the knowledge of its nominal information, which certainly guarantees an efficient operation of the EcoQuad if used as the only energy source.

The quantification of energy provided by a photovoltaic system should be performed based on its month of lowest insolation, since otherwise, the results based on months of highest insolation would provide data that do not cover the whole year, causing the energy supply not to be guaranteed in all months. The average daily insolation rate per square meter in most Brazilian locations is 5000 Wh/m²/day. In the South of the country this number drops to 4500 Wh/m²/day and in the Northeast

can reach more than 6000 Wh/m²/day (VILLALVA, 2012).

Equation (1)

$$EP = ES \,.\, AM \,.\, nM$$

When performing the calculation, the value of 7845 Wh is obtained, which if converted into joules is approximately $2.82.10^7$J in a whole day. Since the power is necessary to make a relationship with time, $2.82.10^7$ divided by $8.64.10^4$ seconds, it is concluded that the power supplied by the solar modules is approximately 325W.

In order to be able to use the EcoQuad through only spontaneous solar irradiation, the energy generated by the solar modules has to be minimally higher than the energy spent by the car. Using the kinetic energy equation, the total mass (*m*) of the EcoQuad was assumed to be 190Kg (60 Kg being the average total mass of the crew members in the tests performed) traveled at a speed (*v*) of 30Km/h (approximately 8.35 m/s).

Equation (2)

$$\frac{mV^2}{2} = \frac{190.(8{,}25)^2}{2} = 6624\ J$$

Thus, it is concluded that the EcoQuad, with a total weight of 190 kg and a speed of 30 km/h (8.35 m/s), needs approximately 6624 joules to start pulling.

By dividing the kinetic energy of the EcoQuad by the insolation power obtained, it is possible to infer that the time for the car to reach the expected speed and results would be 20 seconds.

Although this figure is significantly reduced by lowering the total weight of the EcoQuad or its expected speed, the design inter receive minimal assistance from the batteries that will provide the initial torque, while the solar plates effectively support the EcoQuad in motion.

Energy hybridization

The hybridization model of electric and solar photovoltaic energy presented in this project is innovative and designed for EcoQ system in the automobile market with an even greater advance compared to electric cars. Along with the new energy system, it is necessary to formulate a different type of vehicle to support the technology and attributes of the hybridization system, so EcoQuad has the potential to transform the transport sector with the replication of its energy system and the production of a simpler, lighter and more everyday type of vehicle.

Based on the theme presented, the hybridization system has as its principle the capture of solar energy so that it is directed to the the hybridization process, the bank could not be recharged when the EcoQuad was parked. Therefore, solar energy passes through the batteries, but in order to be used first and, when necessary, the engines will acquire a minimum amount of batteries, making the vehicle's autonomy always greater compared to just a common battery bank, used in electric cars, for example.

IV. RESULTS AND DISCUSSION OF RESULTS

In this chapter we present a complete analysis of the data obtained in tests to prove the functioning and efficiency of EcoQuad. It is also developed in this same section the approach of comparison topics between the EcoQuad and ordinary cars, designed mainly for short and daily routes, in order to show its relevance in current times and a better cost benefit to be explored by the population. Due to the different types of energy sources used, the tests were divided into two groups, which will be called "Sections" .

Section 1: battery bank

The tests were carried out in a multi-sports court with high exposure to sunlight and the objective was to measure the running time of the prototype in relation to different traction loads and the expected speed (30Km/h with a total crew mass of 170Kg). The energy source used in these experiments was from the fully charged battery bank, without the use of solar photovoltaic energy. These tests were also carried out to prove the ability of the battery bank to provide sufficient power to the engine and thus perform the movement. It should be noted that the same test was repeated several times in order to verify the veracity of the results obtained.

As previously mentioned, stationary batteries are characterized by being deep cycle, i.e.: they can be discharged without major loss of life. The tests done with only the use of the batteries did not exceed the safe discharge limit.

After each test, the batteries were properly recharged. In this way, the test period took around 15 days to be completely completed. It was decided to do only, for most of the analysis period, one test per day, in order not to change the characteristics of the battery or the way they could be recharged. In addition, in the tests of the batteries as a single source of energy, several tests were carried out in order to determine the autonomy of the EcoQuad in 4 types of load depth, being 100%, 80%, 60% and 20%.

In an attempt to simulate different masses of different conductors, the first phase of each test section was done with a 13-year-old 52 kg child who drove the prototype alone in a first stage. In the second phase of testing, two crew members were used, the 52Kg child from the first phase and an adult weighing approximately 80Kg. In the third test phase, two adults were used, one weighing approximately 90 kg and the other 80 kg.

According to the results obtained in the 15 days of tests, it was possible to build a graph illustrating the

autonomy as a function of the mass pulled by the vehicle and the percentage of the loading depth. The masses described in the graph are not consistent with the tests performed as they were used to show a more accurate curve, instead of the large weight differences used in the analysis. Therefore, we performed the tests with the weights described above, identified the pattern of decrease and applied them to mass values closer to each other.

Assuming the driver uses the EcoQuad on a flat surface, it is possible to produce a projection of its range (Figure 2).

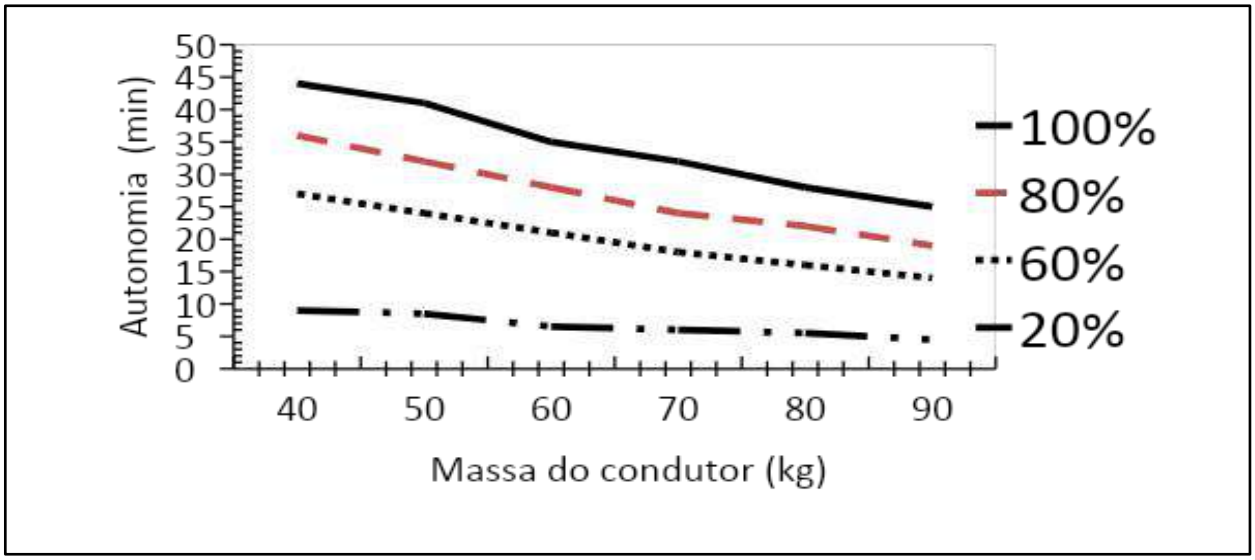


Fig.2 - Autonomy Versus Driver Mass

Assuming that the EcoQuad is used on a flat surface, it is possible to estimate a relationship between the distance traveled and the total mass of the driver (Figure 3).

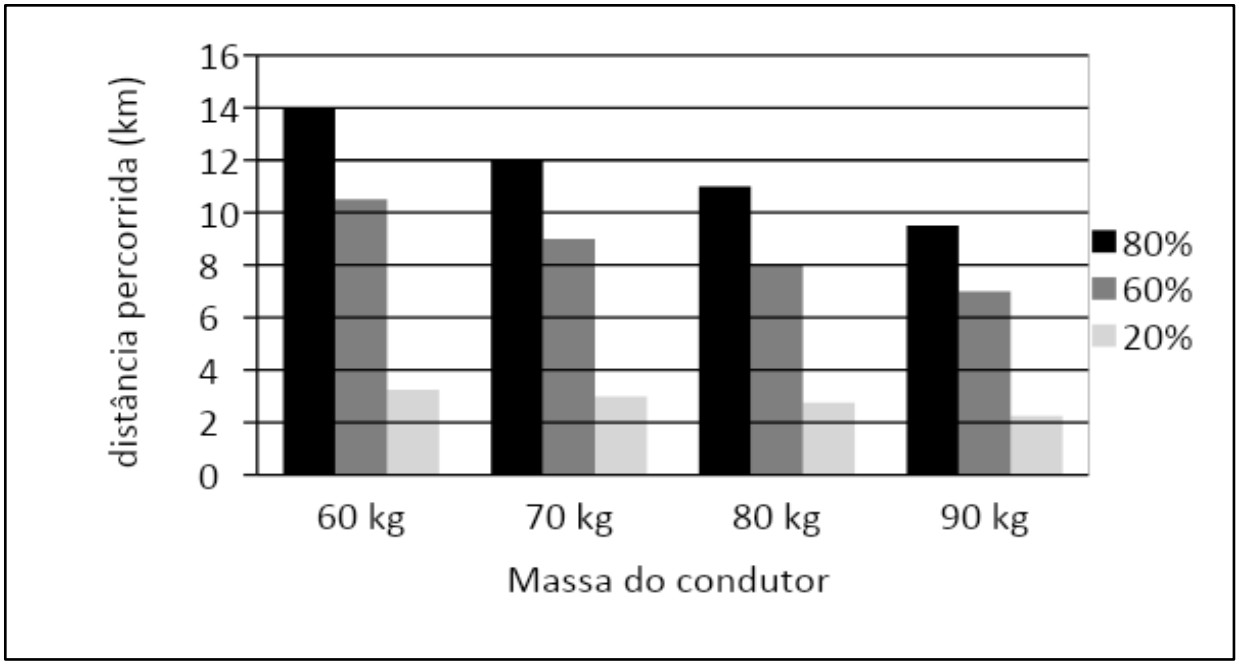


Fig.3 - Distance traveled versus conductor mass

Section 2: solar modules

The project had the pretext of building a vehicle totally free of any source of electricity and toxic to the environment, so it was thought only to use solar plates to drive the vehicle to drive at least one medium-sized adult. However, when analyzing the nominal specifications of the solar plate, it became clear that the total generated power of 325W of the plates would not be enough to perform the initial torque of the vehicle and also to drive it in areas of little insolation. Reservations are made if the total mass of the crew member is 52Kg and the period of use was close to noon. If the plates adopted to the project were more powerful, in addition to presenting greater efficiency, the proposal to only use solar plates could be considered. On ordinary streets, fast acceleration is required due to the constant traffic in cities. Therefore, as an example, if the EcoQuad stopped in front of a traffic light, it would not be able to keep up with the acceleration of other cars and get back into motion quickly, causing serious obstacles and possible traffic accidents.

After the testing period with batteries, tests were carried out using the energy coming from the solar modules in real time, in addition to being assisted by the batteries. This period lasted around 4 days. To perform the experiments, the structure of these analyses was schematized similar to that of the tests with batteries, being 3 phases with 52 Kg in the first, 132 Kg in the second and 170 Kg in the third. Due to the way solar modules work, the tests were not done considering the discharge percentage. It is not necessary to demonstrate the values obtained by means of graphs, since the autonomy would be basically unlimited, if there were not the small aids of the battery. Thus, the autonomy results using the hybrid configuration of electric energy and solar photovoltaic completely exceeded the metrics found during the tests using only the battery bank, thus becoming representative values because they do not match the daily use expected for this car, that is, less intense.

Project cost

EcoQuad's solar panels and bicycles were donated by Mariana de Almeida Castro, a businesswoman who sympathized with the project and had the initiative to contribute. The electric motor, the charge controller and all the components necessary for the distribution of energy to the motor were donated by the businessman Otto Wener Kuth, in order to help with the costs of the project. The three batteries were borrowed from an electronic platform system with a *nobreak* system from Colégio Puríssimo Coração de Maria, so that the tests could be carried out. The aluminum plates were found in a junkyard. Finally, the EcoQuad seats are donations from the advisor of this article, Professor Filippi Benevenuto Ongarelli, who took them from an Ultralight Flyer GT.

The following table describes each part used in the making of the EcoQuad and also the context of each material, together with its quantity and price.

Table 2 - Project cost

Devices	Quantity	Total Price
Solar plate (donation)	2 pcs.	R$800
Battery (borrowed)	3 pcs.	R$1410
Bicycle (donation)	2 pcs.	R$500
Engine, accelerator system (donation)	1 pcs.	R$2000
Parent company (donation)	1 pcs.	R$650
Aluminum sheets (found)	0,42 m²	R$30
Metal bars, welding and bolts	25 m	R$180
	Total	**R$5570**

Relevance of the project

Unlike other vehicles available on the market, EcoQuad is more attractive to the majority of the population by adapting and being developed based on the strengths of each of the modes of transportation evaluated in this project.

Firstly, EcoQuad addresses some of the difficulties faced when using electric scooters. However, although they have been gaining significant notoriety lately, the fact that they only hold one person and do not have the expected comfort during an average journey makes electric scooters potentially problematic in some situations, something that does not happen in EcoQuad, since it holds two passengers and has the comfort similar to that of a conventional car. Furthermore, based on the rate of motorcycle accidents and their resolutions, society is impacted by this data through a deep stigma regarding vehicles with only two wheels, which makes the EcoQuad and its four wheels even more attractive to the consumer market.

Another factor to be considered in transportation vehicles is the environment for which they were designed. The EcoQuad is intended to be used in a common lifestyle, which aligns with the daily priorities of the Brazilian population. In other words, the EcoQuad was developed based on average commutes such as from home to the owner's work, or to a local supermarket. Thus, smaller cities and, consequently, the interior, are the most suitable for the operation and efficiency of EcoQuad. However,

this vehicle can be used perfectly in large cities with heavy traffic. This is due to the use of cycle paths, since their width is compatible with the width and size of the EcoQuad, in addition to being relatively far from other cars, which reduces the possibility of accidents.

EcoQuad's main goal is to promote a new style of energy to be used by large automotive companies, based on the intelligent hybridization between solar energy and electric energy only when needed. This new energy configuration provides the most sustainable model among all those already present in the market, being: fossil fuels, fossil fuels and electric energy and electric energy only. If compared to the first two models, EcoQuad presents clearly more positive results in favor of the reduction of polluting gases, but when compared to electric cars, its differential turns out to be slightly more specific. Currently, electric cars are considered the best and least polluting means of transportation on the market. However, if we conduct a long-term study, it is realized that batteries as the only source of energy for these cars, their use ends up being extreme and very harmful, which ends up leading to a relatively frequent maintenance and potentially irregular disposal of batteries, generating serious damage to the environment. The EcoQuad, on the other hand, uses mainly solar energy and leaves its source of electricity only for more specific situations, so as not to demand excessively from the batteries, extending its useful life and making its maintenance much later compared to that of an electric car.

Finally, although it is possible and even foreseen for the EcoQuad batteries to be recharged through solar energy, their charging through domestic electricity still proved to be cheaper than a popular car. When performing the tests described above, we realized that charging the EcoQuad using sockets cost approximately R$1.50 (R$0.50/KWh) after traveling 14Km. After collecting this data, we calculated how much it cost to fuel a Volkswagen Up! after traveling the same 14Km, which ended up resulting in R$4.50, since it travels on average 12Km / L of Ethanol. Therefore, recharging the EcoQuad is up to 200% cheaper compared to refueling a popular car.

V. FINAL RESULT

The vehicle was built and successfully put into operation. Figure 4 shows the finished vehicle and figure 5 a test in the courtyard of Colégio Puríssimo, together with high school students.

Fig.4 - Final result of EcoQuad

Fig.5 - Final result of EcoQuad - Walking in the courtyard of Colégio PUríssimo

The project was presented at the Brazilian Science and Engineering Fair (FEBRACE) in 2023, winning 1st place in the Engineering category and 4th place overall in the largest Science and Engineering Fair in

Latin America. Figure 6 depicts the moment when the medals were awarded to the group.

Fig.6 - Awards – FEBRACE

VI. CONCLUSIONS

In view of all the experiments, tests and analyzes carried out, the efficiency of EcoQuad is proven, which through improvements and the use of more suitable parts can be further improved. The problems mentioned at the beginning of this article, currently responsible for the high emission of harmful gases to the environment and the lack of accessibility of more ecological products due to their prices are partly solved with the introduction and propagation of this vehicle. Although there is no evidence to prove such improvements, the objective of the work in disseminating the construction of a more affordable, higher performance and more environmentally friendly vehicle than ordinary cars and even electric cars has been achieved. EcoQuad has achieved the expected results and aims to contribute to the automotive industry.

The goal of producing a vehicle like the EcoQuad was never to revolutionize the automotive market in a way that could be replicated on a large scale for the population. Its real purpose is to prove greater accessibility, efficiency and sustainability through the use of solar photovoltaic and electric energy together, working mutually with each other, as is described in the title of this project. Current electric cars use only batteries, which promotes much greater wear and tear, leading to a drop in efficiency gradually and a more advanced replacement, costing a lot of money and damage to the environment. In the future, companies are expected to produce simpler, more efficient cars with solar panels, so that the mutualistic relationship between batteries and solar modules reaches a balance between efficiency and clean energy consumption, as demonstrated in the construction of EcoQuad.

With the arrival of the electric car and even electric and solar hybrids, there will be extremely positive transformations in the transport, economic and social sectors. However, these transformations will bring about changes and obstacles with which people will have to adapt. In addition, with positive developments there will always be negative aspects. It is up to us to find solutions to these obstacles and thus evolve technologically and as a society.

ACKNOWLEDGMENTS

The Colégio Puríssimo Coração de Maria was the place where everything happened, streamlining activities and fostering the search for knowledge, in addition to bearing part of the costs of parts, equipment and teachers' working time.

A very special thanks to the ICM Education Network, of which Colégio Puríssimo is proudly a part. The ICM Network provided the school with the right equipment to carry out our projects, from 3D printers to laser cutting machines and hand tools.

Our project had the financial support of families from our school community, without which the realization of the project would not be possible. Our sincere thanks to the Capretz, Kurth, Schlemper and Castro families for making this project possible.

We would also like to thank Greencycle, a reseller of electric vehicles, on behalf of the owner Fabio Antonio Barbosa, who gave a class to our students on circuits and motors, as well as advice on the purchase of equipment.

REFERENCES

[1] ALVARENGA, CARLOS A. **Solar Energy.** Lavras: UFLA/FAEPE, 2006. 118p.: iL. - Postgraduate Course: "Latu Sensu" (Specialization) - Alternative Forms of Energy.

[2] ALVES DOS ANJOS, Talita. **Batteries.** Available at: https://mundoeducacao.uol.com.br/fisica/pilhas-baterias-1.htm . Accessed on: May 2022.

[3] BARAT, JOSEF. Logistics, transportation and economic development. São Paulo: CLA Publishing House, 2007.

[4] BOTTURA, CELSO P.; BARRETO, GILMAR. Electric Vehicles. 1st ed., Campinas: UNICAMP, 1989.

[5] COSTA,WASHINGTON. Methodology for conversion of vehicles equipped with internal combustion engines to electric traction: application of permanent magnet synchronous motor with radial magnetic flux to a van: 2009.

Dissertation (Master of Mechanical Engineering) - State University of Rio de Janeiro - UERJ, Rio de Janeiro.

[6] FOLHA DE SÃO PAULO **Temperature of car standing in the sun can reach 70 degrees [...] - Folha de São Paulo**

[7] Available at: <https://f5.folha.uol.com.br/estranho/2014/02/1413144-temperatura-de-carro-parado-no-sol-pode-chegar-a-70-graus-diz-estudo.shtml#:~:text=RECEBA%20AS%20NOT%C3%8DCIAS%20DO%20F5&text=Second%20research%20from%20University%20of,can%20alcan%C3%A7ar%20the%2070%20degrees .> Accessed: September 20, 2022.

[8] SCHINDWEIN, MANOEL. Urban Mobility - The solution to traffic chaos. Desafios do desenvolvimento, Brasília, e. 43, p. 38-43, 2008.

[9] SOLENERG. Solenerg Engenharia e Comércio Ltda.

[10] Available at: < http://www.solenerg.com.br > Accessed on: October 11, 2022.

[11] ONE PLANET - SCIENCE AND ENERGY **COP 26: end of fossil fuel car era set for 2040.**

[12] Available at: <http://www.elogica.com.br/users/gmoura/refere.html> Accessed on: September 26, 2022.

[13] VASCONCELLOS, EDUARDO. Urban transportation in developing countries: reflections and proposal. 1° Ed. São Paulo: Annablume, 2000.

[14] VILLALVA, MARCELO. Photovoltaic solar energy: concepts and applications. 2° Ed. São Paulo: Érica, 2012.

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-7; Jul, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.117.4

Family or Non-Family Ownership Type Impact, in the enterprise risk management: a contingency perspective

Michael de Alencar Silva, Marcia Zanievicz da Silva

Fundação Universidade Regional de Blumenau

Received: 18 May 2024,

Receive in revised form: 25 Jun 2024,

Accepted: 01 Jul 2024,

Available online: 13 Jul 2024

Keywords*— *Enterprise Risk Management. Contingency Theory. Family Businesses. Corporate Performance.

***Abstract*—** *The growing research interest on family businesses motivated this study, which aimed to assess the family control impact in the relationship between contingency variables and Enterprise Risk Management (ERM), and its influence on organizational performance. ERMI was quantified based on the index proposed by Gordon et al (2009). The results show that, although the literature substantially relates the use of risk management, to non-family firms, family firms that have higher risk management index, also have an effect on performance. This may suggest that family ownership type positively influences ERM use, consequently influences in a higher market performance. The results of this study contribute to literature and organizational studies on ownership type impact in the relationship between ERM and contingency variables, by confirming the inferences that family firms that have higher ERMI, present better market performance.*

I. INTRODUCTION

In recent years there has been a growing advance in accounting and management control scholars in family firms' interest, (e.g., Giovannoni *et al*, 2011; Speckbacher and Wentges, 2012; Songini and Gnan, 2015; Frezatti *et al* 2017; Oro and Lavarda, 2019); Almeida and Flach, 2020). However, according to Quinn *et al* (2018), despite this recent increase, certain attributes of these numerically dominant firms in all economies, which differentiate them from non-family firms, have not yet been incorporated into general research in accounting and management control. When emphasizing specific managerial control mechanisms, one notes a relevant lack of studies investigating Enterprise Risk Management (ERM), in family firms' contexts, with emphasis on the studies by (Hiebl *et al*, 2019) and (Glowka, *et al*, 2020).

Regarding to ERM as a management mechanism, Gordon *et al* (2009) noticed that a paradigm shift has occurred in relation to how organizations face risk management. Replacing the silo-based perspective, the trend is to adopt a holistic view of risk management in an organization, which is commonly referred to as Enterprise Risk Management.

Notably, risk management efforts are growing, however, so are the complexity of the risks. ERM is a systematic process, usually introduced in organizations through a board of directors, and is widespread across all business spheres (Lunardi *et al*, 2019). Additionally, the current global environment evokes the importance of integrated risk management and the need for organizations to improve their approach to manage risks and to meet the demands of a constantly evolving business environment.

For Sax and Andersen (2018), ERM is associated with higher profitability and lower financial leverage, and that strategic planning enforces these favorable outcomes. In this context, environmental scanning, decision analysis, control systems, and communication devices help managers to observe changes and adapt in competitive contexts.

As a primary function, ERM must identify key risks and find a consistent way to measure the organization's exposure to the identified risks. ERM, integrating with strategy and performance, highlights the importance of considering risk both in the strategy-setting process and performance of its conduct (COSO, 2017). ERM requires the controls and systems establishment with a goal of making companies more resilient and adaptable to major changes in the external environment (Dickinson, 2001).

Recent economic crises have shown the increasing dynamics and markets complexity evoking a debate on the importance of implementing ERM (Bromiley and Mcshane, 2018). Uncertainties that put an organization's competitive advantage at risk can come from technological innovation, regulation, competition, and even a pandemic like the one currently experienced. With origins in managerial accounting and controls, ERM has presented a shift in the way companies deal with risk, using core management approaches to holistically assess the major risks facing the organization (Power, 2009).

Despite the existence of many studies involving ERM, there are still gaps for making new inferences. One of them is the control type influence (family and non-family) on environmental factors and organizational performance. From this gap, the following research problems arise: what is the family control impact of organizations, on the relationship between contingency environmental factors and ERM? What is the influence of this relationship on organizational performance? To answer the problem, this study aims to examine the family control impact on the relationship between environmental factors and Enterprise Risk Management (ERM) and its influence on organizational performance.

The research makes theoretical contributions as it extends research on ERM, performance and family firms. In particular it advances the application of the ERM assessment index proposed by Gordon *et al* (2009), which empirically examines the argument that ERM is related to organizational performance and Lunardi *et al* (2019) who assess the relationship between ERM and contingency variables through the business performance of organizations. The study is further justified by the importance of risk management as a fundamental concern in organizations, in an increasingly global and dynamic business context, where several approaches have been observed regarding risk management. From a practical perspective, by examining the effect of ERM and environmental factors on organizational performance in family and non-family businesses, this study offers subsidies for organizations to identify the main risks moderated by the variables evidenced in this research and find a consistent way to measure their exposure to the identified risks.

The study also aims to contribute to the current debate observed in literature, exploring how the control type influence (family and non-family), as a contingent variable moderating the environmental factors to which organizations are exposed, alters organizational performance behavior. According to McShane *et al* (2011), ERM has emerged as a construct that ostensibly overcomes the limitations of traditional silo-based analysis, but that there are still significant limitations on its effectiveness on organizational performance. Some authors argue that ERM has significant potential to create competitive advantage by identifying, assessing, and managing risks that affect firm value (Sax and Andersen, 2018). However, several studies provide mixed support for the claim that ERM enhances organizational performance and value. For some there is the positive effect (e.g., Gordon *et al*, 2009; Hoyt and Liebenberg, 2011) others have evidenced no effect (e.g., Pagach and Warr, 2010; Quon et al, *2012)*.

The article is organized, besides this section, in four sections. The second section discusses the theoretical framework and the formulation of the research hypotheses. Starting from the contingency theory, the study advances through the approaches of risk management and the use of ERM, as a tool of managerial control. The third section contains the methodology used in the research, which was a survey with a quantitative approach, having as population the publicly traded companies listed on B3 (Brazil, *Bolsa* e *Balcão*), in the period from 2012 to 2019. It was used the Cluster Analysis statistical technique to identify the control type (family and non-family) of the organizations and panel data regression to test the research hypotheses. In the fourth section, initially presents the descriptive statistics of the variables and the test of means is presented, performed to verify if there are significant differences between family and non-family companies in the use of ERMI. Next, Pearson's Correlation between the variables analyzed in the study is shown. The section concludes with the analysis of the data through panel data regression, with the presentation of the results. The fifth section contains the conclusion with the answer to the research problem, with the theoretical and practical contributions of the study. It also includes the study limitations and recommendations for future research, which include the investigation of other samples, possibly from different countries, with a comparative analysis between the different contexts.

II. THEORETICAL FRAMEWORK AND RESEARCH HYPOTHESES

Among organizational studies, contingency theory has provided a coherent paradigm for analyzing the structure of

organizations. The recurring set of relationships among organizational members can be considered to be the organization structure (Reed, 1999). Contingent structural theory assumes that each of the different aspects of organizational structure is contingent on one or more contingent factors. Thus, the task of contingency research is to identify the particular contingency factor or factors to which each aspect of organizational structure needs to conform (Donaldson, 1976).

The contingency theory states that there is no single organizational structure that is highly effective for all organizations, and structure optimization will vary according to certain factors (Reed, 1999). Given this context, the type of family or non-family control, as a selected approach to the set of possible relationships among organizational members, which also characterizes the organizational structure, is considered a dichotomous moderator variable, to observe its influence on the relationship between environmental variables and ERM, which affect organizational performance.

These factors, which are organizational characteristics, reflect the influence of the environment in which the organization is inserted. Thus, in alignment with the study objective, the theoretical model predicts the contingency variable (family and non-family control), as a contingency factor moderating the relationship between ERM, measured by ERMI (dependent variable) and the environmental factors (independent variables).

For Gordon *et al* (2009) the relationship of business performance and ERM depends on the proper match between the ERM system and the contingency factors. The authors address the five factors that have an impact on the relationship of business performance and ERM, which are: environmental uncertainty, industry competition, company complexity, company size and company growth (Gordon *et al*, 2009). To measure this relationship, the authors developed the Enterprise Risk Management Index (ERMI).

The ERMI proposed by Gordon *et al* (2009) has been applied in several studies to quantify ERM, (e.g., Chang *et al*, 2015; Zou *et al*, 2019; Naseem *et al*, 2020; Adam *et al*, 2021). In the Brazilian context, Lunardi *et al* (2019) note that risk management in some organizations consists only in controlling the business for compliance with risk limits and policies, while in others, the function is to assist the organization in knowing the uncertainties in its competitive environment. Given this context, it is believed that organizations that are more exposed to contingency factors use a higher ERM index. From this, the following research hypothesis was developed:

H1: Exposure to environmental contingency factors is positively related to ERM use.

This hypothesis will be subdivided into the following sub hypotheses:

H1a: Environmental uncertainty is positively related to ERM use.

H1b: Complexity is positively related to ERM use.

H1c: Industry competition is positively related to ERM use.

Managers' perceptions of risks in family and non-family firms, both internal and external risks have rarely been considered in literature (Brustbauer and Peters, 2013). In their study, the authors argue that the risk perceptions of managers of family firms differ from the risk perceptions of managers of non-family firms.

Glowka *et al.* (2020) argue that family firms usually deal with risk management in a more informal manner. The authors suggest that family dynamics further influence risk behavior within the organization. The authors find that ERM is negatively moderated by family involvement. Anderson and Reeb (2003), in a relationship between founding family ownership and firm performance investigation, observed that family ownership was predominant and substantial. They also suggest that family firms may perform better than non-family firms.

Given this still unresolved context, we adopt the premise that the control type (family or non-family) moderates the relationship between contingency variables and ERM, measured based on ERMI. From this, the following research hypothesis was elaborated:

H2: Family control type moderates the positive relationship between contingent environmental variables and ERM.

This hypothesis will be subdivided into the following sub hypotheses

H2a: Family control type moderates the positive relationship between environmental uncertainty and ERM use.

H3b: Family control type moderates the positive relationship between complexity and ERM use.

H3c: Family control type moderates the positive relationship between industry competition and ERM use.

III. METHODOLOGY

To fulfill the purpose of this study, the method used was a descriptive documentary research, with a quantitative approach. The research population is composed of publicly traded companies listed on the B3 (Brazil, *Bolsa e Balcão*). For the sample were selected the companies that presented data for the calculation of the dependent, independent, control and performance variable, in the period from 2012 to 2019.

Then the organizations control type (family and non-family) was observed. Resulting from the established criteria, the sample consists of 278 companies in 2012, 282 companies in 2013, 290 companies in 2014, 295 companies in 2015, 302 companies in 2016, 304 companies in 2017, 305 companies in 2018, and 307 companies in 2019. Table 1 presents the number of family and non-family firms by sample considered in this study.

Table 1 - Family and non-family businesses and total sample

Item	2012	2013	2014	2015	2016	2017	2018	2019
Family Businesses	75	78	78	80	80	80	80	81
Non-Family Businesses	203	204	212	215	222	224	225	226
Total	278	282	290	295	302	304	305	307

Source: Research data (2020).

To segregate the sample according to the type of ownership (family and non-family) it was adopted, similar to the studies of (Pamplona, 2020), the following criteria adopted as usual: family members (two or more) participate in the management, and/or, family members own 10% or more of the organization's shares (Anderson and Reeb, 2003). From the data presented in Table 1 it can be seen that, based on the criteria for determining ownership (family / non-family) adopted in this study, between the year 2012 and 2019 the number of companies belonging to the non-family sample increased by 8% (from 75 to 81) while the sample of non-family companies rose by 11.3% (203 to 226) and the total sample by 10.4%.

Table 2 contemplates the study construct, which is segregated into three groups of variables (dependent, independent, control, and moderator), describes their definitions, calculation formula, source of data collection, and studies that supported the selection of variables.

Table 2 - Research Construct

Variables	Definition	Formula	Collection	Authors
Dependent Variable (Regression)				
Enterprise Risk Management Index (ERMI)	Index used to measure ERM	Equation 1, Equation 2, Equation 3, Equation 4, Equation 5.	Refinitiv Eikon ® e B3	Gordon *et al* (2009)
Independent Variables (Regression)				
Environmental Uncertainty (INAM)	Market variability, technology and income	Equation 6	Refinitiv Eikon ® e B3	Duncan (1972); Kren (1992); Hartmann (2005)
Sector Competition (CONC)	Proportion of sales in relation to the total sales of the sector	$\frac{\text{Sales amount}}{\text{Total industry sales}}$		Bourgeois (1985); Gordon *et al* (2009)
Company Complexity (CMPX)	Diversity of business transactions	Number of company business segments		Ge and McVay (2005); Doyle *et al* (2007)
Control Variable (Regression)				
Company size (TAMA)	Size of the organization	Ln of Assets	Refinitiv Eikon ® e B3	Gordon *et al* (2009)

Sales Growth (CRES)	Sales Growth	$\frac{(\text{Revenue}_{t} - \text{Revenue}_{t-1})}{\text{Revenue}_{t-1}}$	Refinitiv Eikon ® e B3	Kleffner *et al* (2003)
Performance variable (sensitivity test)				
Net Margin (MARG)	Organization Net Margin	$\frac{\text{Net profit}}{\text{Net Sales}}$	Refinitiv Eikon ® e B3	Bolton *et al* (2011)
ROA	Return on Assets	$\frac{\text{Net profit}}{\text{Total assets}}$	Refinitiv Eikon ® e B3	Alves and Matias (2014)
Market-to-Book (MKBK)	Organization Market-to-book Index	$\frac{\text{Market Value}}{\text{Equity value}}$	Refinitiv Eikon ® e B3	Santanna *et al* (2003)
Contingential Moderator (Regression)				
COTR	Control Type	$0 =$ Family businesses 1= Non-Family Businesses	Refinitiv Eikon ® e B3	Pamplona (2020)

Source: Research data, 2020.

The data to measure the variables were obtained from the Refinitiv Eikon ® database on the B3 website and from the Investor Relations (IR) section on the companies' websites. In detail, the procedure consisted of checking the ownership type of the organizations, published on each company's website or on the B3 reference form, during the analyzed period from 2012 to 2019. Next, the calculation model for the dependent variable is demonstrated.

1.1 Enterprise Risk Management Index (ERMI)

As proposed by Gordon *et al* (2009), the Index is based on the four COSO ERM indicators, Therefore, ERM effectiveness in an organization is measured by the Enterprise Risk Management Index (ERMI) and derives from the company's ability to achieve the following objectives: i) strategy; ii) operations; iii) reporting; iv) compliance, as shown in Equation (1):

$$ERMI = \sum_{k=1}^{1} Estrategy + \sum_{k=1}^{1} Operation + \sum_{k=1}^{1} Report + \sum_{k=1}^{1} Conformity$$

Equation (1)

The Strategy indicator is related to the company's market positioning in relation to its competitors. By defining and executing its strategy, a company aims to achieve a competitive advantage in relation to participants in the same industry (Porter, 2008). This competitive advantage should promote a differentiation in relation to the competitor that is able to mitigate the organization's survival risks. The metric adopted in this study to measure whether a strategy is successful was the amount of standard deviations that its sales (Refinitiv Eikon®), deviate from the sales of its industry. The underlying idea proposed in the model is that ERM favors meeting organizational strategy, as shown below:

$$Estrategy = \frac{Sales - \mu_{sales}}{\sigma_{sales}}$$

Equation (2)

Where:

Sales = Company Sales

μ_{sales} = Average company sales

σ_{sales} = Standard deviation of sales of all firms

Operations are defined as a relationship between input and output in the operational processes of a company (Banker *et al*, 1989). In other words, more output for a given level of input or less input for a given level of output means better operational efficiency. Thus, as Kiymaz (2006) noted, the

value of sales (Refinitiv Eikon®), divided by total assets (Refinitiv Eikon®) is a measure of operational efficiency, which was measured as follows:

$$Operation = \frac{Sales}{Total\ assets} \quad \text{Equation (3)}$$

Inadequate financial reporting is likely to increase a company's risk of failure and thus decrease its performance and value. One measure of a firm's reliability, is how well quality of accounting information is evidenced in accounting reports. For this study the Total Accruals model according to (Kothari *et al*, 2005) was used which captures the effects of firms' performance by adding return on total assets (ROA) to the model as shown below:

$$Report = \frac{(Ebitda - Cash\ Flow)}{(Total\ assets)} \quad \text{Equation (4)}$$

Compliance is related to legislation and regulations. When a company promotes an adequate *compliance* management, authors such as Shavell (1982) and Gordon *et al* (2009) consider that in a company, there should be a mitigation of its general risks of failure and, consequently, an increase in its performance and value. The measure of compliance used in the study, similar to the one adopted in the study by Gordon *et al.* (2009), is the ratio of auditor's fees to total assets (Refinitiv Eikon®).

$$Compliance = \frac{auditor\ fees}{Total\ Assets} \quad \text{Equation (5)}$$

Environmental uncertainty is defined as the variability or change in the environment, in which the organization is embedded. As noted by Kren (1992) environmental uncertainty is measured as the combination of three metrics as shown below:

(1) Market: coefficient of sales variation;

(2) Technological: Coefficient of variation of the sum of R&D and capital expenditures divided by total assets; and

(3) Income: Coefficient of variation of net income before taxes.

According to the model of Gordon *et al* (2009), environmental uncertainty is calculated as shown in equation (6) below:

$$INAM = \log + (\sum_{k=1}^{3} CV(X_k)), \quad \text{Equation (6)}$$

Where: CV(Xk) = $CV(X_k) = \frac{\sqrt{\sum_{t-1}^{5} \frac{(z_{k,t} - z_k)^2}{5}}}{z_k}$, $Z_{k,t}$ = $(X_{k,t} - X_{k,t-1})$, $X_{k,t}$= uncertainty k in the year $t, CV(X_k)$ = coefficient of variation of uncertainty $k, t = 1,2, \ldots,8$ to represent the years 2012-2019, $k = 1, 2, 3$ to represent market, technological or income uncertainty, z_k means changes in eight years of uncertainty k. The absolute value of z_k is used as the denominator of $CV(X_k)$ to avoid the case where a negative z turns a situation of uncertainty into a situation of certainty.

1.2 Model Test

Initially, the Cluster Analysis technique was used to classify the organizations into family and non-family businesses. Clusters or data clustering analysis is the set of data mining techniques that aims to classify organizations into similarity groups (Fávero and Belfiore, 2017). Next, it was tested the relationship between enterprise risk management and contingent variables, considering, as observed Gordon *et al* (2009), that companies more exposed to contingent factors have a higher rate of ERM use.

Thus, the relationship between ERMI (which is used as a proxy for enterprise risk management according to Equation 1) and contingency factors was verified. To test H1, robust OLS (Ordinary Least Squares) regressions were performed, controlling for sector and year, using Statistics Data Analysis software (Stata® 13.0), as follows:

$$\text{ERMI} = \beta_0 + \beta_1 INAM + \beta_2 TAMA + \beta_3 CRES + fixed\ effects\ year + fixed\ effects\ industry + \varepsilon \quad \text{Equation (7)}$$

$$\text{ERMI} = \beta_0 + \beta_1 CMPX + \beta_2 TAMA + \beta_3 CRES + fixed\ effects\ year + fixed\ effects\ industry + \varepsilon \quad \text{Equation (8)}$$

$$\text{ERMI} = \beta_0 + \beta_1 CONC + \beta_2 TAMA + \beta_3 CRES + fixed\ effects\ year + fixed\ effects\ industry + \varepsilon \quad \text{Equation (9)}$$

Where:

ERMI = Enterprise Risk Management Index

INAM = Environmental Uncertainty

CMPX = Complexity

CONC = Sector Competition

TAMA = Company Size

CRES = Company Growth

ε = Regression error

To test H2, the impact of the contingency moderator variable on the relationship between ERMI (which is used as a proxy for enterprise risk management according to Equation 1) and the contingency factors was verified. Robust Ordinary Least Squares (OLS) regressions were adopted, controlling for sector and year, using Statistics Data Analysis software (Stata® 13.0), as follows:

$$\text{ERMI} = \beta_0 + \beta_1 INAM + \beta_2 TAMA + \beta_3 CRES + \beta_4 COTR + \beta_5 MOD0 + fixed\ effects\ year + fixed\ effects\ industry + \varepsilon \quad \text{Equation (10)}$$

$$\text{ERMI} = \beta_0 + \beta_1 CMPX + \beta_2 TAMA + \beta_3 CRES + \beta_4 COTR + \beta_5 MOD1 + fixed\ effects\ year + fixed\ effects\ industry + \varepsilon \quad \text{Equation (11)}$$

$$\text{ERMI} = \beta_0 + \beta_1 CONC + \beta_2 TAMA + \beta_3 CRES + \beta_4 COTR + \beta_5 MOD2 + fixed\ effects\ year + fixed\ effects\ industry + \varepsilon \quad \text{Equation (12)}$$

$$\text{ERMI} = \beta_0 + \beta_1 INAM + \beta_2 CMPX + \beta_3 CONC + \beta_2 TAMA + \beta_3 CRES + \beta_4 COTR + \beta_5 MOD3 + fixed\ effects\ year + fixed\ effects\ industry + \varepsilon \quad \text{Equation (13)}$$

Where:

ERMI = Enterprise Risk Management Index

INAM = Environmental Uncertainty

CMPX = Complexity

CONC = Sector Competition

TAMA = Company Size

CRES = Company Growth

COTR = Control Type

MOD0 = Control Type Moderation on Environmental Uncertainty

MOD1 = Control Type Moderation on Complexity

MOD2 = Moderation of the Control type in Sector Competition

MOD3 = Control Type Moderation on All Contingency Variables

ε = Regression error

IV. RESULTS ANALYSIS

Initially, the descriptive statistics of the variables and the test of means are presented, carried out to verify whether there are significant differences between family and non-family companies in the use of ERM measured by ERMI. The descriptive statistics are shown in Table 3. The avarage ERMI for the family business is 0,4416, as compared to 0,5044 for the non-Family business. These two groups are not statistically different in the means of their ERMI. Ind addition, the means for all five contingency variables of the family business are not statistically different than the means for de non-family business.

However, it is noted a decrease in the indicators that measure the contingency variables for companies classified as family businesses. This shows that contingency indicators are higher for companies classified as non-family businesses, thus these companies are more prone to risk management when exposed to contingency factors in carrying out their activities.

Table 3 - Descriptive statistics of the variables

Variables	Family Business			Non-Family Business		
	Average	Med.	D.P	Average	Med.	D.P
ERMI	0,4416	0,2727	1,1737	0,5044	0,1882	1,4217
INAM	5,2689	7,6038	4,0326	5,8478	8,1512	4,0655
CMPX	2,9877	3,0000	0,8394	2,6667	3,0000	0,8239
CONC	0,0232	0,0039	0,0552	0,0400	0,0079	0,0916
TAMA	20,5505	20,9366	3,8488	20,9188	22,0139	5,0658
CRES	0,0585	0,0257	0,41134	0,5217	0,0364	9,4408

Key: ERMI: *Enterprise Risk Management Index*; INAM: Environmental Uncertainty; CMPX: Complexity; CONC: Competition; TAMA: Size; CRES: Company Growth; Med: Median; S.D: Standard Deviation. Source: Research data (2020).

As Gordon *et al* (2009) noticed, ERMI measures a firm's ability to achieve objectives through strategy, operations, reporting, and compliance. It was observed here that on average this index is higher for non-family firms, which shows that family firms are less likely to use risk management when exposed to contingent factors. This result corroborates the results of Glowka *et al* (2020), who argue that family firms usually deal with risk management in a more informal way. Next, Table 4 shows the Pearson's Correlation between the variables analyzed in the study.

Table 4 - Pearson's Correlation

Variable	ERMI	INAM	CMPX	CONC	TAM	CRES	COTR
ERMI	1	0.3240	0.0086***	0.7020	0.3370	0.0760*	0.0144**
INAM		1	0.6704	0.2053	0.4232	0.3280	0.0627*
CMPX			1	-0.0739*	0.0210**	-0.0410**	-0.1858
CONC				1	0.2881	0.0298**	0.0884*
TAMA					1	0.0570*	0.0341**
CRES						1	0.0535*
COTR							1

Caption: Legend: ERMI: Enterprise Risk Management Index; INAM: Environmental Uncertainty; CMPX: Complexity; CONC: Competition; TAMA: Size; CRES: Company Growth; COTR: Control Type. Notes: Significance levels: * p<0.1, ** p<0.05, *** p<0.01. Source: Research data (2020).

Regarding the Pearson's Correlation, the existence of correlation among the variables can be noticed. The COTR presents a positive correlation with INAM, CONC, TAMA and CRES. Regarding the CRES, a negative correlation is observed with CMPX and positive with CONC and TAMA. A positive correlation is also observed between TAMA and CMPX and a negative correlation between CONC and CMPX. As far as ERMI is concerned, a positive correlation is observed with CMPX, CRES and COTR, thus the risk management index is correlated with the contingency variables. In general, the data in Table 4 demonstrate that there is no high correlation among the variables analyzed, which allows ruling out possible multicollinearity problems in the following regression models (Table 5) calculated according to Equations 7, 8 and 9.

Table 5 - Regression results exposure to contingency factors and the use of ERM.

Variables	Predicted Signal	Model 1		Model 2		Model 3	
		Coefficient	*t-statistic*	Coefficient	*t-statistic*	Coefficient	*t-statistic*
_Cons	+/-	-1.2008	-6.85	-1.3570	-7.11	-1.6878	-8.88
INAM	+	0.0701***	10.75				
CMPX	+			-0.0369**	-1.35		
CONC	+					11.2899	26.11
TAMA	+	0.0663***	13.37	0.0906***	19.23	0.0340**	14.46
CRES	+	-0.0744***	-1.67	0.1389	2,46	0.1747	4.19
Significance		0.0000*		0.0000*		0.0000*	
R^2		0.2127		0.1705		0.6023	
VIF		1.49 – 5.64		1.26 – 5.58		1.25 – 5.86	
DW		1.9395		1.9019		1.9361	
N		2.471		2.471		2.471	

Notes: *Significance at 1% level, **Significance at 5% level, ***Significance at 10% level

Source: Research data (2020).

Table 5 shows that Durbin-Watson presented a value very close to 2 for the three models analyzed, demonstrating that the independence of errors in the data analyzed is satisfactory and that there is no autocorrelation between the residuals (Fávero and Belfiore, 2017). Finally, the multicollinearity test (VIF) demonstrates the absence of multicollinearity problems, considering that its values should be between 1 and 10 (Hair *et al*, 2009). Thus, it can be seen that there were no multicollinearity problems, since the values of the variables analyzed were between 1.49 -

5.64 in model 01, 1.26 - 5.58 in model 2, and 1.25 - 5.86 in model 03.

The three models analyzed are found to be statistically significant, and the explanatory power (^{R2}) was 21.27% for Model 1, 17.05% for Model 2, and 60.23% for Model 3. These results are similar to the study by (Gordon *et al*, 2009). Regarding the relationship between ERM use and contingency variables, a positive and significant relationship was found in Models 1, 2 and 3 at the 1 % level. When operationalizing the use of ERM with the contingency variables and with the other control variables, in Model 1 the positive and significant relationship between the use of ERM and the contingency variables INAM and TAMA, is confirmed, in Model 2 the positive and significant relationship between the use of ERM and the contingency variables TAMA and CRES is confirmed and in Model 3 the positive and significant relationship between the use of ERM and the contingency variable TAMA is confirmed. In all models the significance level was 5% and 10%.

Table 6 - Regression result of ownership type moderation on exposure to individual contingent factors and the use of ERM

Variables	**Predicted Signal**	**Model 4**		**Model 5**		**Model 6**	
		Coefficient	***t-statistic***	**Coefficient**	***t-statistic***	**Coefficient**	***t-statistic***
_Cons	+/-	-1.2398	-6.70	-1.6633	-6.75	-1.6774	-8.97
INAM	+	0.0639***	6.34				
CMPX	+			0.0343**	0.60		
CONC	+					13.6262	29.59
TAMA	+	0.6598	13.19	0.0907***	19.26	0.0342**	14.47
CRES	+	-0.0766***	-1.72	0.1369	2.41	0.1718	4.13
COTR	+	0.0425**	0.59	0.3730	2.01	0.0409**	1.21
MOD0	+	0.0089*	0.74				
MOD1				-0.1033	-1.64		
MOD2						-27582	-4.25
Significance		0.0000***		0.0000***		0.0000***	
R^2		0.2139		0.1721		0.6063	
VIF		4.33 – 5.66		3.58 – 5.60		7.22 – 5.95	
DW		1.9404		1.9124		1.9010	
N		2.471		2.471		2.471	

Notes: *Significance at 1% level, **Significance at 5% level, ***Significance at 10% level

Source: Research data, 2020

Table 7 - Regression results of property type moderation on exposure to the combined contingency factors and the use of ERM

Variables	Predicted Signal	Model 7	
		Coefficient	*t-statistic*
_Cons	+/-	-1.6174	-8.10
INAM		0.0444**	6.73
CMPX		0.0425**	1.67
CONC		11.0689	25.69
TAMA		0.0200**	7.24
CRES		0.0433**	1.18
COTR		0.0009*	0.01
MOD3		-0.0018	-0.24

Significance	0.0000***
R^2	0.6193
VIF	4.14 – 6.01
DW	1.9951
N	2.471

Notes: *Significance at 1% level, **Significance at 5% level, ***Significance at 10% level

Source: Research data, 2020

Tables 6 and 7 also show that the Durbin-Watson presented a value close to 2 for the four models analyzed, demonstrating that the independence of errors in the data analyzed is satisfactory and that there is no autocorrelation between the residues. Thus, it can be seen that there were no multicollinearity problems, since the values of the variables analyzed were between 4.33 - 5.66 in model 4; 3.58 - 5.60 in model 5; 7.22 - 5.95 in model 6; and 4.14 - 6.01 in model 7. The models analyzed are found to be statistically significant, and the explanatory power (R^2) was 21.39% for Model 4, 17.21% for Model 5, and 60.63% for Model 6 and 61.93% for Model 7.

Regarding the contingency moderator variables impact in the relationship between the use of ERM, measured by ERMI, and the contingency factors, it was found in models 4, 5, 6 and 7 a positive and significant relationship at the 1% level. When operationalizing the impact of moderator variables and ERM use on exposure to contingency variables, with the other control variables, in Model 4 a positive and significant relationship is confirmed between ERM use and the contingency variables INAM, COTR and MOD0 and negative for the variable CRES. In Model 5 the positive and significant relationship between ERM use and the contingency variables CMPX and TAMA is confirmed. In Model 6 it is confirmed the positive and significant relationship between the use of ERM and the contingent variable TAMA and COTR, in Model 7, it is confirmed the positive and significant relationship between the use of ERM and the contingent variable INAM, CMPX, TAMA, CRESC and COTR, and a negative relationship with the variable MOD3 at 1%, 5% and 10% levels.

To test the first research hypothesis, one has models 1, 2 and 3 (which deals with the relationship between ERM and contingent factors), organizations demonstrated a better correspondence between ERMI and the variables of Environmental Uncertainty (INAM) and Company Size (TAMA). These results suggest that companies are placing greater importance on the information obtained through data from the INAM variables. Therefore, the effectiveness of their ERM consisting of strategy, operation, reporting and compliance variables, related to environmental uncertainty, tends to be higher.

Similarly, the greater observance of the Company Size Index (TAMA), seems to be linked to a high ERM index. These results corroborate the findings of (Gordon *et al* 2009) amplifying its robustness, considering that the authors analyzed such correlations only in 2005, in the context of American companies, whereas in the present model the time span of 8 years (2012 - 2019) is observed. However, diverging from the results of Gordon *et al* (2009), a negative correlation was found for the variables Corporate Complexity (CMPX) and Growth (CRES) and no significant results were found for Sector Competition (CONC).

Thus, hypothesis **H1a** is confirmed**:** environmental uncertainty is positively related to the use of ERM. Gordon *et al* (2009) evidenced that ERM is intended to identify and manage uncertain future events that may negatively influence the organization's performance.

However, hypotheses **H1b**: complexity is positively related to the use of ERM and **H1c**: sectorial competition is positively related to ERM are rejected. By not evidencing a relationship between complexity and ERM, this study diverges from Bourgeois (1985), Liebenberg and Hoyt (2003) and Beasley *et al* (2008), who show that organizational complexity increases the risks and hinders the achievement of organizational strategy. It can be seen from these findings that ERM is related to the environmental uncertainties suffered by organizations.

To test the second research hypothesis, family control type positively moderates the relationship between environmental contingent factors and ERMI, we have Equations 10, 11, 12 and 13 (which deals with the control type variable moderation in the relationship between ERM, measured by ERMI, and contingent variables). The organizations also showed a better correspondence between ERM and the variables of Environmental Uncertainty (INAM), Company Size (TAMA). But in the context of family businesses, they also demonstrated a better correspondence between ERM and Complexity (CMPX), Company Growth (CRES) and Type of Control (COTR).

Regarding to contingent factors, the results suggest that the type of control (family or non-family) is a relevant and moderating variable. Therefore, ERM effectiveness, consisting of strategy, operation, reporting and compliance variables, when related to the variable Environmental Uncertainty (INAM), Size (TAMA), Company Growth (CRES), Complexity (CMPX) and Type of Control (COTR) tends to be higher. This finding is relevant in the context of family firm research, as Glowka *et al* (2020) note, family firms tend to have more informal controls. The authors suggest that family dynamics further influence risk behavior within the organization. Also, Brustbauer and Peters (2013) argue that the risk perceptions of managers of family firms differ from the risk perceptions of managers of non-family firms.

Thus, the sub-hypotheses **H2a:** the type of family control moderates the positive relationship between environmental uncertainty and the use of ERM and **H2b**: the type of family control moderates the positive relationship between complexity and the use of ERM. However, **H2c** is rejected: family type of control moderates the positive relationship between sector competition and ERM use.

It can be seen, from these findings, that ERM in a family businesses scenario also has a relationship with the environmental uncertainties suffered by organizations and with complexity. In the Brazilian national context, these findings agree with the studies of (Lunardi *et al*, 2019) when they observe that environmental uncertainty generates difficulties for companies in terms of predicting future events that may affect their operations. The risks associated with an appropriate response to events of environmental uncertainty suggest that organizations tend to monitor environmental uncertainty in order not to suffer negative impacts on their results.

Gordon *et al.* (2009) evidenced that ERM is intended to identify and manage uncertain future events that may negatively influence the organization's performance. Anderson and Reeb (2003), in investigating the relationship between founding family ownership and firm performance, observed that family ownership was prevalent and substantial. They also suggest that family firms may perform better than non-family firms. From these statements, sensitivity test was conducted (table 8) to check the impact of ownership type on the performance of organizations:

Table 8 - Sensitivity test

Variables	Predicted Signal	Dependent variables: MKTB, ROA and MARG	
		Coefficient	*t-statistic*
-Cons	+/-	-0.0275**	-0.60
INAM	+	0.0186**	10.61
CMPX	+	0.0074*	1.04
CONC	+	0.1616	4.04
TAMA	+	-0.0031*	-4.74
CRES	+	-0.0234**	-1.43
COTR	+	-0.0629***	-2.87
MOD3	+	0.0049*	2.53
GRCON	+	0.0005*	2.68
Significance		0,000***	
R2		0.2469	
VIF		4.12 – 5.82	
DW		2.0404	
N		2.456	

Key: ROA: *Return on Asset*; MKTB: *Market-to-Book;* MARG: Net Margin; INAM: Environmental Uncertainty; CMPX: Complexity; CONC: Competition; TAMA: Size; CRES: Company Growth; COTR: Type of Control; MOD3: Moderation of Contingency Factors; GRCON: Family Firm x ERMI. Notes: *Significance at 1% level, **Significance at 5% level, ***Significance at 10% level

Source: Research data, 2020

To verify the impact on the organizations' performance, moderated by the type of family control, in the relationship between the ERM and the contingency variables, the family companies were isolated from the study sample and the regression model was applied according to Table 8. According to the observed results, in the context of family businesses, there is a positive relationship between ERM and performance. The higher the ERMI the better the performance measured by Return on Asset (ROA), Market-to-Book (MKTB) and Net Margin (MARG). It can be seen that Durbin-Watson presented a value of 2 for the model analyzed, demonstrating that the independence of the errors in the data analyzed is satisfactory and that there is no autocorrelation between the residuals. Finally, the multicollinearity test (VIF) demonstrates the absence of multicollinearity problems. Thus, it can be seen that there were no multicollinearity problems, since the values of the variables analyzed were between 4.12 - 5.82 in the model.

The model analyzed here is found to be statistically significant, and the explanatory power (R^2) was 24.69% for the model. Regarding the impact of ownership type on performance, a positive and significant relationship was found at the 1 % level. When operationalizing the type of control impact in moderating the relationship of ERMI with the contingency variables and with the other control variables, the positive and significant relationship between the contingency variables INAM, CMPX, MOD3 and GRCON is confirmed and negative for the variable CRES and COTR, at the 1%, 5% and 10% levels. It can be inferred from this result that family businesses that have higher risk management index, also have an effect on market performance**.** This result corroborates with the study of Yazdi (2018) who concluded that strategic planning has positive relationship with family business and better organizational performance. Also, Hiebl and Mayrleitner (2017) whose study when investigating the professionalization of managerial accounting in family firms, suggests that the presence of family management, such as CFOs, may be related not to less, but to higher levels of managerial accounting professionalization. Florio and Leoni (2017) show that companies with advanced levels of ERM implementation perform better in both financial performance and market valuation.

Environmental uncertainty creates difficulties for companies when it comes to predicting future events that may affect their operations. The risks associated with an appropriate response to environmental uncertainty events suggest that organizations tend to monitor environmental uncertainty in order not to suffer negative impacts on their results, so companies with an efficient ERM system (high ERMI) are prone to greater monitoring of environmental uncertainties. In the same vein, sectoral competition and complexity must be closely monitored by organizations. Analyzing the products and services offered in the market by other companies, both similar and different, can help the entity in the competition for sales in the various market niches. Thus, companies with greater management of this information tend to have higher rates of ERMI. It is also inferring that organizations of large size, that is, those considered larger, tend to adopt risk management systems.

According to Arena et al. (2010) highlight that ERM can be seen as a way for managers to prepare their organizations in the face of uncertainties in the corporate sphere. In addition, Gordon, Loeb and Tseng (2009) showed that the ERM is intended to identify and manage uncertain future events that can negatively influence the organization's performance. Corroborating the findings of Baxter et al. (2013), the quality of business risk management, is associated with organizational performance.

V. CONCLUSIONS

This research aimed to assess the impact of family control on the relationship between contingency variables and ERM and its influence on organizational performance. By using the ERM-index proposed by Gordon *et al* (2009) it uses data from companies listed on B3 in a longitudinal cut-off of eight years (2012 to 2019). The results show that the use of ERM is related to environmental uncertainty, which allowed us to accept H1a. However, contrary to expectation, we conclude for the sample and period investigated, the greater the business complexity and competition, the lower the ERMI. We highlight two directions for the contradictory results, the ERM-index may not be adequate to capture these variables or the complexity and competition have attributes that need to be better observed by studies that investigate their relationship with managerial mechanisms such as the ERM.

The second group of hypotheses, still with emphasis on the first research question, focuses attention on the moderating effect of ownership type, family and non-family, on the relationship between environmental uncertainty, complexity and competition and ERM. The results show that the use of ERM is related to environmental uncertainty and complexity. This allows inferring that, for the analyzed context, family ownership type moderates the positive relationship between environmental uncertainty and ERM use and complexity and ERM use.

In relation to performance, for the specific sample of family firms, it is concluded that ERM has an effect on market performance. This answers the second research problem of this study, by evidencing that family ownership type positively influences the use of ERM, consequently, it positively influences market performance. The results of

this study contribute to the literature on the impact of ownership type on the relationship between ERM and contingency variables, by confirming the inferences that family-owned firms that have higher ERMI, perform better. It is worth noting that taking the right amount of risk is essential for organizational performance. Thus, as a response to the importance of risk management, the effectiveness and implementation of Enterprise Risk Management (ERM) is a critical factor. Further testing also supports the expectation that effective ERM systems lead to improved performance by reducing risk exposure and that reverse causality between ERM and organizational performance is not present.

This study contributes to the literature and organizational studies, on the impact of ownership type on the relationship between ERM and contingent variables, by confirming the inferences that family firms that have higher ERMI, exhibit better market performance.

From a practical perspective, by examining the effect of ERM and environmental factors on organizational performance in family and non-family businesses, this study offers subsidies to managers. In general, firms with more sophisticated ERM have better ability to manage the uncertainties of the environment. ERM, regardless of ownership type, is related to environmental uncertainty, business complexity, competition, size and growth. The present research presents limitations, such as the impossibility of the generalization of the results, since only companies listed in B3 (Brazil, *Bolsa e Balcão*) with information available in the Refinitiv Eikon® database were analyzed, in the period from 2012 to 2019. Although the ERM-Index proposed by Gordon *et al.* (2009) and adopted in this study as a proxy for measuring ERM is widely used, its non-adequacy for the Brazilian context may be a limitation of the study. It is recommended for future researches the investigation of other samples, possibly from different countries, being carried out a comparative analysis between the different contexts investigate particularities of countries that may impact the effectiveness of the ERM-index. Another possibility would be to conduct similar research, using other contingency variables and/or adding such variables in the present analysis and to expand the studies related between managerial mechanisms and the variables complexity and competition.

REFERENCES

[1] Adam, M., Soliman, A., Mahtab, N. (2021). Measuring Enterprise Risk Management implementation: a multifaceted approach for the banking sector. *The Quarterly Review of Economics and Finance.* https://doi.org/10.1016/j.qref.2021.01.002.

[2] Almeida, D. M, Flach L. (2020). Family Ownership and Corporate Performance: Evidence from Brazilian Companies Making up the B3 ibrx100 Index". *Accounting Viewed & Reviewed 31* (2). https://doi.org/10.22561/cvr.v31i2.4924.

[3] Alves, M. T., Matias, Francisco J. F. (2014). Operational risk management and disclosure and the basel accords: the case of the largest Portuguese banks. *Revista Universo Contábil*, v. 10, n. 3, 172-193.

[4] Anderson, R. C; Reeb, D. M. (2003). Founding Family Ownership and Firm Performance: Evidence from the S&P 500. *The Journal of Finance*, n 58(3), 101-1327.

[5] Arena, M.; Arnaboldi, M.; Azzone, G.. The organizational dynamics of enterprise risk management. Accounting, Organizations and Society, v. 35, n. 7, p. 659-675, 2010.

[6] Banker, R. D., Datar, S., Kaplan, R.S., (1989). Productivity measurement and management accounting. *Journal of Accounting, Auditing and Finance 4* (4), 528-554.

[7] Baxter, R.; Bedard, J.; Hoitash, R.; Yezegel, A.. Enterprise risk management program quality: Determinants, value relevance, and the financial crisis. Contemporary Accounting Research, v. 30, n. 4, p. 1264-1295, 2013.

[8] Beasley, M, Pagach, D.; Warr, R. (2008). Information conveyed in hiring announcements of senior executives overseeing enterprise-wide risk management processes. *Journal of Accounting, Auditing & Finance, v.* 23, n. 3, 311-332.

[9] Bolton, P., Chen, H., Wang, N. (2011). A unified theory of Tobin's q, corporate investment, financing, and risk management. *The journal of Finance*, v. 66, n. 5, 1545-1578,

[10] Bourgeois III, J. (1985) Strategic goals, perceived uncertainty, and economic performance in volatile environments. *Academy of management journal*, v. 28, n. 3, 548-573.

[11] Bromiley, P., Mcshane, M., Nair, A., Rustambekov, E. (2015). Enterprise risk management: Review, critique, and research directions. *Long range planning*, v. 48, n. 4, 265-276.

[12] Brustbauer, K. J. Peters, M. (2013) Risk perception of family and non-family firm managers. *Int. J. Entrepreneurship and Small Business***,** 20, 96-116.

[13] Chang, S. H., Wang, T. S., Chiu, A. A. (2015). Corporate governance and the value of cash holdings: Evidence from enterprise risk management and internal control weakness. *International Research Journal of Applied Finance*, v. 6, n. 4, 336-365.

[14] Coso. (2017). Enterprise Risk Management Integrating with Strategy and Performance. Committee of Sponsoring Organizations of the Treadway Commission.

[15] Dickinson, G. (2001). Enterprise risk management: Its origins and conceptual foundation. *The Geneva Papers on Risk and Insurance. Issues and Practice*, v. 26, n. 3, 360-366.

[16] Donaldson, L, (1976). Woodward, technology, organization structure and performance - a critique of universal generalization. *Journal of Management Studies*, 13(3): 255-273.

[17] Doyle, J., Ge, W. Mcvay, S. (2007). Determinants of weaknesses in internal control over financial reporting.

Journal of accounting and economics, v. 44, no. 1-2, 193-223.

[18] Duncan, R. (1972) Characteristics of organizational environments and perceived environmental uncertainty. *Administrative science quarterly*, 313-327.

[19] Fávero, L. P., Belfiore, P. (2017). Handbook of Multivariate Data Analysis - 1. Ed. - Rio de Janeiro: Elsevier.

[20] Florio, C, Leoni, G. (2017). Enterprise risk management and firm performance: The Italian case. *The British Accounting Review v*. 49, 56 and 74.

[21] Frezatti F, Bido, D. de S., Mucci, D. M, Beck, F. (2001). Life Cycle Stages and Profile of Family Firms, *RAE*, v. 57, n. 6, 601-619, 2001.

[22] Ge, W., Mcvay, S. (2005). The disclosure of material weaknesses in internal control after the Sarbanes-Oxley Act. *Accounting Horizons*, v. 19, n. 3, 137-158.

[23] Giovannoni E. , Maraghini MP. , Riccaboni A. (2011) Transmitting knowledge across generations: the role of management accounting practices. *Fam. Business Review* 24(2): 126-150

[24] Glowka, G., Kallmunzer, A., Zehrer A. (2019). Enterprise risk management in small and medium family enterprises: the role of family involvement and CEO tenure. *International Entrepreneurship and Management Journal.* doi.org/10.1007/s11365-020-00682-x

[25] Gordon, L. A., Loeb, M. P., Tseng, C. Y. (2019). Enterprise risk management and firm performance: A contingency perspective. *Journal of accounting and public policy*, v. 28, n. 4, 301-327.

[26] Hair, J., Black, W., Babin, B., Anderson, R., Tatham, Ronald. (2009). *Multivariate data analysis*. Bookman Editora.

[27] Hartmann, F. (2005). The effects of tolerance for ambiguity and uncertainty on the appropriateness of accounting performance measures. *Abacus*, v. 41, n. 3, 241-264.

[28] Hiebl, M. R. W., Mayrleitner, B. (2017). Professionalization of management accounting in family firms: the impact of family members. *Springer-Verlag GmbH Germany, part of Springer Nature.*

[29] Hoyt, R., Liebenberg, A. (2011). The value of enterprise risk management. *Journal of risk and insurance*, v. 78, n. 4, 795-822.

[30] Kiymaz, H., (2006). The impact of announced motives, financial distress, and industry affiliation on shareholders' wealth: evidence from large sell-offs. *Quarterly Journal of Business and Economics* 45, 69-89.

[31] Kleffner, A., Lee, R., Mcgannon, B. (2003). The effect of corporate governance on the use of enterprise risk management: Evidence from Canada. *Risk Management and Insurance Review*, v. 6, n. 1, 53-73.

[32] Kothari, S. P.; *et al*. (2005). Performance matched discretionary accrual measures. *Journal of Accounting and Economics*, v. 39, n. 1, 163-197.

[33] Kren, L. (1992). Budgetary participation and managerial performance: The impact of information and environmental volatility. *Accounting Review*, 511-526.

[34] Liebenberg, A., Hoyt, R. (2003). The determinants of enterprise risk management: Evidence from the appointment of chief risk officers. *Risk Management and Insurance Review*, v. 6, n. 1, 37-52.

[35] Mcshane M. K., Nairl A. and Rustambekov E. (2011) Does Enterprise Risk Management Increase Firm Value? *Journal of Accounting, Auditing & Finance 26(4)* 641-658.

[36] Naseem, T., Shahzad, F., Asim, G. A., Rehman, I. U., & Nawaz, F. (2020). Corporate social responsibility engagement and firm performance in Asia Pacific: The role of enterprise risk management. *Corporate social responsibility and environmental management*, *27*(2), 501-513.

[37] Oro, I. M., lavarda, C. E. F. (2019). Interface of Managerial Control Systems with Strategy and Performance Measures in Family Business. Journal Accounting & Finance - USP, 30(79), 14-27.

[38] Pagach, D., Warr, R. (2010). The effects of enterprise risk management on firm performance. *Social Science Research Network (SSRN).*

[39] Pamplona, E. Ames, A. C. , Silva, T. P. (2020) Capital structure and financial distress in Brazilian family and non-family firms. *Contemporary journal of accounting*, v. 17, 17-32.

[40] Porter, M. E. (2008). The five competitive forces that shape strategy. *Harvard Business Review* 86 (1), 78-93.

[41] Power. M. (2009), The risk management of Nothing. *Accounting Organizations and Society*: 34: 849-855.

[42] Quinn, M. *et al.* (2018). Future research on management accounting and control in family firms: suggestions linked to architecture, governance, entrepreneurship and stewardship. *Journal of Management Control*, v. 28, n. 4, 529-546.

[43] Quon, T. K., Zeghal D. Maingot M. **(**2012), "Enterprise risk management and firm performance". *Procedia - Social and Behavioral Sciences*, 62: 263-267.

[44] Reed, M. (1999). "Organizational Theorizing: A historically contested field" in Clegg, Hardy and Nord, *Handbook of Organizational Studies*. São Paulo, Atlas, V 1.

[45] Santanna, D. P, Teixeira, A. J. C. , Louzada, L. C.. (2003). The relationship between market-to-book equity and abnormal earnings in capital markets in Brazil. In: *XXVII ENANPAD*, Atibaia (SP). Held from Sep 20 to 24.

[46] Sax, J., Andersen, T. J. (2018). Making Risk Management Strategic: Integrating Enterprise Risk Management with Strategic Planning. *European Management Review.*

[47] Shavell, S. (1982). Suit, settlement, and trial: A theoretical analysis under alternative methods for the allocation of legal costs. *The Journal of Legal Studies*, v. 11, n. 1, 55-81.

[48] Silva, M. Z., Lunardi, M. A., Jacomossi, F. (2019). Enterprise Risk Management and business performance: A Contingential Perspective. *Revista Mineira de Contabilidade* v.20, 45-58.

[49] Songini L, Gnan L (2015) Family involvement and agency cost control mechanisms in family small and medium-sized enterprises. *J Small Business Management* 53 (3), 748-779

[50] Speckbacher G, Wentges P. (2012) The impact of family control on the use of performance measures in strategic target setting and incentive compensation: a research note. *Management Account Res* 23(1), 34-46

[51] Yazdia, N. H. M. H. (2018) The impact of F-PEC scale and strategic planning in the family business, *Accounting* 4 11-20, (2018).

[52] Zou, X., Isa, C. R., Rahman, M. (2019). Valuation of enterprise risk management in the manufacturing industry. *Total Quality Management & Business Excellence, v.* 30, n. 11-12, 1389-1410.

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-7; Jul, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.117.5

Influence of the Investor's Short-Term Horizon on IPO Performance: An Emerging Markets Perspective

Michael de Alencar Silva, Tarcísio Pedro da Silva

Fundação Universidade Regional de Blumenau

Received: 11 May 2024,

Receive in revised form: 22 Jun 2024,

Accepted: 02 Jul 2024,

Available online: 13 Jul 2024

***Keywords*— Investor Sentiment, Behavioral Finance, Country Risk, IPO.**

***Abstract*—** *The present study aimed to investigate the relationship between investor sentiment and the return on the first day of an IPO, moderated by emerging market risk factors, from 2013 to 2021. The sample included 105 companies that carried out an IPO in this period. The econometric method used was the regression analysis. As main results, it was observed that investor sentiment, measured by market variables and trading volume, positively affected returns on the first day of the IPO, even when moderated by idiosyncratic country risk factors. Thus, the research hypotheses were accepted. In addition to the debate on the influence of investor sentiment on the performance of IPOs, the theoretical contribution of the research involves the empirical expansion of the effects of country risk factors. Therefore, it was concluded that investors seek returns on the first day of the IPO, considering their sentiment towards the market and reacting positively to the risk factors of emerging markets.*

I. INTRODUCTION

Recent studies in the field of Behavioral Finance highlight a new scenario in which attention turns to the impact of investors' bounded rationality and its influence on market behavior and asset returns. For Santos (2017), investors are motivated by sentiment, contributing to the prices distancing from their fundamental value, especially when the market is optimistic. Thus, the preference for asymmetry can be understood as the behavior in which agents show a preference for asymmetric returns, not following fundamentalist indicators (Brunnermeier; Gollier; Parker, 2007).

An example of this type of behavior is underpricing in IPOs. Ibbotson (1975) defined "underpricing" as the difference between the closing price of the stock on the first trading day and the subscription price in the initial offering. When the issue price is lower than the one reached at the close of the first trading day, underpricing occurs. Rock (1986) argued that underpricing occurs due to information asymmetry between the issuer and new investors. Therefore, the share is measured at a price lower than the fair value to attract more investors.

Since then, research on underpricing has been carried out under different approaches, such as: abnormal returns (Stoll and Curley, 1970), underwriter autonomy (Baron, 1982), "hot issue" and "cold issue" (Ritter, 1984), "winner's curse" (Rock, 1986), company size (Welch, 1989), speculation (Ritter, 1991), investor attractiveness (Benveniste and Busaba, 1997), intentional underpricing to attract investors (Krigman, Shaw, and Womack, 1999), information asymmetry (ljungqvist, 2005; Green and Hwang 2012); influence of individual investors (Colaco, De Cesari and Hedge, 2017) and investor sentiment (Zainudin, Zaki, Hadi, Hussain and Kantakji, 2019; Che-Yahya and Matsuura, 2021).

However, according to Agathee, Sannasse and Brooks (2012), there is still no framework that integrates all the factors that affect underpricing. Increasingly, under the lens of theories such as signaling, agency, information asymmetry and investor sentiment, theoretical models have been developed to help in understanding underpricing. However, all this variety demonstrates the complexity involved in evaluating performance in Initial Public Offerings (IPO). The works developed usually assumed that the initial returns of an IPO were extracted from a normal distribution. Nevertheless, with the development of new research, it was observed that the IPOs prices were stabilized by their underwriters (Asquith; Jones; Kieshnick, 1998).

When investors oppose expected utility principles and are not so risk averse, they ought to prefer skewed positive yield distributions (Veras Machado *et al.*, 2020). Green and Hwang (2012) stated that IPO returns are related to a preference for asymmetry, in which IPOs with a high asymmetry expectation offered significantly higher returns on the first day. He (2012) highlighted that it is common for the underlying issue of investor sentiment to be about how investors interpret and react to news to shape their positions because it is understood as a belief about future cash flows and investment risks that cannot be justified by the facts.

Colaco, De Cesari and Hedge (2017) observed the influence of individual investors on the valuation of companies during IPOs. Thus, as observed by Veras Machado *et al.* (2020), empirical research aimed at explaining the behavior of stock prices through investor sentiment and bounded rationality, soon after an IPO issuance, is important. The diversity of approaches may be a factor that makes it difficult to reach a consensus on the metrics to evaluate the IPOs performance. Despite the existence of several studies on underpricing, there still are some gaps to make new inferences in the Brazilian stock market, essentially due to its emerging market characteristics, which differ significantly from the capital markets of developed countries, such as the USA. One of these gaps is assessing the influence of investor sentiment in its short-term horizon on the performance of companies at the time of the IPO, considering the risk factors of emerging markets. From this gap, the following research problem arises: **What is the moderating effect of country risk factors on the relationship between investor sentiment in the short term and the IPO performance in emerging markets?** To answer the problem, this study will aim to analyze the moderating effect of country risk factors in the relationship between short-term investor sentiment and the IPO underpricing performance from the companies listed on Brasil Bolsa and Balcão - B3 from January 2013 to December 2021.

Investigating underpricing in the Brazilian environment is justified because, as Daily et al. (2003) argue, there is a growing interest from researchers in understanding the underpricing phenomenon not only empirically, but also through the establishment of theoretical connections. Brazil stands out in terms of relevance among emerging countries, due to the recent growth in the attractiveness of the Brazilian capital market for national and foreign investors, motivated, among other factors, by the significant reduction in interest rates on government bonds promoted by the Brazilian Central Bank in recent years.

This research will also bring theoretical contributions, as it reinforces the debate on IPO performance. The study contributes to the literature related to underpricing, particularly in the Brazilian environment, as it advances in empirical research on the relationship between investor behavior and the companies' performance in their Initial Public Offering, developing the connection established by recent literature on the subject, with the Catering Theory. The study is also justified by the importance of analyzing factors that are complementary to the Finance Classical Theory ones, such as studies that assess variables of economic-financial performance as a variable of the intrinsic value of shares. The article also contributes by offering performance assessment and comparison tools so that equity investors can evaluate their portfolios, also considering the influence of investor sentiment on the IPO performance.

In addition to this section, the article will be organized in four other ones. The second section addresses the theoretical framework, which contextualizes the underpricing phenomenon, the investor's short-term horizon and the risk factors of emerging markets. In the third part, the methodology used in the research is presented. The fourth section contains the results obtained during the research and, finally, the last section presents the final considerations.

II. THEORETICAL REFERENCE AND RESEARCH HYPOTHESES

2.1 IPO Underpricing

Underpricing is characterized and conceptualized in the literature in several ways, such as: phenomenon, anomaly, obstacle, attraction strategy in environments with high information asymmetry (Rodarte, & Camargos, 2009). Underpricing, which, according to Ibbotson (1975), is equivalent to the difference between the share price on the first day and the share issue price in the initial offering, is present in a significant number of IPOs. When the issue

price is lower than the one reached on the first trading day, underpricing occurs. To Rock (1986), underpricing occurs due to the asymmetry of information between the issuer and new investors. The stock is advertised at a lower price than fair value to attract more investors. Johnston and Madura (2009) add that the greater the information asymmetry between the company and the market, the greater the underpricing.

The first studies on underpricing in IPOs were carried out by Akerlof (1970), Stoll and Curley (1970), Logue (1973), Ibbotson (1975) and Reilly (1977). The results found in these surveys showed that stock returns on the first trading day after the IPO were positive and higher than market returns. However, when analyzing long-term returns, the authors found some lower than the market ones.

These results were also confirmed in other studies, such as Ritter (1991), Loughran and Ritter (1995), and Ritter and Welch (2002) in the American market. In Brazil, although still incipient, the analysis of stock returns in the short and long term can be found in the research by Teixeira et al. (2012), Saito and Maciel (2006), Procianoy, Cigerza (2008), Rodarte and Camargos (2013), and Kreuzberg and Rodrigues Jr (2017).

For Ritter and Welch (2002), underpricing is a natural practice, since agents who sell shares have more information than buyers. Therefore, underpricing is seen as an award offered to new investors for negotiating with agents who have more information about the business. However, when this difference in the share price is very high, what happens is the excessive loss of primary shareholders, harming the company (Leal, 2001). Thus, to Ibbotson (1975), Ritter (1984), Booth and Chua (1996), Howton, Howton and Olson (2001), Daily, Certo, Dalton and Roengpitya (2003), the most recommended indicator for measuring performance of going public is underpricing.

Recent theories, each starting from a different set of assumptions, show that idiosyncratic asymmetry may be a component that consequently impacts stock returns when inserted in prices (Brunnermeier; Parker, 2005; Huang et al., 2006; Mitton; Vorkink, 2007; Brunnermeier; Gollier; Parker, 2007). Although the understanding derived from more traditional finance theories states that the idiosyncratic asymmetry of a stock should be irrelevant, the behavior of several investors has been contrary to this concept (Boyer; Mitton; Vorkink, 2009), essentially when considering the investor sentiment, caused by the short-term horizon as advocated by catering theory.

Underpricing occurs in the IPO context. The decision to go public (Initial Public Offering – IPO) derives from the growth of companies and the need for more resources for the expansion of activities (Teixeira, Barbosa & Souza, 2012). Another motivation for entering the capital market is the opportunity to minimize the cost of capital and the possibility of increasing the reputation and publicity of companies (Modigliani & Miller, 1963; Maksimovic & Pichler, 2001).

Green and Hwanf (2012) found evidence that initial public offerings with a high expectation of asymmetry offered significantly higher returns on the first day. When studying the IPOs carried out in the North American market between 1997 and 2010, Loughran and McDonald (2013) report that higher levels of uncertainty promoted higher returns on their first day. Yoshinaga & Castro Junior (2012) found a negative relationship between the investor sentiment and future stock returns, suggesting a reverse pattern in them. That is, after a period of bullish sentiment, the subsequent impact of stock returns is negative. Aissia (2014) found that IPOs with high initial returns had a high idiosyncratic asymmetry influenced by the investor sentiment. For Gao, Meng and Chan (2016), if the sentiment of individual and institutional investors is positively correlated with the IPO first day in the short term, only the sentiment of individual investors is relevant in the long-term return. Bonaventura, Giudici and Vismara (2017) report a tendency for underwriters to target overvalued stocks to individual investors, capitalizing on their appetite for high returns in the early days of the IPO. Cesari and Hedge (2017) showed greater presence and attention of individual investors to the high initial valuations of companies when analyzing IPOs from 2004 to 2011 in the American market.

2.2 The Investor Sentiment and the Catering Theory

The focus of corporate decisions may turn to the short term at the expense of the long term. This action focuses on the idea that managers suffer external influences, usually from investors with a short-term investment horizon, resulting in managerial decisions that conflict with the companies performance (Stein, 1996; Bushee, 1998). Derrien, Kecskés & Thesmar (2013) argue that managers have the appropriate timing to adjust their results to keep stock prices above their fundamental value during bullish moments in the market, when stocks are expected to be overvalued.

From the studies of Stein (1996), the theoretical basis of the Catering Theory finds its propositions. In this context, managers serve the interests of investors according to their investment horizon (short or long terms). The short-term bias, characterized by short-termism, encourages investment funds to dispense with shares of companies that do not meet quarterly performance targets, leading large players to adopt the same mechanism (Phelps, 2010).

Consequently, managers have the discretion to act in search of short-term growth and current profits, whether based on context (Gryglewicz, Mayer, & Morellec, 2019) or opportunism (Terry, 2017). To Glushkov & Bardos (2012), even with the preference for time-varying growth, managers will act in favor of managerial short-termism, in an attempt to maximize the current stock price.

In periods of high sentiment, there is an opportunity for managers to boost current stock prices, inflating their earnings (Baker & Wurgler, 2011; Simpson, 2013). In the case of publicly traded companies, listed on the stock exchange, moments of market optimism are opportune to make decisions aimed at maximizing share prices (Miranda, & Veras Machado, 2020). If investors are interested in the increase in stock prices, whose reversal to the fundamental value is late, it is expected that the earnings report can be managed to avoid a decrease in earnings as it contains discretionary aspects of management, or by aversion to the disclosure of losses (Z. Zhu, Sun, & Yung, 2020).

In this context, two points are important: the opportune moment for the manager to meet market pressures and the identification of investors with a short-term investment horizon (Miranda, & Veras Machado, 2020). The identification of the opportune moment from bad pricing of assets is studied by different aspects: discretionary accruals (Polk & Sapienza, 2009), book-to-market index (Alzahrani & Rao, 2014), Tobin's Q (Zhaohui & Wensheng, 2013) and investor sentiment indexes (Baker & Wurgler, 2007; Rajgopal, Shivakumer, & Simpson, 2007; Simpson, 2013; Sibley, Wang, Xing, & Zhang, 2016; Shen, Yu, & Zhao, 2017). In this context, the investment horizon follows the tendency to meet market pressures, especially in shares of companies that have high trading volume, and are more subject to the influence of optimistic investors and market speculators.

In view of the above, we have the following research hypothesis:

H1: Short-term investor sentiment positively influences stock returns on the first day of listing companies.

The hypothesis will be tested by the following model:

$$R_{IPO} = \beta_0 + \beta_1 VN_{i,t}\,\lambda_{i,t} + \beta_2 SI_{i,t}\lambda_{i,t} + \beta_3 ID_{i,t}\lambda_{i,t} + \beta_4 TM_{i,t}\lambda_{i,t} + \beta_5 RV_{i,t}\,\lambda_{i,t} + \beta_6 PA_{i,t}\,\lambda_{i,t} + \beta_7 CM_{i,t}\lambda_{i,t} + \varepsilon$$

In which:

R_{IPO} : return of the first IPO day from share i on date t;

B_0 a B_7: represent the coefficients to be estimated;

$VN_{i,t}$: logarithm of the turnover average on the first month;

$\lambda_{i,t}$: the importance of the attributes;

$SI_{i,t}$: investor sentiment in the month prior to the IPO;

$ID_{i,t}$: number of years since the company was founded at the time of the IPO;

$TM_{i,t}$: company size represented by the asset Ln;

$RV_{i,t}$: percentage change in prices of share i on date t;

$PA_{i,t}$: proportion of held and offered shares;

$CM_{i,t}$: Market Return 15 days before the IPO;

ε: regression error.

2.3 Emerging Markets Risk Factors

EMBI+ (Emerging Markets Bonds Index Plus) which estimates the daily performance of emerging country debt bonds in relation to US Treasury bonds, helps investors understand the risk of investing in the country. The literature highlights that the level of investor protection and the effectiveness of corporate governance mechanisms provided by companies to market participants in countries under development are different from those observed in developed countries (Berkowitz et al., 2003; Latridis, 2012; Bao and Lewellyn, 2017).

Although most of the published works that address the shares performance at the time of IPO focus on the American market, as it is the largest and most liquid corporate debt market in the world, there is also a growing movement to produce works on the theme in other markets, such as: Wasserfallen and Wydler (1988), who observed the phenomenon in the Swiss market, and Matsui (2006), who carried out a similar study in the Japanese market. Although still in its infancy, studies that examine the characteristics of debt securities are also growing in the Brazilian market, with a vast discussion on the impact of secondary market liquidity on asset profitability (Unterberger, 2012).

According to Ibbotson and Ritter (1995), the first study on underpricing in the stock market was documented in the SEC (Securities and Exchange Commission), in 1963. He mentions that the phenomenon of underpricing exists in all countries that have a stock market, but that the amount varies from nation to nation. Still, some seminal studies, of a descriptive nature, were pioneers in presenting elements about the financing pattern of companies in emerging markets. Among them are those by Singh (1994), Glen and Pinto (1994), and Booth, Aivazian, Demirgüç-Kunt and Maksimovic (2001). Some of these studies concluded that companies from emerging markets used equity more than

debt capital in their capital structure, even considering that the equity market in emerging countries is still developing.

In general, studies that address the capital structure of companies from emerging countries conclude that being in a particular country is an important element to explain a company's capital structure decision, for example: De Jong, Kabir and Nguyen, 2006; Jalal, 2007; Glen and Singh, 2004; and Fan, Titman and Twite, 2006. Glen and Sing (2004) observed that companies in emerging economies use less long-term debt than those based in developed markets. They found that the level of funding through debt issuance is falling over time in emerging economies. Myers (1984) proposes two approaches to dealing with capital structure: tradeoff and pecking order. For the former, the company would establish a target indebtedness and gradually move towards it, and for the latter, the company would adopt an order of preference (hierarchy) in its form of financing, prioritizing internal over external financing.

Baker and Wurgler (2011) argue that the environment of optimism predicts a hierarchy in financing decisions. According to the authors, a manager would never sell their capital at inopportune moments; however, overconfidence may reverse the hierarchy proposed by the pecking order. If overconfidence is modeled as reducing earnings risks, managers may view their debt as undervalued and too expensive as a source of capital. On the other hand, managers may perceive their actions as overvalued under the influence of optimism (Machado & Miranda, 2020).

In view of the above, we have the following research hypothesis:

H2: Emerging market risk factors positively influence on the relationship between investor sentiment in the short term and stock returns on the companies' first day of listing.

The hypothesis will be tested by the following model:

$$R_{IPO} = \beta_0 + \beta_1 VN_{i,t}\lambda_{i,t} * EMBI + \lambda_{i,t} + \beta_2 SI_{i,t}\lambda_{i,t} * EMBI + \lambda_{i,t} + \beta_3 ID_{i,t}\lambda_{i,t} + \beta_4 TM_{i,t}\lambda_{i,t} + \beta_5 RV_{i,t}\ \lambda_{i,t} + \beta_6 PA_{i,t}\ \lambda_{i,t} + \beta_7 CM_{i,t}\lambda_{i,t} + \varepsilon$$

In which:

R_{IPO} : return of the first IPO day from share i on date t;

B_0 a B_7: represent the coefficients to be estimated;

$VN_{i,t}$: logarithm of the turnover average on the first month;

$\lambda_{i,t}$: the importance of the attributes;

$SI_{i,t}$: investor sentiment in the month prior to the IPO;

EMBI+: Emerging Markets Bond Index Plus

$ID_{i,t}$: number of years since the company was founded at the time of the IPO;

$TM_{i,t}$: company size represented by the asset Ln;

$RV_{i,t}$: percentage change in prices of share i on date t;

$PA_{i,t}$: proportion of held and offered shares;

$CM_{i,t}$: Market Return 15 days before the IPO;

ε: regression error.

III. METHODOLOGY

Delimited by the research goal, which consists of evaluating the moderating effect of country risk factors on the relationship between the investor sentiment in the short term and the IPO performance from companies listed on *Brasil, Bolsa and Balcão – B3* from January 2013 to December 2021, the research can be characterized as descriptive, as proposed by Collis & Hussey (2005), since it presents the market performance of Brazilian companies at the time of listing on B3, establishing a correlation with the investor sentiment on the short-term horizon, moderated by country risk factors. With regard to the procedures adopted, the research is documentary as it collects data in documents from the Refinitiv Eikon® database, in the IPO prospectuses and in the reference forms on the B3 website. Regarding the approach to the problem, the research is quantitative because a statistical method was used for the treatment and analysis of data (Fávero and Belfiore, 2017).

3.1 Population and sample

Companies listed on B3 from January 2013 to December 2021 will be considered as the research population, with a sample of companies that presented all the information necessary for the research, consisting of 105. Thus, according to the defined selection criteria, the number of companies observed per year can be verified in the sample presented in Table 1.

Table 1 – Total number of IPO

Item	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
IPO number	10	1	1	1	10	3	5	28	46	105

Source: Research data (2022).

3.2 Data collection and research variables

The variables adopted to achieve the research goal are those identified in the literature. To measure the IPO performance, the return on the first day of the stock IPO was used as follows (Loughran and Mcdonald, 2013):

$$R_{IPO} = LN\left(\frac{PFechamento\ it}{PAberturait}\right) \quad \text{Equation 01}$$

To measure the investor sentiment, the proxies used are: the trading volume (VN) according to Aissia (2014) and the sentiment index. This way, the sentiment index (SI) was used, adapted from the model by Baker and Wurgler (2006), using the following proxies: the ratio between the number of securities traded by rising and falling stocks (NEI), the number of IPOs and Follow-on (NIPO), the ratio between the volume of shares traded in relation to the number of transactions with shares and debt (AD), the participation of individual investors in the IPO and Follow-on (InvInd), the participation of foreign investors in the IPO and Follow-on (InvEst), and the interest rate on government bonds (TJLP) to measure the attractiveness of capital, according to the following equation:

$$SI_t = NEI_t + NIPO_{t-12} + AD_t + InvInd_t + InvEst_t + \text{TJTP} \quad \text{Equation 02}$$

To measure the characteristics of emerging markets in Brazil, the Emerging Markets Bond Index Plus – EMBI+ (Brazil Risk), created by JP Morgan to estimate the daily performance of debt securities of emerging countries in relation to US Treasury bonds, will be used.

The control variables, which consider an uncertainty factor that impacts the initial returns, were used in this study according to a model adapted from Aissia (2014): company age (ID), company size (TM), which replaces the company's sector, the absolute value of the percentage change in prices (RV), proportion of held and offered shares (PA), as well as the market return inherent in the 15 days prior to the IPO date (CM).

Table 2 presents a summary of the indicators and variables used in the research.

Table 2 – Research variables

Variables	Definition	Formula	Collection	Authors
IPO Performance (dependent variable)				
Underpricing R_{IPO}	Share performance in the IPO	Equation 01	Refinitiv Eikon ® and B3	Loughran and McDonald (2013)
Investor Sentiment (independent variable)				
SI	Investor Sentiment Index	Equation 02	Refinitiv Eikon ® and B3	Baker e Wurgler (2006)
VN	Trading Volume	Average logarithm of the turnover on the first month	Refinitiv Eikon ® and B3	Aissia (2014)
Moderator variable				
EMBI+	Brazil Risk	Index calculated by JP Morgan	IPEA data	Cai *et al*. (2003)
Control Variables				
ID	Company age	Number of years from foundation to IPO	Refinitiv Eikon ® and B3	Aissia (2014)
TM	Company size	Asset LN		
RV	Percentage change in prices	△ of the share price		

PA	Proportion of held and offered shares	$\frac{Held\ shares}{Offered\ shares}$		
CM	Market Return 15 days before the IPO	△ of market return 15 days prior to IPO		

Source: Research data (2022).

3.3 Data analysis procedure

After collecting the data through the Refinitiv Eikon® database, they will be tabulated in electronic spreadsheets to perform the calculations in the Microsoft Excel® program. Due to the variations identified in the data of the companies studied, such as values on different scales in their results, the data will be normalized and the Entropy will be used to define the importance of the attributes classified as independent and control variables, according to Zeleny (1982). The model and data normalization equations, as per Tambosi et al. (2021), are shown below:

Here, $d_i = (d_i^1, d_i^2, ..., d_i^n)$ are the normalized values, in which: $d_i^k = \frac{xi^k}{xi^*}$, characterizing the D set as the i-th attribute. We define $D_i = \sum_{k=1}^{n} \frac{di^k}{di} LN\left(\frac{di^k}{di}\right)$, in which $\alpha = \frac{1}{emax} > 0$ and $e_{max} = LN(m)$. It is highlighted that $0 \leq d_i^k \leq 1$ and $d_i^k \geq 0$. In the event that all k i d are identical for a given i, in such case $\frac{di^k}{di} = \frac{1}{n}$ e $e(d_i)$ admits maximum value, that is, $e_{max} = LN(m)$. By setting $\alpha = \frac{1}{emax}$, we designate $0 \leq$ and $(d_i) \leq 1$ to all the d_i's. Such normalization is essential for comparison purposes. The total D entropy is determined by: $E = \sum_{i=1}^{n} e(di)$.

As the weight $\lambda i^{\sim}$ is oppositely concatenated to $e(d_i)$ is used $1 - e(d_i)$, instead of $e(d_i)$, and normalized to ensure that $0 \leq o\ \lambda i^{\sim} \leq 1$ e $\sum_{i=1}^{n} \lambda i \cong 1$. Thus, we have: $\lambda i^{\sim} = \frac{1}{n-E}[\ 1 - e\ (d_i)] = \frac{[1-e\ (di)]}{n-E}$.

Having established the indicators and weights to be used, the following procedure is based on testing the models that will be used to analyze the relationship between the returns on the first day of the IPO and its relationship with the variables related to the investor, emerging markets and control sentiment.

IV. RESULTS ANALYSIS

Table 3 shows the descriptive statistics for the variables used in the study, that is: mean, median, standard deviation, minimum and maximum.

Table 3 – Descriptive statistics of variables

Variables	From 2013 to 2021				
	Mean	Median	S. D.	Minimum	Maximum
RIPO	0.0900	0.0007	0.1235	-0.2555	0.6779
SI	0.6980	0.6710	1.1770	-2.6370	2.1240
VN	23.1635	22.9183	0.6223	22.3363	24.3659
RV	22.5563	20.9350	11.9664	10.2000	123.9400
ID	29.6762	24.0000	21.2958	1.0000	101.0000
TM	14.4199	14.1940	14.1940	9.0045	21.3543
PA	0.0050	0.0046	0.1087	0.000	0.5050
CM	0.1148	0.1155	0.2834	10.7195	11.7722
EMBI+	285.0000	270.0000	70.1130	146.0000	531.0000

Key: RIPO: Return on IPO; SI: Investor Sentiment Index; VN: Trading Volume; RV: Percentage Change in Prices; ID: Company Age; TM: Company Size; PA: proportion of shares held and offered; CM: Market Return; EMBI+: Brazil Risk; S. D.: Standard Deviation.

Source: Research data (2022).

As can be seen, the average return on the first day of the IPO for the companies that made up the sample was 9%, but with companies presenting up to 68%. This finding was lower than the average returns of similar studies in the North American market, such as that of Green and Hwang (2012), who found an average of 14.34% from 1975 to

2008, and the study by Lowry, Officer and Schwert (2010), who obtained an average return for the first day of the IPO of 16.6% from 1965 to 2005. Comparing with studies carried out in Brazil, this finding was higher than the average return of similar studies such as Veras Machado *et al.* (2020), who found an average return of 1.00% from 2005 to 2017. Thus, in line with previous studies, the return on the first day of the companies' listing was positive, suggesting the occurrence of Underpricing in IPO.

Loughram and McDonald (2013), when studying the behavior of the returns of the first day of IPO for North American companies from 1997 to 2010, obtained even higher returns: 34.80%. Aissia (2014), when carrying out a similar study in the French financial market, found an average return of 30.32%. The author highlights that IPO returns are related to market returns, which have increased over the years. Therefore, the difference found in the studies between the highest and lowest returns can be explained by the selected period of analysis or by intrinsic characteristics of the Brazilian stock market.

The investor sentiment index recorded more pessimistic moments at its minimum value of -2.6370 and more optimistic at its maximum value of 2.1240, with the sample showing an average sentiment more prone to optimism: 0.6980. The logarithm of the average volume in the first month after the IPO proved to be less dispersed and composed of companies with an average volume of 23.1635, close to the maximum value of 24.3659, denoting the companies' liquidity. The percentage variation of the average market return in the analyzed period was approximately 22.5% and showed greater dispersion with a standard deviation of 11.9664.

Regarding the return 15 days prior to the IPO, it is observed that companies had a return of 11.49% on average, reaching 11.77%. Considering the standard deviation of 0.2834 in relation to this average value, the returns for the 15 days prior to the IPO are dispersed. As for the age of the companies, it can be seen that the companies in the sample had an average of 30 years of existence at the time of the IPO, with the oldest company in the sample being 101 years old. Regarding the natural logarithm of assets, companies have an average size of 14.4199. Finally, it was observed that the companies held less than 0.5% of the shares in treasury, which demonstrates the characteristic of these public offerings of making all the capital offered available, while the Brazil Risk presented an average of 285 points close to the maximum value, evidencing greater risk during the period.

Table 4 – Pearson Correlation

Variables	RIPO	SI	VN	RV	ID	TM	PA	CM	EMBI+
RIPO	1	0,01**	0,049**	0,015**	0,014	0,050	0,040*	0,170	0,438*
SI		1	0,488	0,482	-0,171	-0,141	-0,034	0,476	0,594
VN			1	0,634	0,029	-0,089	0,028	0,449*	0,416
RV				1	-0,055	-0,095	0,021	0,206	0,618
ID					1	0,251	-0,105	-0,078	0,055
TM						1	-0,021	-0,189	-0,080
PA							1	-0,006	0,040
CM								1	0,389
EMBI+									1

Key: RIPO: Return on IPO; SI: Investor Sentiment Index; VN: Trading Volume; RV: Percentage Change in Prices; ID: Company Age; TM: Company Size; PA: proportion of shares held and offered; CM: Market Return; EMBI+: Brazil Risk;

Notas: Significance levels: * p<0,1, ** p<0,05, *** p<0,01.

Source: Research data (2022).

Table 4 demonstrates the correlation matrix to verify the degree of association between each of the variables, helping to verify the multicollinearity of the model. The matrix generally indicated a low correlation between the variables. In the group of explanatory variables, the highest correlation recorded (in absolute terms) was between the Trading Volume (VN) and the Percentage Change in Prices (RV), with a positive coefficient (0.634). The returns on the first day of the IPO (RIPO) have a positive correlation with all independent variables, deviating from the expected relationship for the variables company age (ID) and the proportion of shares held and offered (PA).

Table 5 – Results of Model 1 Estimates

Panel A - Regression Result								
Variables	Constant	SI	VN	RV	ID	TM	PA	CM
Coefficients	-0.092	0.018**	0.476**	0.017**	0.000	0.054*	0.265***	0.238
Standard Error	0.024	0.005	0.004	0.003	0.000	0.007	0.098	0.219
t-statistic	-1.207	2.219	1.676	1.355	1.210	1.512	2.701	1.084
VIF		1.556	1.858	1.080	1.162	1.114	1.029	1.581
Panel B – Regression Adjustments								
R^2		Adjusted R^2			F-statistic		DW	
0.352		0.340			2.335 (0.038)		1.845	

Key: ***Significance at the 1% level, **Significance at the 5% level, *Significance at the 10% level

Source: Research data (2022).

The low correlation between the explanatory variables shown in Table 4 suggests evidence of an inexistent multicollinearity between the model variables. Even so, as shown in Table 5, the variance inflation factor (VIF) test was carried out to test hypothesis 1, which demonstrates the inexistence of multicollinearity problems, considering that its values, according to Hair, Black, Babin, Anderson and Tatham (2009), are between 1 and 10. It was also verified that the *Durbin-Watson* presented a value very close to 2 for the analyzed model, demonstrating that the independence of errors in the analyzed data is satisfactory and that there is no autocorrelation between the residuals (Fávero & Belfiore, 2017).

The coefficients presented in Table 5 (Panel A), with the exception of company age before at the IPO (ID), and the Ibovespa return in the 15 days prior to the IPO (CM), proved to be significant. Regarding the expected sign, the proportion of shares held in relation to those offered (PA), although with a significant coefficient, presented a positive sign, diverging from the expectation. On the other hand, the investor sentiment interest (SI) and trading volume (VN) variables proved to be statistically significant and with an expected converging sign.

Table 6 presents the results for the second regression model, which aims to test hypothesis 2. It is observed that the test (VIF) showed the absence of multicollinearity problems, considering that its values are between 1 and 10, according to Hair, et al. (2009). It was also verified that the *Durbin-Watson* presented a value very close to 2 for the analyzed model, demonstrating that the independence of errors in the analyzed data is satisfactory and that there is no autocorrelation between the residuals (Fávero & Belfiore, 2017).

Table 6 – Results of Model 2 Estimates

Panel A – Regression Result								
Variables	Constant	SI	VN	RV	ID	TM	PA	CM
Coefficients	-0.092	0.038**	0.284**	0.072**	0.000	0.048*	0.376**	0.212
Standard Error	0.024	0.005	0.004	0.003	0.000	0.007	0.098	0.219
t-statistic	-1.207	2.219	1.676	1.355	1.210	1.512	2.701	1.084
VIF		1.556	1.858	1.080	1.162	1.114	1.029	1.581
Panel B – Regression Adjustments								
R^2		Adjusted R^2			F-statistic		DW	
0.289		0.275			2.996 (0.030)		1.652	

The coefficients presented in Table 6 (Panel A), with the exception of company age before at IPO (ID) and the Ibovespa return in the 15 days prior to the IPO (CM), proved to be significant and in line with model 1. Regarding the expected sign, the proportion of shares held regarding those offered (PA), in this model with a significance of 5%, presented a positive sign, diverging from the expectation, although maintained with a significant coefficient. On the other hand, the investor sentiment interest (SI) and trading volume (VN) variables, considering the moderation of the risk factor measured by EMBI+, proved to be statistically significant and with an expected converging sign. Next, the results of Tables 5 and 6 will be commented, in line with the corresponding literature.

4.1 Discussion of Results

For the investor sentiment, measured by the sentiment index formed by market variables and trading volume, a positive and significant relationship was observed with returns on the first day of the IPO, suggesting that a favorable sentiment influences returns, in accordance with with Lee, Shleifer and Thaler (1991). These results converge with the idea that warmer market periods, whether contemporary (Volume) or past (Sentiment Index), influence IPO returns. Huang, W. *et al.* (2006) noted that there is a tendency for abnormal above-average turnover when sentiment is linked to negative experiences or when they are more pronounced, which can positively impact returns.

For Tian and Liu (2017), investor sentiment is the most significant factor in the relationship with IPO returns excess. Thus, the results shown in Table 5 do not reject Hypothesis 1, as there was a positive relationship between investor sentiment and the return on the first day of the IPO. These results also converge with the findings of Veras Machado *et al.* (2020), when investigating the topic in the Brazilian stock market from 2005 to 2017. As for Hypothesis 2, the variables of interest, investor sentiment (SI) and trading volume (VN), moderated by the risk factor measured by the EMBI+, had a positive and significant influence on the relationship with the IPO return, suggesting that emerging market risk factors do not mitigate the search for IPO returns in moments of optimism. Consequently, Hypothesis 2 is accepted. Li and Grunde (2022) suggest that a greater participation of individual and foreign investors is positively related to the increase in investments aimed at raising the current value of the share, observed even in companies with greater idiosyncratic risk. The authors also suggest that a greater presence of institutional investors may serve as a mechanism to reduce the degree of overinvestment caused by a greater investor sentiment.

Regarding the control variables, the relationship between the company age before at IPO (ID) and the IPO return was not significant. However, the existence of a positive and significant relationship at the level of 10% between the size of the company (TM) and the IPO return was observed. As for the proportion of shares offered and retained (PA), Ljungqvist and Wilhem (2002) state that companies sometimes offer a large number of IPOs, and this can reduce expectations of large later gains from their revenues. Therefore, the expected relationship between the proxy for the proportion of shares offered and held (PA) and the IPO returns is negative. However, in line with the studies by Veras Machado et al. (2020), although the expected sign found was different from that found for the variable referring to the proportion of shares offered and retained, there was statistical significance at the level of 1% in the first model, and 5% in the second model, suggesting that Brazilian investors, despite perceiving the excessive amount of shares issued by a given company, would not show negative expectations regarding their returns.

Regarding the control variables referring to market conditions, represented by the market return (RV) in this study, they were significant and positive. According to Assia (2014), the market return can measure the incorporation of public information into the true value of the company in the offer price during the subscription period. Regarding the market returns of the 15 days prior to the IPO (CM) date, there was no statistical significance, even with a confirmed positive relationship, indicating that this variable did not prove to be a good indicator of the behavior of the IPO return.

V. CONCLUSION

The present study aimed at the relationship between investor sentiment and stock return on the first day of an IPO, as well as analyzing the moderating effect of the country risk factors, on the relationship between investor sentiment and IPO performance at the companies listed on Brasil Bolsa e Balcão - B3 from January 2013 to December 2021. It was based on the premise that optimistic investor sentiment can positively influence the return on the first day of the IPO, evidencing underpricing. Therefore, it was expected that investors would seek higher returns on the first day of the IPO in moments of market optimism, considering their sentiment towards the market at that moment. Thus, it was expected that this search would positively affect the returns on the first day of the IPO, a fact that was confirmed in the observed empirical evidence. Consequently, it is concluded that investor sentiment positively affected IPO returns in the Brazilian scenario. In

view of the results obtained, Hypothesis H1 could not be rejected.

With regard to the moderation of emerging market risk factors, a positive relationship was expected in the relationship between investor sentiment and the return on the first day of the IPO, suggesting that a favorable sentiment would influence returns, even in market scenarios with accentuated risks characteristic of emerging economies. This fact would confirm the assumption that in warmer market periods there would be a tendency to observe an above-average trading volume and a sentiment index positively related to returns. According to the results obtained, it was observed that the volume traded and the sentiment index positively affected the IPO returns, as expected in the Brazilian emerging market scenario. Therefore, Hypothesis H2 was accepted, according to which investor sentiment moderated by emerging market risk factors positively affects first-day IPO returns for Brazilian companies.

Among the characteristics of the companies that influenced the return on the first day of IPOs, the control variable related to the proportion of shares held in relation to those offered stands out. Despite presenting statistical significance, when related to the first day's returns, the positive value of the coefficients was unexpected. The logic would be that their expectations regarding the returns on the first day of the IPO would be negative when they realize that companies are offering too many shares. Thus, it is concluded that Brazilian investors' expectations remain optimistic about the future performance of these companies, even with the large number of shares offered.

The main theoretical contribution of the study is focused on the moderation of risk factors in the relationship between investor sentiment and the return on the first day of an IPO, as it expands the study by Veras Machado *et al.* (2020), adding an idiosyncratic variable of the market studied to the results found in Brazil. Consequently, further research aimed at understanding the excess return on the first day of an IPO must consider other factors, characteristic of emerging markets.

REFERENCES

[1] Agathee, U. S., Sannasse, R. V., & Brooks, C. (2012). The underpricing of IPOs on the Stock Exchange of Mauritius. *Research in International Business and Finance*, 26: 281-303.

[2] Aissia, D. B. (2014). IPO first-day returns: Skewness preference, investor sentiment and uncertainty underlying factors. *Review of Financial Economics*, v. 23, n. 3, p. 148-154.

[3] Akerlof, G. (1970). The Market for "Lemons": Quality Uncertainty and the Market Mechanism, *Quarterly Journal of Economics*, 84(3): 488-500.

[4] Almarayeh, T. S.., Aibar-Guzmán, B., & Abdullatif, M. (2020). Does audit quality influence earnings management in emerging markets? Evidence from Jordan. *Spanish Accounting Review*, 23 (1). 1–51.

[5] Alzahrani, M., & Rao, R. P. (2014). Managerial behavior and the link between stock mispricing and corporate investments: evidence from market-to-book ratio decomposition. *Financial Review*, *49*(1), 89–116.

[6] Asquith, D.; Jones, J.; Kieschnick, R. (1998) Evidence on Price Stabilization and Underpricing in Early IPO Returns. *Journal of Finance*, v. 53, n. 5, p. 1759-1773.

[7] Baker, M., & Wurgler, J. (2007). Investor Sentiment in the Stock Market. *Journal of Economic Perspectives*, *21*(2), 129–151.

[8] Baker, M., & Wurgler, J. (2011). Behavioral corporate finance: an updated survey. *NBER*

[9] *Working Paper Series*, *1*, 1–103. Retrieved from http://www.nber.org/papers/w17333

[10] Baker, M.; Wurgler, J. (2006). Investor sentiment and the cross-section of stock returns. *Journal of Finance*, v. 61, n. 4, p. 1645-1680,

[11] Bao, S.R., & Lewellyn, K.B. (2017). Ownership structure and earnings management in emerging markets - An institutionalized agengy perspective. International Business Review, 26(5), 828-838. https://doi.org/10.1016/j.ibusrev. 2017.02.002

[12] Baron, D. P. (1982). A Model of the Demand for Investment banking Advising and Distribution Services for New Issues. *Journal of Finance*, 37 (4): 955-976.

[13] Berkowitz, D., Pistor, K., & Richard, J.-F. (2003). Economic development, legality, and the transplant effect. European Economic Review, 47(1), 165-195. https://doi.org/10. 1016/S0014-2921(01)00196-9

[14] Bonaventura, M.; Giudici, G.; Vismara, S. (2017). Valuation and performance of reallocated IPO shares. *Journal of International Financial Markets, Institutions & Money*, *in press*., doi http://dx.doi.org/10.1016/ j.intfin.2017.05.005,

[15] Booth, J. R., & Chua, L. (1996). Ownership dispersion, costly information, and IPO underpricing. *Journal of Financial Economics*, 41 (2): 291-310.

[16] Booth, L; Aivazian, V; Demirgüç-Kunt, A; Maksimovic, V. (2001). Capital structures in developing countries. Journal of Finance, v. 56, n. 1, p. 87-130.

[17] Boyer, B.; Mitton, T.; Vorkink, K. (2009). Expected idiosyncratic skewness. *Review of Financial Studies*, v. 23, n. 1, p. 169-202

[18] Brunnermeier, M. K.; Gollier, C.; Parker, J. (2007) Optimal Beliefs, Asset Prices and the Preference for Skewed Returns. *American Economic Review Papers and Proceedings*,v. 97, n. 2, p. 159-65.

[19] Brunnermeier, M. K.; Parker, J. (2005). Optimal Expectations. *American Economic Review*, v.95, n. 4, p. 1092-118.

[20] Bushee, B. J. (1998). The influence of institutional investors on myopic R&D investment behavior. *The Accounting*

Review, *73*(3), 305–333. Retrieved from www.jstor.org/stable/248542

[21] Colaco, H. M. J.; De Cesari, A.; Hegde, S. P. (2017). Retail Investor Attention and IPO Valuation. *European Financial Management*, v. 23, p. 691-727,

[22] Collis, J. & Hussey, R. (2005). Pesquisa em administração: um guia prático para alunos de graduação e pós-graduação. 2. ed. Porto Alegre: *Bookman*.

[23] Daily, C. M., Certo, S. T., Dalton D. R., & Roengpitya, R. (2003). IPO underpricing: A meta-analysis and research synthesis. *Entrepreneurship Theory and Practice*, 27(3), 271-295.

[24] De Jong, A; Kabir, R; Nguyen, T. (2008) Capital Structure Around the World: The Roles of Firm- and Country-Specific Determinants. Journal of Banking and Finance, Vol. 32, nº 9.

[25] Derrien, F., Kecskés, A., & Thesmar, D. (2013). Investor horizons and corporate policies. *Journal of Financial and Quantitative Analysis*, *48*(06), 1755–1780.

[26] Fan, J; Titman, S; Twite, G. (2011). An International Comparison of Capital Structures and Debt Maturity Choices. Working paper. http://dx.doi.org/10.2139/ssrn.423483

[27] Fávero, L. P., Belfiore, P. (2017). Manual de Análise Multivariada de Dados – 1. Ed. –Rio de Janeiro: *Elsevier*.

[28] Gao, S.; Meng, Q.; Chan, K. C. (2016). IPO pricing: Do institutional and retail investor sentiments differ?. *Economics Letters*, v. 148, p. 115-117,

[29] Glen, J; Pinto, B. (1994). Debt or equity? How Firms in Developing Countries Choose. Discussion paper 22. Washington, DC: International Finance Corporation.

[30] Glen, J; Singh, A. (2004). Comparing capital structures and rates of return in developed and emerging markets. Emerging Markets Review, v. 5, n. 2, p. 161-192.

[31] Glushkov, D., & Bardos, K. S. (2012). Importance of catering incentives for growth dynamics. *Journal of Behavioral Finance*, *13*(4), 259–280.

[32] Green, C.; Hwang, B. (2012) Initial public offerings as lotteries: Skewness preference and first-day returns. *Management Science*, v. 58, n. 2, p. 432-444,

[33] Gryglewicz, S., Mayer, S., & Morellec, E. (2019). Agency conflicts and short- versus longtermism in corporate policies. *Journal of Financial Economics*, (in press), 1–25.

[34] Hair, J., Black, W., Babin, B., Anderson, R., Tatham, Ronald. (2009). *Análise multivariada de dados*. Bookman Editora.

[35] He, L. T., (2012). The investor sentiment endurance index and its forecasting ability. *International Journal of Financial Markets and Derivatives*, v. 3, n. 1, p.61-70

[36] Howton, S.D., Howton, S. W., & Olson, G. T. (2001). Board ownership and IPO returns. *Journal of Economics and Finance*, 25 (1): 100-14.

[37] Huang, W.*et al.* (2006). Another Look at Idiosyncratic Risk and Expected Returns. *Working Paper, University of Hawaii at Manoa*.

[38] Iatridis, G.E. (2012). Audit quality in common-law and code-law emerging markets: evidence on earnings conservatism, agency costs and cost of equity. Emerging Markets Review, 13(2), 101-117. https://doi.org/10.1016/j.ememar. 2012.01.001

[39] Ibbotson, R. (1975). Price performance of commom stock new issues. *Journal of Financial Economics*, 2(3): 235-272.

[40] Ibbotson, R. G., Ritter, J. R. (1995). Initial Public Offerings, in R. Jarrow et al., eds. North-Holland Amsterdam, Handbooks of Operation Research & Management Science: Finance. Chapter 30, p. 993-1016.

[41] Jalal, A. (2007). The Pecking Order, Information Asymmetry, and Financial Market Efficiency. University of Minnesota working paper. http://dx.doi.org/10.2139/ssrn.939588.

[42] Johnston, J., & Madura, J. (2009). The pricing of IPOs post-sarbanes-oxley. *Financial Review*, 44(2), 291-310.

[43] Kreuzberg, Rodrigues, Jeske & Rodrigues Jr. (2017). Métodos TOPSIS e VIKOR na verificação da resource advantage theory em empresas têxteis brasileiras. *Contabilidad y Negocios* 23 (12): 96-110.

[44] Krigman, L., Shaw, W., Womack, K. (1999). The persistence of IPO mispricing and the predictive power of flipping. *The Journal of Finance*, 54(3): 1015-1044.

[45] Lee, C. M. C.; Shleifer, A.; Thaler, R. H. (1991). Investor Sentiment and the Closed-End Fund Puzzle. *The Journal of Finance*, v. 46, n. 1, p. 75-109.

[46] Li, H.; Grundy, B. (2022). The effect of investor sentiment and the structure of shareholder ownership on corporate investment. *International Journal of Managerial Finance*, Doi: 10.1108/IJMF-11-2021-0558.

[47] Ljungqvist, A. (2005). IPO underpricing. Handbook in Corporate Finance: *Empirical Corporate Finance*, 2: 375-422.

[48] Ljungqvist, A.; Wilhelm, W. (2002). IPO allocations: Discriminatory or discretionary? *Journal of Financial Economics*, v. 65, n. 2, p. 167-201.

[49] Logue, D. E. (1973), On the pricing of unseasoned equity issues: 1965-1969. *Journal of Financial and Quantitative Analysis*, 8(1): 91-103.

[50] Loughran, T., & Ritter, j. R. (1995). The new issues puzzle. *The Journal of Finance*, 5091), 23-51.

[51] Loughran, T.; Mcdonald, B. (2013). IPO first-day returns, offer price revisions, volatility and form S-1 language. *Journal of Financial Economics*, v. 109, n. 2, p. 307-326,

[52] Lowry M.; Officer, M. S.; Schwert, G. W. (2010).The Variability of IPO Returns. *The Journal of Finance*, v. 65, n. 2, p. 425-465.

[53] Maksimovic, V., & Pichler, P. (2001). Technological innovation and initial public offerings. *Review of Financial Studies*, 14(2): 459-494.

[54] Matsui, K. (2006). Overpricing of New Issues in the Japanese Straight Bond Market, Applied Financial Economics Letters, v. 2, n. 5, p. 323-327.

[55] Miranda, K. F.; & Veras machado, M. A (2020). Gerenciamento de resultados, sentimento do investidor e o short-temism. *XIV Congresso Anpicont*. Foz do Iguaçu/PR

[56] Mitton, T.; Vorkink, K. (2007). Equilibrium Underdiversification and the Preference for Skewness. *Review of Financial Studies*, v. 20, n. 4, p. 1255-1288,

[57] Modigliani, F. & Miller, m. H. (1963). Corporate income taxes and the cost of capital: a correction. *The American Economic Review*, 53(3): 433-443.

[58] Myers, S. C. (1984). The Capital Structure Puzzle. The Journal of Finance, 39(3), 575–592.
[59] Phelps, E. S. (2010). Short-termism is undermining America. *New Perspectives Quarterly*, *27*, 17–19.
[60] Polk, C., & Sapienza, P. (2009). The stock market and corporate investment: a test of catering theory. *The Review of Financial Studies*, *22*(1), 187–217.
[61] Procianoy, J. L., & Cigerza, G. C. (2008). IPOs in emerging markets: a comparison of Brazil, India and China. India and China (August 2007). *SSRN Working Paper Series*. Disponível em: http://ssrn.com/abstract=968300.
[62] Rajgopal, S., Shivakumar, L., & Simpson, A. V. (2007). A catering theory of earnings
[63] management. *SSRN Electronic Journal*.
[64] Reilly, F. (1977). New Issues Revisited. *Financial Management*, 6(4): 28-42.
[65] Ritter, J. R. (1984). The "Hot Issue" Market of 1980. *The Journal of Business*, 57(2): 215-240.
[66] Ritter, J. (1991). The long-run performance of initial public offerings. *The Journal of Finance*, 46(1): 3-27.
[67] Ritter, J. R., & Welch, I. (2002). A review of IPO activity, pricing, and allocations. The *Journal of Finance*, 57(4), 1795-1828.
[68] Rock, K. (1986). Why new issues are underpriced. *Journal of Financial Economics*, 15(1-2), 187-212.
[69] Rodarte, J. R., & de Camargos, M. A. (2013). Underpricing e desempenho acionário em IPOs de companhias brasileiras: uma análise pré-crise financeira internacional. *Teoria e Prática em Administração* (TPA), 3(2), 121-146.
[70] Saito, R., & Maciel, L. P. (2006), Underpricing of Brazilian IPOs: empirical evidence from 1999 to 2005. *Anais do Encontro Annual da Associação nacional de Pós-Graduação e Pesquisa em Administração*, Salvador, BA, Brasil, 30.
[71] Santos, F. (2017).IPO market timing with uncertain aftermarket retail demand. *Journal of Corporate Finance*,v. 42,p. 247-266.
[72] Shen, J., Yu, J., & Zhao, S. (2017). Investor sentiment and economic forces. *Journal of Monetary Economics*, *86*, 1–21.
[73] Sibley, S. E., Wang, Y., Xing, Y., & Zhang, X. (2016). The information content of the sentiment index. *Journal of Banking & Finance*, *62*, 164–179.
[74] Simpson, A. (2013). Does Investor Sentiment Affect Earnings Management? *Journal of Business Finance & Accounting*, *40*(7–8), 869–900.
[75] Singh, A. (1994). How do large corporations in developing countries finance their growth? In: O'brien, R. Finance and the International Economy 8, Oxford: Oxford University Press, p. 121-142.
[76] Stein, J. C. (1996). Rational capital budgeting in an irrational world. *The Journal of Business*, *69*(4), 429–455.
[77] Stoll, H. & Curley, A. (1970). Small business and as new issues market for equities. *Journal of Financial and Quantitative Analysis*, 5(3): 309-322.
[78] Tambosi, S. S. V.; Hein, N.; Tambosi Jr., J.; Kroenke A., (2021). Dimensões da importância da controladoria nas organizações: um estudo multivariado e multicritério. *Revista Contemporânea de Contabilidade*, 46(18): 03-15.
[79] Teixeira, E. E. M., Barbosa, F. V., & Souza, A. A. (2012). Análise do desempenho de longo prazo de *initial public offerings* no mercado acionário brasileiro. *Revista de Ciências da Administração*, 14(33): 79-72.
[80] Terry, S. J. (2017). The macro impact of short-termism. *Working Paper*, *1*, 1–42. Windmeijer, F. (2005). A finite sample correction for the variance of linear efficient two-step GMM estimators. *Journal of Econometrics*, *126*, 25–51.
[81] Tian, L.; Liu, C. (2017). Investor sentiment on the first day excess returns of initial public offerings. *BoletínTécnico*, v. 55, n. 9, p. 728-736,
[82] Unterberger Filho, V. (2012). Prêmio de Emissão em Bonds de Dívida Corporativa Denominados em Dólares para Mercados / Valter Unterberger Filho - 55 p.
[83] Veras Machado, M. A.; da Costa, Y. C. L., Miranda, K. F. (2020). Retorno no primeiro dia de IPO, preferência pela assimetria e sentimento do investidor. *Redalyc*: https://doi.org/10.4025/enfoque.v39il.41963.
[84] Wasserfallen, W., Wydler, D. (1988). Underperforming of Newly Issued Bonds: Evidence from the Swiss Capital Market, Journal of Finance, v. 43, p. 1177-1191.
[85] Welch, I. (1989). Seasoned offerings, imitation cost, and the underpricing of initial public offerings. *The Journal of Finance*, 44(2): 421-449.
[86] Yahya-Che, N., Matsuura, Y. (2021). Does Individual Investor Sentiment Explain Japanese IPO Aftermarket Performance? *Journal of Asian Finance, Economics and Business.* Vol 8, nº 4, 1079-1090.
[87] Yoshinaga, C. M.; & de Castro Junior, F. H. F. (2012). The relationship between marketing sentiment index and stock rates of return: a panel data analysis. *Brazilian Administration Review*, 9(2): 189-210.
[88] Zainudin, Z., Zaki, Z., Hadi, A., Hussain, H,, & Kantakji, M. (2019). Investor Sentiment and Firm Financial Performance of Malaysian IPO Firms: Pre and Post Financial Crisis. *International Journal of Financial Research*. Vol. 10, nº 5. https://doi.org/ 10.5430/ijfr.v10n5p450.
[89] Zeleny, M. (1982) Multiple Criteria Decision Making. *McGraw Hill*, New York.
[90] Zhaohui, Z., & Wensheng, H. (2013). Investor sentiment and firms' investiment: an empirical study based on catering channel. *Journal of Applied Sciences*, *13*(8), 1199–1205.
[91] Zhu, Z., Sun, L., & Yung, K. (2020). Fundamental strength strategy: The role of investor sentiment versus limits to arbitrage. *International Review of Financial Analysis*, (In Press), 1–51.

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-7; Jul, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.117.6

Enhanced Integration of Kinematic free surface boundary condition to third order Accuracy for Wave Transformation Modeling

Syawaluddin Hutahaean

Ocean Engineering Program, Faculty of Civil and Environmental Engineering, -Bandung Institute of Technology (ITB), Bandung 40132, Indonesia
syawalf1@yahoo.co.id

Received: 19 May 2024,

Receive in revised form: 27 Jun 2024,

Accepted: 06 Jul 2024,

Available online: 14 Jul 2024

***Keywords*— wave amplitude function, critical wave steepness and breaker length index.**

***Abstract*—** *The relationship between wave amplitude and other wave constants is derived through the integration of the Kinematic Free Surface Boundary Condition (KFSBC) over time, yielding the wave amplitude function. This function presents the characteristics of wave breaking to determine the breaker length index—the ratio of breaking wave height to breaking wave length. Previous research achieved integration at a zero-order accuracy level, assuming small wave amplitude and long wave, resulting in a notably large critical breaker length index and wave steepness. In this research, KFSBC integration was advanced to second and third-order accuracies, yielding a wave amplitude function that significantly reduces the critical breaker length index and wave steepness compared to zero-order integration. Subsequently, utilizing the third-order wave amplitude function, a comprehensive wave transformation model incorporating shoaling, breaking, refraction, and diffraction was developed, demonstrating robust model performance.*

I. INTRODUCTION

This research aimed to improve the accuracy of critical wave steepness and breaking wave steepness estimation. The breaking wave steepness equation is derived from the wave amplitude function obtained through the integration of KFSBC over time (Hutahaean, 2024). Critical wave steepness is determined by identifying the maximum wave amplitude in the dispersion equation, where the dispersion equation results from applying the wave amplitude function to the Euler conservation momentum equation. Therefore, both critical wave steepness and breaking wave steepness are derived from the wave amplitude function.

Hutahaean (2024) conducted integration with zeroth-order accuracy, yielding a wave amplitude function that produced significant critical and breaking wave steepness. This research extended the integration to second and third-order accuracy levels, examining resulting critical wave steepness and breaking wave steepness.

Additionally, Hutahaean (2024) developed a water wave transformation model based on the wave amplitude function. This research further refined the model with a new wave amplitude function, investigating breaking parameters such as breaking wave height and depth. The findings demonstrate that higher integration accuracy improves the wave amplitude function's effectiveness in predicting these parameters, validating the chosen integration method's efficacy.

II. COMPLETE SOLUTION OF THE LAPLACE EQUATION

The complete solution of the weighted Laplace Equation using the separation variable method, Hutahaean (2024) in deep water where the bottom slope has no effect, is

$$\phi(x,z,t) = G\,(\cos k_x x + \sin k_x x)\cosh k_z(h+z)\sin\sigma t \quad \ldots..(1)$$

$\phi(x,z,t)$: velocity potential

G : wave constant

k_x : wave number on the horizontal-x axis

$$k_x = \frac{k}{\sqrt{\gamma_x}}$$

k_z : wave number on the vertical-z

$$k_z = \frac{k}{\sqrt{\gamma_z}}$$

k is the general wave number

γ_x and γ_z is weighting coefficient in weighted Taylor series, see section (3).

$\sigma = \frac{2\pi}{T}$ is angular frequency, where T is wave period.

h : water depth

Equation (1) is carried out at the characteristic point where $\cos k_x x = \sin k_x x$,

$$\phi(x,z,t) = 2\,G\,\cos k_x x \cosh k_z(h+z)\sin\sigma t \quad .(2)$$

III. WEIGHTED KINEMATIC FREE SURFACE BOUNDARY CONDITION

a. Weighted Taylor series

The Weighted Taylor series refers to a modified Taylor series truncated to first-order terms, where each first-order term incorporates a specific weighting coefficient in place of higher-order terms (Hutahaean, 2023).

Weighted Taylor series for function $f = f(x,t)$,

$$f(x+\delta x, t+\delta t) = f(x,t) + \gamma_{t,2}\delta t\frac{\partial f}{\partial t} + \gamma_x \delta x\frac{\partial f}{\partial x} \quad \ldots\ldots(3)$$

Weighted Taylor series for function $f = f(x,z,t)$,

$$f(x+\delta x, z+\delta z, t+\delta t) = f(x,z,t) + \gamma_{t,3}\delta t\frac{\partial f}{\partial t} + \gamma_x\delta x\frac{\partial f}{\partial x} + \gamma_z\delta z\frac{\partial f}{\partial z} \quad \ldots\ldots(4)$$

$\gamma_{t,3}$, $\gamma_{t,2}$, γ_x and γ_z are weighting coefficients. The basic values of the weighting coefficient are, $\gamma_{t,3} = 3.0$, $\gamma_{t,2} = 2.0$, $\gamma_x = 1.0$ and $\gamma_z = 1$. The corrected weighting coefficient values as a function of the optimization coefficient ε are presented in Table (1) as follows.

Table (1). Corrected weighting coefficients values.

ε	$\gamma_{t,2}$	$\gamma_{t,3}$	γ_x	γ_z
0.010	1.9998	3.00465	0.99879	1.01093
0.011	1.99975	3.00563	0.99854	1.01325
0.012	1.99971	3.00671	0.99826	1.0158
0.013	1.99966	3.00788	0.99795	1.01858
0.014	1.99960	3.00915	0.99763	1.02159
0.015	1.99954	3.01052	0.99727	1.02484
0.016	1.99948	3.01198	0.9969	1.02832
0.017	1.99941	3.01355	0.99649	1.03205
0.018	1.99934	3.01521	0.99607	1.03601
0.019	1.99926	3.01697	0.99561	1.04022
0.020	1.99918	3.01883	0.99514	1.04468

b. Weighted Kinematic Free Surface Boundary Condition (KFSBC).

For the water surface elevation equation $\eta = \eta(x,t)$, the weighting Taylor series is,

$$\eta(x+\delta x, t+\delta t) = \eta(x,t) + \gamma_{t,2}\delta t\frac{\partial \eta}{\partial t} + \gamma_x\delta x\frac{\partial \eta}{\partial x}$$

The first term on the right side is moved to the left, and the Equation is divided by δt,

$$\frac{\eta(x+\delta x, t+\delta t) - \eta(x,t)}{\delta t} = \gamma_{t,2}\frac{\partial \eta}{\partial t} + \gamma_x\frac{\delta x}{\delta t}\frac{\partial \eta}{\partial x}$$

As δt approaches zero, the left side of the equation represents the speed of change in water surface elevation, which corresponds to the total vertical velocity of surface water particles.

$$w_\eta = \gamma_{t,2}\frac{\partial \eta}{\partial t} + \gamma_x u_\eta\frac{\partial \eta}{\partial x} \quad \ldots.(5)$$

This equation is denoted as KFSBC. Here, w_η represents the vertical velocity of surface water particles, and u_η denotes the horizontal velocity at the water surface.

Equation (5) can thus be expressed as the equation describing changes in water level elevation, namely,

$$\gamma_{t,2}\frac{\partial \eta}{\partial t} = w_\eta - \gamma_x u_\eta\frac{\partial \eta}{\partial x} \quad \ldots.(6)$$

IV. KFSBC INTEGRATION WITH 0TH ORDER ACCURACY.

Hutahaean (2024) utilized zeroth-order integration to establish the relationship between wave amplitude and wave constants G, such as wave number k and angular frequenc σ, termed as the wave amplitude function. The subsequent section will reiterate the steps involved in the

zeroth-order integration process to outline the formulation of the equation for the wave amplitude function.

1.1. The formulation of wave amplitude function.

Using equation (2), the vertical water particle velocity is:

$$w = -\frac{\partial \phi}{\partial z} = -2\ Gk_z\ \cos k_x x \sinh k_z(h+z) \sin \sigma t$$

Surface vertical water particle velocity is

$$w_\eta = -2\ Gk_z\ \cos k_x x \sinh k_z\big(h+\eta(x,t)\big) \sin \sigma t \quad \text{.....(7)}$$

Meanwhile, the horizontal water particle velocity is

$$u = -\frac{\partial \phi}{\partial x} = 2Gk_x\ \sin k_x x \cosh k_z(h+z) \sin \sigma t$$

Surface horizontal water particle velocity is

$$u_\eta = 2Gk_x\ \sin k_x x \cosh k_z\big(h+\eta(x,t)\big) \sin \sigma t \quad \text{.....(8)}$$

The substitution of (7) and (8) number (6),

$$\gamma_{t,2}\frac{\partial \eta}{\partial t} = -2Gk_z \cos k_x \sinh k_z\left(h+\eta(x,t)\right) \sin \sigma t - 2\gamma_x Gk_x \sin k_x \cosh k_z\left(h+\eta(x,t)\right) \sin \sigma t \frac{\partial \eta}{\partial x}$$

To derive the equation for water surface elevation, integrate this equation over time t,

$$\gamma_{t,2}\eta(x,t) = -2Gk_z\ \cos k_x x \int \sinh k_z\big(h+\eta(x,t)\big) \sin \sigma t\ dt - 2\gamma_x Gk_x \sin k_x x \int \cosh k_z\big(h+\eta(x,t)\big) \sin \sigma t\ \frac{\partial \eta}{\partial x}\ dt \quad \text{...(9)}$$

The water surface elevation equation obtained depends on the integration solution's accuracy level. Theoretical accuracy ranges from order 0 to order n, determined by the presence of $\frac{\partial^n \eta}{\partial t^n}$ in the integration solution.

Order 0 integration assumes $\frac{\partial^0 \eta}{\partial t^0}$ in the results, while order 1 implies $\frac{\partial^1 \eta}{\partial t^1}$, order 2 involves $\frac{\partial^2 \eta}{\partial t^2}$, etc. This research was limited to order 3 accuracy.

In zero-order integration, the assumption is made that in deep water and with small wave amplitudes $\left|\sinh k_z h\left(1+\frac{\eta(x,t)}{h}\right)\right|$ and $\left|\cosh k_z h\left(1+\frac{\eta(x,t)}{h}\right)\frac{\partial \eta}{\partial x}\right|$ fluctuates very little with time, allowing it to be treated as constant and excluded from integration.

$$\gamma_{t,2}\eta(x,t) = -2Gk_z \sinh k_z\big(h+\eta(x,t)\big)\ \cos k_x x \int \sin \sigma t\ dt - 2\gamma_x Gk_x \cosh k_z\big(h+\eta(x,t)\big)\ \sin k_x x \frac{\partial \eta}{\partial x}\int \sin \sigma t\ \ dt$$

This integration can be completed by integrating the sinusoidal function alone. After integrating, the characteristic point property is worked out, namely $\cos k_x x = \sin k_x x$ and substituted with $k_x = \frac{k}{\sqrt{\gamma_x}}$ and $k_z = \frac{k}{\sqrt{\gamma_z}}$,

$$\gamma_{t,2}\eta(x,t) = \frac{2Gk}{\sigma}\ \cosh k_z\big(h+\eta(x,t)\big) \left(\frac{\tanh k_z\big(h+\eta(x,t)\big)}{\sqrt{\gamma_z}} + \sqrt{\gamma_x}\frac{\partial \eta}{\partial x}\right)\cos k_x x\ \cos \sigma t$$

In the integrated results, the absence of the $\frac{\partial \eta}{\partial t}$ term indicates a zero-order integration.

In deep water, where $\tanh k_z\big(h+\eta(x,t)\big) \approx 1$, $k_z\big(h+\eta(x,t)\big) = \theta\pi$. θ is referred to as deep water coefficient with $\theta > 1$, for instance $\theta = 1.75$.

$$\eta(x,t) = \frac{2Gk}{\sigma\gamma_{t,2}}\ \cosh \theta\pi \left(\frac{\tanh \theta\pi}{\sqrt{\gamma_z}}\ \sqrt{\gamma_x}\frac{\partial \eta}{\partial x}\right)\cos k_x x\ \cos \sigma t$$

As a periodic function, hence

$$A = \frac{2Gk}{\sigma\gamma_{t,2}}\ \cosh \theta\pi \left(\frac{\tanh \theta\pi}{\sqrt{\gamma_z}} + \sqrt{\gamma_x}\frac{\partial \eta}{\partial x}\right)$$

A is wave amplitude.

Water surface elevation equation is

$$\eta(x,t) = A \cos k_x x\ \cos \sigma t \quad \text{...(10)}$$

At the characteristic point of space and time,

$$\frac{\partial \eta}{\partial x} = -\frac{k_x A}{2}$$

The wave amplitude function is

$$A = \frac{2Gk}{\sigma\gamma_{t,2}}\ \cosh \theta\pi \left(\frac{\tanh \theta\pi}{\sqrt{\gamma_z}} - \frac{kA}{2}\right) \quad \text{...(11)}$$

This equation is the wave amplitude function equation resulting from zero order integration.

1.2. 0th order breaking characteristics.

In (11), breaking occurs when

$$\frac{\tanh \theta\pi}{\sqrt{\gamma_z}} - \frac{kA}{2} = 0$$

$$\frac{H_b}{L_b} = \frac{2 \tanh \theta\pi}{\pi\sqrt{\gamma_z}} \quad \text{.....(12)}$$

Equation (12) applies universally across all wave periods, accommodating the specific wave height relevant to each period.

1.3. 0^{th} order dispersion equation

The dispersion equation is formulated based on surface-weighted Euler momentum conservation, excluding the convective acceleration term.

$$\gamma_{t,3}\ \frac{\partial u_\eta}{\partial t} = -g\frac{\partial \eta}{\partial x}$$

With u_η from (8) and η and (10), the following is obtained

$$\gamma_{t,3}\ \frac{\partial u_\eta}{\partial t} = 2\gamma_{t,3}Gk_x\sigma\ \sin k_x x \cosh k_z\big(h + \eta(x,t)\big)\cos\sigma t$$

$$-g\frac{\partial \eta}{\partial x} = gk_x A \sin k_x x\ \cos\sigma t$$

Substitute these two equations into (13),

$$2\gamma_{t,3}G\sigma\ \cosh\theta\pi = gA$$

Wave amplitude on the right side is substituted with (11),

$$2\gamma_{t,3}G\sigma\ \cosh\theta\pi = \frac{2gGk}{\sigma\gamma_{t,2}}\ \cosh\theta\pi\left(\frac{\tanh\theta\pi}{\sqrt{\gamma_z}} - \frac{kA}{2}\right)$$

$$\frac{gA}{2}\ k^2 - \frac{g\tanh\theta\pi}{\sqrt{\gamma_z}}k + \gamma_{t,2}\gamma_{t,3}\sigma^2 = 0 \qquad \ldots\ldots(13)$$

This equation is the dispersion equation resulting from zero order integration.

The steps in formulating the wave amplitude function are:

a. Completing the integration of KFSBC
b. The integration results are collected to form an Equation:$\eta(x,t) = (\ldots\ldots)\cos k_x x \cos\sigma t$
c. Defining wave amplitude function $A =$(……), obtaining $\eta(x,t) = A\cos k_x x\cos\sigma t$

From this Equation, we obtain the Equation of $\frac{\partial \eta}{\partial x}$, which is then substituted into the wave amplitude function equation, to obtain the final Equation of the wave amplitude function.

V. KFSBC INTEGRATION WITH 2ND ORDER ACCURACY.

The integration will be completed until there is an element $\frac{\partial^2 \eta}{\partial t^2}$. Integration is carried out using the integral inversion method (Hutahaean (2010).

a. $\int \sinh k_z\big(h+\eta(x,t)\big)\sin\sigma t\ dt$

Is defined as,

$$f(t) = \sinh k_z\big(h+\eta(x,t)\big)\cos\sigma t$$

$$\frac{df}{dt} = -\sigma\sinh k_z\big(h+\eta(x,t)\big)\sin\sigma t + k_z\cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\ \frac{\partial\eta}{\partial t}$$

This differential equation is integrated over time t,

$$\int df = -\sigma\int \sinh k_z\big(h+\eta(x,t)\big)\sin\sigma t\ dt + k_z\int \cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}dt$$

Integration of the left side produces $f(t)$, substitution $f(t)$and the rearranged Equation is obtained

$$\int \sinh k_z\big(h+\eta(x,t)\big)\sin\sigma t\ dt = -\frac{1}{\sigma}\sinh k_z\big(h+\eta(x,t)\big)\cos\sigma t + \frac{k_z}{\sigma}\int \cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}dt \qquad \ldots\ldots\ldots\ldots(14)$$

In second-order integration, the fluctuations $\left|\cosh k_z h\left(1+\frac{\eta(x,t)}{h}\right)\frac{\partial\eta}{\partial t}\right|$ with respect to time are significant enough that the integration of the two terms on the right side necessitates the use of the integral inversion method.

$$\int \cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}dt = ?$$

Is defined as,

$$f(t) = \cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\frac{\partial\eta}{\partial t}$$

$$\frac{df}{dt} = k_z\sinh k_z\big(h+\eta(x,t)\big)\sin\sigma t\ \left(\frac{\partial\eta}{\partial t}\right)^2 + \sigma\cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t} + \cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\frac{\partial^2\eta}{\partial t^2}$$

Is integrated into,

$$\int df = \int k_z\sinh k_z\big(h+\eta(x,t)\big)\sin\sigma t\ \left(\frac{\partial\eta}{\partial t}\right)^2 dt + \sigma\int \cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}\ dt + \int \cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\frac{\partial^2\eta}{\partial t^2}\ dt$$

The left side is substituted with $f(t)$ and rearranged

$$\int \cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}\,dt = \frac{1}{\sigma}\cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\frac{\partial\eta}{\partial t} - \frac{k_z}{\sigma}\int \sinh k_z\big(h+\eta(x,t)\big)\sin\sigma t\,\left(\frac{\partial\eta}{\partial t}\right)^2 dt - \frac{1}{\sigma}\int \cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\frac{\partial^2\eta}{\partial t^2}\,dt$$

In this 2nd order integration, the assumption is made that fluctuations over time t from $\left|\sinh k_z h\left(1+\frac{\eta(x,t)}{h}\right)\left(\frac{\partial\eta}{\partial t}\right)^2\right|$ *and* $\left|\cosh k_z h\left(1+\frac{\eta(x,t)}{h}\right)\frac{\partial^2\eta}{\partial t^2}\right|$ is very small and can be considered constant that it can be excluded from the integral.

$$\int \cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}\,dt = \frac{1}{\sigma}\cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\frac{\partial\eta}{\partial t} - \frac{k_z}{\sigma}\sinh k_z\big(h+\eta(x,t)\big)\left(\frac{\partial\eta}{\partial t}\right)^2\int \sin\sigma t\;dt - \frac{1}{\sigma}\cosh k_z\big(h+\eta(x,t)\big)\frac{\partial^2\eta}{\partial t^2}\int \sin\sigma t\;dt$$

The final integration is completed by simply integrating the sinusoidal function, obtaining the followings.

$$\int \cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}\,dt = \frac{1}{\sigma}\cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\frac{\partial\eta}{\partial t} + \frac{k_z}{\sigma^2}\sinh k_z\big(h+\eta(x,t)\big)\cos\sigma t\,\left(\frac{\partial\eta}{\partial t}\right)^2 + \frac{1}{\sigma^2}\cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial^2\eta}{\partial t^2}$$

Or,

$$\frac{k_z}{\sigma}\int \cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}\,dt = \frac{k_z}{\sigma^2}\cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\frac{\partial\eta}{\partial t} + \frac{k_z^2}{\sigma^3}\sinh k_z\big(h+\eta(x,t)\big)\cos\sigma t\,\left(\frac{\partial\eta}{\partial t}\right)^2 + \frac{k_z}{\sigma^3}\cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial^2\eta}{\partial t^2}$$

Since $k_z\big(h+\eta(x,t)\big)=\theta\pi$ and calculating the integration outcomes at the specific time point, $\cos\sigma t=\sin\sigma t$

$$\frac{k_z}{\sigma}\int \cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}\,dt = \frac{1}{\sigma}\cosh\theta\pi\left(\frac{k_z}{\sigma}\frac{\partial\eta}{\partial t}+\frac{k_z^2}{\sigma^2}\tanh\theta\pi\left(\frac{\partial\eta}{\partial t}\right)^2 + \frac{k_z}{\sigma^2}\frac{\partial^2\eta}{\partial t^2}\right)\cos\sigma t$$

The results of this integration are substituted into (14),

$$\int \sinh k_z\big(h+\eta(x,t)\big)\sin\sigma t\;dt = -\frac{\cosh\theta\pi}{\sigma}\left(\tanh\theta\pi-\left(\frac{k_z}{\sigma}\frac{\partial\eta}{\partial t}+\frac{k_z^2}{\sigma^2}\tanh\theta\pi\left(\frac{\partial\eta}{\partial t}\right)^2 + \frac{k_z}{\sigma^2}\frac{\partial^2\eta}{\partial t^2}\right)\right)\cos\sigma t \;\ldots\ldots(15)$$

Based on the integration results, there are terms $\frac{\partial^2\eta}{\partial t^2}$ that is equivalent to $\left(\frac{\partial\eta}{\partial t}\right)^2$, classifying this integration as second-order accurate.

b. $\int \cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\;\frac{\partial\eta}{\partial x}\,dt$

Is defined as,

$$f(t)=\cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial x}$$

$$\frac{df}{dt} = -\sigma\cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\frac{\partial\eta}{\partial x} + k_z\sinh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}\frac{\partial\eta}{\partial x} + \cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial^2\eta}{\partial t\partial x}$$

Multiplied by dt is integrated into,

$$\int \cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\frac{\partial\eta}{\partial x}\,dt = -\frac{1}{\sigma}\cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial x} + \frac{k_z}{\sigma}\int \sinh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}\frac{\partial\eta}{\partial x}\,dt + \frac{1}{\sigma}\int \cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial^2\eta}{\partial t\partial x}\,dt$$

In this second order integration, the assumption is made that the fluctuation $\left|\sinh k_z h\left(1+\frac{\eta(x,t)}{h}\right)\frac{\partial\eta}{\partial t}\frac{\partial\eta}{\partial x}\right|$ with respect to time t is quite small that it can be considered constant and can be excluded from the integral.

Likewise, the fluctuation $\left|\cosh k_z h\left(1+\frac{\eta(x,t)}{h}\right)\frac{\partial^2\eta}{\partial t\partial x}\right|$ with respect to time t is considered too small that it can be excluded from the integral.

$$\int \cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\frac{\partial\eta}{\partial x}\,dt = -\frac{1}{\sigma}\cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial x} + \frac{k_z}{\sigma}\sinh k_z\big(h+\eta(x,t)\big)\frac{\partial\eta}{\partial t}\frac{\partial\eta}{\partial x}\int\cos\sigma t\,dt + \frac{1}{\sigma}\cosh k_z\big(h+\eta(x,t)\big)\frac{\partial^2\eta}{\partial t\partial x}\int\cos\sigma t\,dt$$

This integration equation can be solved by integrating $\int\cos\sigma t\,dt$ directly. Once integrated and substituting $k_z(h+\eta(x,t))=\theta\pi$, the equation is evaluated at the characteristic time point where $\cos\sigma t=\sin\sigma t$, yielding:

$$\int \cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\frac{\partial\eta}{\partial x}\,dt = -\frac{1}{\sigma}\cosh\theta\pi\left(\frac{\partial\eta}{\partial x}-\frac{k_z}{\sigma}\tanh\theta\pi\frac{\partial\eta}{\partial t}\frac{\partial\eta}{\partial x}-\frac{1}{\sigma}\frac{\partial^2\eta}{\partial t\partial x}\right)\cos\sigma t \quad ...(16)$$

Regarding the presence of $\frac{\partial\eta}{\partial t}\frac{\partial\eta}{\partial x}$ and $\frac{\partial^2\eta}{\partial t\partial x}$, then the result of the integration is called the second order level of accuracy.

Equation-Equation (15) and (16) are substituted to (9),

$$\eta(x,t)=\frac{Gk_z}{\sigma\gamma_{t,2}}\cosh\theta\pi\left(\tanh\theta\pi+\left(k_zA-\frac{k_z^2A^2}{4}\tanh\theta\pi\right)\right)\cos\sigma t\cos k_xx + \frac{\gamma_xGk_x}{\sigma\gamma_{t,2}}\cosh\theta\pi\left(\frac{\partial\eta}{\partial x}-\frac{k_z}{\sigma}\tanh\theta\pi\frac{\partial\eta}{\partial t}\frac{\partial\eta}{\partial x}-\frac{1}{\sigma}\frac{\partial^2\eta}{\partial t\partial x}\right)\cos\sigma t\cos k_xx$$

As a periodic function, therefore

$$A=\frac{Gk_z}{\sigma\gamma_{t,2}}\cosh\theta\pi\left(\tanh\theta\pi+\left(k_zA-\frac{k_z^2A^2}{4}\tanh\theta\pi\right)\right) + \frac{\gamma_xGk_x}{\sigma\gamma_{t,2}}\cosh\theta\pi\left(\frac{\partial\eta}{\partial x}-\frac{k_z}{\sigma}\tanh\theta\pi\frac{\partial\eta}{\partial t}\frac{\partial\eta}{\partial x}-\frac{1}{\sigma}\frac{\partial^2\eta}{\partial t\partial x}\right)$$

obtaining

$\eta(x,t)=A\cos\sigma t\cos k_xx$

Within the characteristic point of

$$\frac{\partial\eta}{\partial x}=-\frac{k_xA}{2}$$

$$\frac{\partial\eta}{\partial t}=-\frac{\sigma A}{2}$$

$$\frac{\partial^2\eta}{\partial t\partial x}=\frac{\sigma k_xA}{2}$$

Is the differential substitution of $\eta(x,t)$ and $k_x=\frac{k}{\sqrt{\gamma_x}}$ and $k_z=\frac{k}{\sqrt{\gamma_z}}$

$$A=\frac{2Gk}{\sigma\gamma_{t,2}}\cosh\theta\pi\left(\frac{\tanh\theta\pi}{\sqrt{\gamma_z}}+\left(\frac{1}{\gamma_z}-1\right)kA-\left(\frac{1}{\gamma_z\sqrt{\gamma_z}}+\frac{\sqrt{\gamma_x}}{\sqrt{\gamma_z}}\right)\frac{\tanh\theta\pi}{4}k^2A^2\right)$$

.....(17)

This equation is the wave amplitude function resulting from integration with 2nd order accuracy.

5.2. Breaking 2nd order characteristics

Breaking occurs when

$$\frac{\tanh\theta\pi}{\sqrt{\gamma_z}}+\left(\frac{1}{\gamma_z}-1\right)kA-\left(\frac{1}{\gamma_z\sqrt{\gamma_z}}+\frac{\sqrt{\gamma_x}}{\sqrt{\gamma_z}}\right)\frac{\tanh\theta\pi}{4}k^2A^2=0$$

Is substituted to $k=\frac{2\pi}{L}$ and sinusoidal wave $A=\frac{H}{2}$,

$$\frac{\tanh\theta\pi}{\sqrt{\gamma_z}}+\left(\frac{1}{\gamma_z}-1\right)\pi\left(\frac{H}{L}\right)-\left(\frac{1}{\gamma_z\sqrt{\gamma_z}}+\frac{\sqrt{\gamma_x}}{\sqrt{\gamma_z}}\right)\frac{\tanh\theta\pi}{4}\pi^2\left(\frac{H}{L}\right)^2=0 \quad ...(18)$$

Using equation (18), $\frac{H}{L}$known as the breaker length index $\frac{H_b}{L_b}$ can be calculated. This equation does not include parameters for wave period or wave amplitude. Therefore, $\frac{H_b}{L_b}$ obtained is valid for all wave periods, provided the appropriate wave amplitude is considered.

5.3. 2nd order Dispersion Equation.

In the same way as the formulation of the dispersion equation in (4.3) where in this case the wave amplitude function (17) is used, the dispersion equation obtained is

$$\left(\frac{1}{\gamma_z\sqrt{\gamma_z}}+\frac{\sqrt{\gamma_x}}{\sqrt{\gamma_z}}\right)\frac{\tanh\theta\pi}{4}gA^2k^3-\left(\frac{1}{\gamma_z}-1\right)gAk^2 - \frac{\tanh\theta\pi}{\sqrt{\gamma_z}}gk+\gamma_{t,2}\gamma_{t,3}\sigma^2=0 \quad \dots(19)$$

The equation is a third-degree polynomial that can be solved using the Newton-Raphson iteration method. Initially, terms containing k^3 are disregarded to simplify the equation to a second-degree polynomial. Once k is found from this simplified equation, it is used in the complete set of equations to calculate k accurately.

VI. KFSBC INTEGRATION WITH 3RD ORDER ACCURACY

In this section the integration process is not discussed in its entirety, just an example. In second order integration there are integration results,

$$\int \cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}\,dt = \frac{1}{\sigma}\cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\frac{\partial\eta}{\partial t} - \frac{k_z}{\sigma}\int \sinh k_z\big(h+\eta(x,t)\big)\sin\sigma t\left(\frac{\partial\eta}{\partial t}\right)^2 dt - \frac{1}{\sigma}\int \cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\frac{\partial^2\eta}{\partial t^2}\,dt$$

In second-order integration, the two integrations on the right side are solved by integrating only the sinusoidal elements. However, in third-order integration, the two right-hand side integrations are solved using the integral inversion method. For example,

$$\frac{k_z}{\sigma}\int \sinh k_z\big(h+\eta(x,t)\big)\sin\sigma t\left(\frac{\partial\eta}{\partial t}\right)^2 dt$$

$$f(t)=\sinh k_z\big(h+\eta(x,t)\big)\cos\sigma t\left(\frac{\partial\eta}{\partial t}\right)^2$$

$$\frac{df}{dt}=k_z\cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\left(\frac{\partial\eta}{\partial t}\right)^3 - \sigma\sinh k_z\big(h+\eta(x,t)\big)\sin\sigma t\left(\frac{\partial\eta}{\partial t}\right)^2 + 2\sinh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}\frac{\partial^2\eta}{\partial t^2}$$

This equation is multiplied with dt and is integrated into,

$$\int df = k_z\int \cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\left(\frac{\partial\eta}{\partial t}\right)^3 dt - \sigma\int \sinh k_z\big(h+\eta(x,t)\big)\sin\sigma t\left(\frac{\partial\eta}{\partial t}\right)^2 dt + 2\int \sinh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}\frac{\partial^2\eta}{\partial t^2}\,dt$$

Substitute $f(t)$ on the left side and is moved to the right, while the second term on the right side is moved to the left,

$$\int \sinh k_z\big(h+\eta(x,t)\big)\sin\sigma t\left(\frac{\partial\eta}{\partial t}\right)^2 dt = -\frac{1}{\sigma}\sinh k_z\big(h+\eta(x,t)\big)\cos\sigma t\left(\frac{\partial\eta}{\partial t}\right)^2 + \frac{k_z}{\sigma}\int \cosh k_z\big(h+\eta(x,t)\big)\cos\sigma t\left(\frac{\partial\eta}{\partial t}\right)^3 dt + \frac{2}{\sigma}\int \sinh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}\frac{\partial^2\eta}{\partial t^2}\,dt$$

The assumption is that fluctuations with time from: $\left|\cosh k_z h\left(1+\frac{\eta(x,t)}{h}\right)\left(\frac{\partial\eta}{\partial t}\right)^3\right|$ and $\left|\sinh k_z h\left(1+\frac{\eta(x,t)}{h}\right)\frac{\partial\eta}{\partial t}\frac{\partial^2\eta}{\partial t^2}\right|$ is very small and can be considered constant, that it can be excluded from integration, and what is integrated into, is only the sinusoidal element. Obtaining,

$$\frac{k_z}{\sigma}\int \sinh k_z\big(h+\eta(x,t)\big)\sin\sigma t\left(\frac{\partial\eta}{\partial t}\right)^2 dt = -\frac{k_z}{\sigma^2}\sinh k_z\big(h+\eta(x,t)\big)\cos\sigma t\left(\frac{\partial\eta}{\partial t}\right)^2 + \frac{k_z^2}{\sigma^3}\cosh k_z\big(h+\eta(x,t)\big)\sin\sigma t\left(\frac{\partial\eta}{\partial t}\right)^3 + \frac{2k_z}{\sigma^3}\sinh k_z\big(h+\eta(x,t)\big)\cos\sigma t\frac{\partial\eta}{\partial t}\frac{\partial^2\eta}{\partial t^2}$$

After all the integrations are completed then add them up and carry out the process as in 2nd order integration, we get,

$$\eta(x,t)=\frac{2Gkcosh\,\theta\pi}{\sigma\gamma_{t,2}}\alpha(k,A)\cos k_x x\cos\sigma t$$

$$\alpha(k,A)=\frac{tanh\,\theta\pi}{\sqrt{\gamma_z}}+\left(\frac{3}{2\gamma_z}-\frac{3}{2}\right)kA - \frac{k^2A^2}{2\sqrt{\gamma_x}\sqrt{\gamma_z}}tanh\,\theta\pi$$

$$+\left(\frac{1}{\gamma_z^2}-\frac{1}{\gamma_z}\right)\frac{k^3A^3}{8}$$

Where the wave amplitude function is

$$A=\frac{2Gkcosh\,\theta\pi}{\sigma\gamma_{t,2}}\alpha(k,A) \qquad \text{…..(20)}$$

Breaking occurs when,

$$\frac{tanh\,\theta\pi}{\sqrt{\gamma_z}}+\left(\frac{3}{2\gamma_z}-\frac{3}{2}\right)kA-\frac{(kA)^2}{2\sqrt{\gamma_x}\sqrt{\gamma_z}}tanh\,\theta\pi+\left(\frac{1}{\gamma_z^2}-\frac{1}{\gamma_z}\right)\frac{(kA)^3}{8}=0 \quad \text{……(21)}$$

From this equation, the kA value can be calculated. It is a third-degree polynomial equation, which can be solved using the Newton-Raphson iteration method. Initially, the kA value is estimated by disregarding the terms. After obtaining an approximate kA value using this simplified equation, it can then be refined using the complete set of equations. For example,

$kA=\lambda$

Considering $k=\frac{2\pi}{L}$ and $H=2A$,

$$\frac{H_b}{L_b}=\frac{\lambda}{\pi}$$

Dispersion equation with wave amplitude function obtained from 3rd order integration is,

$$\left(\frac{1}{\gamma_z^2}-\frac{1}{\gamma_z}\right)\frac{A^3}{8}k^4-\frac{tanh\,\theta\pi\,A^2}{2\sqrt{\gamma_x}\sqrt{\gamma_z}}k^3+\left(\frac{1}{2\gamma_z}-\frac{3}{2}\right)Ak^2+\frac{tanh\,\theta\pi}{\sqrt{\gamma_z}}\,k-\frac{\gamma_{t,3}\gamma_{t,3}\,\sigma^2}{g}=0 \quad \text{….(22)}$$

This equation is a 4th-degree polynomial, which can be solved using the Newton-Raphson iteration method. The initial iteration value is obtained by disregarding the terms with powers of 4 and 3.

VII. WAVELENGTH, CRITICAL WAVE STEEPNESS AND BREAKER LENGTH INDEX

In this section, a comparative research of wavelength, maximum wave height, and critical wave steepness is conducted. The research utilizes the dispersion equation with an optimization coefficient ε of 0.01 for the weighting coefficient.

In the dispersion equation derived from zero-order integration using the wave amplitude function, the maximum wave height corresponds to the wave height at which the determinant value of equation (13) becomes zero.

For the dispersion equation (19) obtained from second-order integration using the wave amplitude function, using an excessively large wave height results in a negative wave number. Therefore, the maximum wave height in equation (19) is the largest wave height that does not produce a negative wave number.

Similarly, in the dispersion equation (22) resulting from third-order integration with the wave amplitude function, using a wave height that is too large also yields a negative wave number. Thus, the maximum wave height in equation (22) is the highest wave height before encountering a negative wave number.

There are two types of wave numbers: the horizontal wave number k_x and vertical wave number k_z, where

$k_x=\frac{k}{\sqrt{\gamma_x}}$ and $k_z=\frac{k}{\sqrt{\gamma_z}}$

Therefore, two wavelengths are,

Horizontal wavelength : $L_x=\frac{2\pi}{k_x}=\frac{2\pi}{k}\sqrt{\gamma_x}=L\sqrt{\gamma_x}$

Vertical wavelength : $L_z=\frac{2\pi}{k_z}=\frac{2\pi}{k}\sqrt{\gamma_z}=L\sqrt{\gamma_z}$

Table (2) presents the maximum wave height of (13)

Table (2). Maximum wave height from (13)

T (sec)	H_{max} (m)	L_x (m)	L_z (m)	$\frac{H_{max}}{L_x}$
6	1.453	4.64	4.699	0.313
7	1.977	6.401	6.481	0.309
8	2.583	8.272	8.377	0.312
9	3.269	10.487	10.619	0.312
10	4.036	12.914	13.077	0.313
11	4.883	15.708	15.906	0.311
12	5.812	18.56	18.795	0.313
13	6.821	21.79	22.064	0.313
14	7.911	25.188	25.506	0.314
15	9.081	29.056	29.422	0.313

Table (3). Maximum wave height from (19)

T (sec)	H_{max} (m)	L_x (m)	L_z (m)	$\frac{H_{max}}{L_x}$
6	1.565	6.169	6.246	0.253
7	2.13	8.41	8.516	0.253
8	2.782	10.988	11.126	0.253
9	3.522	13.76	13.934	0.256
10	4.348	17.027	17.241	0.255

11	5.261	20.618	20.878	0.255
12	6.261	24.542	24.852	0.255
13	7.348	28.799	29.162	0.255
14	8.522	33.389	33.81	0.255
15	9.783	38.31	38.793	0.255

Based on the data presented in Tables 2, 3, and 4, it is evident that the difference between the horizontal wavelength L_x and the vertical wavelength $L_z$is minimal.

Table (4). Wave height maximum from (22)

T (sec)	H_{max} (m)	L_x (m)	L_z (m)	$\frac{H_{max}}{L_x}$
6	1.53	6.201	6.279	0.247
7	2.082	8.468	8.575	0.246
8	2.72	11.023	11.162	0.247
9	3.444	13.839	14.013	0.249
10	4.252	17.07	17.285	0.249
11	5.146	20.474	20.733	0.251
12	6.124	24.437	24.745	0.251
13	7.186	28.835	29.199	0.249
14	8.336	33.015	33.432	0.252
15	9.568	38.292	38.775	0.25

As the integration order increases, the critical wave steepness decreases. Specifically, the difference between the critical wave steepness values derived from equations (19) and (22) is relatively small, typically in the third decimal place. This suggests that increasing the integration order to 4th order would yield a critical wave steepness not significantly different from that obtained at 3rd order. In general, the critical wave steepness is estimated to be 0.250.

Toffoli et al. (2010) propose a critical wave steepness of 0.170, while suggesting it could reach up to 0.20. It is noted that the wave steepness calculated at 3rd order accuracy closely approximates the criteria proposed by Toffoli et al.

The comparison of the breaker wave steepness $\frac{H_b}{L_b}$from equations (12), (18), and (21), using parameters $\theta = 1.75$ and $\varepsilon = 0.01$, progresses from the lowest to highest integration order.

Dari (12), $\frac{H_b}{L_b} = 0.629$

Dari (18), $\frac{H_b}{L_b} = 0.446$

Dari (21), $\frac{H_b}{L_b} = 0.437$

The critical wave steepness in deep water differs from the wave steepness at the breaking point, $\frac{H_b}{L_b}$, where breaking waves concentrate a significant amount of energy. Among the three $\frac{H_b}{L_b}$ values, the smallest is obtained from equation (21), which corresponds to 3rd order integration. The difference between $\frac{H_b}{L_b}$from equation (18) and $\frac{H_b}{L_b}$from equation (21) is negligible, indicating that increasing the integration accuracy will not lead to substantial changes.

In conclusion, the breaking wave steepness $\frac{H_b}{L_b}$is generally estimated to be 0.437

VIII. WAVE TRANSFORMATION MODEL

The wave amplitude function equation, which establishes the relationship among various wave constants, serves as a foundational equation for developing wave transformation models (Hutahaean, 2024). By deriving a new wave amplitude function, different wave transformation phenomena can be modeled.

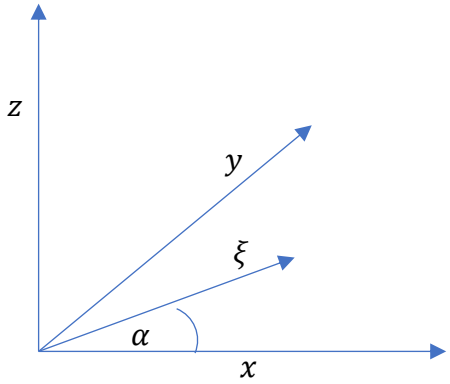


Fig (1)Axis system for wave transformation modeling.

The wave transformation model is constructed within the coordinate system depicted in Figure (1), where the wave propagates along the ξ axis in the (x, y) plane, forming an angle α with the horizontal x.

8.1 Shoaling-breaking model.

Shoaling breaking equations were developed for waves moving on the ξ-axis. The wave amplitude function resulting from 3rd order integration, namely (20), is written as,

$$A = Gk\,\lambda(k, A) \qquad \text{.....(23)}$$

$$\lambda(k, A) = \frac{2cosh\,\theta\pi}{\sigma\gamma_{t,2}}\left(\frac{tanh\,\theta\pi}{\sqrt{\gamma_z}} + \left(\frac{3}{2\gamma_z} - \frac{3}{2}\right)kA\right) + \frac{2cosh\,\theta\pi}{\sigma\gamma_{t,2}}\left(-\frac{k^2A^2}{2\sqrt{\gamma_x}\sqrt{\gamma_z}}tanh\,\theta\pi + \left(\frac{1}{\gamma_z^2} - \frac{1}{\gamma_z}\right)\frac{k^3A^3}{8}\right)$$

Equation (23) is differentiable to axis-ξ,

$$\frac{dA}{d\xi} = \left(G\frac{dk}{d\xi} + k\frac{dG}{d\xi}\right)\lambda(k,A) \quad \text{.....(24)}$$

Where considering the law of conservation of wave number which will be shown in the next section, then $\frac{d\lambda}{d\xi} = 0$.

The conservation of energy equation (Hutahaean (2024) applies,

$$G\frac{\partial k}{\partial \xi} + 2k\frac{\partial G}{\partial \xi} = 0$$

This equation is written as,

$$k\frac{\partial G}{\partial \xi} = -\frac{G}{2}\frac{\partial k}{\partial \xi}$$

Substituted to (24), obtaining

$$\frac{dA}{d\xi} = \frac{G}{2}\frac{dk}{d\xi}\lambda(k,A) \quad \text{.....(25)}$$

This equation is multiplied by $\frac{k}{k}$, Considering (23), the following is obtained

$$\frac{dA}{d\xi} = \frac{A}{2k}\frac{dk}{d\xi} \quad \text{.....(26)}$$

Wave number conservation (Hutahaean (2024)),

$$\frac{dk\left(h+\frac{A}{2}\right)}{d\xi} = 0$$

This equation is expressed as,

$$\frac{dA}{d\xi} = -\frac{2}{k}\left(h+\frac{A}{2}\right)\frac{dk}{d\xi} - 2\frac{dh}{d\xi}$$

Substituting the left side with (26)

$$\frac{A}{2k}\frac{dk}{d\xi} = -\frac{2}{k}\left(h+\frac{A}{2}\right)\frac{dk}{d\xi} - 2\frac{dh}{d\xi}$$

Therefore,

$$\frac{dk}{d\xi} = -\frac{4k}{(4h+3A)}\frac{dh}{d\xi} \quad \text{....(27)}$$

The equation (25) is used to calculate changes in wave number k. To compute changes in wave amplitude, equation (26) should be utilized. Equation (26) incorporates breaking characteristics through $\lambda(k,A)$, where the values of k and A determine its behavior.

As water depth decreases, both k and A increase, causing λ to decrease continuously until it reaches zero, signifying the onset of breaking. Post breaking, λ turns negative, resulting in a gradual reduction of wave amplitude until it diminishes completely.

For a wave moving from point ξ to point $\xi + \delta\xi$, the change in k and A is

$$k_{\xi+\delta\xi} = k_\xi + \delta\xi\ \frac{dk}{d\xi}$$

$$A_{\xi+\delta\xi} = A_\xi + \delta\xi\ \frac{dA}{d\xi}$$

The equation for calculating changes in G is formulated using the energy conservation equation which can be written as.

$$\frac{\partial G}{G} = -\frac{1}{2}\frac{\partial k}{k}$$

Equation ini Is integrated into,,

$$\int_\xi^{\xi+\delta\xi}\frac{\partial G}{G} = -\frac{1}{2}\int_\xi^{\xi+\delta\xi}\frac{\partial k}{k}$$

$$\ln G_{\xi+\delta\xi} = \ln G_\xi - \frac{1}{2}\left(\ln k_{\xi+\delta\xi} - \ln k_\xi\right)$$

$$G_{\xi+\delta\xi} = e^{\ln G_\xi - \frac{1}{2}\left(\ln k_{\xi+\delta\xi} - \ln k_\xi\right)}$$

8.2. Outcome of the shoaling-breaking model.

The shoaling-breaking model examines waves with a period of 8 seconds and a significant wave height, $H = 2.72$ m (See Table 4), propagating over a bottom slope characterized by $\frac{dh}{dx} = -0.02$.

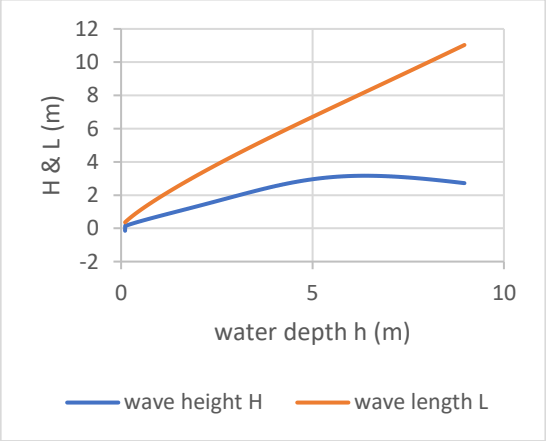


Fig (2) Shoaling-breaking analysis

The calculation employs parameters $\theta = 1.75$ and $\varepsilon = 0.01$. Fig (2) illustrates the outcomes of the shoaling and breaking analysis.

The shoaling-breaking analysis results are depicted in Figure (2), where the breaker height H_b =3.165 m, breaker depth h_b =6.387 m, and the breaker depth index $\frac{H_b}{h_b} = 0.496$. This differs notably from McCowan's (1894) criterion, where $\frac{H_b}{h_b} = 0.78$.

According to Komar and Gaughan (1972), the breaking wave height is given by:

$$H_b = 0.39\ g^{1/5}(T_0 H_0^2)^{2/5}$$

Using $T_0 = 8.0$ sec., $H_0 = 2.72$ m, $g = 9.81$ m/sec^2, $H_b = 3.15$ m. The breaking wave height from the model closely aligns with the Komar and Gaughan (1972) equation.

Next, we will examine the results of the shoaling-breaking model across several wave periods, focusing on the

maximum wave height in each period as detailed in Table (4). The calculations maintain consistent parameters $\theta = 1.75$ and $\varepsilon = 0.01$. The model outcomes are summarized in Table (5).

Table (5) Shoaling breaking outcomes

T (sec)	H_0 (m)	H_b (m)	h_b (m)	$\frac{H_b}{h_b}$	H_{b-KG} (m)
6	1.53	1.781	3.593	0.496	1.772
7	2.082	2.426	4.896	0.496	2.411
8	2.72	3.165	6.387	0.496	3.15
9	3.444	3.995	8.06	0.496	3.988
10	4.252	4.93	9.95	0.496	4.923
11	5.146	5.945	11.996	0.496	5.958
12	6.124	7.081	14.289	0.496	7.091
13	7.186	8.331	16.811	0.496	8.321
14	8.334	9.662	19.499	0.496	9.65
15	9.568	11.081	22.363	0.496	11.079

Based on the results of the shoaling-breaking model, $\frac{H_b}{h_b}$ remains constant across all wave periods, specifically $\frac{H_b}{h_b} = 0.496$. The breaker height H_b closely matches the Komar-Gaughan (1972) breaker height H_{b-KG}, with a minimal difference typically in the second decimal place.

To achieve $\frac{H_b}{h_b}$ closer to McCowan's (1894) criterion, the model is executed using a deep water coefficient $\theta = 1.182$.

Table (6) presents the results of the shoaling-breaking analysis

T (sec)	H_0 (m)	H_b (m)	h_b (m)	$\frac{H_b}{h_b}$	H_{b-KG} (m)
6	1.528	1.779	2.28	0.781	1.77
7	2.08	2.42	3.101	0.78	2.409
8	2.718	3.152	4.038	0.78	3.148
9	3.44	3.988	5.111	0.78	3.984
10	4.246	4.932	6.32	0.78	4.918
11	5.138	5.965	7.645	0.78	5.951
12	6.116	7.085	9.08	0.78	7.083
13	7.178	8.313	10.652	0.78	8.313
14	8.324	9.65	12.368	0.78	9.641
15	9.556	11.073	14.192	0.78	11.068

It shows a reduction in H_0 and H_b with a relatively minor decrease, while there is a significant decrease in breaker depth h_b, resulting $\frac{H_b}{h_b} = 0.78$, aligning with McCowan's criterion.

The initial criterion for determining θ is based on wave number conservation, where $\frac{dk(h+z)}{dx} = 0$, implying $k(h+z) = constant$. This condition is crucial for solving the Laplace equation using separation of variables. For deep water, $\tanh k\left(h+\frac{A}{2}\right) \approx \tanh kh \approx 1.$, leading to $k\left(h+\frac{A}{2}\right) \approx kh = \theta\pi$, where $\tanh\theta\pi \approx 1$. Typically, $\theta \geq 1.75$ satisfies this condition. However, from the shoaling-breaking model results, $k\left(h+\frac{A}{2}\right)$ or $\approx kh$ does not need to be exactly 1. With $\theta = 1.182$, we find $\tanh\theta\pi = 0.988104$, which is slightly less than 1 but still close.

To achieve $\frac{H_b}{h_b} = 0.8$, one could consider $\theta = 1.158$. However, determining the most suitable θ and $\frac{H_b}{h_b}$ values requires additional data, including laboratory and analytical results.

By adhering to McCowan's breaker depth index (1894), the deep water depth is

$$h_0 = \frac{1.182\pi}{k_0} - \frac{A_0}{2}$$

h_0 is deep water depth , A_0 is deep water wave amplitude and k_0 is deep water wave number.

8.2 Refraction-Diffraction Model

The shoaling-breaking analysis discussed focuses on wave transformation along the direction of wave propagation, specifically along the ξ axis. Refraction-diffraction analysis, on the other hand, examines wave transformations within a plane, typically the (x, y) plane. The changes in wave number k and wave amplitude A along the horizontal axis x, as depicted in Figure 1, are related to the variables ξ and x.

$$\frac{\partial k}{\partial x} = \frac{\partial k}{\partial \xi}\cos\alpha$$

$$\frac{\partial A}{\partial x} = \frac{\partial A}{\partial \xi}\cos\alpha$$

With these two equations, the values of $k_{x+\delta x}$ and $A_{x+\delta x}$ can be calculated. By knowing the value of $k_{x+\delta x}$ the value of $G_{x+\delta x}$can be calculated.

$$G_{x+\delta x} = e^{\ln G_x - \frac{1}{2}(\ln k_{x+\delta x} - \ln k_x)}$$

Wave direction at point $x + \delta x$, calculated by Equation,

$$\alpha = \text{atan}\left(\frac{u}{v}\right)$$

$$\frac{\partial \alpha}{\partial x} = \frac{u\frac{\partial v}{\partial x} - v\frac{\partial u}{\partial x}}{u^2 + v^2}$$

In the following section, we present the results of the refraction-diffraction model applied to submerged island bathymetry (Fig. 3). The model considers a wave with a period $T = 8.0$ sec and amplitude $H = 2.4$ m, incident at an $\alpha = 0^0$relative to the horizontal -x. The calculation parameters used are $\theta = 1.182$ and $\varepsilon = 0.01$.

Figures 4 and 5 depict the results of the refraction-diffraction model. These figures demonstrate that the model effectively simulates both refraction-diffraction and shoaling-breaking phenomena.

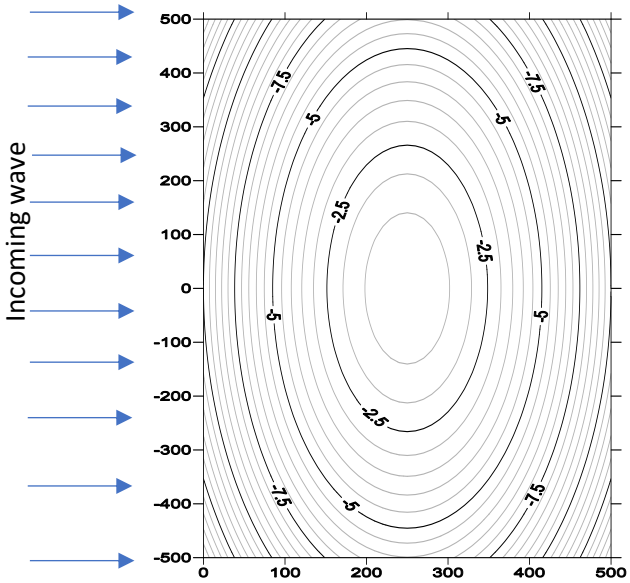


Fig (3) Submerged island bathymetric contour.

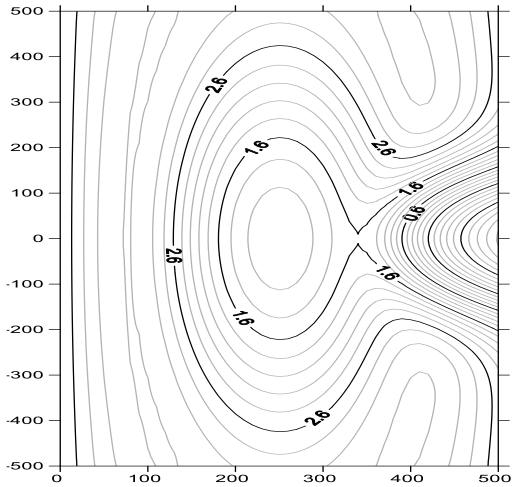


Fig (4) Wave height contour on the submerged island

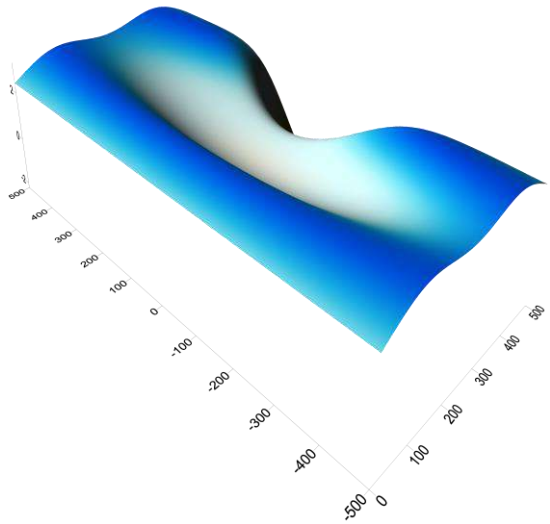


Fig (5) 3-D Wave height, on submerged island

IX. CONCLUSION

Increasing the accuracy of KFSBC integration leads to improvements in both critical wave steepness and breaking wave steepness. Moving from zero-order integration accuracy to second-order accuracy results in significant changes in both critical wave steepness and breaking wave steepness. However, the transition from second-order to third-order accuracy shows minimal changes in these parameters, indicating convergence of integration.

The first conclusion drawn is that the integration method employed is correct and suitable for the analysis. Furthermore, the convergence of integration results suggests that third-order accuracy can be considered sufficient, with the resulting wave amplitude function showing excellent performance.

The critical wave steepness and breaking wave steepness obtained represent final values and can serve as reliable references. Similarly, the resulting breaking wave height is accurate.

Although analytical equations for calculating breaker depth or breaker depth index were not derived in this research, the shoaling model provides estimates of breaker depth. There exists a correlation between deep water depth and breaker depth: greater deep water depth corresponds to greater breaker depth, and vice versa. Certainty about breaker depth implies certainty about deep water depth, and vice versa. Currently, the breaker depth index derived from empirical research by previous investigators serves as an approach for estimating deep water depth based on breaker depth.

REFERENCES

[1] Hutahaean, S. (2024). Breaking Index Study on Weighted Laplace Equation. International Journal of Advance Engineering Research and Science (IJAERS). Vol. 11, Issue

1; Jan, 2024, pp 34-43. Article DOI: https://dx.doi.org/10.22161/ijaers.11.6

[2] Hutahaean, S. (2023). Method for Determining Weighting Coefficients in Weighted Taylor Series Applied to Water Wave Modeling. International Journal of Advance Engineering Research and Science (IJAERS). Vol. 10, Issue 12; Dec, 2023, pp 105-114. Article DOI: https://dx.doi.org/10.22161/ijaers.1012.11.

[3] Hutahaean, S. (2010). Pengerjaaan Metoda Inversi Integral pada Perumusan Persamaan Muka Air Gelombang Air Nonlinear, Jurnal Teknik Sipil Institut Teknologi Bandung, Vol.17 No. 2 (2010). :https://doi.org/10.22161/ijaers.10.5614/jts.2010.17.2.6

[4] Toffoli, A., Babanin, A., Onaroto, M. and Wased, T. (2010). Maximum steepness of oceanic waves : Field and laboratory experiments.Geophysical Research Letters. First published 09 March 2010.https://doi.org/10.1029/2009GL.0441771

[5] Komar, P.D. & Gaughan M.K. (1972). Airy Wave Theory and Breaker Height Prediction, Coastal Engineering Proceedings, 1 (13).

[6] Mc Cowan, J. (1894). On the highest waves of a permanent type, Philosophical Magazine, Edinburgh 38, 5th Series, pp. 351-358.

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-7; Jul, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.117.7

Resource Estimation in a Rock Salt Deposit, Brazil- A case study

José Batista Siqueira

Departmento de Geologia, Universidade Federal do Rio Grande do Norte, Brazil
Email: jose.siqueira@ufrn.br

Received: 22 May 2024,

Receive in revised form: 29 Jun 2024,

Accepted: 07 Jul 2024,

Available online: 14 Jul 2024

***Keywords*— Estimation, Itaúnas member resources, salt deposit.**

***Abstract*—** *This work presents the results of Geological Modeling and resource estimation of a salt deposit, in an eastern margin basin of the Espirito Santo state - Brazil. This work had, among other objectives, the geological evaluation of the evaporite sequence in the onshore part of the basin and delimitation of the area of occurrence of soluble salts. Therefore, the object of study focuses on the Mariricu Formation, which is composed of the fluvial continental Mucuri and evaporitic Itaúnas members. It is the essentially evaporitic unit, in which the rock salt deposit is found. Through modeling, a total resource of the order of* $4.65x10^9t$ *were estimated. Which are grouped into the following categories: measured resources of the order of* $4,38x10^9t$*, with an average of 85,40% NaCl, indicated resources* $0,23x10^9t$*, with an average of 84,63% NaCl and inferred resources* $2,1x10^6t$*, with an average of 76,63% NaCl. These are interesting resources and should be considered.*

I. INTRODUCTION

This work presents the results of Geological Modeling and resource estimation of a salt deposit, in an eastern margin basin of the Espirito Santo state. This work had, among other objectives, the geological evaluation of the evaporite sequence in the onshore part of the basin and delimitation of the area of soluble salts occurrence.

Like other basins on the equatorial and eastern margins of Brazil, the Espirito Santo basin had its origin related to the breakup of the supercontinent Gondwana. In this basin, the rocks are related to the tectonics of the rift and drift phases, which were responsible for its evolution [1] (Matos, R.M.D. 1992).

The geology of the area consist of sediments from the Tertiary to Lower Cretaceous (Andar Rio da Serra). It comprises the Rio Doce, Urucutuca, Barra Nova and Mariricu formations, which unconformably overlap the basement. Only the Rio Doce Formation appears on the surface, locally covered by recent sediments. The others formations only occur in the subsurface.

The Mariricu Formation is composed of the fluvial continental Mucuri and evaporitic Itaúnas members. It is the essentially evaporitic unit, in which the rock salt deposit is found.

In this work, the Leapfrog software was applied to integrate geophysical data from subsurface, geological and geochemical data from wells in the Espirito Santo basin, 3D modeling and obtaining resource estimation.

II. MATERIAL AND METHODS

Preliminary search

The work carried out during the initial phase of research aimed to geologically evaluate the evaporite

sequence of the Espirito Santo basin and delimit the area where soluble salts occur in the onshore part of the basin.

Around 300 km of seismic reflection lines were examined, in addition to gutter samples, cores and profiles, relating to 44 wells.

At this stage, the following works were developed:

1. analysis of electrical, radioactive and acoustic profiles of wells (DLL, GR, LDL, BHC, CNL, CDS and HRT), with the aim of identifying sequences of soluble salts, in places where there was no coring;

2. stratigraphic correlation through the profiles that intercepted the sequence of soluble salts;

3. detailed macroscopic description of the evaporite sequence of the pioneer wells in which coring was carried out;

4. identification of the clastic intercalations in the evaporite sequence, and consequently the determination of the quality of the salt for use through a viable mining method;

5. integration of subsurface and surface data, with the purpose of selecting the most favorable ones for detailed research.

Detail search

At this stage, holes were drilled and cored to identify and characterize the soluble salt zone.

The data obtained at this stage complemented the information obtained in the preliminary research. And seismic reflection was fundamental in making the decision where to locate the holes, instead of following a pre-established drilling network.

In each hole drilled, electrical, radioactive and acoustic profiles were run, which were used for lithological identification and stratigraphic correlations.

All data obtained at this stage were processed and interpreted, and served as support in updating the preliminary research data.

The database was organized and loaded into the Leapfrog software, where the 3D geological modeling was carried out. And from this, a resource estimate was obtained for a portion of this basin, as detailed below.

Geological 3D modeling

The modeling was carried out based on four main steps: import of drilling data (database containing geological and geochemical information of the wells in the study area), creation of the topography of the land surface of the area, creation of intervals (selecting the subdivision of the lithotypes), creating the contact surfaces and generating volumes.

Currently the representation of data made in a simple and direct way is extremely important in all area of geology, where the 3D models obtained stand out. Successor of block diagrams, and can be classified into two types: explicit and implicit modeling [2] (Garcia, L.M. & Gonçalves, I.G. 2021). Explicit modeling is essentially similar to an engineering drawing process. Implicit modeling is algorithmically generated directly from a combination of measured data and user interpretation [3] (Lane, R. 2015). This approach is faster, more flexible and fundamentally better suited for geological modeling. Then, geostatistical methods are used to interpolate the drilling data and thus seek the geological behavior of the solid to be modeled, optimizing the process. Applying this foundation of implicit modeling, the 3D geological model was generated.

III. RESULTS

Data statistics

From the 3D geological model, a statistical analysis of the information from the geochemical results of the well was carried out, to see the distribution of values in the model.

In this step, with the purpose of relating the information contained in the geochemical data of the well with the geology and others properties, the merged table was combined.

According to the statistical analysis, using scatter plot, Q-Q plot and Box plot alternative the data was explored to verify the relationships between NaCl concentration and evaporite grade designed as low, mid and high (Table 01, Figure 01 and 02).

Table 01: Statistics of samples.

Name %	Mean	Std. dv	Coef. var.	Variance	Minimum	Lower Q	Median	Upper Q	Maximum
Br2	0,09	0,65	7,56	0,43	0,00	0,03	0,04	0,05	9,96
Ca	1,45	1,65	1,14	2,72	0,08	0,42	0,72	1,72	7,85
Cl	46,89	17,02	0,36	289,66	0,17	36,73	56,51	58,85	60,01
H2O	1,26	7,05	5,62	49,72	0,01	0,17	0,33	0,57	70,00
K	0,02	0,01	0,40	0,00	0,01	0,02	0,02	0,03	0,06
Mg	0,05	0,10	2,11	0,01	0,01	0,02	0,03	0,04	1,20
Na	30,87	10,48	0,34	109,79	0,02	26,36	36,67	38,10	39,99
R1	15,07	22,53	1,50	507,67	0,02	0,67	1,94	23,09	77,32
SO4	3,78	6,46	1,71	41,69	0,03	0,81	1,42	4,15	58,40

From this verification of the consistency of the data, a careful analysis of the geostatistical parameters was carried out, starting with the search for the appropriate variogram for numerical modeling of the data on the X, Y and Z axes of the search ellipsoid in the estimation salt grade inside the rock salt deposit.

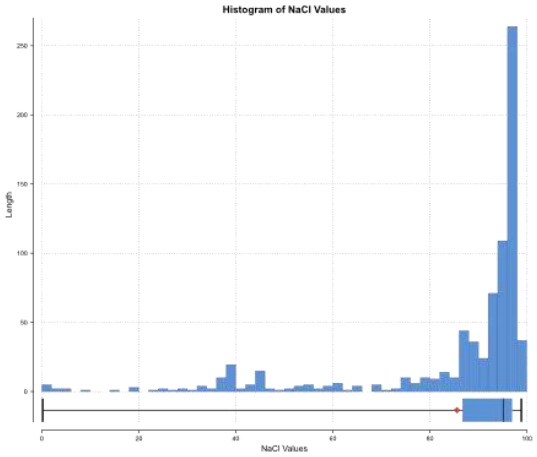


Fig. 01. Histogram of NaCl distribution in the deposit samples.

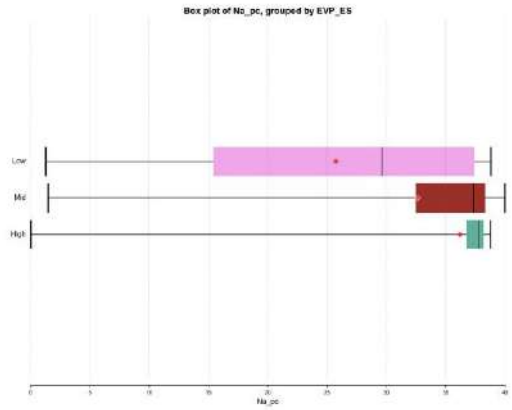


Fig. 02. Box plot Na % and relations with grade levels.

Data geostatistics

Variography

The variography of the data was carried out with the purpose of verifying the spatial behavior of the NaCl variable, aiming to determine directions of greatest, intermediate and least continuity of the samples as well as the range of the variogram (Figures 03 to 05).

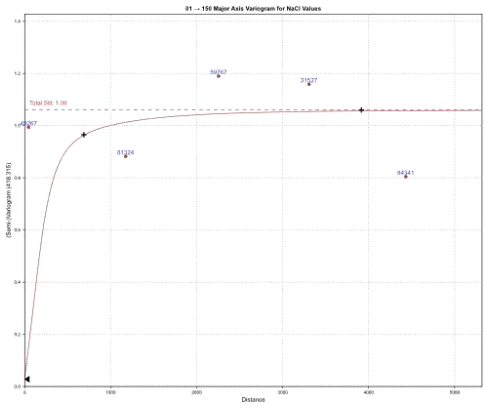


Fig. 03. Major axis variogram

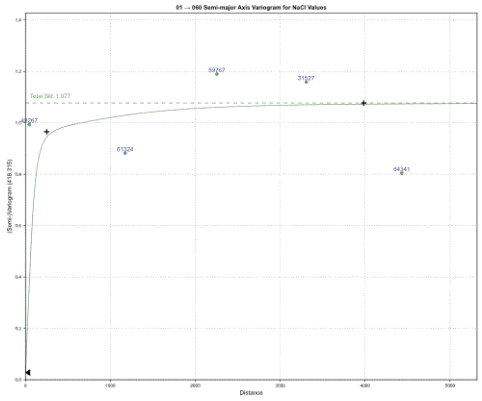


Fig. 04. Intermediate axis variogram

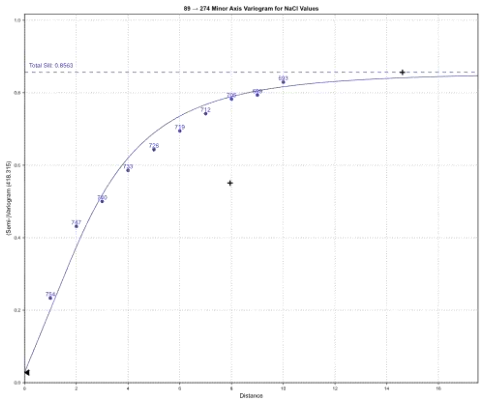


Fig. 05. Minor axis variogram

After the variographic study, the block model was created with the aim of estimating the volumes and contents of the salt deposit light blue color (Figure 06).

When estimating resources, simple and ordinary kriging was used, but simple kriging was chosen.

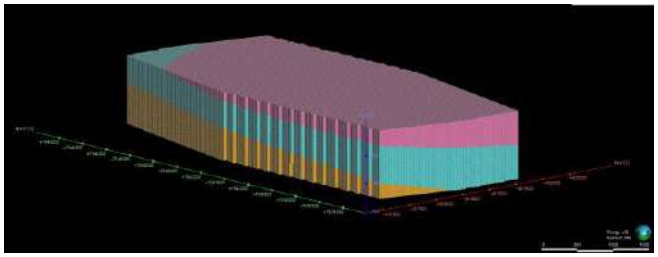


Fig. 06. 3D block model of the salt deposit (light blue).

Volume estimation

After the modeling and deposit estimation stage, total resources of the order of $4.65x10^9$t were estimated. Which are grouped into the following categories: measured resources of the order of $4,38x10^9$t, with an average of 85,40% NaCl, indicated resources $0,23x10^9$t, with an average of 84,63% NaCl and inferred resources $2,1x10^6$t, with an average of 76,63% NaCl (Table 02).

Table 02: Estimated volume of the study area

Resource	Volume	Mass	Mean NaCl%
measured	1.991.937.500	4.382.262.500	85,40
indicated	104.862.500	230.697.500	84,63
inferred	987.500	2.172.500	76,63

IV. CONCLUSION

After the modeling and deposit estimation stage, total resources of the order of $4{,}65x10^9$t were estimated. Which are grouped into the following categories: measured resources $4{,}38x10^9$t, indicated resources $0{,}23x10^9$t and inferred resources $2{,}17x10^6$t.

These are interesting resources and should be considered as carriers of alternative elements to support the energy transition.

ACKNOWLEDGEMENTS

We thank the Federal University of Rio Grande of Norte for institutional support, Seequent/Bentley for granting the academic license of the Leapfrog software and the reviewers of the journal.

REFERENCES

[1] Matos, R.M.D. (1992). The Northeast Brazilian System. Tectonics, 2(4), 766-791.

[2] Garcia, L. M. & Gonçalves, I. G. (2021). Implementação da modelagem implícita na graduação. In: Anais do 13º Salão Internacional de Ensino, Pesquisa e Extensão da UNIPAMPA, 13(1).

[3] Lane, R. (2015). Why Implicit Modelling. In: SEEQUENT/BENTLEY. Available in https://www.seequent.com/why-implicit-modelling. Accessed on: January 2022.

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-7; Jul, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.117.8

Epidemiological Profile of Hospital Morbidity and Mortality from Malignant Neoplasms of the Stomach in the Northern Region of Brazil Between 2011 and 2021

Vando Delgado de Souza Santos[1], Gabrielly Carvalho Leão[1], Rafaela Luiza da Costa Rocha[1], Sebastiana Brandão da Costa[1], Elivanira Bento da Silva Rabêlo Guajajara[1], Joxanti Jotumre Kokaproti[1], Denise Maria Sampaio Guimarães[1], Paola Bitar de Mesquita Abinader[2], Roberta Figueiredo Pamplona[2], Vittória Marques Bigatão[2], Lilian Rose Martins Reis[2], Israel Mariano Rabelo[2], Aline Moreira Moraes[3], Gislaine Mendes Marangon[3], Kassio Renê Gomes[3], Valnilson Dias Reis[4], Alcilene Monteiro Lima[4], Marcos Gabriel Barbosa Castello Branco[4], Eric Santos Carvalho da Silva[4], Rakel de Moraes Pedrosa[5], Brenda Raine Batista Duck de Freitas[1], Igor Carvalho dos Santos[1]

[1]Universidade Federal do Pará, Brasil
[2]Centro Universitário do Pará, Brasil
[3]Universidade de Rio Verde, Brasil
[4]Centro Universitário Metropolitano da Amazônia, Brasil
[5]Faculdade Integrada da Amazônia, Brasil

Received: 25 May 2024,

Receive in revised form: 30 Jun 2024,

Accepted: 07 Jul 2024,

Available online: 18 Jul 2024

Keywords*— *Gastric Neoplasms; Epidemiologia; Public Health.

Palavras-chave*— *Neoplasias Gástricas; Epidemiologia; Saúde Pública.

***Abstract*—** *Stomach cancer is a neoplastic pathology affecting the inner lining cells of this digestive organ, representing a significant public health concern globally due to its mortality and the strain it places on health systems. Various risk factors are associated with this neoplasm, such as age, sex, color/race, diet, among others. In the northern region, stomach cancer is the second most common type of neoplasm among men. Objective: to analyze the epidemiological profile of hospital admissions for stomach cancer in the northern region of Brazil from 2011 to 2021. Methodology: this is a longitudinal epidemiological study based on secondary data from the Department of Informatics of the Unified Health System (DATASUS) regarding the number of hospital admissions, gender, age group, and color/race, as well as the mortality rate from gastric tumors in the northern region of Brazil from 2011 to 2021. Results: during the analyzed period, 13,965 hospital admissions for gastric neoplasms were recorded in the north. The state of Pará recorded the highest numbers in the period, with 5,595 cases, followed by the state of Amazonas. The profile of hospitalized patients was: population over 60 years old, male sex, and mixed race. The mortality rate was 22.13% with the same epidemiological profile as the admissions. Conclusion: the impact of gastric cancer on the northern population is a public health problem that requires the creation and maintenance of public policies for prevention, early diagnosis, and treatment.*

I. INTRODUÇÃO

O termo “câncer” designa um processo patológico cuja ocorrência compreende a proliferação desregrada de novas células, as quais podem se disseminar para locais adjacentes ou longínquos do corpo humano, sendo que a formação cancerosa pode se estabelecer em diversas áreas do organismo e exibir sintomas diversos (RODRIGUES et al, 2020). Sob essa perspectiva, o câncer de estômago é uma patologia neoplásica que acomete as células de revestimento interno desse órgão digestivo, configurando uma enfermidade de grande impacto na saúde pública global por sua mortalidade e desgaste dos sistemas de saúde (ANDAGANA et al, 2023).

Vários fatores de risco estão associados ao desenvolvimento dessa doença complexa e multifacetada. Entre eles, destaca-se a infecção pelo *Helicobacter pylori*, uma bactéria conhecida por causar inflamação crônica no estômago, que pode levar ao desenvolvimento de lesões pré-cancerosas e, eventualmente, ao câncer. Além disso, hábitos alimentares inadequados, como o baixo consumo de vegetais e o alto consumo de alimentos ricos em sal e conservantes, têm sido associados ao aumento do risco de câncer gástrico. O tabagismo e o consumo excessivo de álcool também desempenham um papel importante, assim como a predisposição genética, que pode influenciar a susceptibilidade de um indivíduo ao desenvolvimento da doença (RIBEIRO et al, 2023).

Além disso, acerca das distinções histopatológicas, vale ressaltar que o Adenocarcinoma é o tipo mais comum, correspondendo a mais de 90% dos casos, entretanto, tumores menos comuns como Linfomas, Sarcomas e GIST (Tumor Estromal Gastrointestinal) também podem acometer esse órgão (INSTITUTO NACIONAL DO CÂNCER [INCA], 2022). No tocante ao prognóstico e tratamento da referida patologia, esses aspectos são delimitados com base na localização tumoral, estadiamento do tumor e comprometimento linfonodal (ZILBERSTEIN et al, 2013).

No Brasil, segundo o Instituto Nacional de Câncer (INCA) espera-se mais de 21.000 novos casos de neoplasia gástrica no triênio 2023-2025. Desconsiderando os tumores de pele não melanoma, o câncer de estômago ocupa a quinta posição na lista dos mais incidentes no país, acompanhando a tendência mundial. Variações regionais e entre os sexos são observadas, de modo que ele é o segundo tipo de câncer mais frequente em homens da Região Norte, com 12,55 casos por 100 mil (INSTITUTO NACIONAL DO CÂNCER [INCA], 2023).

Logo, por sua ampla incidência o Câncer de Estômago é uma patologia que necessita de constante investigação epidemiológica para subsidiar o processo de vigilância em saúde, considerando as diversas particularidades e limitações de cada território. No contexto da região norte, as inúmeras vulnerabilidades socioeconômica e as diversas discrepâncias em relação às outras regiões e até mesmo entre os estados integrantes, suscita a necessidade de compreensão dos grupos populacionais mais afetados e o impacto da neoplasia em questão na morbimortalidade regional nos últimos anos.

II. OBJETIVOS

Analisar o perfil epidemiológico da morbimortalidade hospitalar por neoplasias malignas do estômago na região norte do Brasil, entre janeiro de 2014 e dezembro de 2023.

III. METODOLOGIA

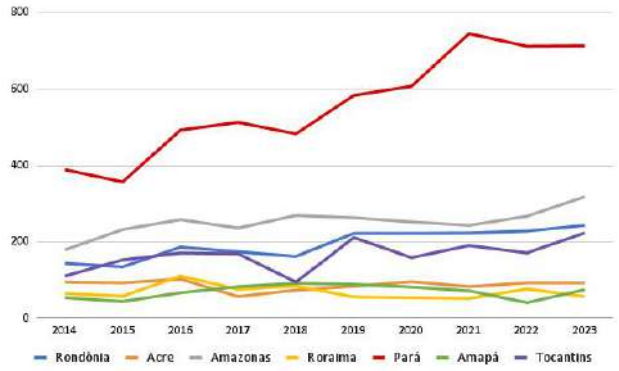
Trata-se de um estudo epidemiológico observacional retrospectivo longitudinal realizado a partir de dados secundários do Departamento de Informática do Sistema Único de Saúde (DATASUS) a respeito do perfil de internações hospitalares por câncer de estômago, foi utilizada as variáveis: ano do processamento, gênero, faixa etária, cor/raça, bem os dias de permanência hospitalar, o número de óbitos e a taxa de mortalidade por tumores gástrico na região norte do Brasil entre janeiro de 2011 a dezembro de 2021.

A faixa etária foi padronizada em 3 grupos: população pediátrica (0 a 19 anos), adulta (20 a 59 anos) e geriátrica (acima de 60 anos), com o intuito de facilitar a apresentação e interpretação dos dados analisados.

IV. RESULTADOS

Durante o período analisado, registrou-se um total de 13.965 internações hospitalares devido a neoplasias malignas no estômago na região norte do Brasil, conforme evidenciado no gráfico 1. O estado do Pará destacou-se com o maior número de casos, totalizando 5.595 internações, seguido pelo estado do Amazonas, com um total de 2.517 casos. Somando-se os registros desses dois estados, obtém-se 58% do total de internações no período. Por outro lado, os estados do Amapá e Acre apresentaram os menores índices de internações por câncer gástrico nos últimos 10 anos, com 699 e 871 internações, respectivamente. No ano de 2023, observou-se o pico de internações por câncer gástrico, totalizando 1.722 casos. Houve estabilidade no número de casos nos estados do Pará e Acre, enquanto houve uma diminuição no estado de Roraima.

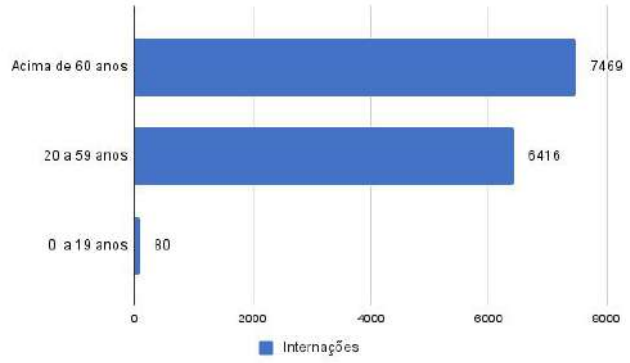
Gráfico 1: Número de internações por câncer de estômago na região norte do Brasil



Fonte: Autores, 2024.

O gráfico/tabela 2 ilustra a distribuição dos casos de internações por câncer gástrico na região norte do Brasil conforme as faixas etárias, sendo a população geriátrica (acima de 60 anos) a mais afetada, representando 53,48% de todos os casos registrados, enquanto a faixa etária pediátrica apresentou menos de 1% dos casos (n=80).

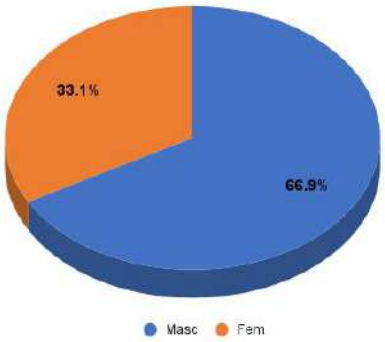
Gráfico 2: Número de Internações por Câncer de Estômago por faixa etária na Região Norte do Brasil (2014-2023)



Fonte: *Autores, 2014.*

O sexo masculino foi o mais atingido em todos os estados da região norte durante o período analisado, com 66,93% dos casos (n=9.347), enquanto o sexo feminino representou 33,06% (n=4.618). (Tabela/gráfico 3)

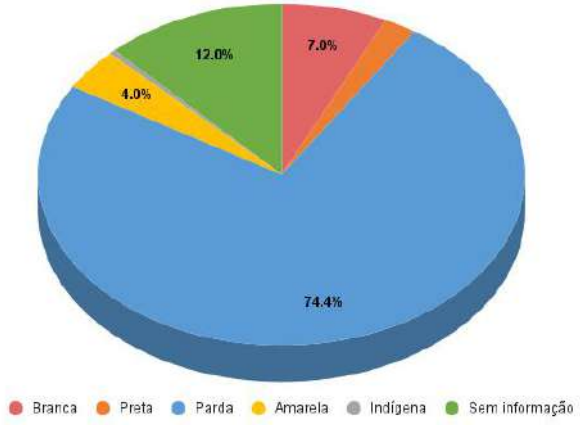
Gráfico 3: Número de Internações por Câncer de Estômago entre os sexos na Região Norte do Brasil (2014-2023)



Fonte: *Autores, 2024.*

Quanto à cor/raça, a população autodeclarada como "parda" correspondeu a 74,42% de todos os casos de internações por câncer gástrico, seguida por pessoas brancas (7%), amarelas (3,95%), pretas (2,14%) e indígenas (0,4%). Não há informações sobre a cor/raça de 1.681 pacientes. (Tabela/gráfico 4)

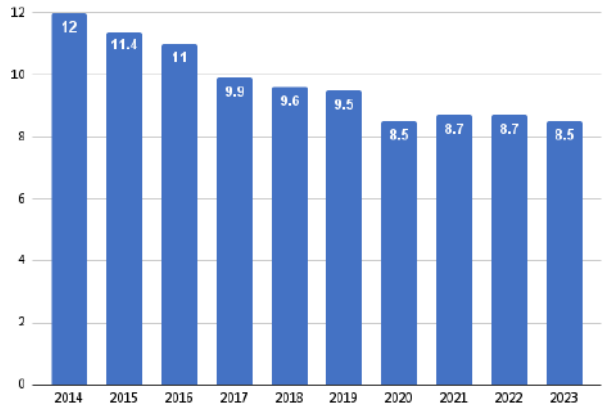
Gráfico 4: Número de Internações por Câncer de Estômago considerando a autodeclaração de cor na Região Norte do Brasil (2014-2023)



Fonte: *Autores, 2024.*

A média de dias de permanência hospitalar foi de 9,6 dias. Três estados se destacaram com períodos de internação acima da média: Acre (10,1 dias), Pará (11,6 dias) e Amapá (12,6 dias). Observou-se também uma diminuição linear de 39,28% nos dias de internação ao longo do período analisado. Em 2014, a média era de 14 dias, enquanto em 2023 reduziu para 8,5 dias.

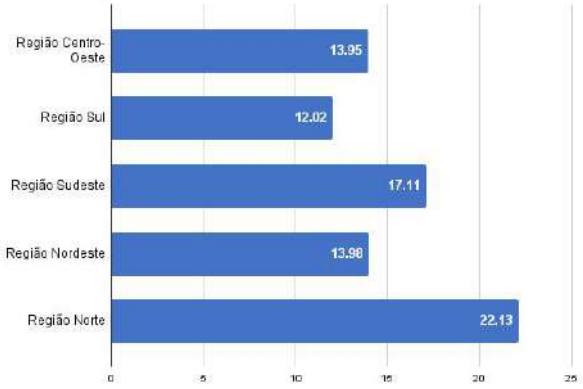
Gráfico 5: Dias de permanência das internações por Câncer de Estômago na Região Norte do Brasil (2014-2023)



Fonte: *Autores, 2024.*

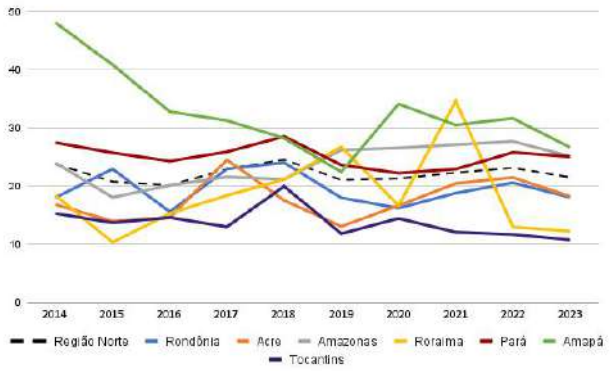
Quanto ao número de óbitos ao longo dos últimos 10 anos, foram registrados 3.090 casos, resultando em uma taxa de mortalidade de 22,13%, valor significativamente superior às outras regiões do Brasil, que registram taxas de 13,98% no nordeste, 17,11% no sudeste, 12,02% no Sul e 13,95% no centro-oeste. Entre os estados da região norte, Amazonas, Pará e Amapá destacam-se por apresentarem taxas de mortalidade acima da média regional e nacional, com valores percentuais de 23,88%, 24,97% e 31,62%, respectivamente.

Gráfico 6: Taxa de mortalidade por Câncer de Estômago nas regiões do Brasil (2014-2023)



Fonte: *Autores, 2024.*

Gráfico 7: Taxa de mortalidade por Câncer de Estômago na Região Norte do Brasil (2014-2023)



Fonte: *Autores, 2024.*

Sendo assim, o perfil epidemiológico dos óbitos segue o mesmo padrão e proporção do número de internações: população autodeclarada parda, faixa etária geriátrica e indivíduos do sexo masculino.

V. DISCUSSÃO

De forma geral, observa-se um comportamento De forma geral, observa-se um comportamento multivariado dos casos de Câncer de Estômago na região na série histórica avaliada. Os cenários de aumento, estabilidade e até queda dos valores entre os estados assemelham-se às tendências apresentadas por outros estudos epidemiológicos na mesma região em períodos precedentes (Silva, 2023; Neves, 2021).

A proeminência da região norte no tocante às neoplasias gástricas exibe provável correlação com particularidades dietéticas regionais, como o amplo consumo de farinha de mandioca e alimentos com muito sal, especialmente peixes, fatores de degradação da mucosa gástrica e aumento da suscetibilidade ao câncer (Martins, Santos e Corrêa, 2021; Gonçalves et al, 2020). A preponderância dos números do Pará e Amazonas alinha-se com os resultados de Neves et al (2021) considerando o período de 2010 a 2019, e expõe a intrínseca correlação com a configuração de demográfica desses estados, de modo que os maiores contingentes populacionais ampliam o quantitativo de pessoas expostas a fatores de risco e passíveis de adoecimento.

Acerca do perfil epidemiológico, o predomínio do sexo masculino e da faixa etária acima de 60 anos acompanha os parametros da epidemiologia geral da doença em questão (Frazão et al, 2021; INCA, 2022), assim como o destaque da etnia parda mostra-se em concordancia com a avaliaçao epidemiológica de Neves et al (2021). A redução

gradativa do número de dias de permanência nas internações contrapõe a tendência crescente observada no estudo de Nascimento et al (2021) realizado no nordeste brasileiro, no qual a média de permanência aumentou no período de 2010 a 2019. É importante distinguir se esse decréscimo sinaliza a lenta aquisição de maiores recursos terapêuticos ou a mais rápida evolução ao óbito.

Por fim, a mortalidade superior à outras regiões pode estar associada a fatores como a dificuldade no acesso aos serviços de saúde, de extrema importância no contexto das regiões interioranas e com menor assistência médica, assim como, ao diagnóstico tardio, aspecto de profunda repercussão do prognóstico, tendo em vista a maior complexidade dos estágios avançados da doença e ao tratamento eficiente e ágil (Souza, 2019).

VI. CONCLUSÃO

O estudo confirma a significativa incidência do câncer de estômago na sociedade, especialmente na população da região norte, o que resulta em despesas com saúde que poderiam ser prevenidas ou adiadas através de intervenções comportamentais, educacionais e sociais. Os dados coletados destacam a importância de compreender o perfil epidemiológico das internações e dos óbitos relacionados ao câncer gástrico na população da região norte. Essa compreensão é essencial para desenvolver estratégias mais eficazes de prevenção, diagnóstico precoce e tratamento da doença. Por meio do mapeamento epidemiológico, é possível elaborar políticas públicas e diretrizes específicas voltadas para melhorar a qualidade de vida e aumentar a sobrevida dos pacientes afetados por essa neoplasia, com o objetivo de reduzir as altas taxas de mortalidade observadas nessa região, buscando equipará-las ou até mesmo diminuí-las em comparação com as taxas de outras regiões do Brasil.

REFERENCES

[1] Rodrigues, G. M., Amaral, S. C. T., Lima, V. G., & Ferreira, K. D. (2020). Prospecto da neoplasia e suas características. *Revista Liberum accessum*, *5*(1), 42-47.

[2] Andagana, V. V. T., Mora, C. S. C., Guacho, M. J. S., & Castillo, E. L. C. (2023). Cáncer gástrico: epidemiología, diagnóstico y tratamiento. *RECIAMUC*, *7*(4), 83-93.

[3] Ribeiro, W. A., Santiago, O. D., de Oliveira, S. L., de Souza, J. L. R., Fassarella, B. P. A., de Almeida, Y. R., ... & de Oliveira Neves, F. G. (2023). CÂNCER DE ESTÔMAGO: FATORES DE RISCO, PREVENÇÃO E TRATAMENTO. *Brazilian Journal of Implantology and Health Sciences*, *5*(5), 1098-1120.

[4] *Câncer de estômago*. (2022). Instituto Nacional de Câncer - INCA. https://www.gov.br/inca/pt-br/assuntos/cancer/tipos/estomago

[5] Zilberstein, B., Malheiros, C., Lourenço, L. G., Kassab, P., Jacob, C. E., Weston, A. C., ... & Gama-Rodrigues, J. (2013). Brazilian consensus in gastric cancer: guidelines for gastric cancer in Brazil. *ABCD. Arquivos Brasileiros de Cirurgia Digestiva (São Paulo)*, *26*, 2-6.

[6] *Ministério da Saúde Instituto Nacional de Câncer José Alencar Gomes da Silva Ministério da Saúde Instituto Nacional de Câncer*. (2022). https://www.inca.gov.br/sites/ufu.sti.inca.local/files//media/document//estimativa-2023.pdf

[7] Souza, M. D. S. R. (2019). Câncer gástrico: um olhar multidisciplinar frente ao diagnóstico precoce. *Revista InterSaúde*, *1*(1), 86-90.

[8] das Neves, I. S., Cruz, M. S. Q. V., de Jesus, D. L., Lima, F. G. F., Nazeba, K. V. J. F. O., & Júnior, M. A. C. M. (2021). Análise epidemiológica dos óbitos por câncer de estômago na região Norte do Brasil. *Research, Society and Development*, *10*(9), e39410917503-e39410917503.

[9] Silva, M. E. M., Pereira, M. S., de Oliveira Alves, J. S., Moreira, J. M., de Souza, C. E. B., Polizelli, P., ... & Bezerra, M. V. (2023). MORTALIDADE PROPORCIONAL POR CÂNCER DE ESTÔMAGO, NA REGIÃO NORTE, ENTRE 2011 E 2021. *REVISTA FOCO*, *16*(9), e3155-e3155.

[10] Gonçalves, F. S., de Melo Sarges, R., Ramos, M. A., José, M., Souza, C., Nemer, C. R. B., & de Oliveira Menezes, R. A. (2020). Perfil clínico epidemiológico do câncer gástrico: revisão integrativa. *PubSaúde*, *3*, a041.

[11] do Nascimento, M. M., Silva, J. M., da Silva Pinheiro, M., Frota, K. D. M. G., RODRIGUES, M. T. P., & MASCARENHAS, M. D. M. (2021). TENDÊNCIA DE INTERNAÇÕES POR CÂNCER GÁSTRICO EM ADULTOS NO NORDESTE BRASILEIRO, 2010-2019.

[12] Frazão, G. A. P., Arraes, G. G. D. M., Oliveira, K. F. P., Alvarez, M. A. M., Barreto, B. P. P., Deprá, J. V. S., & dos Reis Ferreira, T. C. (2021). Perfil epidemiologóico dos casos de câncer gástrico no Brasil de 2010 a 2020. *Revista CPAQV–Centro de Pesquisas Avançadas em Qualidade de Vida*, *13*(1), 2.

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-7; Jul, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.117.9

Fishing Settlements and Sustainability – Task I

Patrícia Diogo[1], Manuel Diogo[2]

[1] CITAD – Research Center of City, Territory, Architecture and Design | Lusíada University, Portugal
Email: patriciadiogo@hotmail.com
[2] CEPESE – Research Center of Population Studies, Economy and Society | University of Oporto, Portugal
Email : mdiogo.phd@gmail.com

Received: 14 May 2024,

Receive in revised form: 15 Jun 2024,

Accepted: 21 Jul 2024,

Available online: 27 Jul 2024

***Keywords*— Architecture, Bibliography, Fishing Settlements, Sustainability, Rural Settlements.**

Abstract *- In the sequence of the research article intitled "Rural Settlements and Smart Green Cities" and our willing to compare this two cases (rural country settlements and rural fishing settlements) we rescued the Leipzig Charter on Sustainable European Cities, since it focuses on the principles of sustainability and urban development framed in the national, regional and local policies of the community countries, following criteria that base high standards of quality of life and functional qualification, on the assumption that they will contribute to attract investment, establish people and knowledge, promote qualified work opportunities and the production of value-added goods. Thus, in the construction of the research project, it is important to look at the relationship between currents of thought that contribute to support concepts related to the issue of sustainability, urban regeneration and the understanding of the morphology of the habitat, exploring bibliographic references of international and national authors associated with the research project.*

I. INTRODUCTION

The analytical approach of fishing settlements and diffuse rural cores uses theoretical readings and methodological reference works, reading case studies and contextualization studies, cartographic and iconographic material, to adjust the construction of the problem, the formulation of hypotheses , the definition of the objectives and the theoretical-methodological analysis grid, to the understanding of the morphological and functional characteristics of the habitat, looking for the members of the research team in this task.

II. TASK I

The development of the Task that origin this research article consisted in the following:

- Define the field of analysis, establishing a diachronic and synchronic reading of the evolution of urban tissues, identifying the main conceptual, structural and symbolic invariants and the modes of evolution of the urban / rural form;

- Understand the morphological and functional characteristics of the habitat, recognizing the types of fishing and rural settlements, the layout and decomposition of the urban fabric, the built mass and the relationship with the activities developed;

- Collect bibliographic, cartographic and iconographic material to support the importance of its rehabilitation in terms of use, historical memory and cultural sense resulting from tradition, while serving as a support to analyze the changes and permanencies that human settlements undergo over time;

- Develop a theoretical study on rural structures considering the level of internationalization of scientific activities to be carried out and the multidisciplinary nature of the theme, deepening the investigation on the different poles of the territorial system - formation, fixation and evolution of morpho-typologies in the formal, spatial

planes and constructive of spaces linked to fishing and agricultural production in the preservation of biodiversity and environmental sustainability in a local, regional, national and international context.

Fig. 1 – World map

Fig. 2 –Portugal map, Matosinhos Map.

III. PLAN AND METHODS

When tracing the path for the research plan and the methodologies to be used in view of the conceptual framework of the Research Project - Sustainability and Urban Regeneration: Fishing Settlements and Diffuse Rural Centers (Case Study, Angeiras, Pampelido Velho, Antela and Avilhoso belonging to the Village de Lavra) - we seek to establish a diachronic reading of the evolution of urban fabrics, in order to perceive, in a synchronous reading, the singularities of its architecture generated in different periods of history, identifying the main conceptual, structural and symbolic invariants established by the intersection between these same readings diachronic and synchronic, to strengthen the development of relational thinking and establish bridges between different times and modes of the evolution of the urban / rural form.

Considering the level of internationalization of the scientific activities to be carried out and the multidisciplinary nature of the theme, the expected results will be the consequence of the following alignment:

1. Deepen the research on the different poles of the territorial system, contemplating their formation, fixation and evolution;

2. Study the morpho-typologies in the formal, spatial and constructive planes;

IV. INTERNATIONAL REFERENCE SCHOOLS

In our research we take as a major reference the British School "Conzeniana" through Michael Robert Gunther Conzen[1] that establishes the historical stratification of the urban landscape and a hierarchy among its constituent elements; Karl Kropf[2], who bases the different levels of the "Urban Structural Units", defining a taxonomy for relatively homogeneous areas as to the type, density and layout of the built and non-built area; Paul Osmond[3], who proposes indicators for the evaluation of urban metabolism and urban sustainability, prioritizing a division into USU (Units of the Urban Form).

Italian School "Muratoriana", with Saverio Muratori[4], focused on the development of urban morphology and the typology of the building; Gianfranco Caniggia[5] aiming at the study of typologies and types using the conceptual separation between space and time; Aldo Rossi[6] with the promotion of the return to traditional types of construction and to historic centers, marking the correspondence between urban morphology and the typology of the building.

French school of "Versailles" heiress to the reflections on the city, in the branches of geography and history, by Antoine-Chrysostome Quatremère de Quincy[7]; from the sociology of Henri Lefebvre[8], Philippe Panerai[9] and Jean-Charles Depaule[10] seeking to consolidate the identification of theoretical models anchored in urban design and the idea that the contemporary does not always represent a complete break with the past.

Deepening scientific knowledge about the morphological and functional characteristics of the cores and places that correspond to the old fishing and rural settlements, means to analyze the organic growth processes of the primitive core to establish a connection between fishing settlements, rural cores, urban and peri urban areas, assuming an instrumental character in the decomposition of the layers that originated the structure of the existing urban form - the genesis of the formation, the road layout, the block, the lot and the building - working with the concepts of mesh type and architectural element in order to provide information related to the structure built and to establish relations with the other elements of the urban system. For this purpose, we consider the general framework of the territory in the local and regional context, the bibliographic collection on morpho-typological analysis and the construction of the respective theoretical framework and the methodological

consolidation and criteria for the analysis and programming of the works.

V. THE TASK DESCRIPTION AND EXPECTATIONS

The analytical approach of fishing settlements and diffuse rural cores uses theoretical readings and methodological reference works, reading case studies and contextualization studies, cartographic and iconographic material, to adjust the construction of the problem, the formulation of hypotheses , the definition of the objectives and the theoretical- methodological analysis grid, to the understanding of the morphological and functional characteristics of the habitat, looking for the members of the research team in this task:

- Define the field of analysis, establishing a diachronic and synchronic reading of the evolution of urban tissues, identifying the main conceptual, structural and symbolic invariants and the modes of evolution of the urban / rural form;

- Understand the morphological and functional characteristics of the habitat, recognizing the types of fishing and rural settlements, the layout and decomposition of the urban fabric, the built mass and the relationship with the activities developed;

- Collect bibliographic, cartographic and iconographic material to support the importance of its rehabilitation in terms of use, historical memory and cultural sense resulting from tradition, while serving as a support to analyze the changes and permanencies that human settlements undergo over time;

- Develop a theoretical study on rural structures considering the level of internationalization of scientific activities to be carried out and the multidisciplinary nature of the theme, deepening the investigation on the different poles of the territorial system - formation, fixation and evolution of morpho-typologies in the formal, spatial planes and constructive of spaces linked to fishing and agricultural production in the preservation of biodiversity and environmental sustainability in a local, regional, national and international context.

VI. CONCLUSION

The relevance of the research project with scientific support centered on sustainability and urban regeneration, to be developed around the fishing settlements located in the territory of the Union of the Parishes of Perafita, Lavra and Santa Cruza do Bispo, in the Municipality of Matosinhos, was understood in the dialectical perspective of an open work, recovering the interaction between formal logic and dialectical logic and between diachronic and synchronous readings that seek to deepen scientific knowledge.

ACKNOWLEDGEMENTS

We are grateful to Matosinhos Mayor House for all the support in our Investigation.

REFERENCES

[1] **Michael Robert Günter Conzen** (Berlin, 21 January 1907 – Newcastle upon Tyne, 4 February 2000) was a geographer, founder of the Anglo-German school of Urban Morphology. Conzen's most influential work is a detailed morphological study of the English market town of Alnwick. His work is noted among others for the micro-scale study of the evolution of plots. https://en.wikipedia.org/wiki/M._R._G._Conzen

[2] Karl Kropf is Director of urban design consultancy Built Form Resource and Senior Lecturer at Oxford Brookes University. He has more than thirty years of experience in the fields of urban design, landscape architecture, architecture and historic conservation, working in the UK, France and US. He combines academic research in urban morphology and practice in urban design with the aim of using insights from one to improve the other. https://www.brookes.ac.uk/profiles/staff/karl-kropf

[3] Paul Osmond has been engaged with sustainable development since the 1980s, both in practice and more recently, through teaching and research. He joined Built Environment in 2010, from his previous position as manager of the UNSW Environment Unit where he was accountable for development and implementation of the University's Environmental Management Plan. Prior to this role, Paul worked in local government, where he was responsible for the delivery of a variety of pioneering environmental management, landscape and urban design programs and projects. His professional background includes experience in consultancy, forestry, freelance journalism and the metal industry. Paul has qualifications in applied science, environmental management and landscape design. His PhD research focused on methods for evaluation and design of sustainable urban form. Paul is the University's representative to the Green Building Council of Australia, and sits on the editorial boards of the journals *Urban Morphology*, *Urban Planning* and *Architecture*. He is a Certified Environmental Practitioner, Registered Environmental Auditor, Green Star Accredited Professional, Fitwel 'Ambassador' and a member of the International Association for Urban Climate and the International Ecological Engineering Society. https://research.unsw.edu.au/people/associate-professor-paul-osmond

[4] Saverio Muratori (Modena, 1910 – Rome, 1973) was an Italian architect, regarded as one of the pioneers

of typomorphological investigations of urban form. Following the completion of his degree in 1933, Muratori wrote articles in the magazine *Architettura*. After World War II, he was involved in housing projects in Rome, and designed public buildings in Bologna, Pisa and Rome. In 1952 he started teaching at the University of Venice, but in 1954 he moved back to Rome where he became Professor of Architectural Composition. https://en.wikipedia.org/wiki/Saverio_Muratori

[5] Gianfranco Caniggia is a pupil of Saverio Muratori. He interprets his teachings with an accentuated attention to the built environment and the reconstruction of the events that marked it, which distinguishes all his interventions in historic centers, starting from the first experimentation carried out in Como (1963) , and in the subsequent works for the recovery of the historic centers of Isernia, Florence, Naples and Benevento. He took part in important competitions and took care of various projects, including those of housing in via Trinità dei Pellegrini in Rome, in collaboration with his father Emanuele (1957), the civic hospital of Isola del Liri (1960-1963), the headquarters of the municipal and judicial offices in Sora (1962), the Palace of Justice in Teramo (1968-1981), various restoration works carried out in Como: the restoration of Borgo Sant'Agostino (1971), Palazzo Volpi (1970) and of the Giovio and Olginati palace (1972). Since 1971 he has continuously held various teaching positions at various universities: Reggio Calabria, Florence, Genoa, Rome; he was also commissioner at the Venice Architecture Biennale. https://journal.urbanform.org/index.php/jum/article/view/4278

[6] Aldo Rossi was known for his use of pure shapes: cubes, spheres, cones, etc. His main books were: A Arquitetura da Cidade and Autobiografia Científica. The latter was written practically inside a hospital, where he spent several months, after suffering an accident. To refer to a type of construction, Rossi used the expression genius loci, mentioned in The Architecture of the City, regarding Roman constructions. The ancient Romans understood that a building should only be built if the place designated for it was under the protection of the genius loci - the divinity or spirit of the place. In 1990 he became the first Italian to be awarded the Pritzker Lifetime Achievement Prize. https://pt.wikipedia.org/wiki/Aldo_Rossi

[7] Antoine-Chrysostome Quatremère de Quincy studied at the Louis-le-Grand college, and distinguished himself there above all by a keen taste for the arts. Intended for the bar, he preferred to devote himself from his youth to in-depth research on architecture and sculpture. Then he went to Rome in 1776, visited Italy, stayed for some time in Naples, and during this trip collected elements which he used in the writing of his Dictionary of Architecture, the first volume of which did not appear until 1788. Linked to the Italian Antonio Canova, the French Percier, Fontaine, Clérisseau and the statuary Pierre Julien, he was laureate, in 1785, of the Academy of Inscriptions and Belles-Lettres for his memoir on this question: “What was the state of architecture among the Egyptians, and what did the Greeks borrow from it? ". This success prompted Charles-Joseph Panckoucke to entrust him with the writing of the Architecture volume of the Encyclopédie Méthodique, which appeared from 1795 to 1825. He had also acquired a solid reputation as an archaeologist. When the Revolution broke out, he adopted its ideas very moderately. Member of the Assembly of Representatives of the Paris Commune, he delivered a speech there on April 2, 1790 in favor of the freedom of the theaters. On July 2, 1791, he was proposed for the post of governor of the Dauphin, a proposal which was not followed up, and, on September 21, 1791, was elected deputy of the department of Paris in the Legislative Assembly. Sitting with the royalists, he defended the constitutional monarchy. He decreed on May 12, 1792, despite strong opposition from the left, that a festival (Fête de la loi) would be celebrated to honor the memory of Jacques Guillaume Simonneau, mayor of Étampes, who died in the exercise of his functions , spoke in favor of the ministers Bertrand de Molleville, Duport-Dutertre and Terrier de Montciel, and opposed on July 10 the permanence of the sections as well as the declaration of the homeland in danger, saying that it was there “a means to achieve a new revolution”. He also intervened in artistic questions, presented observations on the honors of the Pantheon, and supported the claims of artists on the distribution of prizes, following the Louvre exhibition. His attitude, favorable to the royalists, made him unpopular in the final stages of the session. Thus, on August 8, 1792, he complained of having been seriously insulted by the crowd at the end of the session, where he warmly defended La Fayette, threatened with a decree of accusation. He was imprisoned in 1793, during the Terror for his opposition to the Jacobin Club, then released following 9 Thermidor. Full of zeal for the counter-revolution, he became president of the royalist section of Fontaine-de-Grenelle, and took an active part in the preparations for the royalist insurrection of 13 Vendémiaire year IV. For this reason, the military commission, sitting at the Théâtre-Français, sentenced him to death in absentia, as well as the Count of Vaublanc. But, six months later, he reappeared and was acquitted by a jury which declared that there had been no rebellion in Vendémiaire. Elected on 22 Germinal Year V (April 11, 1797) deputy for the Seine to the Council of Five Hundred, he showed himself more ardent than ever for the royalist cause, fought republican institutions, and was included on the proscription lists with the party Clichyen after the coup d'état of 18 Fructidor Year V. He managed to hide, and was recalled after the coup d'état of 18 Brumaire by the consular government which named him secretary general of the general council of the Seine on March 20 1800. He entered the Institute in 1804, and eagerly joined the royal government in 1814. The same year he was appointed royal censor, a position from which he immediately resigned to remain faithful to his opinions of 1790 on the freedom of the theaters, and, in January 1815, intendant of the arts and civil monuments. He received the officer's cross of the Legion of Honor and the cord of Saint-Michel, and occupied from 1816 to 1839 the position of perpetual secretary of the Academy of Fine Arts. In 1818, he was appointed professor

of archeology in the antiques cabinet of the national library. From 1820, he was part of the commission of subscribers for the acquisition of the Château and Domaine de Chambord which was offered to Henri V, grandson of Charles X1. He was again elected, on November 13, 1820, deputy for the Seine to the grand college with 1090 votes out of 1846 voters. He then sat in the center and voted until 1822 with the moderate royalists. https://fr.wikipedia.org/wiki/Antoine_Chrysostome_Quatremère_de_Quincy

[8] Henri Lefebvre coined the term "Right to the city" with which he argued that the population should have access to urban life and which was developed in the book of the same name published in 1968 in French: “Le droit à la ville”. In his books on urban space, such as Right to the City (1968) and The Urban Revolution, in (1970), in which he analyzes the influence of the capitalist economic system on urban space, based on the need for industrial power to "shape" the city according to its interests, but without excluding the influence of other social agents. Henri Lefebvre's work is quite extensive (he wrote more than 70 books), covering analyzes of Marxism in the 20th century in the light of Marx's own texts, and maintaining an intense debate with great philosophers of the time, such as Sartre. He was opposed to the '"empiriocriticist"' Marxists who, according to him, immobilized theory, taking discourse as absolute and replacing experience (lived) with knowledge (conceived). He criticized the Althusserians for erasing the action of subjects in the communication process. According to him, important factors such as the experience of the recipients, the "decoding through everyday life", the mediations and the places of the subjects were forgotten. His debates on Marxism led him to separate Marx's texts from the texts produced about Marx. According to Lefebvre, many Marxists killed dialectics, halting the historical movement towards consolidation of the State and pessimism. In his studies, which were very optimistic, he refused to create theoretical models and establish development programs (see The Urban Revolution). His theory does not have fixed contours, because, along the lines of Nietzsche's writing, Lefebvre's language has something poetic, in a clear attempt to rediscover the totality of the social, made possible by the work, as opposed to the product (fragmented real-fiction of reality), the result of alienated labor. In Brazil, the philosopher's publications are rare. There are around 1/3 of his works in Portuguese - largely from before the 1970s. From the 2000s onwards, the following were published in Brazil: 'The Urban Revolution, Space and Politics and O Vale de Campan'. However, one of his most important works, The State (in four volumes) was not translated into Portuguese. In 2020, the work Lenin's thought was published by Lavrapalavra Editorial. An important study that clearly demonstrates the breadth and density of this philosopher's work is the book organized by José de Souza Martins: Henri Lefebvre and the return to dialectics. Philosopher and sociologist, his studies also contributed to the development of sociology and geography. In sociology, the production of the regressive-progressive method, used by Sartre in Critique of Dialectic Reason, stands out. His contribution to geography was more profound, as the entire current theory of this discipline is due to the thesis that space is social, that is, it is socially produced. Its theoretical triad: lived - perceived - conceived, made possible the studies of David Harvey and Milton Santos, great names in contemporary geography. https://pt.wikipedia.org/wiki/Henri_Lefebvre

[9] Philippe Panerai (1940-2023) graduated in Architecture in 1967 from the École Nationale Supérieure des Beaux-Arts in Paris, and in Urban Planning in 1969, from the Institut d'Urbanisme in Paris. His academic career as a teacher was developed, especially, at the 'École Nationale Supérieure d'Architecture de Versailles, where he founded the research laboratory ADROS-UP3, later LADRHAUS. From the year 2000 he directed, for many years, the Ecole Nationale Supérieure d'Architecture Paris-Malaquais. He worked on different architecture and urban planning projects related to the transformation of the relationship between the city and the rural environment, the integration of infrastructure in cities and urban mutations. In 1999 he won the Grand Prix for Urban Planning (Grand Prix de l'Urbanisme) awarded by the Ministère de la Cohésion des Territoires of France, and in 1989 he became a member of the Académie d'Architecture. He published important books in the area of urbanism, some translated into Portuguese and very present in the bibliography of undergraduate and postgraduate courses in Brazil – such as the books Formas Urbanas, a Dissolução da Quadra (Formes Urbaines, de l'Ilot à la Barre , 1977) and Urban Analysis (Analyse Urbaine, 1999). Panerai was very linked to Brazil – and was a particularly important reference for the PPG-AU UFBA, especially for the disciplines, research, theses and dissertations linked to the History of the City and Urbanism line. K. Elissa, “Title of paper if known,” unpublished. https://es.wikipedia.org/wiki/Philippe_Panerai

[10] Born in Toulon in 1945, lives in Paris. Jean-Charles Depaule taught at the Versailles School of Architecture before continuing his research in urban anthropology on the Arab East at the CNRS (Cairo, Aix-en-Provence, Ivry-sur-Seine). Author of several collections of poetry, he publishes, in addition to his texts, translations (from English and Arabic) and critical essays. He was interested in the formal questions of the composition of the sestina and the writing of the decasyllable as well as the problems of translation. Member of the editorial board of ‘Gradhiva’, he was editorial manager of social science collections. Was part of the editorial boards of the magazines 'Action Poétique', 'Impressions du Sud' and 'If'. Co-founder, with Jérôme Saint-Loubert Bié and Susanna Shannon, of 'Irrégulomadaire'. He regularly contributes to the 'Cahier critique de poetry'. https://www.m-e-l.fr/jean-charles-depaule,ec,685

International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-11, Issue-7; Jul, 2024
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.117.10

Snow Depth Measurement using GNSS-R Techniques: A Review

Arvindd Kshetrimayum, Hari Shanker Srivastava, Ashutosh Bhardwaj, Vaibhav Garg, Gugulothu Srilatha

Indian Institute of Remote Sensing, Dehradun, India
arvindd4gis@gmail.com, hari.isro@gmail.com, ashutosh@iirs.gov.in, vaibhav@iirs.gov.in, iirs.srilatha@gmail.com

Received: 16 May 2024,

Receive in revised form: 17 Jun 2024,

Accepted: 23 Jul 2024,

Available online: 29 Jul 2024

***Keywords*— GNSS-R; Snow depth; Signal-to-Noise Ratio (SNR); carrier phase pseudorange**

***Abstract*—** *Snow is a widespread atmospheric constituent on Earth, as well as one of the cryosphere's most important seasonal and inter-seasonal fluctuations. Estimating the amount of snow in hilly areas is essential for a variety of socioeconomic endeavours and environmental research. Traditional methods for monitoring snow depth include accessibility, expense, and coverage limits, especially in isolated and difficult terrain. Global Navigation Satellite System-Reflectometry (GNSS-R) technology has emerged as a promising tool for remote sensing applications that include snow depth estimation. This review study synthesises and evaluates current literature on the use of GNSS-R technology for snow depth retrieval, concentrating on its potential and constraints in various mountainous places around the world. The paper includes a detailed explanation of GNSS-R working principles and receiver's advancement, snow depth retrieval methods using both traditional and remote sensing methods like active microwave, passive microwave, GNSS-R integrating with machine learning and deep learning models to develop a snow depth assessment in diverse geographical contexts. GNSS-R technology aids in snow depth retrieval through Signal-to-Noise Ratio (SNR) and carrier phase pseudorange methods, with optimal choice based on application requirements, accuracy, environmental conditions, resources, and complexity-precision trade-offs. The review study aims to provide a comprehensive understanding of the advances in GNSS-R-based snow depth estimation, as well as insights and guidance for future advancements in this field, particularly in addressing the complexities of snow depth estimation in diverse terrains such as those found in India..*

I. INTRODUCTION

Snow is one of the most extensively dispersed atmospheric constituents on Earth, as well as one of the cryosphere's most significant seasonal and inter-seasonal fluctuations. It is the principal source of water in many parts of the planet. It is vital to global climate variability and hydrological cycles. The amount of snow that falls varies. Snowfall is heavier at higher elevations, and snowpack varies greatly over the landscape. Snow, once on the ground, can be transported by wind, avalanches, and sloughing. As a consequence, high-precision and quick gathering of snow depth data benefits not only human safety, snow disaster avoidance, and hydrological research progress but also monitoring changes in the natural environment. The most essential measure for hydrological analysis is snow-water equivalence (SWE). SWE represents the volume of water potentially available for discharge. Forecasting the rate of

snowmelt and evaluating the water content of the snowpack is essential for managing water supply and flood control systems. These variables are critical for forecasting the timing and amount of water released from snowpack, which can help avert flooding and provide a consistent water supply.

Snow depth has historically been monitored through manual measurement or with certain sophisticated sensors on the ground [1]. These approaches give precise assessments of snow depth, but they are either costly or have a limited temporal and geographical resolution. Snow cover area (SCA), snow depth, and SWE are all estimated using satellite and aerial remote sensing systems. In general, satellite estimates provide better consistency in time and distance than ground-based measures. SCA at a medium resolution may be obtained using optical data [2], [3]. Cloud cover, on the other hand, makes measuring snow depth more difficult. Large-scale, very accurate snow depth measurements have been transformed by ground-based LiDAR technology. These technologies, however, are still costly, hardly automated, and frequently need bare-earth terrain elevation measurements [4]. Active and passive microwave methods are also employed to estimate snow depth and SWE. Microwave retrieval is difficult in several ways. When compared to snow fluctuations, passive approaches have a significantly big geographical footprint. Both methods are affected by uncertainties in snow size distribution and upper and lower snow characteristics [5].

Remote sensing technologies have not consistently generated accurate estimations of snow depth or SWE across time. This has led to a growing demand for technology capable of not only accurately retrieving snow depth with higher temporal resolution but also covering larger geographical extents. Reflected GNSS signals have been claimed to offer useful information on the composition of the land surface during the last decade, including snow depth, lake ice thickness, soil moisture content, electrical characteristics of the ground, and sea ice conditions. Jacobson was among the first to propose the use of GPS L1 frequencies for measuring dry snow density [6]. In addition, Larson worked on estimating dry snow density using a GPS multipath signal, suggesting that snow depth can also be estimated using SNR time series, which includes direct as well as reflected signal elements [7]. In the past few years, GNSS reflectometry, a novel approach based on GNSS-reflected signals, has been developed to assess physical and geometric characteristics around the antenna [7], [8]. Using current GNSS station networks and sampling across a 1000 m2 region surrounding the antenna, this strategy may give continuous snow depth monitoring in a global reference frame [9], [10]. The proliferation of GNSS Continuously Operating Reference Stations (CORS) worldwide, particularly in snow regions, has further facilitated the application of GNSS data for snow depth determination [11]. Consequently, GNSS-R-based snow depth calculation offers an economical option capable of achieving high temporal and spatial resolution.

The paper is further organized as follows: in Section 2, a detailed explanation of GNSS-R working principles and receiver's advancement. In section 3, snow depth retrieval methods have been discussed both traditional and remote sensing methods. In section 4, the study is concluded with the potential and challenges of utilizing GNSS-R technology for snow depth retrieval in the diverse and challenging terrains of India.

II. GNSS-R

Global Navigation Satellite Systems (GNSS) is a network of satellites that provides positioning, navigation, and timing information (PNT) to users worldwide. The system works by continuously transmitting signals from multiple satellites to receivers on Earth. The fundamental principle underlying GNSS operation is trilateration. The best-known GNSS is the Global Positioning System (GPS) operated by the United States, but there are also other systems like GLONASS (Russia), Galileo (European Union), BeiDou (China), QZSS (Japan) and NavIC (India), each offering its unique set of capabilities and coverage. In addition to its core PNT function, GNSS radio occultation may detect the atmosphere and compute tropospheric relative humility as well as ionospheric total electron content. [12]. GNSS reflectometry (GNSS-R) is the alternative type, which encompasses GNSS interferometric reflectometry (GNSS-IR) that leverages signals reflected off the Earth's surface to gather valuable environmental data. Unlike traditional GNSS receivers, which rely solely on direct signals from satellites, GNSS-R receivers analyze signals that bounce off various surfaces, such as land, water bodies, and ice, providing insights into surface characteristics and environmental parameters. The reflected signals carry signatures indicative of surface characteristics, such as roughness, moisture content, and vegetation density, among others. By analyzing these signatures, GNSS-R can provide insights into a wide range of environmental parameters, including soil moisture, sea surface height, snow depth, and vegetation health. Land and sea surface information can be inferred using GNSS-R [13], [14], [15] . Additionally, snow depth data and sea ice parameters have been computed using GNSS-R [16], [17], [18]. The Global Navigation Satellite System-Reflectometry (GNSS-R) idea was introduced by Hall and Cordey [19], and since then, it has been effectively used for a variety of remote sensing applications. It is also one of the main areas of research for

remote sensing. Despite multipath signals often being suppressed in high-accuracy applications due to their potential for introducing inaccuracies [20]. Nonetheless, multipath signals carry an abundance of geophysical data that is valuable for GNSS-R systems. The GNSS antenna receives data on the signal-to-noise ratio (SNR), which is crucial for GNSS-R technology as well as signal intensity caused by direct and reflected signal interference. Martin Neira discovered the signal interference occurrence among the direct and reflected signals [21]. SNR power spectrum maps were proposed by Bilich and Larson for multipath evaluation. SNR is therefore mapped with a multipath scenario [22].

2.1 Working and Principles

GNSS-R operates as a bistatic radar technique utilizing signals from GNSS satellites like GPS, GLONASS, Galileo, BeiDou, QZSS, or NavIC to reflect off various surfaces. This technique is grounded in radar and remote sensing principles. GNSS-R relies on the reflection of GNSS signals from diverse surfaces, including the Earth's surface, oceans, ice, buildings, and vegetation. When a GNSS signal comes into contact with a reflecting surface, a portion of the signal is scattered back into space. These reflected signals change phase, amplitude, and polarization as they interact with different surface types and conditions. When a reflected signal returns to a GNSS-R receiver, it contains information about the signal propagation delay (the amount of time it takes for the signal to travel to the reflecting surface and back) and the Doppler shift (the frequency change resulting from the motion of the reflecting surface), forming a Delay-Doppler map. The power gathered by a GNSS receiver following the GNSS signal's scattering throughout the surface of the Earth is referred to as a Delay-Doppler map [23], [24]. The sensing footprint for a specific SNR trace is defined as the First Fresnel zones at various elevation angles. As the satellite elevation angle (e) changes, the First Fresnel zone fluctuates accordingly. Precisely, as the satellite ascends, the Fresnel zone moves nearer to the antenna and diminishes in size. [25].

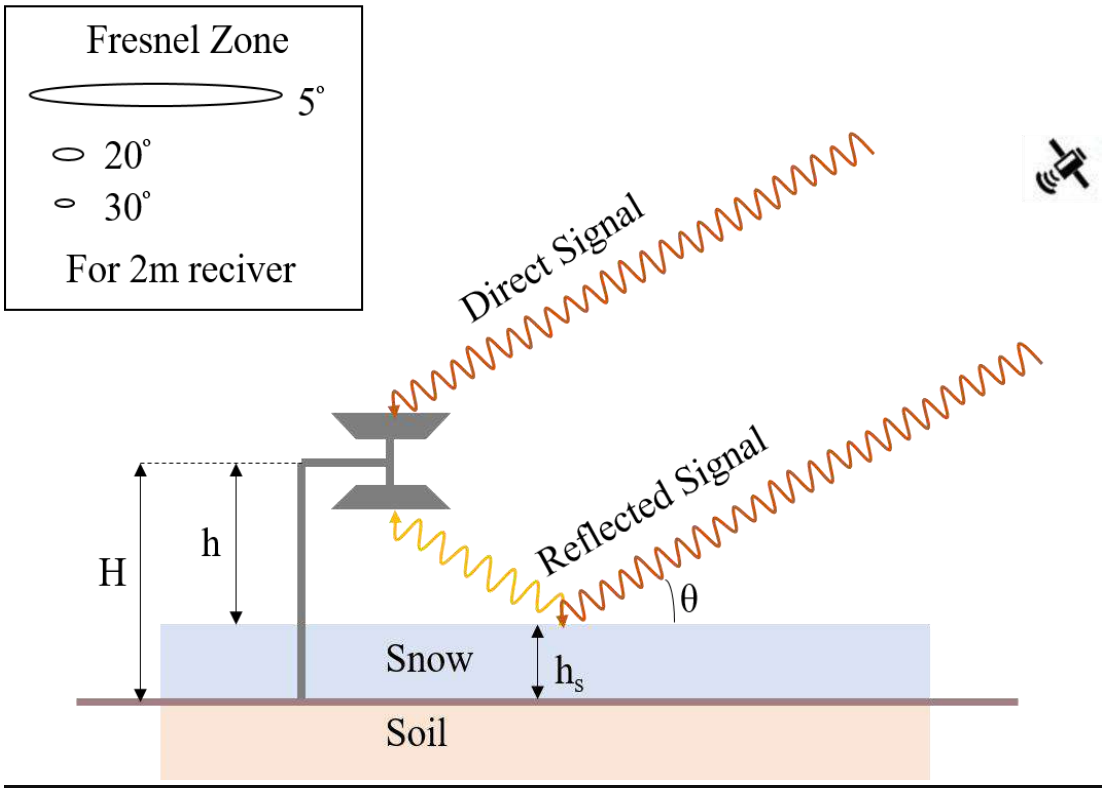


Fig.1. Working of GNSS-R.

After a reflection polarisation change, GNSS signals undergo a polarization change: direct signals become Right Hand Circularly Polarized (RHCP), while reflected signals become Left Hand Circularly Polarized (LHCP), as illustrated in Figure 1 [26]. Interference between direct and reflected signals on SNR data indicates signal quality. GNSS user antennas have dual polarisation, RHCP for direct signals, and LHCP for reflected signals. Each polarization is associated with its unique radiation pattern, designed to optimize the reception of RHCP signals (high gain) for omnidirectional acquisition while minimizing antenna sensitivity to LHCP signals (low gain).

In general, the gain for RHCP signals tends to be greater than that for LHCP signals for elevation angles greater than about 10-15 degrees. These disparities, however, reduce at lower angles, where radiation patterns have been optimized to suppress signals at extremely small or negative angles. SNR values are affected by satellite elevation angle in addition to interference. The SNR signal comprises a high amplitude, low-frequency component in SNR direct (SNRD) and a low amplitude, high-frequency component in SNR reflected (SNRR). The design of radiation patterns results in a lower amplitude and clearer appearance of higher frequency signals at low elevation angles. The amplitude of the SNRR is

lower than the noise of the observations at high elevation angles, whereas the multipath effect is visible at low satellite elevations.

2.2 Receivers and their advancement

2.2.1 Ground-based receivers

The GNSS-IR technology was distinctly developed in the early 2010s. Initially, geodetic GNSS receivers were employed for applications such as assessing vegetation characteristics and estimating soil moisture [27], [28]. GNSS-IR, however, uses commercial geodetic receivers, hence the majority of the advancements have come from fresh techniques rather than new receivers or technology [29]. Nevertheless, it is important to note that the GNSS-IR paradigm has led to the development of new applications. The GNSS-IR concept was used to monitor sea level [30], multi-frequency observations alongside a four-layer scattering model were also used to retrieve sea ice and snow thicknesses [31], and lake ice thickness was first retrieved [32]. An innovative method of technology that creates an image resembling synthetic aperture radar (SAR) by utilizing the dispersed GNSS-R signals [33]. This system relies on ground-based GNSS-R receivers, which accurately calculate and compensate for the Doppler shift and delay of a satellite's reflected signal as it passes across the sky. An image of a large area can be created by performing a processing procedure similar to SAR [34].

2.2.2 Airborne receivers

Airborne GNSS-R receivers have been essential in showcasing new techniques and technologies, with Katzberg and Garrison acquiring the first signal from an airborne platform [35]. Before the CYGNSS constellation was put into operation, there were a lot more GNSS-R sensors in airborne operations. The instruments in this section include those that have seen major technological advancements recently. The GOLD-R instrument, developed by ICE-CSIC/IEEC, UPC, and ESA, was a ground-breaking device that could operate in the GPS L1 band at different polarizations. It has a single-LHCP patch antenna that can sample up to 20 MHz bandwidth and can function in various modes by taking samples of both direct and reflected signals [36], [37]. Another noteworthy instrument is the Global Navigation Satellite System Reflectometry Instrument (GLORI), designed in 2015, which conducts polarimetric measurements using a dual-polarization RHCP/LHCP antenna system [38], [39]. The GLORI has demonstrated the ability to differentiate between RHCP and LHCP signals, making it useful for future spaceborne missions like HydroGNSS [39]. The Microwave Interferometric Reflectometer (MIR), developed between 2015 and 2018, is the initial GNSS-R sensor designed to provide integrated GNSS L1 and L5 readings [40]. According to Ruf et al. [41], the forthcoming generation of GNSS-R equipment can operate in the L1/L5 bands in the GPS and Galileo constellations and was created for airborne platforms. It was implemented by Air New Zealand in the middle of 2021 for continuous operation in domestic aircraft, combining features from the GLORI and MIR instruments [42]. Research centres are developing UAV-based GNSS-R receivers for Earth observation with lower cost and higher resolution, demonstrating the potential of incorporating these receivers into commercial aircraft [43].

2.2.3 Spaceborne receivers

The initial capture of a spaceborne GNSS-R signal occurred in 2002 during a Space Shuttle radar imager calibration routine. Subsequently, the UK Disaster Monitoring Constellation-1 mission launched the first GNSS-R receiver into space to validate its potential for ocean study [44]. NASA's Cyclone GNSS (CYGNSS) mission utilized a Delay-Doppler map imager (DDMI) receiver, covering mid-latitudes to showcase the potential of microsatellite constellations with moderate costs for Earth observation [45]. The UK-TDS-1 mission, equipped with an enhanced SSTL GNSS-R receiver (SGR-ReSi) using a zoom transform correlator correlation approach, collected data across ocean, land, and ice regions [46]. In 2019, the China Aerospace Science and Technology Corporation (CASC) launched the BuFeng-1 A/B constellation, mirroring the design of the SSTL SGR-ReSi and the CYGNSS DDMI instruments [47]. Additionally, the China Meteorological Administration (CMA) deployed the FY-3E mission in 2021, offering near-real-time data in a polar orbit with a 3-hour latency [48]. The NanoSat-Lab of the Universitat Politècnica de Catalunya (UPC) made contributions to the creation of spaceborne GNSS-R instruments. Launched in 2016, 3Cat-2 was the first CubeSats mission to introduce the dual-band polarimetric GNSS-R instrument. However, data recovery problems were discovered due to a failure in the satellite bus [49]. With the help of software-defined radio technology, UPC NanoSat-Lab oversaw the 2020

FSSCat mission of ESA, combining an L-band radiometer with a GNSS-R receiver [50], [51]. Spire Global Inc., renowned for CubeSat GNSS radio occultation (GNSS-RO), deployed multiple CubeSats for global GNSS-R measurements [52]. The upcoming HydroGNSS mission will feature SSTL's latest SGR-ReSi variant, enabling multi-constellation, multi-polarization, and multiband GNSS-R measurements [53]. Other space mission proposals, including iGNSS-R receivers, have been developed but have never been implemented or launched [54], [55].

III. SNOW DEPTH RETRIEVAL

3.1 Traditional Snow Depth Retrieval Methods

Traditional snow depth estimation methods rely heavily on field-based techniques. A key strategy is field surveys, which involve human examinations using probing equipment or snow stakes put at several sites throughout snow-covered landscapes. These surveys provide direct and exact depth readings, capturing regional snow accumulation fluctuations. Snow pits, which require physical excavation to examine snowpack qualities such as layering, density, and depth, complement this technique by offering an in-depth awareness of the snowpack's properties at specific spots [56]. Furthermore, snow depth probing technologies, such as inserting snow probes or tubes into the snow until they reach the ground, allow for quick and direct depth assessments [57]. Snow courses, which are predefined routes with specific measurement stations, serve as standardized places for periodic measurements, assisting in monitoring changes in snow depth over time, especially for water resource management purposes. Furthermore, in avalanche-prone areas, the construction of avalanche poles or snow stakes allows for constant monitoring and tracking of snow accumulation and stability changes [58]. While these classic field-based procedures require labour-intensive manual efforts and have limited coverage, they remain critical for providing precise and thorough point-specific snow depth readings across a wide range of terrains.

3.2 Snow Depth Retrieval Using Remote Sensing Applications

3.2.1 Active microwave remote sensing

Active microwave sensing, a method for obtaining Snow Water Equivalent, combines interferometric techniques with Synthetic Aperture Radar (SAR). However, limitations exist with the pass frequency of these satellites, occurring just twice per month, rendering them impractical for certain scenarios [59]. Consideration of terrain geometry is crucial since the accuracy of active microwave measurements relies on correcting the phase of reflected and refracted signals to appear orthogonally incident on the snowpack. Despite satellites' excellent resolution, precision is compromised in mountainous regions due to additional length components [60]. Moreover, vegetation and snow metamorphism can cause an uneven snowpack, which can introduce inaccuracies into active microwave observations. Active SAR has advanced to the point where Ku-band and X-band radiation are used simultaneously. By combining surface and volume scattering effects, this method may reduce inaccuracies brought on by reflections in an uneven snowpack [61].

3.2.2 Passive microwave remote sensing

Snow Water Equivalent (SWE) has been determined since 1978 through the use of passive microwave techniques. These measurements evaluate soil microwave radiation and estimate SWE by comparing measurements with and without snow [61]. These measurements have a swath width of 25 kilometres, limiting their applicability to regional or hemispheric scales. Moreover, in mountainous terrain, the resolution decreases when translating measurements to distances along slopes [62]. Passive microwave detection is challenged by snow transformation and the presence of water concentration, particularly in alpine and sub-alpine areas where snow is frequently near the melting threshold, leading to significant temperature variations inside the snowpack [63]. These variables fluctuate on an hourly temporal and spatial scale inside the snowpack across tens of meters. To solve these problems, Walker & Goodison [64] suggested a method for measuring liquid water content, and hyperspectral remote sensing can be used to calculate grain size. SWE measures of less than 150 millimetres are usually well suited for passive microwave measurements. When accounting for partially covered cells, the presence of vegetation may affect SWE measurement accuracy by up to 50%. Currently, available techniques combine MODIS readings to determine the amount of vegetation cover [65].

3.2.3 Global Navigation Satellite System (GNSS)

Larson et al. were the first to showcase the retrieval of snow depth utilizing signal-to-noise ratio (SNR) data from a high-precision GNSS receiver in a standard setup. They established strong correlations between these retrievals and on-site measurements [7]. The majority of the data used in this study were at low elevation angles ranging from 5 to 25 degrees. A 2nd order polynomial was used to remove the direct signal component. To convert GPS multipath data changes into snow depth: 1) by estimating the multipath peak frequency f using a Lomb Scargle Periodogram [66][67][68]; and 2) utilizing a model that correlates f with snow depth across a wide range of snow densities.

According to Larson and Nievinski's method [10]:

$$SNR \propto P_d + P_r + \sqrt{P_d P_r \cos\varphi} \quad (1)$$

where P_d is the direct power, P_r is the reflected power and φ is the interference phase. Low elevation angles result in smooth SNR measurements without multipath effects. Nevertheless, at these low satellite elevation angles, multiple oscillations appear in SNR measurements due to the presence of multipath effects or interferences. The initial direct trends P_d and P_r need to be eliminated in GNSS-R. Once these direct trends are removed from equation 1, we can isolate the multipath pattern, which is best expressed in simplified terms as follows

$$SNR = A\cos(2\pi f \sin E + \varphi) \quad (2)$$

where E is the satellite elevation angle; A is the amplitude; and φ is the phase. f is the oscillation frequency expressed in hertz, it is not a regular temporal frequency. The GNSS antenna receives signals from numerous locations, although the realistic reflection of GNSS signals is dispersed due to surface roughness and snow layers affecting the GNSS signal. The majority of signal energy comes from signals near the fresnel point, as it has the minimum transmission path of all reflected signals that it has received. A quasi-sinusoidal signal about the sine of the elevation angle oscillates repeatedly in the sequence of multipath SNR measurements [69]. The primary frequency of a series (f) is related to the antenna height (H) concerning the snow-covered ground surface using the sine of the elevation angle as an independent variable.

$$H = \frac{\lambda f}{2} \quad (3)$$

To compute snow depth h, using the method below, where $H_\circ$ is the antenna height in the snow-free scenario, which is known ahead of time:

$$h = H_\circ - H \quad (4)$$

The SNR approaches involve the elimination of the low-frequency components of the time series, which are produced by low-pass filtering or low-order polynomial fitting. The resulting SNR time series has quasi-sinusoidal signals with damping amplitudes at high frequencies. This is known as the detrended SNR series. The major frequency of the detrended SNR series fluctuates with antenna height, allowing us to estimate snow depth based on this variation. However, the effective omission of low-frequency components from the SNR data is a major factor determining the snow depth estimation accuracy of the SNR approach [11].

Subsequently, many researchers used Signal to signal-to-noise ratio (SNR) to study GNSS-IR. To validate GNSS-IR snow depth estimates based on SNR L2 frequency, Gutmann used observation data spanning eight months. These estimates were contrasted with airborne LIDAR scans and manual and laser-ranging snow depth observations. When compared to laser data, the GNSS-IR retrievals during the winter season showed a 10 cm bias and 13 cm RMSE [4]. The L4 approach uses a linear combination of carrier phases to estimate snow depth. Despite the geometry independence of the L4 technique, residual ionospheric delays have the potential to taint the combined time series, increasing the inaccuracies associated with snow depth estimate [70].

Furthermore, when comparing snow depth retrievals to manual measurements, Hefty and Gerhátová's analysis of the Signal-to-Noise Ratio (SNR) data of L1 and L2 signals as well as L4 showed that the consistency was better than 5 cm. Nonetheless, biases as large as 10 cm were noted at specific times [71]. Nievinski developed inverse snow depth estimation models based on GPS SNR observations. GPS estimates were validated with GPS constraints and in situ sampling errors by simulations, which also illustrated trends, fringes, susceptibility to parameter changes, and the possible inaccuracy in reflector height inversion. The study suggested an approach for quality controlling (QC) GPS snow sensing estimations that rely on track clusters and underlined the need to assess presently ignored effects. The usefulness of GPS SNR measurements for snow monitoring is heavily influenced by site conditions, making quality control mandatory for GPS-MR operational use. In unfavourable built-up environments, precipitation and melting accumulation are accurately captured in daily snow depth estimates derived from GNSS data, according to the study [72], [73]. There is a strong correlation between the snow depth data from ultrasonic sensors and the GNSS-derived estimates obtained during four winter seasons. Snow depth variability and diverse observation methods cause minor variations of up to 10 cm. GNSS and ultrasonic snow depths have high agreement, making them suitable for urban building snow sensors. Although they are not as accurate as those relying on L2C signals, the L1 and L2P signals from geodetic antennas can nonetheless yield trustworthy estimations of the depth of snow [74]. Larson and Small assessed the usefulness of SNR L1 data in snow depth studies by analyzing L1 SNR data collected over 5 years from 23 sites and comparing the findings of SNR L2C data and in situ measurements. A correlation of 0.95 and 1 cm mean bias was observed when comparing the SNR L1 and SNR L2C values [9]. An alternate method, unaffected by geometry or ionospheric delays, was put forth by Yu et al. utilizing SNR data from L1, L2, and L5 signals for enhanced snow depth estimation. In comparison to previous investigations, they demonstrated improved findings by establishing a relationship between the change in reflector height and spectral maximum frequency [69]. Later, Zhou et al. presented a method that reduces random errors by

combining modelling techniques with SNR data from GPS triple-frequency signals. They showed the accuracy in terms of Root Mean Square Error improvement is over 30%, and the suggested method has a good correlation of 0.95 [75].

Yu et al. introduced a method using dual-frequency GNSS signals' pseudorange and carrier phase to calculate snow depth, which is independent of ionospheric delays and geometric characteristics. This makes GNSS viable, as practically all of them can capture carrier phase and pseudorange data, as well as analyze single-frequency signals. However, the SNR approach may be avoided due to the restricted availability of SNR observables, especially in early GNSS devices and RINEX files. Furthermore, some receivers might fail to receive dual frequency signals or triple frequency signals, making combination methods that were used at that time not relevant [76]. To improve applicability, Li et al. processed just single-frequency signals and came up with a method based on carrier phase and pseudorange measurements from single-frequency GNSS signals [11]. Zhou et al. used dual-frequency and triple-frequency signals with pseudorange measurements to offer two innovative approaches for measuring snow depth, respectively. Their methodology avoids the SNR method's mistake in low-frequency component removal and is less affected by snowstorms, which is probably why their results showed somewhat better performance than the SNR method [77]. All of these techniques rely on carrier phase measurements, even though they all show excellent accuracy in measuring snow depth and reduce mistakes caused by the SNR method's insufficient low-frequency signal reduction. To handle carrier phase observations, cycle slips, and integer ambiguity must be addressed. If cycle slips are not identified or fixed, this could complicate snow depth estimate methods and introduce multipath signature contamination. This can result in inaccurate snow depth estimation, affecting the algorithm's overall performance.

The accuracy of estimating snow depth using SNR relies significantly on the accuracy of the primary frequency calculation derived from the SNR series. This estimation is achieved through spectral analysis methods suitable for irregularly sampled data, for instance, the Lomb Scargle Periodogram method. Bilich's work highlighted that changes in antenna environments lead to considerable variability in SNR data due to multipath effects. The SNR observation series can be distorted by unaccounted multipath signals and receiver noise, which can lead to series peak frequency bias and jeopardize the precision of any measurement [22]. The estimation of antenna height derived from an equation is influenced by assuming that the GNSS signal is reflected by a single snow layer. However, numerous layers of snow can reflect signals, resulting in an overestimation of antenna height and an incorrect estimate of snow depth [69]. Z. Zhang et al. proposed various parameter Multi-Layer Retrieval (MLR) models to analyze snow depth variations and SNR measurements, using the Baseline Estimation and Denoising using Sparsity (BEADS) approach to normalize power into baseline and short-term changes. Their results showed that whereas normalized power showed a negative link with snow depth variations, short-term changes from normalized power consistently coincided with snow depth differences. However, because of environmental conditions, the connection between SNR measures and changes in snow depth was smaller at the start of the snow season [78].

Several researchers have engaged in recent studies involving machine learning (ML) and deep learning (DL) techniques for snow depth retrievals. ML, being data-driven, has the potential to yield more precise outcomes by constructing reliable models based on the relationship between data providing for input and output [79]. In contrast to prior machine learning (ML) studies, which mostly employed reconstructed GNSS signals to analyze or combine airborne and spaceborne data, Wang et al. employed deep learning to retrieve snow depth by augmenting the station density of their data sample. Between 2008 and 2017, 25 GNSS-R stations across Alaska were utilized to investigate snow depth retrieval using deep learning approaches, with on-site data and reference values provided from the PBO H2O ground-based GNSS-R network [80]. Zhan et al. presented a back propagation neural network (BPNN) based approach for retrieving snow depth from available satellite data. While showing notable variations in snow depth retrieval outcomes, their model outperformed earlier techniques in terms of accuracy and dependability, with an RMSE of less than 3 cm and a correlation of 0.94 [81]. Altuntas et al. compared three machine learning classifiers with conventional GNSS-IR techniques using GNSS SNR data over 2 years. They found that training ML algorithms within a range of 0–20 cm of GC values produced superior results. This study demonstrated how ML can be used to estimate a variety of parameters using GNSS-IR, including sea level, vegetation water content, soil moisture, and snow depth accumulation [82]. Hu et al. proposed a universal algorithm applicable to diverse snow scenarios, using SNR arcs for snow depth estimation methods and analyzing ground snow detection feasibility through the SVM method. The results revealed high accuracy in ground state detection and improved initial snow retrieval results, reducing RMSE from 20 to 15 cm, especially in snow-free conditions. This algorithm doesn't rely on prior ground measurements and can learn the topographical environment from historical SNR data, widening its applicability to different snow scenarios [83].

Table 1 provides a thorough overview of the existing body of research on snow depth retrievals using GNSS, consolidating essential studies and their specific findings, and providing a comprehensive insight into the advances made in this area of study.

Table 1 Notable literature of snow depth retrieval using GNSS.

Sl no.	*Authors*	*Objectives*	*Results*	*Remarks*
1	Larson et al., (2009)	GPS SNR data snow depth measurement was introduced.	The geodetic receiver, conventional snow sensors, and field observations have shown excellent agreement in measuring plate boundary deformation.	The use of GPS networks for cryosphere research by global geophysical and geodetic agencies is being explored.
2	Gutmann et al., (2012)	Snow depth estimates with airborne LIDAR scans, manual and laser-ranging snow depth observations based on SNR L2 frequency.	Showed a bias of 10 cm and a RMSE of 13 cm	More research is needed to understand the GPS's spatial footprint and its impact on terrain, including significant alterations in reflector height, slope, and surface roughness.
3	Ozeki & Heki, (2012)	Snow depth estimation by L4 introduced and compared with SNR L2P and L2C	A pattern of systematic underestimation of about 10 cm was noted, which is typical for both L4 and SNR methods.	Snow depth estimation uses L4 data, but SNR data yields more accurate results, and even less precise L2P SNR data performs adequately in determining snow depths. Further research into the potential uses of L4 for GPS multipath applications would be insightful.
4	Nievinski & Larson, (2014a)	Inverse modelling of snow depth estimation has been formulated.	For measured snow depths up to 2.5 meters, the evaluation findings show a significant correlation of 0.98 and an RMSE (Root Mean Square Error) range between 6 and 8 cm. Nonetheless, the height of snow in-situ is typically underestimated by the GPS measurements by 5% to 15%.	Quality control measures are necessary because of the significant impact that the site's characteristics have on the usage of GPS signal-to-noise ratio (SNR) measurements for snow monitoring. Several tests are necessary for an ideal quality control plan, which takes the fit quality, statistical degrees of freedom, peak elevation angle, and reflector height uncertainty into account. To precisely determine reflector height over bare soil, more investigation is required.
5	Nievinski & Larson, (2014b)	Inverse modelling of snow depth estimation has been validated		
6	Hefty & Gerhátová, (2014)	The snow depth estimation method utilizes three independent observations focusing on SNR L1 frequencies, SNR L2 frequencies, and carrier phase linear combination L4.	Manual snow depth sensing and GPS multipath analyses show consistency over 5 cm, with some biases at 10 cm.	GPS antennas in terrain topography near buildings and structures are suitable for analyzing ground signals. The study suggests that analyzing multipath behaviour at fixed GNSS stations and its application in assessing the surroundings around antenna installations can enhance the interpretation of observed geodynamic changes.
7	Yu et al., (2015)	Snow depth retrieval using a linear combination of L1, L2,	The methodology outperforms the L4 model and is comparable to the SNR method, demonstrating the	The goals of future research will be to achieve constellation diversity gain, use multiple satellite constellations for

		and L5 GPS frequency signals.	undervaluation of snow depth by the SNR and L4 approaches.	triple-frequency schemes, and improve precision and accuracy.
8	Vey et al., (2016)	Snow depth calculation by GNSS SNR data and Ultrasonic sensor in a built-up environment.	RMSE of 4.3 cm has been shown among GNSS and ultrasonic snow depths	Snow depth estimates obtained from geodetic antenna signals in L1 and L2P bands are consistent but demonstrate lesser accuracy when compared to estimates derived from L2C signals. In the future, hydrological models may incorporate near-real-time GNSS-based predictions of snow depth.
9	Larson & Small, (2016)	Development of an algorithm for L1 SNR data snow depth calculation and comparison with L2C data and in situ observations.	The findings revealed a 1 cm mean bias and 0.95 correlation, with a bias of -4cm, comparable to a previous study of the L2C retrieval algorithm.	The algorithm is useful for geodetic networks that lack L2C signal tracking or archive data. However, stricter quality control is needed for the L1 SNR data method.
10	W. Zhou et al., (2019)	A snow depth measurement method based on the SNR combination of GPS L1, L2, and L5 frequencies.	The suggested approach has a substantial correlation of 0.95 and improvement of more than 30% in terms of RMSE	The study suggests that the new method could aid in tracking snow depths and aid in the creation of multi-system and multi-frequency GNSS reflectometry models.
11	Yu et al., (2019)	Snow depth measurement methods using dual GNSS receiver systems: dual-frequency combination and single-frequency combination are introduced.	The superposition of peaks affects the accuracy of these methods, with the dual-frequency combination method having a larger effect. While the SNR approach is more accurate in the L2 band, the single-frequency combination method is more accurate in the L1 band.	These methods eliminate geometric distance and ionospheric delay, simplifying data processing. Subsequent research will concentrate on noise mitigation, antenna selection, and snowfall measurement using SWE.
12	Li et al., (2019)	Snow depth measurement using GNSS single-frequency signals using pseudorange and carrier phase observations	The method is validated using geodetic-grade receivers and shows a 2-6 cm RMSE based on GPS, BDS, and Galileo.	The method is independent of satellite selection and measurement location. Future research should focus on weighting different GNSS constellations and methods.
13	Wang et al., (2020)	Snow depth estimation based on deep learning approach and GNSS.	The newly introduced deep belief network model demonstrates superior performance by incorporating GNSS estimation, showcasing 0.85 R with 15.40 cm RMSE.	The current spatial resolution of Satellite data is coarse, and further research is needed to enhance spatial resolution and explore other deep-learning models.
14	Hu et al., (2022)	This study uses machine learning to detect ground truth information before snow depth retrieval, classifying snow-free and snow-covered states and using SNR arcs for snow depth retrieval.	The study shows a 96% accuracy with support vector machines, reducing RMSE from 20 cm to 15 cm.	The algorithm doesn't rely on prior ground measurements and can learn the topographical environment from historical SNR data, widening its applicability to different snow scenarios

15	Z. Zhou et al., (2022)	Snow depth retrieval utilizing pseudorange measurements obtained from GNSS signals of both dual and triple frequencies.	RMSE of the proposed methods is less than 3.2 cm	The proposed method, the Triple psuedorange combination, maintains its effectiveness despite geometric distance data and cycle slip issues and avoids ionospheric delays. It outperforms the SNR method and shows slight improvements in snowstorm conditions.
16	Altuntas et al., (2022)	Snow depth measurement using GNSS SNR data and machine learning classifiers.	Enhance the correlations by as much as 19%, while reducing the RMSE from 15.4 to 4.5 cm.	The research illustrates how machine learning algorithms effectively retrieve snow depth using GNSS, indicating ML's capability to estimate different environmental aspects. Subsequent research will concentrate on employing deep learning methods with concealed layers to achieve similar estimation outcomes.
17	Zhan et al., (2022)	GNSS-IR SNR retrieving snow depth method using the backpropagation neural network algorithm	The results show an RMSE of 0.0297 m and a mean absolute error of 0.0219 m, with a correlation coefficient of 0.9407 utilizing in-field data obtained through the snow telemetry (SNOTEL)	The method employs the backpropagation algorithm, which takes advantage of the self-learning and self-adaptive capabilities of the backpropagation neural network to maximize the contribution of various satellites. Future investigations should emphasize harnessing data from various systems to achieve greater precision and dependability in retrieving snow depth measurements.
18	Z. Zhang et al., (2023)	Multi-Layer Retrieval (MLR) models have been introduced, offering distinct parameters designed specifically for estimating variations in snow depth.	The accuracy of the RMSEs dropped from 22.05 to 3.89 and 3.40 cm, respectively, after the MLR models were used. The corrected estimates have strong agreement with meteorological data, displaying deviations in regression slope of under 2% and correlation coefficients surpassing 0.97.	The MLR models showed good accuracy and and appears to be no systemic inaccuracy between the estimates and references. Future research should aim to propose a model with more universal applicability.

The estimation of snow depth using GNSS Reflectometry (GNSS-R) is a rapidly advancing field that leverages the unique properties of signal reflections to measure and monitor snow cover. The Signal-to-Noise Ratio (SNR) approach, particularly through the analysis of detrended SNR series, has shown significant promise. By filtering out low-frequency components, researchers can extract quasi-sinusoidal signals that vary with antenna height, providing a basis for accurate snow depth estimation. Despite its potential, the SNR method faces challenges related to low-frequency component removal and signal multipath effects, which can impact measurement precision. Quality control remains a critical aspect of GNSS-R snow depth estimation. The accuracy of snow depth estimates is heavily influenced by site conditions, multipath effects, and receiver noise. Research by Nievinski and Larson has highlighted the importance of quality control measures such as track clustering and peak elevation angle analysis to ensure reliable measurements. The development of inverse modelling techniques and the use of advanced spectral analysis methods, like the Lomb-Scargle Periodogram, have contributed to mitigating these issues and enhancing the robustness of snow depth estimates [72], [73].

Recent advances, such as the utilization of dual-frequency and triple-frequency GNSS signals, have demonstrated significant advantages over single-frequency systems. Zhou et al.'s approach, which combines modelling techniques

with SNR data from multiple GNSS frequencies, has demonstrated substantial reductions in RMSE and high correlation with in situ measurements [77]. This multi-frequency approach mitigates the effects of ionospheric delays and geometric dependencies, providing more reliable snow depth estimates even in adverse weather conditions. The integration of machine learning (ML) and deep learning (DL) techniques with GNSS-R data has further enhanced snow depth retrieval accuracy. Studies by Wang et al., Zhan et al., and Altuntas et al. have demonstrated the efficacy of these approaches, showing improvements in Root Mean Square Error (RMSE) and correlation coefficients. These methods leverage large datasets and sophisticated algorithms to model the relationship between GNSS signals and snow depth, outperforming traditional SNR-based methods [80], [81], [82]. Overall, the continuous advancements in GNSS-R techniques, coupled with the integration of ML and DL models, are paving the way for more accurate and reliable snow depth estimation. These developments are crucial for enhancing our understanding of snow dynamics, improving hydrological models, and supporting climate studies. As research progresses, the implementation of these methods in operational snow monitoring systems will significantly contribute to environmental monitoring and disaster management.

IV. CONCLUSION

The review comprehensively examines the potential and challenges of utilizing GNSS-R technology for snow depth retrieval in the diverse and challenging terrains of India. Throughout this research, it has become obvious that GNSS-R shows significant promise as a remote sensing instrument for estimating snow depth, providing a non-intrusive and potentially cost-effective way to check this essential parameter. However, the complexity inherent in India's varied geography, where mountainous regions bring distinct challenges such as signal interference, changing snowfall characteristics, and a lack of comprehensive ground truth data, tempers this promise. To address these issues, specialized algorithmic breakthroughs and thorough validation efforts targeted at India's different landscapes are required. Notably, the examined literature emphasizes the importance of performing lengthy field campaigns to collect precise ground truth data that can be used to evaluate and refine GNSS-R-derived calculations. Snow depth retrieval using GNSS-R technology can be achieved using signal-to-noise ratio (SNR) and carrier phase pseudorange methods.

The SNR method is simpler and more accessible, based on the strength of the received signal relative to background noise. It is cost-effective and accessible, offering estimations based on variations in SNR data. The carrier phase pseudorange method, on the other hand, offers increased precision and accuracy by analyzing carrier phase changes caused by signal reflection off the snow surface. It can mitigate error sources and enhance the reliability of snow depth estimations. However, it often requires more sophisticated equipment and algorithms, making it more complex and expensive. The optimal choice depends on specific application requirements, desired accuracy, environmental conditions, available resources, and the trade-off between complexity and precision. Machine learning and deep learning models can revolutionize snow depth estimation in challenging environments. ML and DL models can process vast amounts of data, extract complex patterns, and create predictive models that adapt to diverse terrains and snow characteristics in India's mountainous regions. The successful implementation of GNSS-R technology for snow depth monitoring in India will revolutionize various sectors, including water resource management, disaster mitigation, and climate change studies. Future research aims to refine algorithms, explore synergies with other remote sensing technologies, and assess socioeconomic implications. This review emphasizes the need for sustained research and innovation to unlock the full potential of GNSS-R technology.

ACKNOWLEDGEMENTS

The authors would like to express our sincere gratitude to all those who have contributed to the completion of this review paper. Furthermore, we extend our gratitude to reviewers for their constructive feedback and suggestions during the review process.

COMPETING INTERESTS AND FUNDING

The authors have no competing interests to declare that are relevant to the content of this article. No funding was received for conducting this study.

AUTHOR CONTRIBUTIONS

HS, AB, VG proposed the research, AK and GS wrote the draft version of the manuscript. AK did review and editing. HS, AB and VG supervised. All the authors polished and approved the final manuscript.

REFERENCES

[1] J. Garvelmann, S. Pohl, and M. Weiler, “From observation to the quantification of snow processes with a time-lapse camera network,” *Hydrol. Earth Syst. Sci.*, vol. 17, no. 4, pp. 1415–1429, 2013, doi: 10.5194/HESS-17-1415-2013.

[2] T. H. Painter, K. Rittger, C. McKenzie, P. Slaughter, R. E.

Davis, and J. Dozier, "Retrieval of subpixel snow covered area, grain size, and albedo from MODIS," *Remote Sens. Environ.*, vol. 113, no. 4, pp. 868–879, Apr. 2009, doi: 10.1016/J.RSE.2009.01.001.

[3] K. Rittger, T. H. Painter, and J. Dozier, "Assessment of methods for mapping snow cover from MODIS," *Adv. Water Resour.*, vol. 51, pp. 367–380, Jan. 2013, doi: 10.1016/J.ADVWATRES.2012.03.002.

[4] E. D. Gutmann, K. M. Larson, M. W. Williams, F. G. Nievinski, and V. Zavorotny, "Snow measurement by GPS interferometric reflectometry: an evaluation at Niwot Ridge, Colorado," *Hydrol. Process.*, vol. 26, no. 19, pp. 2951–2961, Sep. 2012, doi: 10.1002/HYP.8329.

[5] A. J. Dietz, C. Kuenzer, U. Gessner, and S. Dech, "Remote sensing of snow – a review of available methods," *Int. J. Remote Sens.*, vol. 33, no. 13, pp. 4094–4134, 2012, doi: 10.1080/01431161.2011.640964.

[6] M. D. Jacobson, "Dielectric-covered ground reflectors in GPS multipath reception - Theory and measurement," *IEEE Geosci. Remote Sens. Lett.*, vol. 5, no. 3, pp. 396–399, 2008, doi: 10.1109/LGRS.2008.917130.

[7] K. M. Larson, E. D. Gutmann, V. U. Zavorotny, J. J. Braun, M. W. Williams, and F. G. Nievinski, "Can we measure snow depth with GPS receivers?," *Geophys. Res. Lett.*, vol. 36, no. 17, Sep. 2009, doi: 10.1029/2009GL039430.

[8] S. Tabibi, F. G. Nievinski, T. van Dam, and J. F. G. Monico, "Assessment of modernized GPS L5 SNR for ground-based multipath reflectometry applications," *Adv. Sp. Res.*, vol. 55, no. 4, pp. 1104–1116, 2015, Accessed: Oct. 06, 2023. [Online]. Available: https://www.academia.edu/25564022/Assessment_of_modernized_GPS_L5_SNR_for_ground_based_multipath_reflectometry_applications

[9] K. M. Larson and E. E. Small, "Estimation of Snow Depth Using L1 GPS Signal-to-Noise Ratio Data," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 9, no. 10, pp. 4802–4808, Oct. 2016, doi: 10.1109/JSTARS.2015.2508673.

[10] K. M. Larson and F. G. Nievinski, "GPS snow sensing: Results from the EarthScope Plate Boundary Observatory," *GPS Solut.*, vol. 17, no. 1, pp. 41–52, 2013, doi: 10.1007/s10291-012-0259-7.

[11] Y. Li, X. Chang, K. Yu, S. Wang, and J. Li, "Estimation of snow depth using pseudorange and carrier phase observations of GNSS single-frequency signal," *GPS Solut.*, vol. 23, no. 4, pp. 1–13, 2019, doi: 10.1007/s10291-019-0912-5.

[12] Y. Shoji, M. Kunii, and K. Saito, "Assimilation of Nationwide and Global GPS PWV Data for a Heavy Rain Event on 28 July 2008 in Hokuriku and Kinki, Japan," *SOLA*, vol. 5, pp. 45–48, 2009, doi: 10.2151/sola.2009-012.

[13] C. Botteron, N. Dawes, J. Leclère, J. Skaloud, S. V. Weijs, and P. A. Farine, "Soil moisture &snow properties determination with GNSS in alpine environments: Challenges, status, and perspectives," *Remote Sens.*, vol. 5, no. 7, pp. 3516–3543, 2013, doi: 10.3390/rs5073516.

[14] X. Chang, T. Jin, K. Yu, Y. Li, J. Li, and Q. Zhang, "Soil Moisture Estimation by GNSS Multipath Signal," *Remote Sens. 2019, Vol. 11, Page 2559*, vol. 11, no. 21, p. 2559, Oct. 2019, doi: 10.3390/RS11212559.

[15] Y. Jia, Y. Pei, P. Savi, and R. Notarpietro, "Soil moisture retrieval from GNSS-R signals," *Proc. 2015 Int. Conf. Electromagn. Adv. Appl. ICEAA 2015*, no. September, pp. 1481–1484, 2015, doi: 10.1109/ICEAA.2015.7297368.

[16] J. Zhang, S. Liu, H. Liang, W. Wan, Z. Guo, and B. Liu, "Using GNSS-IR Snow Depth Estimation to Monitor the 2022 Early February Snowstorm over Southern China," *Remote Sens.*, vol. 14, no. 18, pp. 1–9, 2022, doi: 10.3390/rs14184530.

[17] M. D. Jacobson, "Inferring snow water equivalent for a snow-covered ground reflector using GPS multipath signals," *Remote Sens.*, vol. 2, no. 10, pp. 2426–2441, 2010, doi: 10.3390/rs2102426.

[18] H. Wei, X. He, Y. Feng, S. Jin, and F. Shen, "Snow depth estimation on slopes using gps-interferometric reflectometry," *Sensors (Switzerland)*, vol. 19, no. 22, pp. 1–15, 2019, doi: 10.3390/s19224994.

[19] C. D. Hall and R. A. Cordey, "Multistatic Scatterometry," *Int. Geosci. Remote Sens. Symp. "Remote Sens. Mov. Towar. 21st Century"*., pp. 561–562, 1988, doi: 10.1109/IGARSS.1988.570200.

[20] J. Gong, R. Ma, D. Li, and J. Zhao, "GNSS Multipath Mitigation Method Based on K-means Classification in Urban Environment," *J. Indian Soc. Remote Sens.*, vol. 50, no. 5, pp. 805–813, May 2022, doi: 10.1007/S12524-022-01494-Y/FIGURES/14.

[21] M. Martm-Neira, M. Caparrini, J. Font-Rossello, S. Lannelongue, and C. S. Vallmitjana, "The paris concept: an experimental demonstration of sea surface altimetry using gps reflected signals," *IEEE Trans. Geosci. Remote Sens.*, vol. 39, no. 1, pp. 142–150, 2001, doi: 10.1109/36.898676.

[22] A. Bilich and K. M. Larson, "Mapping the GPS multipath environment using the signal-to-noise ratio (SNR)," *Radio Sci.*, vol. 42, no. 6, 2007, doi: 10.1029/2007RS003652.

[23] S. Jin, E. Cardellach, and F. Xie, "Introduction to GNSS," pp. 3–16, 2014, doi: 10.1007/978-94-007-7482-7_1.

[24] S. Jin, E. Cardellach, and F. Xie, "GNSS Remote Sensing," vol. 19, 2014, doi: 10.1007/978-94-007-7482-7.

[25] S. Jin, X. Qian, H. Kutoglu, R. Gloaguen, and P. S. Thenkabail, "Snow Depth Variations Estimated from GPS-Reflectometry: A Case Study in Alaska from L2P SNR Data," *Remote Sens. 2016, Vol. 8, Page 63*, vol. 8, no. 1, p. 63, Jan. 2016, doi: 10.3390/RS8010063.

[26] R. B. Langley, P. J. G. Teunissen, and O. Montenbruck, "Introduction to GNSS," *Springer Handbooks*, pp. 3–23, 2017, doi: 10.1007/978-3-319-42928-1_1.

[27] V. U. Zavorotny, K. M. Larson, J. J. Braun, E. E. Small, E. D. Gutmann, and A. L. Bilich, "A Physical Model for GPS Multipath Caused by Land Reflections: Toward Bare Soil Moisture Retrievals," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 3, no. 1, pp. 100–110, 2010, doi: 10.1109/JSTARS.2009.2033608.

[28] N. Rodriguez-Alvarez *et al.*, "Land geophysical parameters retrieval using the interference pattern GNSS-R technique," *IEEE Trans. Geosci. Remote Sens.*, vol. 49, no. 1 PART 1, pp. 71–84, Jan. 2011, doi: 10.1109/TGRS.2010.2049023.

[29] C. Roesler and K. M. Larson, "Software tools for GNSS interferometric reflectometry (GNSS-IR)," *GPS Solut.*, vol. 22, no. 3, pp. 1–10, Jul. 2018, doi: 10.1007/S10291-018-0744-8/FIGURES/9.

[30] T. S. Dahl-Jensen, O. B. Andersen, S. D. P. Williams, V. Helm, and S. A. Khan, "Gnss-ir measurements of inter annual sea level variations in thule, greenland from 2008–2019," *Remote Sens.*, vol. 13, no. 24, p. 5077, Dec. 2021, doi: 10.3390/RS13245077/S1.

[31] J. F. Munoz-Martin *et al.*, "Snow and Ice Thickness Retrievals Using GNSS-R: Preliminary Results of the MOSAiC Experiment," *Remote Sens. 2020, Vol. 12, Page 4038*, vol. 12, no. 24, p. 4038, Dec. 2020, doi: 10.3390/RS12244038.

[32] Y. Ghiasi *et al.*, "Application of GNSS Interferometric Reflectometry for the Estimation of Lake Ice Thickness," *Remote Sens. 2020, Vol. 12, Page 2721*, vol. 12, no. 17, p. 2721, Aug. 2020, doi: 10.3390/RS12172721.

[33] S. Wu, D. Yang, Y. Zhu, and F. Wang, "Improved GNSS-Based Bistatic SAR Using Multi-Satellites Fusion: Analysis and Experimental Demonstration," *Sensors 2020, Vol. 20, Page 7119*, vol. 20, no. 24, p. 7119, Dec. 2020, doi: 10.3390/S20247119.

[34] S. Wu, Z. Xu, F. Wang, D. Yang, and G. Guo, "An Improved Back-Projection Algorithm for GNSS-R BSAR Imaging Based on CPU and GPU Platform," *Remote Sens. 2021, Vol. 13, Page 2107*, vol. 13, no. 11, p. 2107, May 2021, doi: 10.3390/RS13112107.

[35] J. L. Garrison, S. J. Katzberg, and M. I. Hill, "Effect of sea roughness on bistatically scattered range coded signals from the Global Positioning System," *Geophys. Res. Lett.*, vol. 25, no. 13, pp. 2257–2260, Jul. 1998, doi: 10.1029/98GL51615.

[36] E. Cardellach, F. Fabra, O. Nogués-Correig, S. Oliveras, S. Ribó, and A. Rius, "GNSS-R ground-based and airborne campaigns for ocean, land, ice, and snow techniques: Application to the GOLD-RTR data sets," *Radio Sci.*, vol. 46, no. 6, pp. 0–04, Dec. 2011, doi: 10.1029/2011RS004683.

[37] E. Cardellach *et al.*, "Consolidating the precision of interferometric GNSS-R ocean altimetry using airborne experimental data," *IEEE Trans. Geosci. Remote Sens.*, vol. 52, no. 8, pp. 4992–5004, 2014, doi: 10.1109/TGRS.2013.2286257.

[38] E. Motte *et al.*, "GLORI: A GNSS-R Dual Polarization Airborne Instrument for Land Surface Monitoring," *Sensors 2016, Vol. 16, Page 732*, vol. 16, no. 5, p. 732, May 2016, doi: 10.3390/S16050732.

[39] M. Zribi *et al.*, "Performance of GNSS-R GLORI data for biomass estimation over the Landes forest," *Int. J. Appl. Earth Obs. Geoinf.*, vol. 74, pp. 150–158, Feb. 2019, doi: 10.1016/J.JAG.2018.09.010.

[40] R. Onrubia, D. Pascual, J. Querol, H. Park, and A. Camps, "The Global Navigation Satellite Systems Reflectometry (GNSS-R) Microwave Interferometric Reflectometer: Hardware, Calibration, and Validation Experiments," *Sensors 2019, Vol. 19, Page 1019*, vol. 19, no. 5, p. 1019, Feb. 2019, doi: 10.3390/S19051019.

[41] J. Bu, K. Yu, Y. Zhu, N. Qian, and J. Chang, "Developing and Testing Models for Sea Surface Wind Speed Estimation with GNSS-R Delay Doppler Maps and Delay Waveforms," *Remote Sens. 2020, Vol. 12, Page 3760*, vol. 12, no. 22, p. 3760, Nov. 2020, doi: 10.3390/RS12223760.

[42] D. Moller, C. Ruf, R. Linnabary, A. O'Brien, and S. Musko, "OPERATIONAL AIRBORNE GNSS-R ABOARD AIR NEW ZEALAND DOMESTIC AIRCRAFT," *Int. Geosci. Remote Sens. Symp.*, vol. 2021-July, pp. 1284–1287, 2021, doi: 10.1109/IGARSS47720.2021.9553159.

[43] A. Perez-Portero, J. F. Munoz-Martin, H. Park, and A. Camps, "Airborne GNSS-R: A Key Enabling Technology for Environmental Monitoring," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 14, pp. 6652–6661, 2021, doi: 10.1109/JSTARS.2021.3076003.

[44] S. T. Lowe, J. L. LaBrecque, C. Zuffada, L. J. Romans, L. E. Young, and G. A. Hajj, "First spaceborne observation of an Earth-reflected GPS signal," *Radio Sci.*, vol. 37, no. 1, pp. 7-1-7–28, 2002, doi: 10.1029/2000RS002539.

[45] M. Unwin, P. Jales, P. Blunt, S. Duncan, M. Brummitt, and C. Ruf, "The SGR-ReSI and its application for GNSS reflectometry on the NASA EV-2 CYGNSS mission," *IEEE Aerosp. Conf. Proc.*, 2013, doi: 10.1109/AERO.2013.6497151.

[46] M. Unwin, P. Jales, J. Tye, C. Gommenginger, and G. Foti, "Developments in GNSS-Reflectometry from the SGR-ReSI in Orbit on TechDemoSat-1," *Small Satell. Conf.*, Aug. 2016, Accessed: Nov. 29, 2023. [Online]. Available: https://digitalcommons.usu.edu/smallsat/2016/TS12SciPayload2/6

[47] C. Jing, X. Niu, C. Duan, F. Lu, G. Di, and X. Yang, "Sea Surface Wind Speed Retrieval from the First Chinese GNSS-R Mission: Technique and Preliminary Results," *Remote Sens. 2019, Vol. 11, Page 3013*, vol. 11, no. 24, p. 3013, Dec. 2019, doi: 10.3390/RS11243013.

[48] G. Yang *et al.*, "FY3E GNOS II GNSS Reflectometry: Mission Review and First Results," *Remote Sens. 2022, Vol. 14, Page 988*, vol. 14, no. 4, p. 988, Feb. 2022, doi: 10.3390/RS14040988.

[49] H. Carreno-Luengo *et al.*, "3Cat-2-An Experimental Nanosatellite for GNSS-R Earth Observation: Mission Concept and Analysis," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 9, no. 10, pp. 4540–4551, Oct. 2016, doi: 10.1109/JSTARS.2016.2574717.

[50] J. F. Munoz-Martin, L. F. Capon, J. A. Ruiz-De-Azua, and A. Camps, "The Flexible Microwave Payload-2: A SDR-Based GNSS-Reflectometer and L-Band Radiometer for CubeSats," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 13, pp. 1298–1311, 2020, doi: 10.1109/JSTARS.2020.2977959.

[51] A. Camps *et al.*, "FSSCAT, the 2017 copernicus masters' 'ESA sentinel small satellite challenge' winner: A federated polar and soil moisture tandem mission based on 6U Cubesats," *Int. Geosci. Remote Sens. Symp.*, vol. 2018-July, pp. 8285–8287, Oct. 2018, doi: 10.1109/IGARSS.2018.8518405.

[52] P. T. Setti and S. Tabibi, "Evaluation of Spire GNSS-R reflectivity from multiple GNSS constellations for soil

moisture estimation," *Int. J. Remote Sens.*, vol. 44, no. 20, pp. 6422–6441, Oct. 2023, doi: 10.1080/01431161.2023.2270108.

[53] M. J. Unwin *et al.*, "An Introduction to the HydroGNSS GNSS Reflectometry Remote Sensing Mission," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 14, pp. 6987–6999, 2021, doi: 10.1109/JSTARS.2021.3089550.

[54] E. Cardellach *et al.*, "GNSS Transpolar Earth Reflectometry exploriNg System (G-TERN): Mission Concept," *IEEE Access*, vol. 6, pp. 13980–14018, Mar. 2018, doi: 10.1109/ACCESS.2018.2814072.

[55] A. Camps *et al.*, "Optimization and performance analysis of interferometric GNSS-R altimeters: Application to the PARIS IoD mission," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 7, no. 5, pp. 1436–1451, 2014, doi: 10.1109/JSTARS.2014.2320873.

[56] G. Osborn, "Handbook of Snow: Principles, Processes, Management & Use, edited by D.M. Gray and D.H. Male," *ARCTIC*, vol. 35, no. 2, pp. 346–346, Jan. 1982, doi: 10.14430/ARCTIC2483.

[57] N. J. Kinar and J. W. Pomeroy, "Measurement of the physical properties of the snowpack," *Rev. Geophys.*, vol. 53, no. 2, pp. 481–544, Jun. 2015, doi: 10.1002/2015RG000481.

[58] A. Fayad *et al.*, "Snow hydrology in Mediterranean mountain regions: A review," *J. Hydrol.*, vol. 551, pp. 374–396, Aug. 2017, doi: 10.1016/J.JHYDROL.2017.05.063.

[59] T. Guneriussen, K. A. HЈgda, H. Johnsen, and I. Lauknes, "InSAR for estimation of changes in snow water equivalent of dry snow," *IEEE Trans. Geosci. Remote Sens.*, vol. 39, no. 10, pp. 2101–2108, 2001, doi: 10.1109/36.957273.

[60] Y. S. Song, H. G. Sohn, and C. H. Park, "Efficient water area classification using radarsat-1 SAR imagery in a high relief mountainous environment," *Photogramm. Eng. Remote Sensing*, vol. 73, no. 3, pp. 285–296, 2007, doi: 10.14358/PERS.73.3.285.

[61] A. W. Nolin, "Recent advances in remote sensing of seasonal snow," *J. Glaciol.*, vol. 56, no. 200, pp. 1141–1150, 2010, doi: 10.3189/002214311796406077.

[62] M. König, J. G. Winther, and E. Isaksson, "Measuring snow and glacier ice properties from satellite," *Rev. Geophys.*, vol. 39, no. 1, pp. 1–27, Feb. 2001, doi: 10.1029/1999RG000076.

[63] D. Clifford, "Global estimates of snow water equivalent from passive microwave instruments: history, challenges and future developments," *Int. J. Remote Sens.*, vol. 31, no. 14, pp. 3707–3726, 2010, doi: 10.1080/01431161.2010.483482.

[64] A. E. Walker and B. E. Goodison, "Discrimination of a wet snow cover using passive microwave satellite data," *Ann. Glaciol.*, vol. 17, pp. 307–311, 1993, doi: 10.3189/S026030550001301X.

[65] J. L. Foster *et al.*, "Quantifying the uncertainty in passive microwave snow water equivalent observations," *Remote Sens. Environ.*, vol. 94, no. 2, pp. 187–203, Jan. 2005, doi: 10.1016/J.RSE.2004.09.012.

[66] N. R. Lomb, "Least-squares frequency analysis of unequally spaced data," *Astrophys. Space Sci.*, vol. 39, no. 2, pp. 447–462, Feb. 1976, doi: 10.1007/BF00648343.

[67] J. D. Scargle, "Studies in Astronomical Time Series Analysis. V. Bayesian Blocks, a New Method to Analyze Structure in Photon Counting Data," *Astrophys. J.*, vol. 504, no. 1, pp. 405–418, Sep. 1998, doi: 10.1086/306064/FULLTEXT/.

[68] J. T. VanderPlas, "Understanding the Lomb–Scargle Periodogram," *Astrophys. J. Suppl. Ser.*, vol. 236, no. 1, p. 16, May 2018, doi: 10.3847/1538-4365/AAB766.

[69] K. Yu, W. Ban, X. Zhang, and X. Yu, "Snow depth estimation based on multipath phase combination of GPS triple-frequency signals," *IEEE Trans. Geosci. Remote Sens.*, vol. 53, no. 9, pp. 5100–5109, Sep. 2015, doi: 10.1109/TGRS.2015.2417214.

[70] M. Ozeki and K. Heki, "GPS snow depth meter with geometry-free linear combinations of carrier phases," *J. Geod.*, vol. 86, no. 3, pp. 209–219, Mar. 2012, doi: 10.1007/S00190-011-0511-X/METRICS.

[71] J. Hefty and L. Gerhátová, "Using GPS multipath for snow depth sensing - First experience with data from permanent stations in Slovakia," *Acta Geodyn. Geomater.*, vol. 11, no. 1, pp. 53–63, 2014, doi: 10.13168/AGG.2013.0055.

[72] F. G. Nievinski and K. M. Larson, "Inverse modeling of GPS multipath for snow depth estimation - Part I: Formulation and simulations," *IEEE Trans. Geosci. Remote Sens.*, vol. 52, no. 10, pp. 6555–6563, 2014, doi: 10.1109/TGRS.2013.2297681.

[73] F. G. Nievinski and K. M. Larson, "Inverse modeling of GPS multipath for snow depth estimation - Part II: Application and validation," *IEEE Trans. Geosci. Remote Sens.*, vol. 52, no. 10, pp. 6564–6573, 2014, doi: 10.1109/TGRS.2013.2297688.

[74] S. Vey, A. Guntner, J. Wickert, T. Blume, H. Thoss, and M. Ramatschi, "Monitoring Snow Depth by GNSS Reflectometry in Built-up Areas: A Case Study for Wettzell, Germany," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 9, no. 10, pp. 4809–4816, Oct. 2016, doi: 10.1109/JSTARS.2016.2516041.

[75] W. Zhou, L. Liu, L. Huang, Y. Yao, J. Chen, and S. Li, "A New GPS SNR-based Combination Approach for Land Surface Snow Depth Monitoring," *Sci. Reports 2019 91*, vol. 9, no. 1, pp. 1–20, Mar. 2019, doi: 10.1038/s41598-019-40456-2.

[76] Yu, Wang, Li, Chang, and Li, "Snow Depth Estimation with GNSS-R Dual Receiver Observation," *Remote Sens.*, vol. 11, no. 17, p. 2056, Sep. 2019, doi: 10.3390/rs11172056.

[77] Z. Zhou, K. Yu, J. Bu, Y. Li, and S. Han, "Snow depth estimation based on combination of pseudorange measurements of GNSS geodetic receivers," *Adv. Sp. Res.*, vol. 69, no. 3, pp. 1439–1450, 2022, doi: 10.1016/j.asr.2021.11.004.

[78] Z. Zhang, F. Guo, X. Zhang, Z. Li, and H. Liu, "Physical Modeling and Compensation for Systematic Negative Errors in GNSS-R Snow Depth Retrieval," *IEEE Trans. Geosci. Remote Sens.*, vol. 61, pp. 1–12, 2023, doi: 10.1109/TGRS.2023.3260808.

[79] X. Chu *et al.*, "Multimodal Deep Learning for Heterogeneous GNSS-R Data Fusion and Ocean Wind

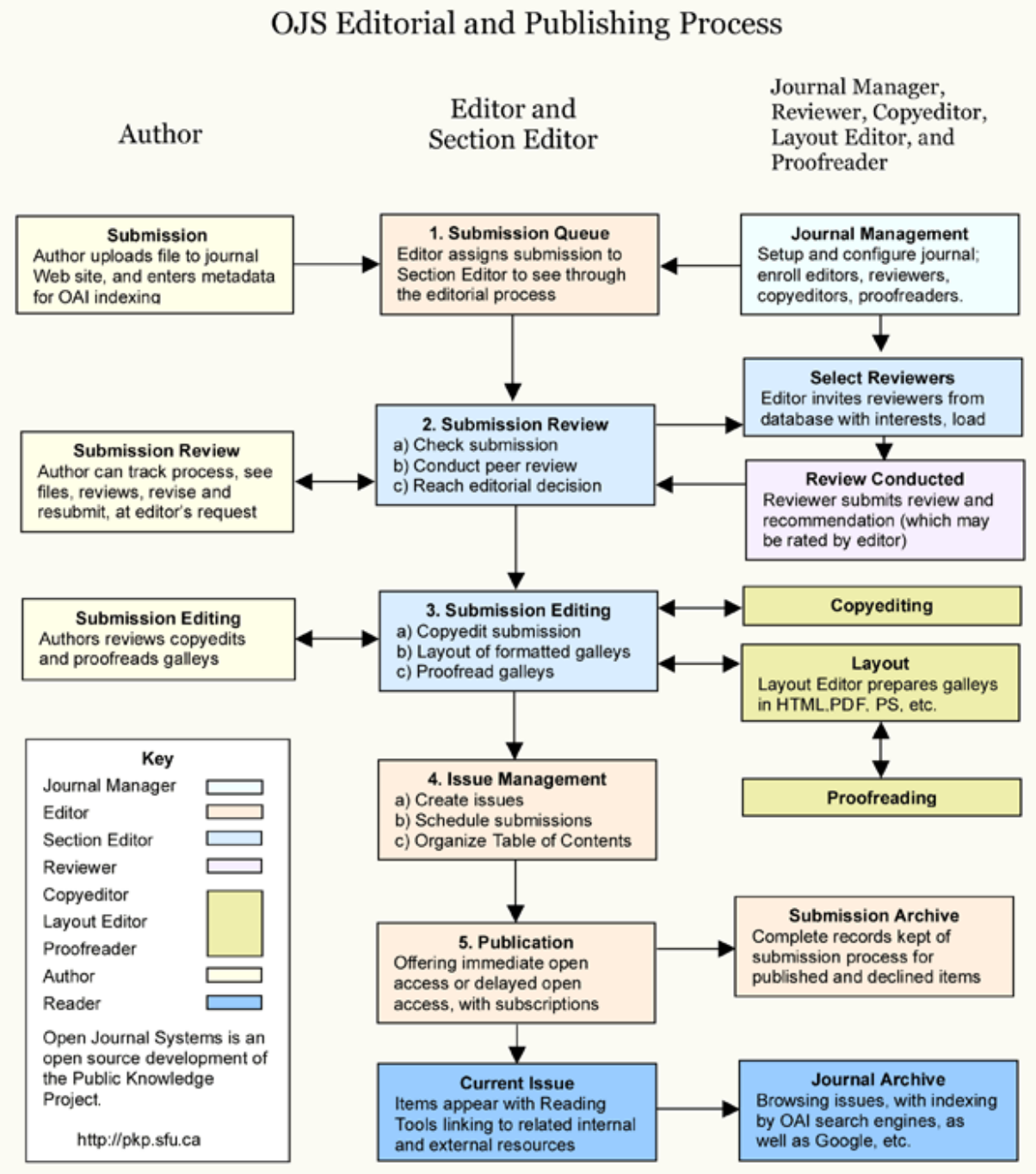
Speed Retrieval," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 13, pp. 5971–5981, 2020, doi: 10.1109/JSTARS.2020.3010879.

[80] J. Wang *et al.*, "Estimating snow depth by combining satellite data and ground-based observations over Alaska: A deep learning approach," *J. Hydrol.*, vol. 585, Jun. 2020, doi: 10.1016/J.JHYDROL.2020.124828.

[81] J. Zhan *et al.*, "GNSS-IR Snow Depth Retrieval Based on the Fusion of Multi-Satellite SNR Data by the BP Neural Network," *Remote Sens. 2022, Vol. 14, Page 1395*, vol. 14, no. 6, p. 1395, Mar. 2022, doi: 10.3390/RS14061395.

[82] C. Altuntas, M. C. Iban, E. Şentürk, U. M. Durdag, and N. Tunalioglu, "Machine learning-based snow depth retrieval using GNSS signal-to-noise ratio data," *GPS Solut.*, vol. 26, no. 4, pp. 1–12, 2022, doi: 10.1007/s10291-022-01307-2.

[83] Y. Hu, X. Yuan, W. Liu, Q. Hu, J. Wickert, and Z. Jiang, "An SVM-Based Snow Detection Algorithm for GNSS-R Snow Depth Retrievals," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 15, pp. 6046–6052, 2022, doi: 10.1109/JSTARS.2022.3193113.



~IJAERS Workflow~

Important links:

Paper Submission Link:
https://ijaers.com/submit-paper/
Editorial Team:
https://ijaers.com/editorial-board/
Peer Review Process:
https://ijaers.com/peer-review-process/
Publication Ethics:
https://ijaers.com/publication-ethics-and-publication-malpractice-statement/
Author Guidelines:
https://ijaers.com/instruction-to-author/
Reviewer Guidelines:
https://ijaers.com/review-guidelines/

Journal Indexed and Abstracted in:

- Qualis-CAPES (A2)-Brazil
- Normatiza (Under Review-Ref.020191511)
- NAAS Score: 3.18
- Bielefeld Academic Search Engine(BASE)
- Aalborg University Library (Denmark)
- WorldCat: The World's Largest Library Catalog
- Semantic Scholar
- J-Gate
- Open J-Gate
- CORE-The world’s largest collection of open access research papers
- JURN
- Microsoft Academic Search
- Google Scholar
- Kopernio - powered by Web of Science
- Pol-Index
- PBN(Polish Scholarly Bibliography) Nauka Polaska
- Scilit, MDPI AG (Basel, Switzerland)
- Tyndale University College & Seminary
- Indiana Library WorldCat
- CrossRef DOI-10.22161/ijaers
- Neliti - Indonesia's Research Repository
- Journal TOC
- WIKI-CFP
- Scinapse- Academic Search Engine
- Mendeley-Reference Management Software & Researcher Network
- Dimensions.ai: Re-imagining discovery and access to research
- Index Copernicus Value(ICV): 81.49
- Citeseerx
- Massachusetts Institute of Technology (USA)
- Simpson University (USA)
- University of Louisville (USA)
- Biola University (USA)
- IE Library (Spain)
- Mount Saint Vincent University Library (Halifax, Nova Scotia Canada)
- University Of Arizona (USA)
- INDIANA UNIVERSITY-PURDUE UNIVERSITY INDIANAPOLIS (USA)
- Roderic Bowen Library and Archives (United Kingdom)
- University Library of Skövde (Sweden)
- Indiana University East (campuslibrary (USA))
- Tilburg University (The Netherlands)
- Williams College (USA)
- University of Connecticut (USA)
- Brandeis University (USA)
- Tufts University (USA)
- Boston University (USA)
- McGill University (Canada)
- Northeastern University (USA)
- BibSonomy-The blue social bookmark and publication sharing system
- Slide Share
- Academia
- Archive
- Scribd
- ISRJIF
- Cite Factor
- SJIF-InnoSpace
- ISSUU
- Research Bib
- infobaseindex
- I2OR
- DRJI journal-repository

AI Publication
International Journal of Advanced Engineering Research and Science (IJAERS)
104/108, Sector-10, Pratap Nagar, Jaipur, India