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Journal of Science and Sustainable Development (JSSD)

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Journal of Science and Sustainable Development (JSSD)

Ambo University

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- To promote the effective teaching of science, technology and management; identifying problems and developing solutions through dissemination of new information from researches align in the direction of solving the basic need of the country.

- To contribute to the pool of scientific information by providing (creating) more access for researchers to have their original scientific work relevant to the need of the country and the world atlarge.

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Pitout JDD, Church DL, Gregson DB, Chow BL, McCracken M, Mulvey M, Laupland KB (2007). Molecular epidemiology of CTXM-producing *Escherichia coli* in the Calgary Health Region: emergence of CTX-M-15- producing isolates. Antimicrob.Agents Chemother. 51: 1281-1286.

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RESEARCH PAPER

Stakeholders' Participation in Adult Education Policy Document Formulation and Implementation in Ethiopia

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Abstract

The purpose of this study was to assess stakeholders' participation on adult education policy document formulation and implementation in Ethiopia. Qualitative method was used for this study. As a result, qualitative data was collected by using interview and document analysis. Qualitative data, including respondents' views and findings from document analysis, were presented by describing the responses in phrases. The finding of this study reveals that there are different categories of stakeholders are involved in implementing adult education program in the country. In Ethiopia, although significant efforts have been made by the government and NGOs, illiteracy rates remain high, and the implementation of related programs is still inadequate. This situation implies that there is no established system that coordinates stakeholders' effort and resources towards the effective implementation of adult education program. This brings about a duplication of efforts and wastage of resources. Therefore, it is recommended that adult education centers and district education offices, in collaboration with other stakeholders such as district agriculture and rural development offices and district health offices, should mobilize the community to promote adult education programs.

Keywords: Stakeholders, participation, policy documents, implementation

Introduction

Basic education, such as literacy, broadens people's perspective and leads learners more open towards change, innovative concepts and approaches. It enables individuals to adopt new production techniques and methods, thereby improving their income (McCaffery *et al*., 2007). Literacy and basic education prepare individuals to accept changes in various aspects of their lives, including lifestyle, production methods, and health practices. These tools allow them to utilize new technologies and benefit from advancements.

Functional literacy programs aim beyond simply teaching adults how to read and write but also to enhance their productivity. Through work-focused literacy initiatives, these programs strive to impact participants' overall lives and transform their social, economic, and value systems (Barton, 2007). Recently, Kebede (2024) emphasized the significance of literacy programs, noting that such initiatives empower participants by enhancing their self-confidence and encouraging more outgoing behaviors. Acquiring skills in reading, writing, and arithmetic is seen as a stepping stone toward achieving broader goals. The literacy program successfully reduced dropout rates among adult learners;' improved their self-esteem, and motivated participants to pursue better living conditions. Learning becomes more appealing to adults when the programs are relevant to their lives; involve practical problem-solving, and lead to improvements in their socioeconomic status.

However, in Ethiopia, previous adult education (AE) programs have been inconsistent, poorly coordinated, and failed to bring meaningful change to participants' lives (MoE, 2008). Ethiopia faces several challenges in delivering

adult education programs, including a high dropout rate, cultural barriers, population mobility, heavy workloads especially for women, poor-quality facilitators, lack of incentives for educators, and limited interest from beneficiaries, as outlined in the National Adult Education Strategy (MoE, 2008). Additionally, the lack of collaboration and commitment from key stakeholders remains a significant obstacle to the success of adult education programs in the country.

Despite Ethiopia have been implemented adult education programs since the 1890s recognizing literacy and basic education as tools for development and modernization, the illiteracy rate in the country remains alarmingly high (Mammo and Kebede, 2005). Supporting this view, UNESCO (2006) reports that 58.5% of the population aged 15 and older is illiterate, placing Ethiopia among the lowest in literacy rates across Sub-Saharan Africa. Similarly, the UNESCO (2019) report revealed that Sub-Saharan Africa has one of the lowest adult literacy rates in the world, with a 61% literacy rate.

The concept of adult education is widely considered as broad and involves several sectors. However, it was only in 2005 that the Ministry of Education called for active involvement, ownership and commitment of communities, NGOs and civil societies. In Education Sector Development Program (ESDP III), in addition to the regions which play active role in organizing the program and preparing materials in the mother tongue, NGOs which work on adult literacy have also been welcomed for the better expansion, local responsiveness and relevance of the program (MoE, 2005).

The National Adult Education Strategy (MoE, 2008) further emphasized the importance of collaboration and coordination across different sectors involved in education and related fields to strengthen the program. Similarly, in ESDP IV, the Ministry of Education reiterated its commitment to strengthening partnerships with the government, private sector, and NGOs for better provision of Integrated Functional Adult Literacy (IFAL) (MoE, 2010b). In response to this, the Ministry of Education, together with five other ministries, signed a Memorandum of Understanding (MoU) to make the Functional Adult Literacy (FAL) program more integrated (MoE, 2010:38).

The Master Plan for Adult Education also highlighted the multidisciplinary nature of adult education, which requires the involvement of various sectors. It stated that functional adult education builds on indigenous knowledge and seeks to link literacy skills to livelihoods and skills training in areas such as agriculture (including off-farm activities), health, civic education, and cultural education. This approach necessitates collaboration among governmental and non-governmental service providers across different settings, ensuring that literacy skills are meaningful and applicable to learners' lives (MoE, 2011b).

According to Genet (2014), the Ministry of Education, along with other government ministries, recognized the active role of institutions such as universities, Technical and Vocational Education and Training (TVET) centers, and NGOs, to meaningful delivery of IFAL. However, previous trends show that most health extension workers and development agents do not perceive IFAL as their responsibility, as the roles of the signing ministries are not adequately cascaded to the grassroots level for integrated program implementation.

In addition to the challenges already mentioned, several studies on stakeholder participation in adult education programs have highlighted significant obstacles to their successful implementation. For instance, Habtamu *et al* (2021) identified three major challenges hindering stakeholder involvement in the Integrated Functional Adult Education Program (IFAEP). These challenges include limited collaboration among stakeholders in developing a comprehensive plan for the program and inadequate cooperation in providing the necessary resources for its execution. Similarly, Anjulo *et al.* (2017) pointed out that poor coordination between board members and technical committees severely affects the effectiveness of adult

education initiatives. Abate and Adamu (2021) echoed these concerns, noting that the implementation of IFAL programs has faced significant barriers due to insufficient cooperation among key stakeholders, particularly in areas such as coordination, communication, and networking.

As clearly highlighted in various policy documents and research findings, one of the major challenges in the adult education sector is the low level of stakeholder participation in program implementation. This issue forms the core rationale upon which the current study is based.

Rationale

As mentioned earlier, numerous investigations at national and international levels have explored the role of stakeholders in adult education programs. For example, a study by Samuel *et al* (2022) titled "Stakeholders' Participation in Adult Education Programme Development in Ethiopia." Their findings indicated that stakeholders generally have a favorable perception of collaboration and recognize the program's contributions to sectoral and national development. Despite this, the study also highlighted that stakeholders are only minimally involved in crucial aspects of program execution, such as management, awareness campaigns, community engagement, budgeting, training, and monitoring and evaluation.

In addition, in 2021 study conducted by Getnet and Yirga, titled "Factors Affecting Inter sectoral Collaboration in the Provision of Adult Education in Ethiopia," the researchers identified several key challenges to effective collaboration between sectors. These included weak political will, unclear responsibilities, poor communication strategies, and a shortage of financial and human resources.

Lastly, study by Abdullah (2024) titled "Active Citizenship and Community Engagement in Adult Education" emphasized the value of forming strong partnerships with local community groups, NGOs, and civil society organizations. These alliances enable adult education programs to better meet local needs by supporting joint projects, sharing resources, and creating networking opportunities. These collaborations also provide learners with opportunities to apply their education directly in community service and civic involvement.

All the studies mentioned above were not focus on stakeholders' participation on policy and strategy related issues more specifically their participation in the development and execution of policy in which the researcher consider as one of the major challenge for the existence of high illiteracy rate and poor management of the program. Consequently, these conditions motivated researcher to investigate the extent of stakeholders engagement in the development and execution of adult education strategy materials in the country. Hence, the study designed to seek answer for the following basic questions.

1. How do adult education stakeholders participate in the development and execution of adult education policy and strategy documents?

2. To what extent are stakeholders committed to the execution of adult education policy and strategy documents?

3. Are stakeholders given a supportive environment to take part in adult education policy documents formulation and execution?

Methodology

The principal aim of the study was to critically examine the extent and nature of stakeholders' engagement in development and execution of adult education policy and strategy documents in Ethiopia. To achieve this, the researcher adopted a qualitative research design which enabled an in-depth exploration of the perspectives and interpretation of key informants regarding the development and execution of adult education policy and strategy documents in Ethiopia. In this research, the researcher applied a process that involved emergent questions or procedures, where data is typically collected in the participants' setting, and data analysis inductively builds from specific to general, and

the researcher provided interpretations of the meaning of the data (Creswell, 2014). To do so, the researcher closely interacted with adult education officials and experts at various positions to explore their interpretation of stakeholders involvement in formulation and implementation of adult education policy documents in the country. Qualitative research is emergent by definition since "what will be learned at a site is always dependent on the interaction between investigator and context which cannot be fully predictable. In this sense, it is believed that qualitative design encourages openness and learning, proponents believe that emergent research designs are more likely to produce interesting data that are generative of insight (Wiedner and Ansari, 2018).

Accordingly, primary data was collected from sub cities/zones and district adult education officials and experts, adult education centre coordinators and facilitators from Addis Ababa City Administration and Oromia regional state through structured interview. Secondary data was secured from adult education strategy and policy documents found at sub city, district and centre level in Addis Ababa City Administration and from region, zone, district and centre level at Oromia Region. Some of these documents were education and training policy, national adult education strategy, Minimum Learning Competencies (MLC) in adult education, adult education Program Implementation Guideline, adult education Curriculum Framework, Master Plan for Adult Education in Ethiopia, adult education path way, adult education Memorandum of Understanding Manual, adult education Benchmarks, adult education Supervision Manual, Teaching Learning Materials Development Manual, education annual abstracts, adult education sector reports, ESDP documents and GTP documents were analyzed. Moreover, to triangulate the accuracy of the information and to substantiate the data literatures pertinent to the study were reviewed.

To secure the necessary data for the study, two zones (West Shoa and South West Shoa) from Oromia and three sub cities (Lideta, Yeka and Bole) from Addis Ababa, a total of 5 zones from the two regions, three districts from each of the five zones (15 districts) and one adult learning centre from each district (15 centers) were selected purposively based on their performance on the implementation of adult education programs. In addition to this, the federal ministry of education was also selected by using the same sampling technique. From these two regions, samples were drawn from various position of the education system according to their involvement in the implementation of adult education program in their respective region, zone, district and center. Accordingly, 6 adult education officials from federal and regional levels, 20 experts from the region, zone and district levels, and 20 adult education facilitators at center level were drawn by applying purposive sampling for all cases.

Data Gathering Instruments

In order to secure relevant and necessary data for the study, two potential data gathering tools were used: interview and document analysis. Interview was applied for all respondents at all levels federal, region, zonal, sub city, district and centre adult education officials, experts and supervisors and adult education centre coordinators and facilitators. The interview provides flexibility to the interviewers to secure views, perception, understandings, experiences of the interviewees in the areas of adult education policy formulation and implementation. In order to substantiate the information gathered through interview, document analysis was also used as data gathering tool. By focusing on the content, context, and meaning within documents, researcher can better understand complex social phenomena.

Population and Sampling

Oromia Regional State and Addis Ababa City Administration were purposively considered for the study. Oromia, the largest region in the country (CSA, 2011), was chosen to represent other regions, while Addis Ababa was selected to reflect the situation of adult education programs in urban areas. From

these two regions, 2 zones in Oromia and 3 sub-cities in Addis Ababa were included. Using purposive sampling technique 20 adult learning centers and 15 districts were deliberately selected for the study. The study involved a total of 46 participants, including 20 facilitators, 20 experts and 6 officials.

Results and Discussions

Types of stakeholders to be participated: The National adult education strategy emphasised the active involvement and coordination among those sectors working to strengthen the adult education programs in Ethiopia (MoE, 2008). This strategy emphasizes that to guarantee quality in curriculum development, various stakeholders must be involved. The adult education implementation guideline further outlines the various stakeholders who should be involved in the curriculum development of adult education programs. These stakeholders include personnel from education, agriculture, labour and social affairs, NGOs, local administrative officials, and community leaders. This idea is directly aligned with the findings of Samuel (2022) and Deriba. *et al* (2022) who emphasize that Ministries of Education, along with regional and local education offices and relevant government departments, play a critical role in policy formulation and implementation.

Furthermore, the strategy identifies the stakeholders responsible for monitoring and provide support supervision in adult education programs. These stakeholders encompasses facilitators, supervisors, community representatives, political leaders, NGOs, civil society organizations, program leaders, coordinators, development workers and adult learners themselves.

Adult education programs are community-centered initiatives that requires careful planning, implementation and evaluation with active involvement from the community. The primary aim of the programs is to enhance the wellbeing and quality of life within the community. In summary, the involvement of the key stakeholders as outlined in the national adult education strategy, especially, the local community is significantly limited in nearly all aspects of the implementing adult education programs. Restricting the involvement of the local community, undermines the overall effectiveness of the programs.

In line with the ideas set out in the adult education national strategy and implementation guideline, the master plan for the adult education program also recognizes the leading role of the Ministry of Education, and recognizes that adult education is not the responsibility of any a single group. Government ministries and institutions, universities, technical and vocational education and training (TVET), NGOs and the private sector all have a significant role to play (MoE, 2008).

Concerning stakeholders' engagement in the implementation of adult education program, respondents across various levels in both regions consistently indicated that the involvement of other sectors to the implementation of adult education remains minimal. In supporting this idea, a zonal experts of the Oromia Regional State noted that,

> *"Adult education was intended to be executed by the joint efforts of different sectors. Some of these are: education, agricultural and rural development, health, gender and other development related sectors; however, these sectors do not consider adult education program as part of their duty and responsibility. They have left the program solely to the education sector. Thus, in practice, the programme is run by education sector at all levels of the structure."*

Dimensions of stakeholders' involvement: In response to the enquiries concerning various 'aspects of stakeholders' engagement, the respondents comprising officials and experts consistently acknowledged that multiple entities are actively engaged in the execution of adult education programs. Gboku and Lekoko (2007) delineate stakeholders participation in to several key modalities, including representational participation,

information sharing, consultation, joint decision-making, acting together and building independent community initiatives.

The Adult education implementation guideline emphasizes the necessity for the Ministry of Education, relevant ministries, and other government institutions prioritize the enhancement of collaboration and networking with NGOs, and sector specific associations and development partners in the area. This is because they have expertise in their different areas of specialisation (MoE, 2011). The guideline further discusses some of the areas of ccollaboration for these organisations and associations: utilisation of existing structures, research and documentation exchange, provision of technical support in specialised areas of training, resource mobilisation, training materials development and production, lobbying and advocacy, curriculum development and monitoring and evaluation among others (MoE, 2011).

Despite the involvement of numerous stakeholders in the implementation of adult education programs across the country, the contribution have not led to significant improvement to the nation's low literacy rates. This is due to lack of organized and coordinated participation, as observed both from the preceding the discussion and the researcher's personal experience.

Regarding community as key as stakeholders, the Ministry of Education (MoE, 2008) emphasizes that stakeholders' participation should prioritize placing the community at the core of the entire process. Similarly, the Oromia Education Bureau (OEB, 2008) underscores the critical role of the community plays in ensuring the success of the adult education programs.

The document identifies the following key activities as requiring the highest level of community participation:

"selecting and preparing education program centers, building facilitators' accommodation and reading rooms up on their own choices, facilitating all the necessary conditions, selecting curriculum content based on their own needs and interests, preparing an educational plan, thoroughly participating in the program, monitoring and evaluating the process, participating in learning and those who are educated in teaching; providing especial assistance for women and girls to learn, participating in the recruitment and evaluation of facilitators, providing the necessary facilities and assistance for coordinators, teachers and supervisors, mobilized to monitor adult non-formal education program and taking part in contributions or support activities necessary to strengthen adult non-formal programs, and following up and evaluating adult non-formal programs."

Areas of participation should be in resource allocation, regulatory frameworks, curriculum development and monitoring and evaluation.

Resource mobilization: The information gathered through interviews with adult education officials and implementers showed that the responsibility of resource mobilization should not rest exclusively with the government. It should be a shared responsibility among the MoE (ministry of education), REBs (regional education bureaus), local communities, workers, non-governmental organisation, private organisations, associations and individuals. The respondents also forwarded that stakeholders should have to actively participate in the area of resource mobilisation for the adult education program. Some of the ways that need to be applied by program stakeholders were:

"*preparing a lottery for fund raising, project proposal writing, taxation (establishing a licence for adult education), regular budget provision by central, regional and district governments; community and learners' contributions and grants and donations from NGOs and private organisations."*

Implementation of policy documents: adult education is widely recognized as multifaceted issue that necessitates the involvement of multiple sectors. Nevertheless, it was not until 2005 that the Ethiopian Ministry of Education

formally advocated the active engagement, ownership and commitment of local communities, NGOs, and civil society actors in adult education agenda. In ESDP-III, in addition to the regions which play an active role in organizing the program and preparing materials in the mother tongue, NGOs which work on adult education have also been welcomed for the expansion, better local responsiveness and relevance of the program (Genet, 2014).

The National adult education strategy (MoE, 2008) also re-emphasized the active involvement and coordination among those sectors working on education and others for strengthening the program. Similarly, in Education Sector Development Program (ESDP IV), the Ministry of Education again showed interest in strengthening its partnership with government, the private sector and NGOs for better provision of adult education. Prompted by this, as indicated above, the Ministry of Education together with five other ministries signed Memorandum of understanding (MoU) to make adult education program more integrated (MoE, 2010). In the same way, in the master plan for adult education, it was stated that the multidisciplinary nature of adult education necessitated the inclusion of various sectors in its provision (MoE, 2010). It reads:

"Functional adult education builds on indigenous knowledge and seeks to link writing, reading and numeracy skills to livelihoods and skills training in areas such as agriculture (including off-farm activities), health, civic, cultural education, etc. Such an approach requires delivery by various governmental and non-governmental service providers in multiple settings and also ensures that literacy skills development is meaningful to the learners".

The Ministry of Education, in addition to other government ministries, recognized the active role institutions, universities, TVETs, NGOs and the private sector play in the effective provision of the adult education program. However, the practice and experience of Ethiopian shows that most health extension workers and development agents do not regard adult education as their responsibility as the signing ministries' roles are not cascaded to the grass roots level for the integrated implementation of the program.

More specifically, according to Knowles (1980), as agents of change, adult educators' responsibilities extend far beyond the routine scheduling of activities.

"Their responsibilities entail, rather, the involvement of clients in deep analysis of higher aspirations and the changes required to achieve them, the diagnosis of obstacles that hinder the achievement of these changes and the planning of an effective strategy for accomplishing the desired results. Their parts in this process is that of helper, guide, encourager, consultant, not that of transmitter, disciplinarian, judge, and authority."

Similarly, the interviewees (facilitators) were asked to evaluate the commitment of stakeholders towards adult education program implementation. Majority of the respondents argued that there is very low commitment among the stakeholders towards adult education program implementation. Concerning this issue, the response of one facilitator from Addis Ababa presented as follows:

"... In truly speaking, I am working in adult education sector until I can secure another job. Because at this position the monthly salary paid for me is about 1200 Ethiopian Birr (equivalent to 40 USD). With this amount of money, it is difficult to lead an independent life. As a result, I am forced to live with my family to get their assistance. In addition to this, there is no chance to continue and upgrade my education in the same field. The only chance that I have is to shift my career to formal education and join teacher training colleges to teach children. Because of these reasons, I am not committed to work in this sector."

In support of this idea, the study conducted by Deriba. *et al* (2022) revealed that lack of training and insufficient payment are rated as high challenges to the implementation of an adult education program.

The existence of conducive environment for stakeholders' Participation: The discussion made with interviewees at all levels of this study revealed that there is no well-defined structure to lead adult education program in the country. Concerning this problem, the respondents argued that the planned institutional system, including the national adult education board and technical committee were not organized well- which resulted in continued fragmentation and poor implementation status of adult education program. This situation may negatively affect the implementation of adult education program in the country. In this regard, one of the officials at Ministry of Education said that:

"Currently the implementation status of the program is not planned well; there is loose coordination among implementers and stakeholders; low commitment from implementers, stakeholders and political leaders' side to run the program."

Consequently, boards and technical committees at all levels have not functioned effectively, primarily due to absence of dedicated professionals to lead and implement the program. As a result, many adult learning centers have been deprived of the necessary technical support.

Regarding the existence of conducive condition for the stakeholders to participate in adult education program, the officials at federal level appreciated the presence of national adult education strategy and more than 10 working policy documents can be considered as a conducive environment for the stakeholders to participate in the program. However, they commented that the existing structure of the adult education sector is not functioning properly, because the program is run by a committee (board) at all levels of the government political structure where there is no accountability for the failure or success of the program. In practice, as stated by one of the respondents from Oromia, read as:

"The coordination among sector ministries in the horizontal relationship is weak and the vertical relationship is limited only within the education sector."

The absence of a well-established and systematic coordination framework has resulted in the fragmentation of stakeholders' efforts and resources, thereby undermining the effective implementation of adult education program. This also brings about duplication of efforts and wastage of scarce resources in the implementation process. For instance, according a higher official from Ministry of education stated that

"...the adult education board established at federal level had not met for the last two years". Some of the contributing factors, according to the same interviewee, were "*lack of commitment, absence of clear structure that enabled the stakeholders to participate in* adult education *program, the absence of clear guidelines and lack of accountability mechanisms for the stakeholders on how to participate in the program*."

From the discussion the researcher concludes that the mere existence of guidelines, manuals, rules and regulations alone is insufficient to achieve the intended outcome of adult education programs. In addition to these system documents, equally important is the presence of well-established organizational structure, responsive and need based approach and active participation and commitment of stakeholders are mandatory. In addition, the involvement of local communities, civil society, and learners in policy design and implementation has paramount importance. Further the existence of feedback mechanisms and responsiveness to needs of the learners is equally important.

Conclusion and Recommendation

The finding of the study reveal that various categories of stakeholders are involved in the implementation of adult education program in the country. Despite considerable efforts by both government and NGOs, illiteracy rates remain high and overall implementation of the program is sub-optional. This situation implies the absence of well-established coordination mechanism to align stakeholders' effort and

resources towards the effective implementation of adult education program. This brings about a duplication of efforts and wastage of resources.

It is therefore recommended that adult learning centers and district education offices, in collaboration with other key stakeholders like agriculture, and health offices should mobilize the community and promote adult education programs. Additionally, communication channels (medias) and community-based structures including public meetings, conferences, forums community-based social support *(idirs)*, community-based financial support (*ikubs*), as well as religious institution like churches and mosques, should be leveraged to enhance outreach efforts and effectively disseminate relevant information to all stakeholders.

Based on personal experience and observation, the researcher recommends that the effective formulation and implementation of adult education policy documents necessitate enhanced collaboration and networking among the Ministry of Education, relevant line ministries, and other governmental institutions, NGOs operating in adult education sector and development partners. These stakeholders possess diverse areas of expertise and comparative advantages, which, if harnessed through strategic partnerships can significantly strengthen policy outcomes. Potential areas of collaboration include utilization of the existing institutional structures; joint research and knowledge exchange; provision of technical support in specialized training areas of training; resource mobilization; development of training materials; curriculum development; and monitoring and evaluation of the program.

Conflict of Interest

The author declares that there are no conflict of interest associated with the publication of this study.

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RESEARCH PAPER

Exploring the Lived Experience of Students with Hard of Hearing Impairments in Primary Schools at Ambo Town

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Abstract

The purpose of the study was to investigate the lived experiences of students with hard of hearing impairment (SWHHI) in Ambo town, Ethiopia. A phenomenological study was employed for this study. Seven students with hard of hearing were purposefully selected and interviewed. The qualitative analysis yielded three overarching themes: challenges of SWHHI, support provision for SWHHI, and coping strategies. The findings of this study showed that participants received support from home and school though not in a consistent and planned manner. SWHHI faced challenges including, communication barriers, social isolation, and community attitude related problem. Moreover, coping mechanisms such as self-help, adaptation, social networking, and creating supportive learning environments, were emerged as crucial strategies for overcoming academic challenges emanated from hearing loss. These findings contribute to a more nuanced understanding of the lived experience of SWHHI and offering implication for creating accessible and inclusive learning environment for SWHHI.

Keywords: Hearing impairment, inclusive education, phenomenology, coping strategies

Introduction

Globally, individuals who are partially deaf are referred to as hearing impaired (WHO, 2011). When someone uses amplification devices like hearing aids to help them hear better (Asres, 2018), it usually relates to their difficulty hearing sounds, especially speech (WHO, 2011). People who have hearing impairments are typically described as having difficulty with communication, social participation (Malado, 2024), and daily functioning, especially in noisy environments or environments where there are many speakers and loudspeakers (Smolen and Paul, 2023). It is recognized that hearing impairment (SWHHI) poses significant barriers in various walks of life, particularly in educational settings (Aldersey *et al*., 2024).

The challenges for primary school students with hearing impairments include a lack of good support provision, the problem with the school physical setting, a lack of community support for SWHHI, a lack of social integration, and the impact on their emotional health (Malado, 2024). Hearing impairment is considered a high difficulty and risk for providing quality education to students with hearing impairment in developing countries (WHO, 2011). Students with hearing impairments have special challenges and opportunities in Ethiopian primary schools (Tesfaye, 2020), which have a significant impact on their academic development and social integration (Wezzie e*t al.,* 2020). According to earlier studies, social isolation, communication hurdles, and educational challenges are common issues faced by SWHHI (Tesfaye, 2020). Overcoming all obstacles, particularly those posed by their classmates and the school community as a whole, is essential for children with SWHHI to

successfully navigate this crucial time (Tedla and Negassa, 2019).

Provision of technical and resource must be available for SWHHI, teachers, and educational experts who work with SWHHI more closely and help them by using sign language (Wolderufael, 2022). Education stakeholders need to acknowledge and assist students with hearing problems (Chimdi *et al*, 2015), regardless of their severity, since they can greatly hinder their capacity to learn and communicate in the classroom (Mekonnen *et al*., 2015). Hearing issues, ranging from minor to severe, can significantly impair students' abilities to communicate and learn in the classroom, and it is the responsibility of education stakeholders to recognize and support them (Tedla and Negassa, 2019). Children with SWHHI require specific assistance, particularly schooling materials and support services for students with hearing impairment because they frequently experience severe problems and hazards with inadequate support (Deginesh and Arsat, 2016). Since primary school sets the groundwork for later learning and personal growth, it is seen as a crucial stage in a child's development (Abunu, 2022).

Extended and systematized help is necessary for students with hearing impairment if we want them to benefit from educational opportunities like their age mates (Tedla and Negassa, 2019), In particular, issues such as adapting teaching strategies, having access to assistive listening devices, or improving learning environment in the way barriers to academic and social activities will be resolved should be thoroughly investigated and put in place (Tesfaye, 2020). However, the poor quality of such provisions (Garbi, 2023), particularly in resource-scarce settings, causes serious challenges on the education of SWHHI. In line with this notion, a study conducted by Mekonnen *et al*. (2015) unpacked the socio-emotional challenges SWHHI had been going through in Ethiopia.

Coming to Ambo town where the principal researcher has been working for over 15 years, there are SWHHI across the schools within the town. And these students have been going through hardships with no or a meager support to address their specific needs. However, there is no formal study conducted and documented the experience and the challenges these students are going through and how they are managing the challenges and able to stay in school. Therefore, this article aimed to explore the lived experiences of students with hearing impairments (SWHHI) in primary school grades 5 to 8, in Ambo Town, Ethiopia. It highlighted issues like their experience of being hard of hearing, available supports, challenges they faced and coping strategies they employed. The results are meant to help concerned bodies create resources and tactics that work for SWHHI.

Materials and Methods

Research Design

Phenomenology is the study of phenomenon, i.e. experience, event or emotion where they lived experiences of people will be explored and conceptualized in the way they understood and lived with (Creswell and Poth, 2018). As a result, a phenomenological study was chosen to study the lived experience of students with hard of hearing in Ambo Town Elementary School.

Participants of the Study

In the phenomenological study, the number of participants typically ranges from 5 to 25 (Creswell, 2014). In this context, 7 students with SWHI from grades 5 to 8 were purposively selected for the study. The purposive sampling method was employed as the primary method for selecting the participants (Creswell, 2013).

Procedures of Data Collection

Three schools having students with Hard of Hearing Impairments were purposefully selected. They are Addis Ketema, Awaro, and Liban Mecha Primary Schools. Following the selection of the schools, the principal investigator reached out to students with SWHHI to obtain their consent (Creswell,

2013) after permission granted from each school. The ethical clearance letter the researchers obtained Ambo university's Department of Special Needs and Inclusive Education were presented to schools while requested them their cooperation.

In-depth interviews were utilized to gather data for this study (Creswell and Poth, 2018). All interview were conducted by principal investigators being supported with interview guides developed by both researchers. During the interview, the researchers was used open-ended prompts to encourage students with SWHI to reflect on their experiences and articulate their perspective. In so doing, the tips and tricks proposed by Creswell and poth (2018), to solicit deep and authentic experiences.

The prompt are designed to elicit rich descriptive account that capture the nuances and complicities of the schooling experiences (Creswell 2014). After conducting in depth interviews ,the researcher transcript each of the seven interviewees in the language of the interview (Afan Oromo). They assigned pseudonyms to each transcript ,labeling them as transcript 1 through 7. All identifiers that could reveals the participants entities were removed. Subsequently, each transcript was translated them in to English, preparing them for analysis. Then, we analyzed data though thematic analyzes to identify key theme and pattern in participants lived experiences.

Finally, we interpreted finding to understand the essence of the phenomenon under investigation; all with an emphasis on the perspectives and meaning participants generate for their experiences (Creswell and Poth, 2018).

Method of Data Analysis

In this article ,a detailed and interactive process of analyzed individual cases to understand the lived experiences of participants was employed. In this study reflective thematic Analyses was employed. Open coding was employed during analysis to break down qualitative data into meaningful codes and concepts (Chinyere and Val, 2023).

This allowed the researcher to identify important themes and arose directly from the experiences of the participants without the needs for preconceived categories ,an essential step in delving into lived experiences. To develop a more thorough understanding of the phenomenon by analysis the interactions between various themes, the researchers then employed axial coding ,which involves finding connection and relationship between the initially coded concepts

The data interpretation involves a deep immersion into students with SWHI impairments narratives ,focusing on identifying key themes and meaning related to their lived experiences of their educational challenges and opportunities. To gain a thorough grasp of participants lived experiences and significant the attach to a given phenomenon ,the researcher coded categorized and analyzed the data

Trustworthiness

Creswell (2009) outlines several strategies for enhancing trustworthiness in phenomenology studies Among these, one is establishing a clear and coherent process for data collection, analysis, and interpretation (Alase, 2017). As a result, the researchers documented their methods thoroughly to allow for replication and verification of the findings (Adler, 2022).

The second strategy is ensuring credibility. The researchers were engaged in prolonged engagement with the phenomenon under study (Adler, 2022). This entails devoting enough time to fully comprehend the research setting to have a thorough comprehension of the experiences of student with hard of hearing impairment (Creswell, 2009).

Additionally, researchers used two types of data sources, such as interviews and observations to triangulate findings and corroborate interpretations (Tsang, 2014). However, the data from observation was not included in the report. We used it only to

triangulate and understand better what has been accounted by interviewees.

In this article, transferability was also ensured. While phenomenology studies often focus on the unique experiences of specific individuals or groups, researchers strive to provide rich, detailed descriptions of the phenomenon to enhance transferability (Adler, 2022). By providing thorough contextual information and vivid descriptions of participants' experiences, researchers enable readers to assess the applicability of the findings to other contexts or populations. In sum, by incorporating these strategies, researchers enhanced the trustworthiness of the study.

The researchers ensured the confidentiality of participants identities and data. This includes securely storing and anonymizing data to prevent unauthorized access or disclosure (Creswell and poth, 2028).The researchers used pseudonyms or code to refer to participants in any report or publication to protect their privacy

In addition, Participation in the study was voluntary ,participation did not feel coerced or pressured to take part (Creswell and poth, 2018). Researchers was made it clear that participation in entirely voluntary and that individual can withdrawal from the study at any time with consequences.

Ethical Consideration

Moreover, in the study the researchers obtained ethical approval from institutional review boards (IRBS) before conducting the study. Ethical Approval ensures that the researcher meets established ethical standards and guidelines and protects the right and welfare of participants (Creswell, 2009).

By adhering to these ethical considerations, the researcher conducted phenomenological studies responsibility and ethically ,respecting the rights, well- being and dignity of participants while producing valuable insight into the schooling of students with disability at primary school in case of Ambo Town.

Results

Table 1. The participants descriptive demographic data

Name	Sex	Grade	Types Disability
P01	Male	7	Hard of hearing impairments
P02	Female	8	Hard of hearing impairments
P03	Female	5	Hard of hearing impairments
P04	Male	5	Hard of hearing impairments
P05	Male	5	Hard of hearing impairments
P06	Male	6	Hard of hearing impairments
P07	Male	6	Hard of hearing impairments

Table 1 indicates that the 7 students with hard of hearing impairments (SWHI) in grades 5 to 8 participants in this study.To maintain secrecy, each student is represented by a code; sex, grade, and kind of disability are among the demographic characteristics. Students with hard of hearing impairments (SWHI) are the focus of this study. This data sheds light on the makeup of the student sample and helps to clarify the traits of the participants who contributed to the study's conclusions.

Theme 1: Challenges of the schooling experience for SWH

Table 2. Themes and Subthemes

Groups	Categories
Theme 1	**Challenges of the schooling experience for SWHI**
Subthemes	Communication barriers
Subtheme	Social isolation
subtheme	Community's attitude
Theme 2	**Support provision for SWHI**
Subtheme	Support from family for SWHI
Subtheme	Support provision in school for SWHI
Theme 3	**Coping strategy for SWHI**
Subtheme	Self-help
Subtheme	Adaptability and resilience
Subtheme	Networking
Subtheme	Creating accessible and inclusive learning environment

Table 2 shows that the study's findings were categorized into themes. Three main themes were developed, with sub-themes established beneath each theme.

Theme 1: Challenges of the Schooling Experience for SWHI

One of the most recurring themes in the discourse of the participants was *the challenge* they were going through in relation to hearing status. *The challenge* appeared to manifest itself in terms of communication barriers, social isolation, and community's attitude.

Communication barrier – In this context, it refers to the lack of effective information flow necessary for creating a shared understanding with one's environment. Shared understanding is crucial for social interaction and the learning process. The creation of this understanding depends on how well individuals receive, analyse, and respond to information from their surroundings. However, communication barrier emerged as one of the common challenges students with hard of hearing impairments are facing. Communication barrier, according to participants, deprives learners' valuable learning opportunities. For illustration:

....I frequently missed important information during lessons and struggled to follow classroom discussions…" (P01).

"....My hearing condition is challenging me to understand my teachers and fellow peers. (P02)

The biggest issue has been understanding the teacher's voice clearly. Particularly when there is a noise and disruption in the classroom, it becomes very difficult to follow what the teacher is saying. This in turn affect my ability to follow instructions, participate in class discussions, and engage in group activities. P07

As the above excerpts show, SWHHI in Ambo town are experiencing communication barriers which negatively interfere with their learning process. Because of the hearing challenges, these students couldn't properly understand instruction, and engaged in the learning process.

Social isolation - being SWHHI in Ambo Town, is not only hindering academic engagement but also contributing to feelings and/or act of *social isolation*. These students are tend to isolate themselves and other also leave them behind. The following excerpts were selected to shed light on the issues from the house's mouth.

I often perceived as silent or withdrawn. Because of that, I ended up distancing myself from my classmates and became quite isolated. This social isolation made it difficult to form network with other classmates. (P07).

I also struggle to communicate with my friends. Because of communication problems, I was often left out. Participating in group work was difficult. I could not understand what was going on, and sometimes others seemed to avoid working with me. This made me feel lonely and less confident. P01.

Sometimes, having a hearing impairment feels like being isolated from others. But I try to stay calm. I know that I'm different from others, and often that brings me anxiety. If someone is angry because I didn't hear them, I feel hurt. P03.

Community's attitude – Another critical challenge faced by SWHHI is the lack of a supportive school community that understands their needs and acts responsibly. While some teachers and classmates offer excessive care, others tend to ignore them, primarily due to a lack of understanding. One student noted:

I experience mixed attitudes. I enjoy learning with friends and teachers who support me, but it's difficult to deal with those who don't understand me. a few others treat me differently. Sometimes they act like I'm not smart just because I can't hear. It makes it hard to talk or play with them. P04.

Another interviewees added:

No one really understands my situation properly. Sometimes, I remain silent in class out of fear because I didn't hear what was said. Teachers tend to overlook my hearing problem. P05

Some teachers don't understand that arranging seat and providing resource that compensate student with hearing impairments is their responsibility. ...these teachers and school leaders don't provide us the support we entitled to received. P06

".....no one can understand me... lack of awareness leads me to misconceptions, inappropriate actions, or even discrimination in educational settings...."(P04)

In general, students who are hard of hearing (SWHHI) face significant challenges related to communication, social isolation, and the community's understanding and attitudes toward their needs. The communication barriers resulting from hearing difficulties often exacerbate these challenges. Many SWHHI struggle to fully comprehend what teachers and fellow students are saying, leading to discomfort and a diminished sense of belonging. This discomfort can result in social withdrawal or exclusion from peers. Additionally, a lack of awareness regarding the nature of hearing impairments, as well as the rights and support required by SWHHI, causes the school community, including teachers, school leaders, and fellow students, to overlook their needs.

Theme 2: Support Provision for SWHI

The support provision for students with hearing impairment in schools is critical for facilitating their academic success. Within this context, the availability and accessibility of learning materials are critical factors that influence the learning experiences of students with hearing impairments. The discussion on support for students with hearing impairments revealed two key subthemes: support from schools and support from families.

School-based support - Schools are normally expected to identified the specific needs of students and make necessary preparation and support that make all learning environment, learning materials, and learning activities accessible to SWHHI. However, as seen from the extracts below, such support is not provided in the study cites in a planned and consistent manner.

"….Throughout my elementary school years in Ambo Town, I had limited access to assistive technology, such as hearing aids."(P07).

Some people try to understand and support me, but many do not. That makes me feel like I lack self-worth or confidence. Sometimes, when I try to explain myself, others don't understand or even seem to ignore me, which feels painful. P02

Most of the time, when teachers assign homework, I don't fully hear what they say. Either their direction or voice doesn't reach me clearly. So, I struggle to understand what I'm supposed to do for homework. P05

From this result, school-based support for students with hearing impairments in primary school in Ambo Town was very limited from year to year. Even the important educational material for SWHI was very limited and needed the attention of the responsible body.

Family-based support - some of the respondents reported that the family-based support provision was a reason for their success at least in school attendance. One participant said: .... *to overcome the difficulties I am with because of my hearing, my family's support has been crucial. They speak out for my needs, emotionally supporting me, and avail resources and accommodations to facilitate my education…"(P06)*

Another participant added:

*Despite the hardships they are going through at home, my family has been the most supportive pillars in my educational journey. Even though my family has a limited budget, they are giving me practical help, motivation, and emotional support. ... They are the only reason for my progress in schooling despite my hearing loss. They constantly support me at home and bring my issues to my teachers through discussion…(*P09).

Family-based support is perceived by many respondents as an immediate and plausible solution for tackling challenged posed by hearing impairment. One important factor in overcoming these difficulties turned out to be family-based assistance. To obtain needed resources and accommodation, respondents mentioned that their families played a crucial role in supporting them emotionally, speaking up for their needs, and advocating for them (P06). The grants not only enhanced their educational path but also enabled them to practice communication strategies at home and interact with teachers in the classroom (P09 & P01). While social and family support were generally found to have some beneficial elements (Wakoya, 2024), it is clear that educational settings need better support systems and more comprehensive assistive technologies (Tedla and Negassa, 2019).

Theme 3. Coping Strategies of SWHI

Students with hearing impairments have their coping strategies in primary school in Ambo Town. *Self-help, adaptability and resilient, networking, and creating accessible and inclusive learning environment*.

The respondents responded that *self-help* (assertiveness) is a way of overcoming the challenges of the schooling experience. *"...For*

me, being hard of hearing in school is about embracing who I am and finding strength in the unique experiences I have had. "…..I have a profound respect for the strength of advocacy and self-determination as a result of overcoming the difficulties associated with attending school while hearing-impaired. I believe in advocating for my needs and rights as a student with a disability, while also empowering others to do the same."(P07).

Another participants added that adapting oneself to and resiliently confronting the challenge posed hearing loss as one of the best coping strategy.

Despite the obstacles, I learned valuable lessons like being resilient and keep on flexibly adapting myself to the situation. I do all possible things to catch up with my classmates…(P06).

Yes, I commit to lifelong learning! My experience has reinforced my belief in the transformative power of education and lifelong learning. Despite the challenges I have faced, I remain committed to pursuing knowledge, growth, and personal development, recognizing education as a lifelong journey of discovery…" (P03).

It is interesting that SWHHI tends to use flexibly combination of strategies such as changing seating position, using assistive device, and seeking support from fellow students.

… I use a range of techniques, including making use of assistive technology, taking a seat in the front of the room to improve my ability to hear the teacher, and being honest with both teachers and peers about my needs. To prevent burnout, I also make sure to give self-care priority and effectively regulate my energy levels. I try to reach out friend also for their help whenever I need…. (P07).

Based on these results, we can infer that an important tactic employed by students with hearing impairments in Ambo Town primary schools to get over obstacles in their educational journey is *self-help* and *assertively adapting self* to the existing situation. . According to the respondent's view, resilience is mostly attributed to accepting oneself and finding strength in one's own experiences.

There are also participants who witnessed the act of initiating and sustaining *social network* as ways of overcoming challenges triggered by hearing loss. Two of the interview extracts presented hereunder for illustration.

…. I have good relationships with some of my classmates. I borrow an exercise book from them. They are cooperative in this regard. …This helps me to compensate for what I missed during teachers' teaching….I do the same with my family members and teachers as well (P04).

I always take the initiative to create a contact and friendship with fellow students. ...My friends are my mirror. They are my second family. They understand me well, and they facilitate everything for me in the classroom… (P05).

The above excerpts, therefore, indicate that students with hearing impairments in primary schools in Ambo Town demonstrated the possibility of overcoming educational challenges driven by hard of hearing through establishing network with fellow students, teachers and family members.

Creating an accessible and inclusive learning environment is another strategy that participants in the study emphasized as essential for ensuring quality primary education for all students, despite having been denied this opportunity themselves. For illustration:

….My experience has made me a firm believer in the value of accessibility and inclusivity in education. I believe that every individual, regardless of their abilities or disabilities, deserves equal opportunities to access education and thrive in a supportive learning environment.…However, reality on the ground is far from this…(P06).

"*…..I couldn't find conducive situation like alternative seating, access to assistive*

technology, and communication support like sign language, or writing services that I actively seek out, and no one at this school remembers this. Sometimes, I need teachers or administrators to meet my needs, but I have learned that I have never spoken to them, and their understanding is low...."(P03).

In general, there are multiple strategies that can be used to overcome education related to challenges by students with hearing impairment. Among these, *self-help, adaptability and resilient, networking, and creating accessible and inclusive learning environment* emerged as core strategies by the study participants. The evidence implies that to ensure equal opportunities for all students, it is necessary to increase inclusion and accessibility in educational settings, educational materials and teaching methods. Besides, school-based and home-based support should be well coordinated and provided in program manner.

Discussions

The study provides insight into the lived experiences of students with hard of hearing impairments .Several recurring themes brought to light the difficulties SWHI students encounter ,as well as the coping mechanisms and network of support that help them remain resilient.

The study highlight how it is for families and educational institution to support SWHI student (Vuuren *et al*., 2023).While it may be difficult for school to make suitable modification (Fite, 2023), family support is essential for promoting students' needs and advancing their education(Asres, 2018). Nonetheless, there are still accessibility and understanding, which suggested that SWHI students require more resources and support.

During their time in school ,SWHHI face a variety of difficulty ,among which *social isolation* is one. This finding is also confirmed by study conducted by Tadla and Negassa (2019), in their study on deaf student in the northern part of the country. Moreover, *communication* obstacle, and lack of understanding from school community also reported as difficulties that affect students well-being and academic achievements which emphasizes the need for more understanding and assistance in learning environments (Asres, 2018). Students at SWHHI show tenacity and resourcefulness in overcoming obstacle to education despite the difficulties they encounter (Chimdi, 2015).The development of supportive relationship, flexibility ,and self-help become as essential strategy for overcoming the challenges of education for those with hard of hearing impairments (Malado, 2024). SWHHI students enable others and themselves to achieve academic success by speaking up for their needs and creating inclusive environments (Wolderufael, 2022)

Conclusion

This study focused on the lived experiences of SWHHI in primary school Ambo Town. The result of this study indicates that SWHHI face difficulties in various aspects of their educational journey.

Notable, challenges such as isolation ,communication barriers ,and issues related to their characteristics of school community were observed. Parents and the school support are seen as crucial to the academic success of children with HHI at Ambo Town Primary School.

The research indicates that children should be able to advocates for themselves and adapt to their environments to overcome challenges. These finding suggest that educational institutional must support system establish inclusive policies and a thorough support system to embraces and children to overcome challenges ,they should be able to advances for themselves and adapt to their environments.

Implication

To ensure that students with hard of hearing impairments can fully participants in educational activities, school should priority proving adequate material support and accessible infrastructure. Training teacher and other school staff on the specific needs of hard

of hearing is essential for creating a more inviting and supportive learning environment. Involving family in the education process and encourages peer support network can enhance educational activities of SWHHI. Additionally, fostering self-assertiveness and resilience's among these students can empower them to overcome challenges and achieve academic success.

Recommendations

Based on the findings of this study students with hard of hearing should receive support tailored to their specific needs and challenges within the educational setting. It's important to increase among classmates, teachers and administrators regarding the problems SWHHI students face, and to be appropriate instructional actions when problem arise. SWHHI students should be provided with adequate resources and accommodation, such as assistive technology and sigh language ,to develop their learning and communication skills and to live well with the community.

In a welcoming and inclusive school culture that celebrate diversity ,it is good to make and encourage students and staff to feel compassion and empathy for each other. To better support SWHHI students it's necessary to provides teachers and with opportunities for professional developments and train to improve their knowledge and skill on the issues of students with SWHHI.

Conflict of Interest

The author declare that there is not conflict interest regarding the publication of the paper.

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RESEARCH PAPER

Analyses of Hepatitis C Virus with Targeted Treatment for Chronic Infections: Mathematical Modeling Perspective

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Abstract

This paper examined the spread of hepatitis C virus (HCV) infection among population of chronically infected individuals receiving treatment. The model classifies individuals into five categories: susceptible, acutely infected, chronically infected, treated, and recovered, and is governed by a system of nonlinear ordinary differential equations. The qualitative analysis focuses on key solution properties such as positivity, boundedness, existence, uniqueness, and the stability of the disease-free equilibrium, along with a sensitivity analysis. MATLAB simulations provide additional insights into the progression of the infection. The study findings highlight the potential of timely intervention, using either direct-acting antivirals (DAAs) or natural herbal supplements under medical guidance, to significantly reduce the duration of chronic HCV infection and ultimately eliminate the virus.

Keywords: acute, chronic, hepatitis c virus, model, reproduction number, sensitivity analysis

Introduction

Hepatitis C virus (HCV) is transmitted through blood-borne infection that inflames and damages the liver, significantly increasing the risk of liver cancer. While the virus may start with a seemingly minor infection, it can progress to chronic diseases such as cancer and liver cirrhosis. Despite being identified in 1989, it has now grown into a serious threat to public health (Shi, R., and Cui, Y. 2016). The virus is transmitted through various routes, including the sharing of contaminated needles and other drug paraphernalia, unsafe blood transfusions, and unprotected sexual contact (Sadki *et al.,* 2023). According to recent WHO report, approximately 185 million people worldwide are affected with HCV. Of these, around 85% develop chronic infections, while experience acute infections. HCV is responsible for an estimated 350,000 deaths each year, and currently, there is no vaccine available to prevent hepatitis C infection. In Australia, direct-acting antivirals (DAAs) have been introduced for the treatment of chronic hepatitis C, offering high cure rates with minimal side effects (Nguyen *et al.,* 2023). While DAAs represent a significant improvement, the "one-size-fits-all" approach has its limitations. The DAAs industry is increasingly recognizing the importance of personalized medicine, tailoring treatment to individual patient characteristics for optimal outcomes (Nguyen *et al.,* 2023).

Mathematical models are powerful tools; they don't just predict, they can also guide research. They help us pinpoint crucial biological factors that need more investigation and suggest changes in behavior or medical care that could improve patient results. HCV, for instance, is a major public health concern because it can lead to severe complications. Yet, surprisingly little attention has been given to developing mathematical models to understand how HCV spreads within communities. Ahmed *et al.* (2022) investigated the dynamic of HCV using a fractal-fractional model, analyzing both local and global stability of the disease. Similarly, Elbasha (2013) developed a mathematical model to study how HCV spreads and how antiviral treatments affect its spread. Their model indicated that higher treatment rates with

more effective drugs, resulting in faster cures and fewer treatment failures, would significantly reduce the number of new infections and the overall impact of the disease.

The researchers also highlighted the importance of reinfection in understanding HCV transmission and the effectiveness of treatment. They concluded that highly effective treatments have the potential to significantly reduce the burden of HCV on public health. Ayobami (2020) developed a mathematical model to study HCV transmission, incorporating treatment and other control measures. The model showed that early intervention, including education, awareness campaigns, and intensive treatment at the initial stages of an outbreak could significantly reduce or even eradicate HCV. Mushayabasa (2014) assessed the impact of antiviral therapy, abstinence, and relapse on the spread of HCV, simulating the long-term dynamics of HCV cases over a 50-year period. The model suggested that increasing abstinence rates and reducing relapse rates could significantly reduce HCV transmission among intravenous drug users. Additionally, Shi, R., and Cui, Y. (2016) studied a mathematical model that examines the transmission of HCV, incorporating both chronic primary infection and the possibility of reinfection.

A fractional-order differential mathematical model was used to analyze the dynamics of HCV infection, considering both virus-to-cell and cell-to-cell transmission pathways, along with a rate of cure for infected cells (Sadki *et al.,* 2023). Martin *et al*. (2011) focused on HCV transmission among injecting drug users, demonstrated that the effectiveness of antiviral treatment is remains strong even in the presence of uncertainties regarding immunity. This suggests that treatment remains a crucial factor in controlling the spread of HCV, regardless of immune factors. In a study by Jia *et al*. (2019), a new model was proposed to understand how HCV spreads in China. Their model showed that the main way the virus spreads is through contact with people who are infected. They suggested several ways to stop the virus's spread, including reducing transmission through contact with infected individuals and speeding up virus detection. Additionally, they mentioned the importance of faster treatment and improving recovery rates for hospitalized patients. Rihan *et al*. (2017) established a mathematical model using a fractional-order derivative to analyze the dynamics of HCV replication. The model incorporated the effects of interferon-alpha (IFN) treatment and accounted for intermediate cellular interactions and delays in the viral life cycle.

The mathematical model presented by Pitcher *et al*. (2019) suggests that prioritizing treatment for individuals with advanced liver disease, while focusing interventions on incarcerated individuals and their injection network partners, could be crucial in eliminating HCV among individuals who vaccinate drugs. Chatterjee *et al.* (2021) used a mathematical model to explore how HCV infection spreads and how to control it. Their findings indicated that regular adherence to direct-acting antiviral (DAA) therapy is effective in preventing the disease, and that the duration and frequency of treatment (pulse therapy) significantly impact the progression and replication of HCV. Rong *et al*. (2013) developed a sophisticated multi-scale model that incorporates intracellular viral replication, allowing for the study of how the HCV changes in persistent cured with Direct-Acting Antivirals. Their analysis of data from persistent cured with the new HCV protease inhibitor, danoprevir, indicated that the drug effectively inhibits the virus from replicating and aids in eliminating the existing virus. Avendano (2002) proposed a model showing that increasing the death rate of infected liver cells and the free virus could effectively lower the viral load, based on a system considering uninfected and infected liver cells, HCV, and T-cells. Nguyen *et al.* (2023) studied how to use a different mathematical approach (optimal control theory) to create treatment plans that are specific to each person with HCV. Computer simulations showed that this approach could reduce the amount of virus and the number of infected liver cells, while also allowing healthy liver cells to grow. Using

adaptive neuro-fuzzy technology, Khodaei *et al*. (2002) developed and tested a new intelligent controller aims to effectively control HCV infection within the population. Wameko (2019) modeled the spread of HCV and analyzed the effectiveness of different control strategies, which include preventing new infections, treating acutely infected individuals, and providing treatment for those with chronic infection. The results indicated that the combined application of these strategies could eradicate HCV. Okosun (2014) investigated how optimal control strategies, including screening immigrants and treating HCV, influence disease transmission in a homogeneous population with constant immigration of susceptible individuals. Their research concluded that targeting both acute and chronic infections through treatment is the most effective approach to control HCV spread. Mehr *et al*. (2021) designed a sophisticated mathematical model to track HCV outbreak dynamics. This model accounts for various population groups, including those unaware and aware of their susceptibility, those with acute and chronic infections, and those receiving treatment. El Youssoufi *et al*. (2020) also developed a discrete mathematical model to study HCV infection dynamics and evaluated the effectiveness of various control strategies, particularly in the context of treatment. Their research explored the impact of each control measure and ultimately concluded that the proposed strategies were effective in reducing HCV burden. To determine the best treatment strategy for HCV among active IDUs, Martin et al. (2011) developed a model simulating HCV transmission and treatment over a 10-year period. Khodaei-Mehr *et al*. (2018) used ANFIS-based optimal control and showed that the proposed strategy effectively reduced the number of infected individuals by approximately 19% compared to other control strategies. Imran *et al*. (2014) also investigated the impact of different control strategies on HCV transmission dynamics using a deterministic model. Their analysis revealed that implementing a time-dependent quarantine strategy is the most effective and cost-efficient way to manage the disease. The study by Ainea *et at*. (2012) also revealed that addressing both treatment and the influx of infected immigrants is essential for effectively managing HCV transmission. Their findings emphasize the need to reduce transmission rates within the community to lower long-term prevalence of the disease.

A study by Mahroug and Bentout, (2023) generalized an age-of-infection model for heterogeneous environments. They addressed well-posedness, proving bounded, positive solutions despite the model's partial degeneracy and non-compact solution map. Djilali *et al*. (2024) explored a generalized nonlocal dispersion SIS epidemic model with spatial heterogeneity, subject to Neumann boundary conditions. Their aim is to analyze the model using a convolution operator for nonlocal spatial movement and a generalized incidence function.

Djilali *et al.* (2025) models a process in heterogeneous environments using spatiotemporal methods and distributed delay. The study by Din *et al*. (2021) examined the existence of a stationary Markov process in degenerate stochastic differential equations. Furthermore, it explores the influence of noise intensity, cell-to-cell infection, and time delays on virus dynamics, using realistic parameter values. tul Ain (2024) introduced a stochastic epidemic model of cholera transmission, designed to analyze long-term dynamics in migrating communities susceptible to pathogen contamination. The model consists of six distinct human and microbial groups, interrelated through mathematical formulas that capture disease traits and environmental noise.

In this article, model that investigates the dynamics of HCV infection among chronically infected individuals receiving treatment was developed and analyzed. The model classifies individuals into five categories such as S(t), C(t), A(t), T(t) and R(t), which stands for susceptible, acutely infected, chronically infected, treated, and recovered, respectively. Our findings demonstrate that rapid identification and treatment of those in chronic stages of HCV infection are key to effective and accelerated elimination. The rest of the paper is organized as follows: Section 2

introduces the mathematical model and the corresponding nonlinear system of ordinary differential equations. Section 3 explains the mathematical analysis of the model. The numerical simulation results and discussion are offered in Sections 4 and 5, with the conclusion delivered in Section 6.

Model Formulations

This model analyzes HCV infection in chronically infected individuals undergoing treatment using a mathematical approach. The model classifies the population at time `t` into distinct epidemiological groups, such as:

- The susceptible group, S(t) represents those in the population who are at risk of contracting HCV,
- The acutely infected class, symbolized by A(t) involves of persons who have newly contracted HCV, are asymptomatic, and may recover spontaneously without treatment,
- Chronically infected persons, symbolized C(t), are those with persistent HCV infection who remain infectious and face a high risk of liver failure or cancer without treatment,
- The treatment class T(t) symbolizes individuals who are actively experiencing treatment for chronic HCV infection, using either Direct-Acting Antivirals or natural herbal supplements. This classes contains those who have not yet succeeded a medication,

The number of recovered individuals at time t, denoted by R(t) represents those in the population who have recovered from HCV infection.

Thus, the total population *N(t)* is given by

$$N(t) = S(t) + A(t) + C(t) + T(t) + R(t)$$

In order to develop our model; we rely on the following assumptions:

(A1) Individuals in all classes have a mortality rate of μ from causes other than HCV.

(A2) The susceptible S(t) persons are engaged into the population through birth and migration at a constant rate π and get the recovered persons from the recovered class by the rate ω.

(A3) The acute infected A(t) group is increased from susceptible group by $\beta\lambda$ screening rate and decreased by disease induced death rate δ_1.

(A4) The chronic infected C(t) class is increased from susceptible group by (1- β)λ screening rate, the acute group by the rate Ɛ and also increased by getting some persons from treatment failure rate ρ and decreased by the disease induced death rate δ_2.

(A5) The treatment T(t) class is increased from chronically infected class by the rate progression η and decreased by the disease induced death rate δ_3.

(A6) The recovered R(t) class grows as individuals from the treatment class are cured at a specific cure rate γ.

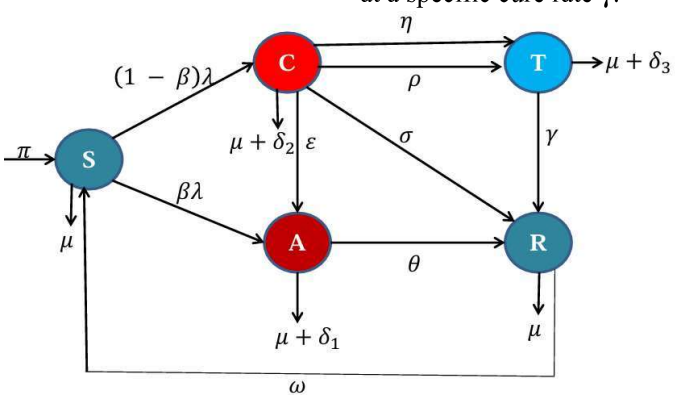

Figure 1: Flow diagram of the HCV infection transmission model, incorporating treatment.

Given the assumptions and the flow diagram (figure 1), we can set up the system of non-linear ordinary differential equations as follows:

$$\frac{dS}{dt} = \pi + \omega R - (\mu + \lambda)S,$$

$$\frac{dA}{dt} = \beta\lambda S - (\varepsilon + \mu + \delta_1 + \theta)A,$$

$$\frac{dC}{dt} = \varepsilon A + (1-\beta)\lambda S + \rho T - (\mu + \delta_2 + \eta + \sigma)C, \quad (1)$$

$$\frac{dT}{dt} = \eta C - (\mu + \gamma + \delta_3 + \rho)T,$$

$$\frac{dR}{dt} = \gamma T + \theta A + \sigma C - (\mu + \omega)R,$$

where $\lambda = \frac{\alpha_1 A + \alpha_2 C}{N}$. Here α_1 is effective contact rate of population with acute HCV and α_2 is effective contact rate of population with chronic HCV. The initial condition of the population is

$S(0) = S_0, A(0) = A_0, C(0) = C_0, T(0) = T_0$ and $R(0) = R_0$

The biological meanings of all parameters are given below in table 1.

Table 1: Description of parameters of model (1)

Parameter	Description
π	New recruits into the population
μ	Natural mortality rate
β	The proportion at which S(t) joining A(t) and C(t)
δ_1	The contribution of disease to mortality in A(t)
δ_2	The contribution of disease to mortality in C(t)
δ_3	The contribution of disease to mortality in T(t)
ε	The rate at which A(t) become C(t)
σ	The recovery rate from C(t)
η	Rate of progression for T(t) from C(t)
p	Treatment failure of C(t)
γ	Treatment cure rate
θ	The rate of A(t) joining R(t)
ω	Removal rate from R(t) to S(t)

Model analyses

Positivity and boundedness of the solution, equilibrium points, reproduction number, stability of disease free equilibrium point and sensitivity analysis will be discussed in this section.

Positivity and Boundedness of the solutions

Since each component of the model represents a population, it's essential to demonstrate that all variables *S(t), A(t), C(t), T(t)* and *R(t)* remain non-negative and bounded for all $t > 0$

Theorem 3.1. (Positivity). If the initial conditions S_0, A_0, C_0, T_0 and R_0, are set for $t_0 > 0$, then for all $t \in (0, t_0)$, the values *S(t), A(t), C(t), T(t) and R(t)* remain positive in R_+^5

Proof. We start with the first equation of the model, which can be expressed as:

$$\frac{dS}{dt} = \pi + \omega R - (\mu + \lambda)S \geq -(\mu + \lambda)S.$$

From this, we derive that:

$S(t) \geq S_0 exp(-\int(\mu + \lambda)dt) > 0$, indicating that S(t) remains non-negative for all t, where S_0 is the initial susceptible population at $t=0$

By applying similar reasoning to the other dynamic variables, we can conclude that they also stay positive for all $t > 0$

$$A(t) \geq A_0 exp\left(-\int_0^t (\varepsilon + \mu + \delta_1 + \theta)\,dt\right) > 0,$$

$$C(t) \geq C_0 exp\left(-\int_0^t (\mu + \delta_2 + \eta + \sigma)\,dt\right) > 0,$$

$$T(t) \geq T_0 exp\left(-\int_0^t (\mu + \delta_3 + \gamma + \rho)\,dt\right) > 0,$$

$$R(t) \geq R_0 exp\left(-\int_0^t (\mu + \omega)\,dt\right) > 0.$$

Thus, for all $t \in [0, t_0)]$, *S(t), A(t), C(t), T(t) and R(t)* are positive in R_+^5.

Theorem 3.2. (Boundedness). For the functions *S(t), A(t), C(t), T(t) and R(t)* there exists a positive constants S_M, A_M, C_M, T_M, *and* R_M such that $\lim_{t\to\infty} \sup S(t) \leq S_M$, $\lim_{t\to\infty} \sup A(t) \leq A_M$, $\lim_{t\to\infty} \sup C(t) \leq C_M$, $\lim_{t\to\infty} \sup T(t) \leq T_M$, and $\lim_{t\to\infty} \sup R(t) \leq R_M$ for all $t \in [0, t_0)]$, $t_0 > 0$.

Proof. To show the boundedness, we add all the equation of proposed model as follows:

$$\frac{dN}{dt} = \frac{dS}{dt} + \frac{dA}{dt} + \frac{dC}{dt} + \frac{dT}{dt} + \frac{dR}{dt} =$$

$$\pi - \mu N - (\delta_1 A + \delta_2 C\ \delta_3 T).$$

This implies that $\frac{dN}{dt} \leq \pi - \mu N$. It follows that $N(t) \leq \pi\mu + N_0 exp(-\mu t)$. Then by considering $t \to \infty$, we have $\lim_{t\to\infty} \sup N(t) \leq \frac{\pi}{\mu}$. Thus, the model is bounded by taking $S_M = A_M = C_M = T_M = R_M = \frac{\pi}{\mu}$. This completes the proof of theorem.

Theorem 3.3. (Closed region).
The region $\Omega = \{(S,A,C,T,R) \in R_+^5 : S(t) + A(t) + C(t) + T(t) + R(t) \leq \frac{\pi}{\mu}\}$ is a positively invariant region for the model.

Proof. From theorem 3.2, we have $\frac{dN}{dt} \leq \pi - \mu N$, and using the initial condition $N_0 > 0$ along with integrating factor, we derive that $0 \leq N(t) \leq \frac{\pi}{\mu} + N_0 exp(-\mu t)$, where N_0 is the initial total population.

As $t \to \infty, N(t) \leq \frac{\pi}{\mu}$. This shows that all feasible solutions of the system will enter the region Ω, which is positively invariant. Thus, all solutions within Ω will remain there for all $t \geq 0$. Therefore, it suffices to analyze the transmission dynamics of the HCV model system within Ω.

Equilibrium points

Disease free Equilibrium (DFE) point

To find the equilibrium points of the model equations in (1), we solve them simultaneously with the time derivatives set to zero and assume that all dynamic variables are non-zero. This process yields two equilibrium points: one representing a disease-free state and the other an endemic equilibrium. In this context, we focus on determining the disease-free equilibrium point, where the disease compartments are treated as zero. Infected compartments include A, C, T while the others are not infected. At infection free steady state $A = C = T = R = 0$. Hence, the disease - free state is $N_0 = (S_0, A_0, C_0, T_0, R_0)$. By setting right hand side of the system to zero, we get: $N^D = (S^D, A^D, C^D, T^D, R^D) = \left(\frac{\pi}{\mu}, 0, 0, 0, 0\right)$.

Disease endemic equilibrium (DEE) point

Next, we identify the endemic equilibrium point of the system where the disease is present in the population this equilibrium point is found by setting each equation in the system to zero while assuming that all dynamic variables are non-zero $(i.e.\ S^* \neq A^* \neq C^* \neq T^* \neq R^* = 0)$ by solving the system of equations in (1) simultaneously with the time derivatives equal to zero we obtain the expression $N^* = (S^*, A^*, C^*, T^*, R^*)$ where $S^* = \frac{\pi + \omega R^*}{\lambda^* + \mu}$, $A^* = \frac{\beta\lambda^*(\pi + \omega R^*) + \omega R^*}{k_1(\lambda^* + \mu)}$, $C^* = \frac{(\pi + \omega R^*) + (\varepsilon\beta\lambda + (1-\beta)\lambda^* k_1)(k_2 k_3)}{k_1 k_2(\lambda^* + \mu)(k_2 k_3 + \eta\rho)}$, $T^* = \frac{(\pi + \omega R^*) + (\varepsilon\beta\lambda^* + (1-\beta)\lambda^* k_1)(\eta k_2)}{k_1 k_2(\lambda^* + \mu)(k_2 k_3 + \eta\rho)}$ and

$$R^* = \frac{[\pi(\eta\gamma + \sigma k_3) + (\varepsilon\beta\lambda^* + (1-\beta)\lambda^* k_1) + \theta\beta\lambda^*(k_2 k_3 + \eta\rho)]}{k_1(\lambda^* + \mu)(k_2 k_3 + \eta\rho) - \omega[(\eta\gamma + \sigma k_3) + (\varepsilon\beta\lambda^* + (1-\beta)\lambda^* k_1) + \theta\beta\lambda^*(k_2 k_3 + \eta\rho)]}.$$

Here $\lambda^* = \frac{\alpha_1 A^* + \alpha_2 C^*}{N^*}$

$k_1 = \varepsilon + \mu + \delta_1 + \theta, k_2 = \mu + \delta_2 + \eta + \sigma$ and $k_3 = \mu + \delta_3 + \gamma + \rho$.

The symbol $'*'$ denotes the population of each variable at the equilibrium point. Let the population in each class at steady state be represented as S^*, A^*, C^*, T^* and R^*. Consequently, the force of infection at the fixed points, denoted λ^*, corresponds to the non-negative roots of $\lambda^* = \frac{\alpha_1 A^* + \alpha_2 C^*}{N^*}$.

Basic reproduction number

Definition 3.1. The basic reproduction number (R_0) represents the typical number of new infections caused by a single infected individual when introduced into a population where everyone else is susceptible to the disease. It can be calculated using the next-generation approach, a method detailed by Driessche and Watmough in their 2002

publication. To compute R_0, it is essential to differentiate new infections from other transitions within the population. The infected classes are A, C and T. We can express system (1) as $\dot{x} = F(x) - V(x)$, $V = V^- - V^+$, where $x = (A, C, T, S, R)$. Here, F represents the rate of new infections in each class, V^+ is the rate of transfer into each class through other means, and V^- is the rate of transfer out of each class. Given the system of non-linear differential equations

$$\begin{aligned}
\dot{A} &= \beta\lambda S - (\varepsilon + \mu + \delta_1 + \theta)A,\\
\dot{C} &= \varepsilon A + (1-\beta)\lambda S + \rho T - (\mu + \delta_2 + \eta + \sigma)C,\\
\dot{T} &= \eta C - (\mu + \gamma + \delta_3 + \rho)T,\\
\dot{S} &= \pi + \omega R - (\mu + \lambda)S,\\
\dot{R} &= \gamma T + \theta A + \sigma C - (\mu + \omega)R.
\end{aligned} \quad (2)$$

Based on the system of equations (2) above, the matrices $F(x)$ for new infection terms and $V(x)$ for the other transition terms are defined as follows:

$$F(x) = \begin{pmatrix} \beta\lambda S \\ (1-\beta)\lambda S \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad (3) \text{ and}$$

$$V(x) = \begin{pmatrix} (\varepsilon + \mu + \delta_1 + \theta)A \\ -\varepsilon A - \rho T + (\mu + \delta_2 + \eta + \sigma)C \\ -\eta C + (\mu + \gamma + \delta_3 + \rho)T \\ -\pi - \omega R + (\mu + \lambda)S \\ -\gamma T - \theta A - \sigma C + (\mu + \omega)R \end{pmatrix}. \quad (4)$$

Calculating the partial derivatives of (3) at disease free state N_0 and bearing in the mind that the system (1) has three infected classes, namely, A, C and T we obtain

$$F = \begin{pmatrix} \beta\alpha_1 & \beta\alpha_2 & 0 \\ (1-\beta)\alpha_1 & (1-\beta)\alpha_1 & 0 \\ 0 & 0 & 0 \end{pmatrix}.$$

In the same manner, partial derivatives of (4) with respect to A, C and T at disease free state N_0 gives $V = \begin{pmatrix} k_1 & 0 & 0 \\ -\varepsilon & k_2 & -\rho \\ 0 & -\eta & k_3 \end{pmatrix}$ and its inverse becomes

$$V^{-1} = \begin{pmatrix} \frac{1}{k_1} & 0 & 0 \\ \frac{\varepsilon k_3}{k_1(k_2k_3+\rho\eta)} & \frac{k_3}{k_2k_3+\rho\eta} & \frac{\rho}{k_2k_3+\rho\eta} \\ \frac{\varepsilon\eta}{k_1(k_2k_3+\rho\eta)} & \frac{\eta}{k_2k_3+\rho\eta} & \frac{k_2}{k_2k_3+\rho\eta} \end{pmatrix}$$

As defined in (Driessche & Watmough, 2002), R_0 is the spectral radius of the next generation matrix, FV^{-1} and it is given by

$$FV^{-1} = \begin{pmatrix} \frac{\beta\alpha_1(k_2k_3+\rho\eta) + \beta\alpha_1\varepsilon k_1k_3}{k_1(k_2k_3+\rho\eta)} & \frac{\beta\alpha_2k_3}{k_2k_3+\rho\eta} & \frac{\beta\rho\alpha_2}{k_2k_3+\rho\eta} \\ \frac{(1-\beta)[\alpha_1(k_2k_3+\rho\eta) + \alpha_2\varepsilon k_1k_3]}{k_1(k_2k_3+\rho\eta)} & \frac{(1-\beta)\alpha_2k_3}{k_2k_3+\rho\eta} & \frac{(1-\beta)\alpha_2\rho}{k_2k_3+\rho\eta} \\ 0 & 0 & 0 \end{pmatrix}.$$

Hence, R_0 of the model (2) can be determined by

$$R_0 = \frac{(1-\beta)\alpha_2k_1k_3 + \beta[k_3(\alpha_1k_2 + \varepsilon\alpha_2) - \alpha_1\rho\eta]}{k_1(k_2k_3+\rho\eta)} \quad \ldots(5)$$

Theorem 3.4. The disease free state is locally asymptotically stable if $R_0 < 1$ and unstable if $R_0 > 1$.

Proof. To prove the theorem, we first construct a Jacobian matrix for the system (1) at disease free state

$$J_{N_0} = \begin{pmatrix} -\mu & \alpha_1 & \alpha_2 & 0 & \omega \\ 0 & \beta\alpha_1 - k_1 & \beta\alpha_2 & 0 & 0 \\ 0 & \varepsilon + (1-\beta)\alpha_1 & (1-\beta)\alpha_2 - k_2 & \rho & 0 \\ 0 & 0 & \eta & k_3 & 0 \\ 0 & -\theta & \sigma & \gamma & -(\mu+\omega) \end{pmatrix}. \quad (6)$$

Now we evaluate the Jacobian matrix at DFE and examine its stability effect due to $R_0 > 1$. From the Jacobian matrix (6), we get a characteristic polynomial by computing $det(\lambda I - J_{N_0}) = 0$ as follows:

Stability of disease free state

Local stability of disease free state

$$\begin{vmatrix} \mu+\lambda & \alpha_1 & \alpha_2 & 0 & -\omega \\ 0 & \lambda-(\beta\alpha_1-k_1) & -\beta\alpha_2 & 0 & 0 \\ 0 & -(\varepsilon+(1-\beta)\alpha_1) & (1-\beta)\alpha_2-k_2 & \rho & 0 \\ 0 & 0 & \eta & k_3 & 0 \\ 0 & -\theta & \sigma & \gamma & -(\mu+\omega) \end{vmatrix} = 0,$$

It is obvious that $\lambda_1 = -\mu, \lambda_5 = -(\mu + \omega)$ are two negative eigenvalues of J_{N_0} from the following block matrix:

$$R_{J_{N_0}} = \begin{pmatrix} \lambda-K_1 & -\beta\alpha_2 & 0 \\ -(\varepsilon+(1-\beta)\alpha_1) & \lambda-K_2 & 0 \\ 0 & -\eta & \lambda-K_1 \end{pmatrix},$$

where $K_1 = \beta\alpha_1 - k_1$ and $K_2 = \alpha_2(1 - \beta) - k_2$. The characteristic polynomial of $R_{J_{N_0}}$ is given by $P(\lambda) = \lambda^3 + A_1\lambda^2 + A_2\lambda + A_3$ where

$$A_1 = k_3 - K_2 - k_1, A_2 = \beta^2\alpha_1\alpha_2 + K_1K_2 - (\beta\alpha_2\varepsilon + \beta\alpha_1\alpha_2 + K_1k_3 + K_2k_3 + \rho\eta)$$

and

$$A_3 = K_1(K_2k_3 + \rho\eta) + k_3(\beta^2\alpha_1\alpha_2 - \beta\alpha_2\varepsilon - \beta\alpha_1\alpha_2).$$

By applying the Routh-Hurwitz stability criterion (Allen, 2007) and performing some algebraic manipulations, it can be demonstrated that the eigenvalues of the block matrix $R_{J_{N_0}}$ have negative real parts $\Re(\lambda_2), \Re(\lambda_3), \Re(\lambda_4) < 0$, when $R_0 < 1$. Conversely, if $R_0 > 1$, then $A_2 < 0$, indicating that the matrix $R_{J_{N_0}}$ has at least one eigenvalue with a positive real part. Therefore, the DFE point of model (1) is locally asymptotically stable when $R_0 < 1$ and unstable when $R_0 > 1$.

Global stability of disease free state

This sub-section examines the global stability of the disease-free state.

Theorem 3.5. If $R_0 < 1$, the disease-free state N_0 of model (1) is globally asymptotically stable within its feasible region.

Proof. We start rewriting model (1) as follows: $\frac{dX}{dt} = F(X,Y)$, $\frac{dY}{dt} = G(X,Y)$, with $G(X,0) = 0$ where $X = (S,R) \in R^2$ shows the non-disease classes and $Y = (A,C,T) \in R^3$ shows the disease classes. Two conditions, H_1 and H_2, are necessary for the global asymptotic stability of the DFE of model (1). (H_1) For $\frac{dX}{dt} = F(X,0)$, the point X^* is globally asymptotically stable, where F(X^*,0) = 0. (H_2) We have $G(X,Y) = BY - \tilde{G}(X,Y), \tilde{G}(X,Y) > 0,$ for $(X,Y) \in \Omega$, where $B = D_Y G(X^*, 0)$ is an M-matrix. The off-diagonal elements of B are non-negative, defining the biologically feasible region in Ω. For model (1), we have:

$$\frac{dX}{dt} = \begin{pmatrix} \pi - \mu S \\ 0 \end{pmatrix}. \quad (7)$$

In fact, the system in (7) above is globally asymptotically stable around $X^* = \left(\frac{\pi}{\mu}, 0\right)$. This can be confirmed by the solution $S(t) = \frac{\pi}{\mu} + (S(0) - \frac{\pi}{\mu})e^{-\mu t}$, which shows that $\lim_{t\to\infty} S(t) = \frac{\pi}{\mu}$. This indicates the global convergence of (7) in Ω. Furthermore, from model (1), we get:

$$B = \begin{pmatrix} \beta\alpha_1 & \beta\alpha_2 & 0 \\ \varepsilon+(1-\beta)\alpha_1 & (1-\beta)\alpha_2-k_2 & \rho \\ 0 & \eta & -k_3 \end{pmatrix}$$

and

$$\tilde{G}(X,Y) = \begin{pmatrix} (\alpha_1 A + \alpha_2 C)\left(\frac{A+C+T+R}{S+A+C+T+R}\right) \\ 0 \\ 0 \end{pmatrix}.$$

Clearly, $\frac{A+C+T+R}{S+A+C+T+R} \geq 0$ inside Ω and therefore, $\tilde{G}(X,Y) \geq 0$. Thus, the two conditions (H_1), and (H_2) satisfied. Hence, the DFE point N_0 of model (1) is globally asymptotically stable when $R_0 < 1$.

Sensitivity analysis

This sub-section discusses the influence of various model parameters on the reproduction number R_0 to understand their comparative effects on disease spread within the community. To conduct the sensitivity analysis, we need to compute the partial derivatives of R_0 with respect to the model parameters. The sensitivity indices related to a parameter p are represented by the normalized forward sensitivity index, which indicates the importance of the parameter in terms of disease transmission and prevalence. Following the methodology outlined in (Chitnis et al., 2008), the normalized forward sensitivity index of the variable R_0, which depends differentiable on the parameter p, is given by:

$$\Psi_p^{R_0} = \frac{\partial R_0}{\partial p} \times \frac{\partial p}{\partial R_0}.$$

From an explicit formula R_0 in equation (5), we obtain a mathematical expression that calculates the normalized sensitivity indices of R_0 with respect to various parameters that affect R_0. For instance, $\Psi_{\alpha_1}^{R_0} = \frac{\partial R_0}{\partial \alpha_1} \times \frac{\partial \alpha_1}{\partial R_0} = 0.65.$ Likewise, we can determine the sensitivity indices for the remaining parameters. The sensitivity indices evaluated at the baseline parameters given in table 2.

Table 2: Sensitivity indices for model parameters.

Parameters	Sensitivity index	Parameters	Sensitivity index
α_1	+ve	μ	-ve
α_2	+ve	ω	-ve
σ	-ve	ρ	-ve
γ	-ve	δ_1	-ve
β	+ve	δ_2	-ve
θ	-ve	δ_3	-ve
ε	+ve	η	-ve

According to table 2 above, if a parameter has a positive sensitivity index, it means that increasing its value will have a significant impact on the frequency of disease spread. For instance, based on the value of $\Psi_{\alpha_1}^{R_0} = 0.65$, we can observe that a 6.5% increase or decrease in the contact rate β will result in a 6.5% increase or decrease in R_0. On the other hand, parameters with negative indices implies that increasing the significance of these parameters would contribute to reducing the severity of the disease.

Table 3: Parameter values of model (1).

Parameters	Value ($\mathbf{year^{-1}}$)	Source	Parameters	Value ($\mathbf{year^{-1}}$)	Source
π	100	Wameko, 2019	σ	0.002	Shi, R., & Cui, Y., 2016
μ	0.0004	Wameko, 2019	θ	0.23	Ainea et al., 2012
β	0.65	Wameko, 2019	γ	0.13	Okosun et al., 2014
δ_1	0.03	Wameko, 2019	ω	0.05	Ainea et al., 2012
δ_2	0.05	Wameko, 2019	ρ	0.05	Teklu et al., 2025
δ_3	0.001	Assumed	α_1	0.002	Wameko, 2019
ε	0.05	Ainea et al., 2012	α_2	0.001	Wameko, 2019

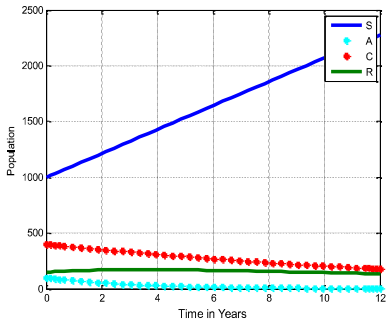

Figure 2. Solution behavior of the HCV model (1) in the absence of treatment.

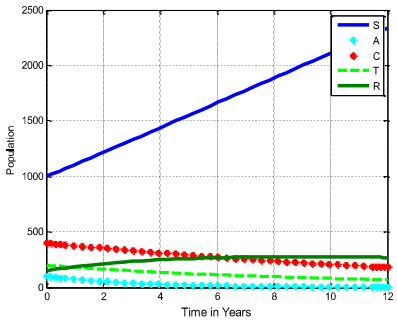

Figure 3. Solution behavior of the HCV model (1) under treatment.

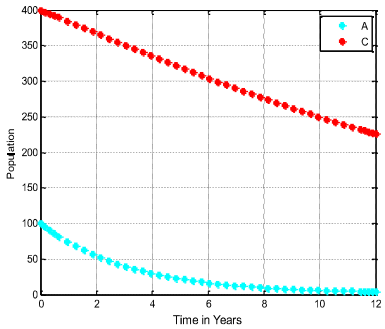

Figure 4. Dynamics of acutely and chronically infected individuals in the absence of treatment.

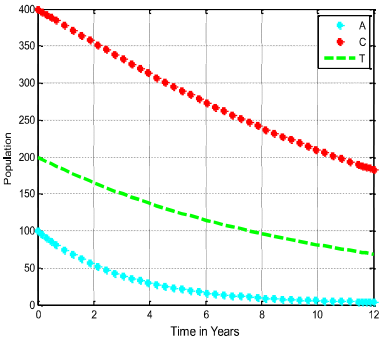

Figure 5. Dynamics of acutely and chronically infected individuals under treatment.

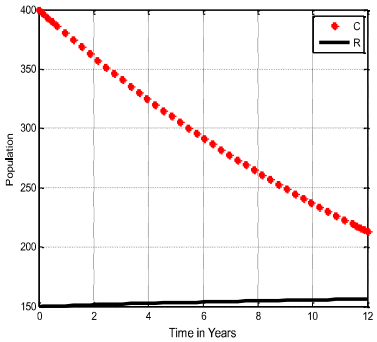

Figure 6. Dynamics of chronically infected and recovered individuals in the absence of treatment.

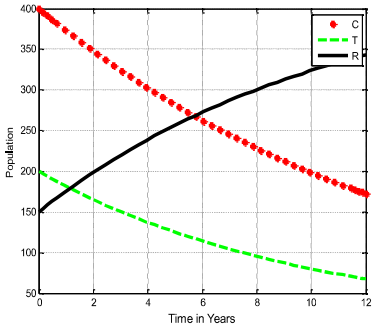

Figure 7. Dynamics of chronically infected and recovered individuals under treatment.

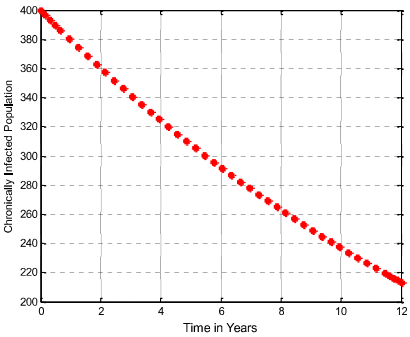

Figure 8. Dynamics of chronically infected individuals in the absence of treatment

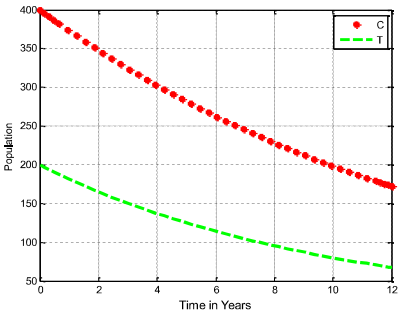

Figure 9. Dynamics of chronically infected treatment

Discussion

This segment aims to explain the simulation results and highlight their implications for the state variables and parameter values. In the absence of treatment, the numerical simulation in Fig. 2 demonstrates a gradual decline in both chronically infected and recovered individuals, with the model solutions converging to an HCV endemic equilibrium after around twelve years. Conversely, Fig. 3 illustrates that, with treatment, the population of chronically infected individuals' decreases while the population of recovered individuals gradually increases over time. A comparison of Figs. 4 and 5 reveals the impact of treatment on acutely and chronically infected individuals. While the acutely infected population decreases similarly in both figures (as treatment is not applied to acute cases), the chronically infected population differs significantly. Without treatment (Fig. 4), this population remains above 200, while treatment (Fig. 5) reduces it below 200. Figs. 6 and 7 illustrate the dynamics of chronically infected and recovered individuals without and with treatment, respectively. In Fig. 6, chronic infections decrease gradually while recovery shows minimal increase. However, Fig. 7 reveals that treatment leads to a more pronounced decline in chronic infections and a rapid increase in recovered individuals. The impact of treatment on chronically infected individuals is evident in Figs. 8 and 9. Fig. 8 illustrates the dynamics of chronically infected individuals in the absence of treatment, while Fig. 9 shows the same dynamics with treatment. The decline in chronically infected persons is significantly faster in Fig. 9 due to the treatment's effects. The timely identification and treatment of chronically infected individuals, employing either direct-acting antivirals (DAAs) or natural herbal supplements with physician consultation, holds promise for effectively eliminating HCV within a shorter time frame.

Conclusion

In this research article, we derived and analyzed a deterministic mathematical model of HCV using a system of first-order non-linear differential equations. Our model uses five non-linear ordinary differential equations to describe the interactions between susceptible, acutely infected, chronically infected, treated, and recovered individuals. The model aims to reduce the number of acute and chronic cases, and it specifically considers treatment for individuals with chronic infection. In this study, we first established basic analytical properties, including positivity, boundedness of solutions, and identification of disease-free and endemic equilibrium points. Subsequently, we investigated the basic reproduction number and proved the local and global stability of the disease-free equilibrium point. We conducted numerical simulations using MATLAB software to validate our theoretical findings and illustrate the impact of treatment on HCV viral dynamics. The numerical simulations closely aligned with our theoretical predictions. The results demonstrated that early identification and treatment of chronically infected individuals accelerates HCV elimination by reducing chronic infections and increasing recovery rates. Future research will refine the model by incorporating optimal control measures to optimize disease management strategies, validating it with real-world population data, and analyzing cost-benefit ratios, resource availability, population demographics, and local healthcare infrastructure.

Data availability

All data were incorporated in the manuscript.

Declaration of competing interest

The writers approve there are no well-known competing financial benefits or individual affairs that could be seen as influencing the work offered in this article.

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RESEARCH PAPER

Carbon Stock Potentials in Woody Plants of Tullu Qondala Exclosure in Ethiopia: its Implications to Climate Change Mitigation

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Abstract

Rehabilitation of degraded land plays a vital role in enhancing carbon stock storage, which is one of the important ecosystem services. The objective of this investigation was to determine the extent to which exclosures contribute to carbon storage by analyzing the carbon stocks of woody plants both above and below ground, utilizing a non-destructive allometric model within the Tullu Qondala Exclosure. A systematic sampling method was used to conduct the vegetation sampling. Vegetation data were collected from a total of 30 main plots each with the size of 20 m x 20 m. Woody plants were measured for diameter at breast height (DBH) of ≥ 5 cm and height of ≥ 1.5 m. The mean above-ground biomass (AGB) and below-ground biomass (BGB) were 56.9 ± 4.38 t/ha and 11.38 ± 0.88 t/ha, respectively. The total mean carbon stock density of woody plant species at the study site was 34.142 ± 13.86 t/ha, with 28.45 ± 2.19 t/ha stored in AGB and 5.69 ± 0.44 t/ha in BGB. The total aboveground and below-ground carbon contents were 853.56 t/ha and 170.71 t/ha, respectively. The carbon stocks density in the above and below ground biomasses were high as compared to some previous studies. These differences among the compared exclosure could be attributed to variations in the presence of bigger sized trees with a higher basal area and, a higher density of woody species. Additionally, the length of time an area has been under exclosure can significantly impact the density of carbon stocks, given that these stocks are influenced by biomass, which tends to increase with prolonged exclosure. This study demonstrated that establishing area exclosures in the region is an effective strategy for sequestering carbon. The carbon stock found in this area highlights its important role in addressing climate change. Therefore, it's crucial for all sectors involved, both local and national, to come together and implement strong conservation strategies to fully utilize these benefits.

Keywords: Biomass, carbon, exclosure, woody plants, climate change mitigation

Introduction

Climate change, along with its environmental challenges, has emerged as one of the most pressing issues we encounter on a global scale. Developing countries particularly in African countries are bearing the burden of it. Ethiopia, for example, has been experiencing extended droughts, erratic rainfall (Belay *et al*., 2025). which affected agricultural production and food security indicating the need for adaptation and mitigation strategies (Chapman *et al.*, 2020).

Mitigating climate change entails storing C in vegetation and understanding the connections between carbon storage and ecosystem health (Don *et al*., 2024). Through carbon storage in above-and belowground structures, woody vegetation significantly contributes to the reduction of greenhouse gas emissions (Kafy *et al*., 2023; Shiferaw *et al*., 2022) . In this regard, tropical forest has a great role in storing substantial quantity of carbon which accounts 50% of the world vegetation biomass (Brown,

2002; Iticha, 2017). However, the provision of ecosystem services has been dramatically reduced due to high deforestation and extensive biodiversity lose (Guariguata and Balvanera, 2009) which in turn limited the carbon storage pools in forests in different part of the world and increased carbon emissions in the atmosphere (Tsegay and Meng, 2021). The CO_2 emission due to deforestation is reported to be about 70% and 13% for Africa and world respectively (FAO, 2020; Pan *et a*l., 2011).

Implementing conservation and management measures, restoring ecosystems and watersheds, and reducing deforestation could all help in reducing the buildup of C in the atmosphere (Brown, 2002; Houghton *et al*., 2001). Thus, forests have the ability to form a major component in the mitigation of global warming and adaptation to climate change. According to (Pan *et al*., 2011), forest stores about 80% of all aboveground and 40% of all below ground terrestrial organic carbon. Protected areas play an important role in capturing and storing carbon from the atmosphere through improved vegetation. They also act as a good strategy for adapting to climate change (Abeje *et al*., 2016; Griscom *et al.*, 2017). It's widely recognized that area closure can enhance the vegetation's cover, composition, density, richness, and diversity. Besides, it can have a positive impact on the economies and ecosystems of the nearby communities(Birhane *et al*., 2006; Gebeyehu *et al*., 2019; Tefera and Soromessa, 2015).

In Ethiopia, there is land degradation because of deforestation, agricultural land expansion, and overgrazing which resulted in environmental degradation and ecosystem services (Mengistu *et al*., 2005; Mulugeta *et al.*, 2005). The level of Ethiopia's forest land and C stock showed a decreasing trend during 1990 - 2015 due to deforestation (FAO, 2020). Ethiopia's total CO_2 emission is reported to be 400 Mt in 2030 (FDRE, 2015)

To deal with these issues, applying different sustainable land management practices such as enclosures is necessary. In reply to this, Ethiopia has followed different conservation strategies such as, watershed management, afforestation, reforestation, and restoration programs, to decrease these environmental risks (Mengistu *et al*., 2005). Before three decades, area closure was suggested as one of restoration strategy to encourage re-vegetation, prevent further ecosystem decline, and improve ecological conditions (Tesfay *et al*., 2020). As a result, there has been an increase in the area of degraded lands dedicated for its rehabilitation (Emiru *et al.*, 2006). The Tullu Qondala Exclosure, a previously degraded natural forest, is one of the areas excluded from human and animal interference through a cooperation between the district agricultural office and local communities.

Although a number of studies have investigated the impact of area enclosures on restoring the diversity and structure of woody species in Ethiopia, we still have a lot to learn about their carbon sequestration capabilities especially in the central regions where these enclosures are used for land rehabilitation. Most research has focused on the northern and southern parts of the country, making it essential to explore biomass accumulation and carbon storage in central exclosures. This study sets out to measure the above and belowground carbon stock density of woody plants in the Tullu Qondala Exclosure to help fill this gap.

Materials and Methods

Description of Study Areas

Tullu Qondala Exclosure is found in Nono District, West Showa Zone, Oromia National Regional State, Ethiopia about 216 km west of the capital city, Addis Ababa. It covers a total area of 693.7 km2. The district is geographically situated between 370 20` to 370 30` Longitude and 80 30` to 80 40` Latitude. The elevation of the Tullu Qondala exclosure varies from 1126 and 2192 m.a.s.l (Nono District Administrative Office, 2021).

Climatically, most of Nono District falls within the Woinadega (90.83%) and Qolla (9.16%) agroclimatic zones (Messay, 2011). The mean annual temperature ranges between 16°C and 26°C. The Tullu Qondala Exclosure, established in 2004, was once a degraded natural forest before its closure for restoration.

The District Office of Agriculture partnered with local communities to enforce area closure, preventing human and livestock interference to promote ecological recovery.

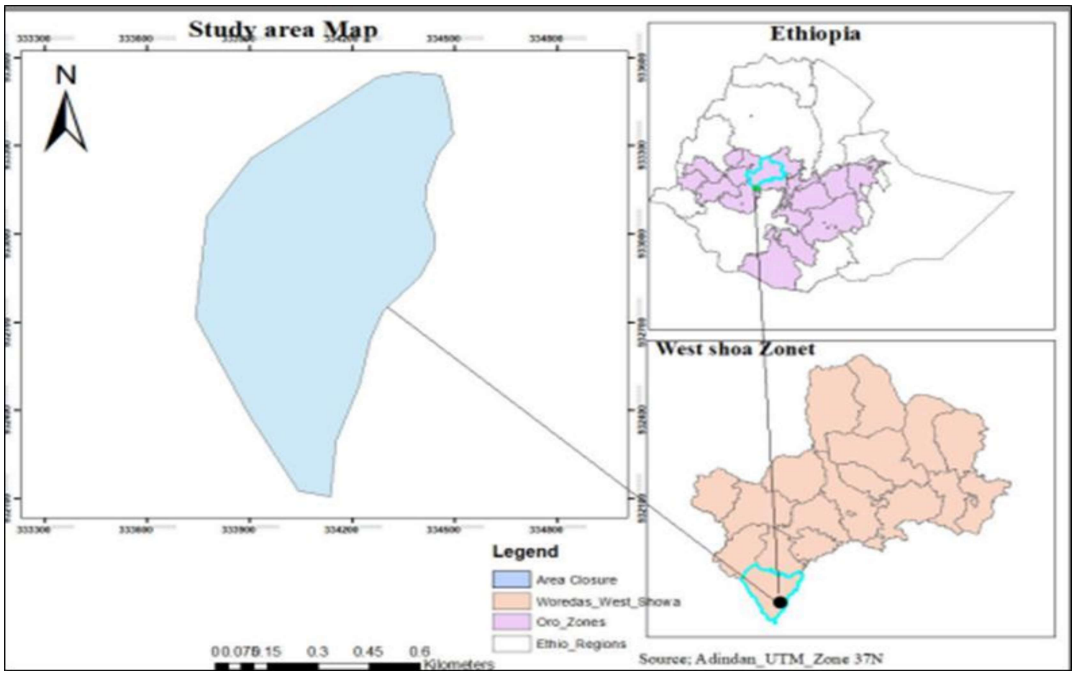

Figure 1: Location map of study area

Sampling design and measurements

Reconnaissance survey was made to obtain an overview of the study site, before the actual survey operation, followed by detailed preliminary survey on biophysical components. This site was chosen because it is relatively better protected and the extent of human disturbance is relatively less than in the other around areas. Systematic sampling design was employed to collect vegetation data from the study site.

The enclosure area covered 31 hectares, sampling was done based on systematic transect sampling technique following Mueller-Dombois, 1994. Three transect lines were established at a distance of 100m apart. Sampling quadrant of 20m x 20m was used to assess woody species. All the sampling plots were distributed along the transect line at a distance of 50m between the quadrants. To estimate the tree biomass, all live trees with a diameter ≥ 5 cm were recorded as indicated by (Pearson *et al*., 2005)

In this research, individual trees measuring ≥ 5cm diameter at breast height (DBH) and shrubs diameter at stump height (DST), about 30 cm above the ground, were measured from each quadrant. The DBH of the woody plants were derived from circumference ($D = C/\pi$, where D = DBH, C = Circumference, π = constant with value 3.14) measured by a measuring tape.

The quadrats were marked using plastic ribbon, four wooden pegs and compass. In each quadrat, the types and number of all individuals of the woody species were identified, counted and recorded by their local and/or scientific names (Azene, 2007; Emiru *et al*., 2006). The height and diameter of trees, shrubs, saplings and seedlings of the woody species were measured using a marked measuring stick and diameter tape, respectively were recorded following a standard method.

Tree diameters were measured at breast height (DBH), while shrubs and saplings were measured at stump height (DSH). Plants reaching 3 meters in height with a DBH

exceeding 2.5 cm were classified as trees or shrubs. Those under 2 meters tall with a DBH below 2.5 cm were recorded as saplings, and plants shorter than 1 meter were considered seedlings only their total counts were counted (Birhane *et al*., 2007; Lai *et al*., 2009).

Carbon stock Data Analysis

Aboveground Biomass (AGB) and Carbon Stock

Various allometric models exist for estimating aboveground biomass, but the (Chave *et al*., 2014) model is recommended here due to its suitability for the study site, particularly for tropical forests with similar life zone characteristics. The AGB of trees with diameter at breast height ≥ 5cm was calculated using the model developed by (Chave *et al*., 2014). The model is as follows:

$$AGB = 0.0673 \times (\rho(DBH)^2H)^{0.976}$$

Where: AGB = aboveground biomass (in kg dry matter)

ρ = wood density (g/cm3)

DBH = diameter at breast height (in cm)

H = tree height (in m)

The place where this study was conducted is part of tropical region, 50% of the woody species biomass was assumed to be the carbon sink. Hence, the aboveground biomass carbon was estimated by biomass-carbon conversion factor of 0.5 (Brown, 2002; Pearson *et al*., 2005).

AGCS= AGB x 0.5

Where, AGCS = Above Ground Carbon Stock

AGB = Above Ground Biomass

To calculate the amount of carbon dioxide equivalence (CO_2e) that have been captured in the aboveground body, AGB is multiplied by 3.67 assuming that each ton of stored carbon is equivalent to3.67 (i.e. the ratio of the molecular weight of carbon dioxide (CO_2) to the atomic weight of carbon (44/12) =3.67 (Brown, 2002; Pearson *et al*., 2005).

Below-Ground Biomass (BGB) and carbon

Belowground biomass was estimated using the equation from Macdieken (1997). Similarly, Brown and (2002) and Pearson *et al*. (2005) described this approach as more efficient and effective, as it applies a regression model to determine belowground biomass based on aboveground biomass data. Therefore, the equation developed by Macdicken, 1997 was adopted for estimating belowground biomass. The equation is provided below

BGB = AGB x 0.2

Where BGB is belowground biomass, AGB is aboveground biomass, 0.2 is the conversion factor (or 20% of AGB).

To calculate the amount of carbon and CO2 in below ground biomass, the same procedure was applied like that of aboveground biomass. Finally, biomass carbon stocks are calculated by summing the carbon stock densities of different carbon pools in the stratum using the formula by Pearson *et al*. (2005).

Results

Biomass and Carbon Stock of woody species in Tullu Qondala Exclosure

Tullu Qondala exclosure had the density of 1349 individuals/ha of woody species with DBH ≥5cm (Table 1).

Table 1. Mean DBH and Height, frequency, relative frequency, density/ha and relative density of woody plant species in Tullu Qondala exclosure

Species Name	No of stems	Average DBH (cm)	Average height (m)	Frequency %	Relative Frequency	Density/ ha	Relative Density
Acacia abyssinica Hochst. ex Benth.	225	16.77	6.2	93.3	7.6	187.5	13.9
Acacia polyacanths (Willd)	57	18.19	7.64	80	6.5	47.5	3.52
Acacia seyal Del.	22	16.55	6.87	36.7	3	18.33	1.36
Albizia schimperiana Oliv.	24	14.18	6.06	33.3	2.7	20	1.48
Calpurnia aurea (Ait.)Benth.	14	5.71	4.04	26.7	2.2	11.67	0.86
Carissa spinarum (C. edulis)	53	6.51	4.3	60	4.9	44.17	3.27
Clausena anisata (Wild.) Benth.	8	6.11	4.23	20	1.6	6.67	0.49
Combretum molle R. Br. ex G.Don	454	12.69	5.62	100	8.2	378.33	28.04
Cordia africana Lam.	28	21.01	7.2	43.3	3.5	23.33	1.73
Croton macrostachyus Hochst. ex Del.	63	14.54	5.97	63.3	5.2	52.5	3.89
Dodonea angustifolia L.F	17	6.24	4.03	33.3	2.7	14.17	1.05
Ehertia cymosa Thonn.	75	11.51	5.06	66.7	5.4	62.5	4.63
Entada abyssinica steud.ex A.Rich.	40	15.37	6.14	43.3	3.5	33.33	2.47
Euclea divinorum Hiern	18	5.84	3.57	26.7	2.2	15	1.11
Ficus sur Forssk.	5	30.34	7.23	13.3	1.1	4.17	0.31
Ficus sycomorus.L	4	27.95	6.18	13.3	1.1	3.33	0.25
Ficus vasta Forssk.	8	35.42	8.23	20	1.6	6.67	0.49
Gardenia ternifolia Schumach. & Thonn.	63	17.09	5.67	66.7	5.4	52.5	3.89
Grewia bicolor Juss	88	8.22	4.16	63.3	5.2	73.33	5.44
Maytenus arbutifolia (A.Rich.) Wilczek	4	8.75	5.23	10	0.8	3.33	0.25
Olea europaea L.subsp. cuspidata (Wall.ex G. Don.) Cif.	8	7.45	5.25	16.7	1.4	6.67	0.49
Rhus natalensis Benth. ex Krauss.	63	6.25	4.57	53.3	4.3	52.5	3.89
Rhus vulgaris Meikle	119	5.68	4.26	86.7	7.1	99.17	7.35
Terminalia macroptera Guill & Perr.	101	16.58	6.18	76.7	6.3	84.17	6.24
Vernonia amygdalina Del.	9	6.05	4.39	23.3	1.9	7.5	0.56
Ximenia americana L.	49	5.63	4.04	56.7	4.6	40.83	3.03
Total	1619					1349.2	

The total mean tree biomass was 68.28±5.25 ranging from 19.77-136.12 t/ha. Due to a wide range in tree biomass of the study site, the quantity of carbon sequestered showed difference between plots ranging from 9.89-68.07 t/ha. The overall C stock of Tulu Qondala exclosure was 1024.3 t/ha with the mean value of 34.14±2.63 t/ha. For all the plots, the total aboveground carbon and belowground carbon was 853.56 t/ha and 170.71 t/ha respectively (table 2).

Table 2. Overall and mean values of biomass and C stock (t ha−1) in in Tullu Qondala exclosure

	AGB	BGB	AGB+BGB	AGC	BGC	AGC+BGC
Mean	56.9±4.38	11.38±0.88	68.28±5.25	28.45±2.19	5.69±0.44	34.14±2.63
Total	1707.1	341.42	2048.5	853.56	170.71	1024.3

AGB = Aboveground biomass, BGB = Belowground biomass, AGC = Aboveground carbon, BGC = Belowground carbon, TB = Total biomass, and TC = Total carbon

Woody Species Contribution for Biomass and C Stock in Tullu Qondala Exclosure

The highest aboveground carbon stock per woody species was recorded from *Acacia abyssinica (*7.63) followed by *Combretum molle(*4.8)*, Terminalia macroptera(*3.31)*, Acacia polyacanths(*2.6)*,Gardenia ternifolia (*1.66) *and Croton macrostachyus(*1.07) tons of Carbon/species ha $^{-1.}$ About 78.195 % of the AGC stock was contributed by these six woody plant of the study area while the rest of the woody plant species contributed only 21.805 % of the AGC. The minimum aboveground C stock of woody plant species was scored from *Vernonia amygdalina* 0.0151 tons/ha (Table 3). High C stock was recorded in *Ficus vasta* (0.125 ton per single tree). *Ficus sur, Ficus sycomorus, Acacia polyacanths,* and *Acacia abyssinica* also contributed high carbon in Tullu Qondala exclosure. The minimum and maximum carbon stock per single tree/shrubs was 0.002 and 0.125 tones recorded for *Vernonia amygdalina* and *Ficus vasta*, respectively (S2).

Table 3. Means (±SD) AGB and C stock of each species from Tullu Qondala area exclosure

Species	AGB	AGC	CO_2 in AGB	GB	BGC	CO_2 in BGB	TB	TC Stock
Acacia abyssinica Hochst. ex Benth.	18.32	9.16	33.61	3.66	1.83	6.72	22	10.99
Combretum molle R. Br. ex G.Don	11.52	5.76	21.14	2.3	1.15	4.23	13.8	6.91
Terminalia macroptera Guill & Perr	7.95	3.97	14.59	1.59	0.79	2.92	9.54	4.77
Acacia polyacanths (Willd)	6.22	3.11	11.41	1.24	0.62	2.28	7.46	3.73
Gardenia ternifolia Schumach. & Thonn.	3.99	1.99	7.32	0.8	0.4	1.46	4.78	2.39
Croton macrostachyus Hochst. ex Del.	2.56	1.28	4.7	0.51	0.26	0.94	3.07	1.54
Cordia africana Lam.	2.07	1.03	3.79	0.41	0.21	0.76	2.48	1.24
Entada abyssinica steud.ex A.Rich	2.03	1.02	3.73	0.41	0.2	0.75	2.44	1.22
Ficus vasta Forssk.	2	1	3.68	0.4	0.2	0.74	2.4	1.2
Ehertia cymosa Thonn.	1.64	0.82	3.02	0.33	0.16	0.6	1.97	0.99
Acacia seyal Del.	1.18	0.59	2.16	0.24	0.12	0.43	1.41	0.71
Albizia schimperiana Oliv.	0.89	0.45	1.64	0.18	0.09	0.33	1.07	0.54
Ficus sur Forssk.	0.82	0.41	1.5	0.16	0.08	0.3	0.98	0.49
Grewia bicolor Juss	0.68	0.34	1.24	0.14	0.07	0.25	0.81	0.41
Rhus vulgaris	0.61	0.31	1.12	0.12	0.06	0.22	0.74	0.37
Ficus sycomorus	0.52	0.26	0.95	0.1	0.05	0.19	0.62	0.31
Rhus natalensis Benth. ex Krauss.	0.42	0.21	0.77	0.08	0.04	0.15	0.5	0.25
Carissa spinarum (C. edulis)	0.38	0.19	0.69	0.08	0.04	0.14	0.45	0.23
Ximenia americana L.	0.33	0.16	0.6	0.07	0.03	0.12	0.39	0.2
Dodonea angustifolia L.F	0.17	0.08	0.3	0.03	0.02	0.06	0.2	0.1
Olea europaea L.subsp. cuspidata (Wall.ex G. Don.) Cif.	0.08	0.04	0.15	0.02	0.01	0.03	0.1	0.05
Euclea divinorum Hiern	0.08	0.04	0.15	0.02	0.01	0.03	0.1	0.05
Calpurnia aurea (Ait.)Benth.	0.07	0.03	0.12	0.01	0.01	0.02	0.08	0.04
Maytenus arbutifolia (A.Rich.) Wilczek	0.07	0.03	0.12	0.01	0.01	0.02	0.08	0.04
Clausena anisata (Wild.) Benth	0.04	0.02	0.07	0.01	0	0.01	0.04	0.02
Vernonia amygdalina Del.	0.04	0.02	0.07	0.01	0	0.01	0.04	0.02
Mean	2.49± 0.82	1.24± 0.41	4.56±1.5	0.5±0 .16	0.25± 0.08	0.91±0. 3	2.98± 0.98	1.49± 0.49
Total	64.61	32.3	118.56	12.92	6.46	23.71	77.5	38.76

AGB = Aboveground biomass, AGC = Aboveground carbon, BGB = Belowground biomass, BGC = Belowground carbon, TB = Total biomass, and TC = Total carbon

Carbon Stock Density of Tullu Qondala Exclosure

In the Tullu Qondala exclosure, the total carbon (C) stock was determined by adding up the

aboveground biomass carbon (AGB) and belowground biomass carbon (BGB) from all the sampled plots. This thorough evaluation showed quite a bit of variation in how much carbon each plot could store, which is influenced by factors like vegetation density, the types of species present, and the characteristics of the soil. Plot 27 had the lowest carbon stock at just 9.9 tons/ha, likely due to its sparse vegetation or some recent disturbances. On the other side, plot 7 boasted the highest stock at 68.1 tons/ha, probably due to its mature woody species (Fig. 2).

Overall, the average carbon stock for the entire study area was 34.14 ± 2.63 tons/ha, suggesting a moderate potential for carbon sequestration when compared to other similar exclosure systems in semi-arid regions.

Furthermore, the carbon sequestration potential representing the capacity of the ecosystem to absorb and store atmospheric CO_2 was estimated to be 118.56 tons/ha in AGB and 23.71 tons/ha in BGB (Table 3).

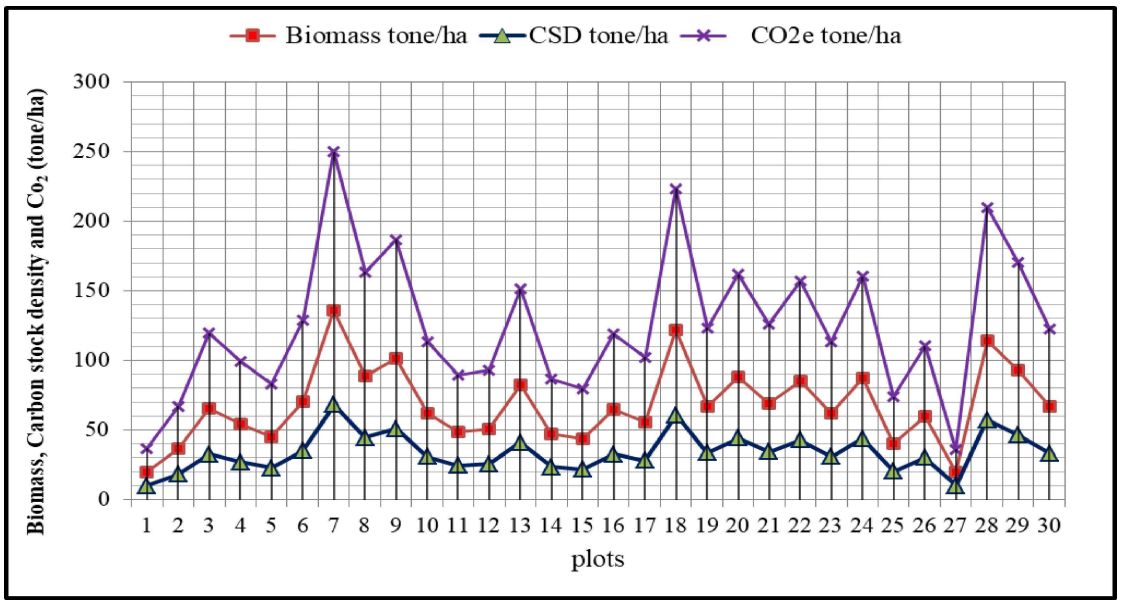

Figure: 2 Biomass, C stock density (CSD) and Co2 tone/ha per plots

In the study area, the ten key tree species showed quite a bit of variation in how much they contributed to total carbon storage. At the top of the list was *Acacia abyssinica*, which was the standout species, capturing the most carbon. Following closely in second place was *Combretum molle*. *Terminalia macroptera* took the third spot, while *Acacia polyacantha and Gardenia ternifolia* came in fourth and fifth, respectively. *Croton macrostachyus, Cordia africana, Entada abyssinica, Ficus vasta, and Ehretia cymosa* showed progressively decreasing carbon storage capacities, listed here in descending order of their contributions

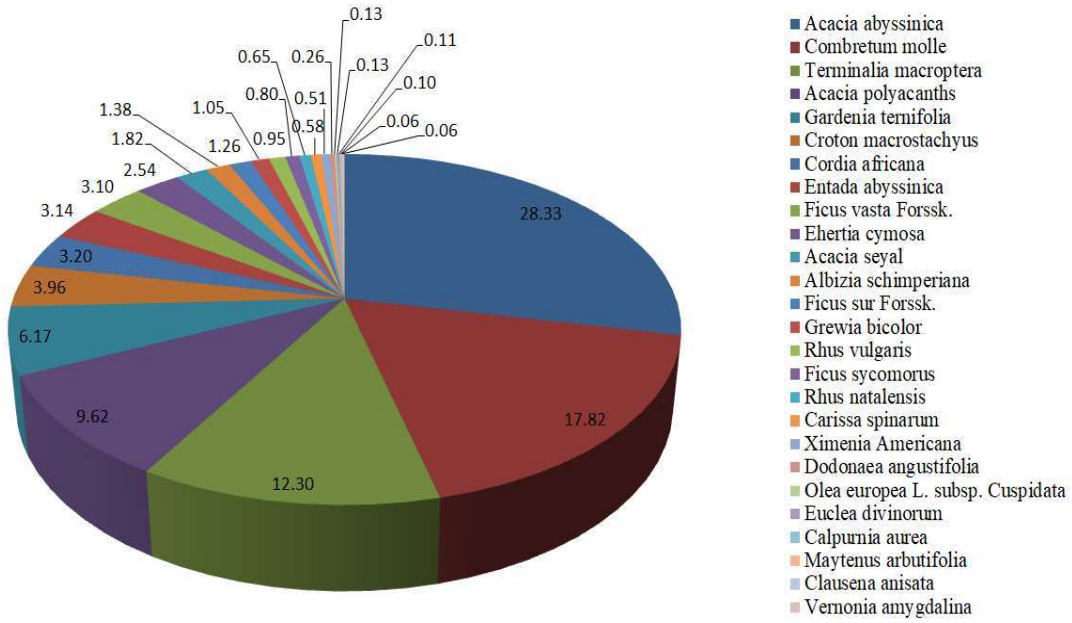

Figure 3. Contribution of woody species for the total carbon of Tullu Qondala exclosure (in percent)

The top 10 most important species accounted for 90.18% of the total aboveground biomass (AGB) and aboveground carbon (AGC) stocks in Tullu Qondala Exclosure, while the remaining species contributed only a minor fraction (Figure 4). Among these dominant species, three, *Acacia abyssinica, Combretum molle,* and *Terminalia macroptera* were particularly significant, collectively representing 58.48% of the entire carbon stock. This highlights their crucial role in carbon sequestration within the exclosure, underscoring their ecological importance in the ecosystem.

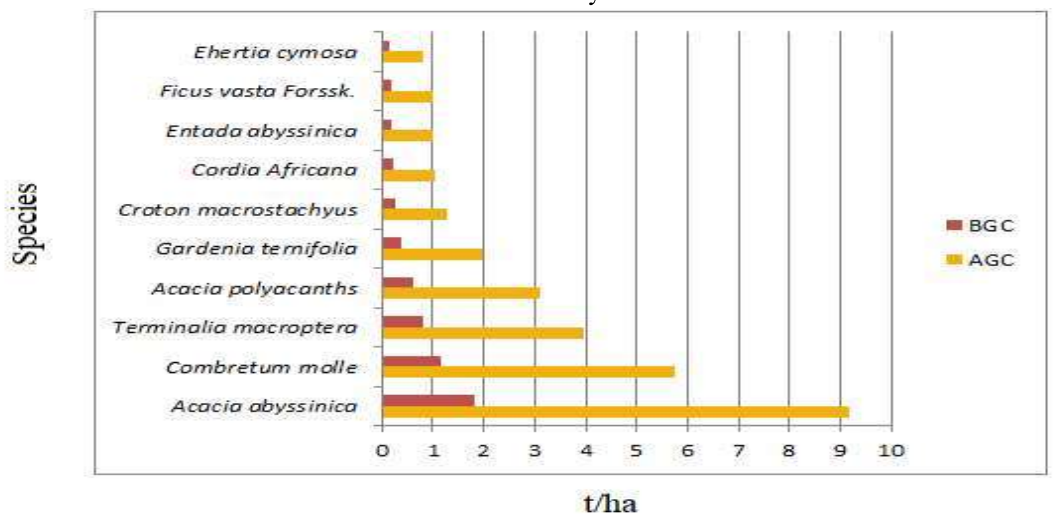

Figure 4. The share of ten most important tree species to the BGC and AGC in Tullu Qondala exclosure

Discussion

Biomass and Carbon Stock of Tullu Qondala Area Exclosure

The study evaluated tree carbon stocks using the IPCC-recommended global carbon fraction of 0.5 (50% of biomass), based on the assumption that half of a tree's dry biomass is carbon. This widely accepted default value is commonly used in forest carbon accounting, especially when direct measurements are not available, as supported by various studies and the IPCC Guidelines (IPCC, 2006). Exclosures, restricted areas for livestock and humans, effectively restore degraded lands (Mekuria *et al*., 2018). Combined with enrichment planting, introducing native or high-biomass species, they boost biomass carbon stocks (Ashenafi *et al*., 2019). However, the Tullu Qondala Area Exclosure showed uneven distribution of carbon stock input between AGB and BGB. This disparity could be attributed to issues like species composition, age structure of vegetation, and soil organic carbon dynamics (Lemenih and Itanna, 2004). Such variations underline the need for site-specific evaluation when carrying out restoration strategies, as carbon sequestration potential can vary based on ecological and management conditions (Chave *et al*., 2014).

This study indicated notable disparities in biomass accumulation across different tree species, with *Acacia abyssinica* demonstrating the highest biomass, succeeded by *Combretum molle, Terminalia macroptera, Acacia polyacantha, Gardenia ternifolia,* and *Croton macrostachyus.* On the other hand, species such as Calpurnia aurea, Maytenus arbutifolia, Clausena anisata, and Vernonia amygdalina contributed relatively less to the total biomass (Table 3). These differences can be attributed to different factors such as wood density, species size (height and DBH), species abundance, and the level of anthropogenic pressure in the area.(Agerie *et al*., 2019; Chave *et al*., 2014).

In the Tullu Qondala Exclosure, we noticed a remarkable dominance of just a handful of key species when it comes to aboveground biomass (AGB) and aboveground carbon (AGC) stocks. The top 10 species alone made up a whopping 90.18% of the total AGB and AGC, leaving the rest of the species with only a tiny contribution . This trend is consistent with what we've seen in other tropical and subtropical dry forests, where a small number of species tend to take the lead in storing carbon in the ecosystem, due to their larger size, denser wood (like Chave *et al*., 2014; Poorter *et al*., 2015).

There is a strong association between stand basal area and aboveground biomass in which they are directly influenced by the diameter of tree. The basal area increases with tree size, which in turn increase the aboveground biomass (AGB) and carbon (C) storage capacity (Agerie Nega *et al*., 2019; Brown, 2002). Larger and denser trees, such as *Ficus vasta*, accumulate more carbon in both aboveground (AG) and belowground (BG) forms relative to smaller species like *Vernonia amygdalina*, which showed the lowest carbon stock in the Tullu Qondala Exclosure (S2). This result is in agreement with similar studies that indicate tree size and wood density as important determinants of carbon sequestration potential (Gibbs *et al*., 2007).

Concerning the ecological and management effect, the presence of high-biomass species such as *Acacia abyssinica* and *Ficus vasta* highlights their ecological significance in carbon storage and ecosystem productivity. On the other hand, the lower contribution of species like *Vernonia amygdalina* could be attributed to their smaller size or lower wood density. Sustainable forest management strategies should focus the conservation of large, high-biomass species to enhance carbon sequestration, particularly in Exclosure systems that enable natural regeneration (Lemenih and Kassa, 2014). Moreover, reducing anthropogenic pressures like selective logging and grazing can increase biomass retention and carbon storage potential in these ecosystems (Aerts *et al*., 2007).

The AGB and C density of woody plant species in Plot 27 were significantly lower than those in the other sampled plots, while Plot 7 showed the highest amount (Figure 2). This difference could be attributed to the presence of several

large-diameter trees in Plot 7, which may have a key role in its increased mean AGB and carbon stocks (Chave *et al*., 2014). Additionally, variation in woody species density and diameter distribution among the plots were observed as critical factors affecting carbon storage capacity (Basuki *et al*., 2009). The higher presence of mature, large-sized trees in Plot 7 likely increased its carbon sequestration potential, whereas the relatively lower tree density and smaller diameter classes in Plot 27 may be the reason for its lower biomass accumulation.

This study showed that the biomass density in Tullu Qondala Exclosure ranged from of 9.88 t/ha to 68.07 t/ha, with mean biomass carbon stock density of 34.142 ± 13.86 t/ha. The corresponding mean carbon dioxide equivalent was 125.3 ± 50.86 t/ha (Table 2). These results were higher than those reported in similar studies, such as (Haftom *et al*., 2019) in Southern Tigray, Northern Ethiopia (4.58 ± 3.75 t/ha), and (Abebe and Mekuria, 2021) in two exclosure sites in SNNPRS, Southern Ethiopia (4.37 ± 0.671 and 11 ± 2 t/ha). The variation in carbon stock density could be attributed to issues such as the occurrence of larger trees with greater basal area, higher woody species density, and the allometric model applied (Lasco and Pulhin, 2009).

The length of exclosure time significantly affects carbon stock density, as carbon stocks are directly related to biomass accumulation, and longer exclosure periods increase total biomass (Abebe and Mekuria, 2021). Activities such as afforestation and the restoration of degraded forest lands, together with effective management approaches, could enhance carbon stocks across major pools through sequestration (Lal, 2005). These activities could also play an important role in mitigating climate change by improving CO_2 sequestration.

In its Intended Nationally Determined Contribution (INDC), Ethiopia has promised to reduce greenhouse gas (GHG) emissions by 64% by 2030, relative to a situation where things just keep going as they are, which would lead to an impressive 255 $MTCO_2eq$. Particularly, the forestry sector is expected to contribute about 50.9% (or 130 $MTCO_2eq$) of the country's emissions (FDRE, 2015). This underlines how important it is to precisely assess the carbon storage potentials of Ethiopia's forest ecosystems.

Conclusion

This research assessed the biomass and total carbon stock of the Tullu Qondala Exclosure, found in West Shewa, Oromia, Ethiopia. The study site has faced degradation problem and been excluded from human and animal interference for more than 15 years. The findings showed that the exclosure has improved both biomass growth and soil carbon storage, indicating its importance as an effective restoration strategy for degraded landscapes. The results also showed that long-term exclosure practices enhance carbon sequestration in both aboveground and belowground biomass. The increase in carbon stock within the Tullu Qondala exclosure indicates its potential in addressing climate change. By changing degraded lands into exclosures, Ethiopia can enhance ecological recovery while increasing carbon stocks, coinciding with the national REDD+ goals..

Conflict of interest statement

The authors declare no potential conflicts of interest with respect to the research, authorship, and publication of this article.

Supplementary information (SI)

List of woody plant species collected from study area

No	Scientific name	Family	Local name	Habit
1	*Acacia abyssinica*	Fabaceae	Laaftoo	Tree
2	*Acacia polyacanths*	Fabaceae	Harmukkoo	Tree
3	*Acacia seyal*	Fabaceae	Waaccuu	Tree
4	*Albizia schimperiana*	Fabaceae	Muka-arbaa	Tree
5	*Calpurnia aurea*	Fabaceae	Ceekaa	Shrub
6	*Carissa spinarum*	Apocynaceae	Agamsa	Shrub
7	*Clausena anisata*	Rutaceae	Ulmaayii	Shrub
8	*Combretum molle*	Combertaceae	Rukeessa	Tree
9	*Cordia africana Lam.*	Boraginaceae	Waddeessa	Tree
10	*Croton macrostachyus.*	Euphorbiaceae	Makkanniisa	Tree
11	*Dodonea angustifolia*	Sapindaceae	Ittacha	Shrub
12	*Ehertia cymosa Thonn.*	Boraginaceae	Ulaagaa	Tree
13	*Entada abyssinica*	Fabaceae	Ambaltaa	Tree
14	*Euclea divinorum Hiern*	Ebenaceae	Mi'eessaa	Shrub
15	*Ficus sur Forssk.*	Moraceae	Harbuu	Tree
16	*Ficus sycomorus L.*	Moraceae	Odaa	Tree
17	*Ficus vasta Forssk.*	Moraceae	Qilxuu	Tree
18	*Gardenia ternifolia*	Rubiaceae	Gambeela	Tree
19	*Grewia bicolorJuss*	Tiliaceae	Harooressa	Shrub
20	*Maytenus arbutifolia*	Celastraceae	Kombolcha	Tree
21	*Olea europea sub sp. Cuspidata*	Oleaceae	Ejersa	Tree
22	*Rhus natalensis*	Anacardiaceae	Xaaxessaa	Shrub
23	*Rhus vulgaris Meikle*	Anacardiaceae	Daboobessa	shrub
24	*Terminalia macroptera*	Combretaceae	Dabaqqaa	Tree
25	*Vernonia amygdalina Del.*	Asteraceae	Eebicha	Shrub
26	*Ximenia americana L.*	Olacaceae	Hudhaa	Shrub

Supplementary information (S2)

Mean AGB (Aboveground Biomass) and carbon stock per total and single tree species recorded from study site

No	Scientific name	Number of stems	Average DBH (cm)	Average height (m)	AGB/ Species (kg)	AGB/ Species (ton)	Carbon/ Species (ton)	Carbon/ Species (ton/ha)	Carbon/ single tree (ton)	CO2/ species (ton)	CO2/ species (ton/ha)	CO2/ single tree (ton)
1	*Acacia abyssinica*	225	16.77	6.2	18316.1	18.316	9.158	7.632	0.041	33.61	28.008	0.149
2	*Combretum molle*	454	12.69	5.62	11519.26	11.519	5.76	4.8	0.013	21.138	17.615	0.047
3	*Terminalia macroptera*	101	16.58	6.18	7949.417	7.949	3.975	3.312	0.039	14.587	12.156	0.144
4	*Acacia polyacanths*	57	18.2	7.64	6217.941	6.218	3.109	2.591	0.055	11.41	9.508	0.2
5	*Gardenia ternifolia*	63	17.09	5.67	3987.288	3.987	1.994	1.661	0.032	7.317	6.097	0.116
6	*Croton macrostachyus*	63	14.54	5.97	2560.14	2.56	1.28	1.067	0.02	4.698	3.915	0.075
7	*Cordia africana*	28	21.01	7.2	2067.199	2.067	1.034	0.861	0.037	3.793	3.161	0.135
8	*Entada abyssinica*	40	15.37	6.14	2030.412	2.03	1.015	0.846	0.025	3.726	3.105	0.093
9	*Ficus vasta Forssk.*	8	35.42	8.23	2002.814	2.003	1.001	0.835	0.125	3.675	3.063	0.459
10	*Ehertia cymosa*	75	11.51	5.06	1643.531	1.644	0.822	0.685	0.011	3.016	2.513	0.04
11	*Acacia seyal*	22	16.6	6.87	1175.019	1.175	0.588	0.49	0.027	2.156	1.797	0.098
12	*Albizia schimperiana*	24	14.2	6.06	893.069	0.893	0.447	0.372	0.019	1.639	1.366	0.068
13	*Ficus sur Forssk.*	5	30.34	7.23	815.4	0.815	0.408	0.34	0.082	1.496	1.247	0.299
14	*Grewia bicolor*	88	8.22	4.16	675.635	0.676	0.338	0.282	0.004	1.24	1.033	0.014

15	*Rhus vulgaris*	119	5.68	4.26	613.378	0.613	0.307	0.256	0.003	1.126	0.938	0.009
16	*Ficus sycomorus*	4	27.95	6.18	520.081	0.52	0.26	0.217	0.065	0.954	0.795	0.239
17	*Rhus natalensis*	63	6.25	4.57	419.147	0.419	0.21	0.175	0.003	0.769	0.641	0.012
18	*Carissa spinarum*	53	6.51	4.3	376.764	0.377	0.188	0.157	0.004	0.691	0.576	0.013
19	*Ximenia americana*	49	5.63	4.04	326.993	0.327	0.163	0.136	0.003	0.6	0.5	0.012
20	*Dodonaea angustifolia*	17	6.24	4.03	165.222	0.165	0.083	0.069	0.005	0.303	0.253	0.018
21	*Olea europea sub sp. Cuspidata*	8	7.45	5.25	81.805	0.082	0.041	0.034	0.005	0.15	0.125	0.019
22	*Euclea divinorum*	18	5.84	3.57	81.395	0.081	0.041	0.034	0.002	0.149	0.124	0.008
23	*Calpurnia aurea*	14	5.71	4.04	68.359	0.068	0.034	0.028	0.002	0.125	0.105	0.009
24	*Maytenus arbutifolia*	4	8.75	5.23	67.104	0.067	0.034	0.028	0.008	0.123	0.103	0.031
25	*Clausena anisata*	8	6.11	4.23	36.933	0.037	0.018	0.0154	0.002	0.068	0.0565	0.008
26	*Vernonia amygdalina*	9	6.05	4.39	36.346	0.036	0.018	0.0151	0.002	0.067	0.0556	0.007
	Mean				2486.41	2.49	1.24	1.04	0.02	4.56	3.8	0.09

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RESEARCH PAPER

Preparation and Characterization of Activated Carbon from Root and Inflorescence of Enset/*Ensete-Vetricosum*/ for the Removal Pb(II) from Aqueous Solution

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Abstract

Activated carbon was synthesized from the inflorescence and root of enset/ensete vetricosum to effectively remove Pb(II) heavy metal ions from aqueous solutions. The process involved chemical activation using H_3PO_4 followed by carbonization at 300°C for 15 minutes. The most effective conditions for creating activated carbon varied depending on the source material. For enset inflorescence (flower), a preparation temperature of 25°C, a pH of 5, and a contact time of 60 minutes yielded the good results. In contrast, the optimal conditions for preparing activated carbon from enset root were a temperature of 30°C, a neutral pH of 7, and a shorter contact time of 30 minutes. Adsorbent doses of 1.5 g and 2 g in 200 mL solution were found to be optimal. The adsorption capacities for Pb(II) by inflorescence and root were determined to be 1.36 mg/g and 1.68 mg/g, respectively. Freundlich adsorption isotherm models provided better fits for the experimental adsorption equilibrium data compared to Langmuir models. FT-IR spectra analysis revealed the presence of functional groups responsible for binding Pb(II) ions onto the adsorbent. Kinetics data suggested that the pseudo-second order model best described the adsorption process. The synthesized activated carbon showed high efficiency in removing Pb(II) ions from aqueous solutions, making it a promising adsorbent for Pb(II) and related heavy metal removal.

Keywords: Adsorption, heavy metals, Langmuir-Freundlich isotherm models, adsorption kinetics

Introduction

Ensete ventricosum, is a notable monocarpic perennial that considered to the family Musaceae which also includes bananas (*Musa spp.*). Originating in Ethiopia, this species has been uniquely domesticated, and as a result, it holds immense cultural, agricultural, and economic significance. Furthermore, it serves as a primary staple food for approximately 20 million people, particularly in the densely populated south and southwestern highlands (Kidane *et al*., 2021).

Researches indicates that different Enset landraces show variations in the nutritional content of their corms, which include considerable amounts of carbohydrates, fiber, and essential minerals such as iron and zinc (Kidane *et al*., 2021). The inflorescence of enset, characterized by a large drooping flower spike, plays a vital role in food production. Specifically, the stalk of the inflorescence, along with the pseudos' term and corm, undergoes processing to produce "kocho" and "bulla." Kocho is made from the fermented pulp, while bulla is a refined starch extracted from the liquid of the pulverized mixture.

Together, these products highlight the importance of enset in the local diet and economy (Kidane *et al*., 2021).

Traditionally, Enset plants are often harvested prior to flowering to optimize the starch content in the vegetative parts (Kidane *et al*., 2021). Unlike its banana relatives, Enset is not cultivated for its fruit, which is small, inedible, and contains hard seeds. Instead, various parts of the plant, including the root (corm) and the inflorescence stalk, are crucial sources of sustenance and have diverse traditional uses (mohammed and Chala, 2014). Studies have demonstrated the effectiveness of activated carbon produced from Activated carbon made from *Ensete ventricosum* leaves effectively removes organic pollutants like phenol from water. When prepared under optimized conditions (considering factors like carbonization temperature, activation agent, and impregnation ratio), this activated carbon exhibits a high surface area and excellent adsorption capabilities (Keder, 2023). This offers a sustainable and environmentally friendly way to treat industrial wastewater.

One of the biggest threats to human health is contaminated water, which is also inappropriate for residential usage. Natural or man-made processes, such as the release of heavy metals into soils and water supplies through the disposal of wastewater, can be the source of contaminated water. Because heavy metals are hazardous to a wide variety of living species, their presence in the environment is a serious concern (Alloway, 2013). These compounds may be the result of pesticide and fertilizer use in agriculture, urban or industrial pollution, or both (WHO, 2011). The effects of toxic contamination on the environment might be either acute or chronic (long-term). This frequently goes above the allowable sanitary norms, which has a negative effect on groundwater and the aquatic environment, as well as on human health (Vasseur, 2008). According to Dagmawi *et al*. (2013), 70% of industrial effluents in developing nations are discharged into the surrounding environment untreated.

Many water bodies are receiving doses of heavy metals from increased industrial activity that surpass the maximum allowable limit for wastewater discharge intended to safeguard people, animals, and the environment (Iqual and Saeed, 2007). Toxic heavy metals are not biodegradable, which is a major concern were also discharge in the environment in many cases. Moreover, they react irreversibly with enzymes and proteins, further complicating their impact on biological systems. Their strength as strong oxidants allows them to be absorbed through the skin, leading to a variety of disorders and diseases (Jaishankar *et al*., 2014; Nordberg *et al*., 2007).

There are several methods for removing these toxic heavy metals, which can be broadly categorized into three groups: chemical, biological, and physical. Each method offers distinct benefits and drawbacks depending on its application. Notably, the World Health Organization (WHO) identifies chromium (Cr), copper (Cu), zinc (Zn), iron (Fe), cadmium (Cd), mercury (Hg), and lead (Pb) as the metals of greatest concern for public health at present (Muhammad *et al.,* 2004).

These metals are not easily detoxified or broken down by the body, and has degree of accumulate in living organisms. Therefore, when selecting appropriate treatment procedures, it is crucial to consider the need to enhance effluent discharge standards to protect the environment. Nowadays, there is a growing emphasis on using environmentally friendly treatment techniques. Furthermore, utilizing certain waste materials that may be beneficial in this context, along with their reuse, can provide a significant advantage (Jaishankar *et al*., 2014).

Research on the application of suitable and affordable technologies for the purification of drinking water in poor nations has been conducted recently. Additionally, studies have concentrated on domestic production of water treatment chemicals using locally sourced raw ingredients (Warhurst *et al.,* 1997).

Adsorption is one of these methods. By using byproducts as starting points to make

commonly used adsorbents, like activated carbons, it is possible to add value to the total amount of biomass gathered. The amount of safe drinking water that is available to the public is limited in most poor nations due to the high expense of importing activated carbon. Wood, lignite, peat, and coal are examples of raw materials having a high carbon content but a low inorganic content that can be used to produce adsorbents like activated carbon (AC) for adsorption (Jabit, 2007).

Carbon precursors can be derived from a broad variety of carbonaceous sources, including wood, coal, peat, and different agricultural byproducts. Due to their widespread availability, affordability, and renewability, agricultural byproducts have drawn more attention lately for the production of activated carbon (Kadirvelu *et al*., 2003). It is evident from many literary works that a wide species of materials are utilized to manufacture activated carbon for adsorption applications. These include wood sawdust (Bogdanka, 2007), teff straw (Mulu, 2013), rice husk (Srivastava et al., 2015), sugarcane bagasse (Kalderis *et al*., 2008), coffee husk (Kanamadi et al., 2010), and other industrial waste (Kadirvelu *et al.,* 2001). As the reports confirmed on the use of enset root and inflorescence's activated carbon as sorption qualities for Pb(II) removals in aqueous solutions. Thus, this study aims to construct and assess enset root and inflorescence adsorption effectiveness for absorbent of Pb(II) from aqueous solutions.

Materials and Methods

Instruments and Equipment

The Fourier Transform Infrared (FT-IR) spectrophotometer (Model: IR Affinity 1S class 1), UV/Vis-SP65 SYANO spectrophotometer, atomic absorption spectroscopy (AAS), Agilent -2000) are used.

Chemicals and Reagents

Analytical-grade chemicals, such as PbNO3 for standard metal ion sample preparation, H3PO4 as an enset root activation agent, and the inflorescence-activated carbon generation procedure, were employed in this investigation. Distilled water was utilized in all trials to get rid of any remaining acid char. For adjusting pH, use NaOH and HCl. All of the solutions used in the experiment were made with distilled water.

Experimental Methods and Procedures

Raw Material Preparation

Enset root and flower were Randomly obtained from a nearby community house in Ambo town, West Shoa, Ethiopia, in order to prepare adsorbents. This settlement is situated in the West Showa of the Oromia Region, west of Addis Ababa. Its elevation is 2101 meters, and its latitude and longitude are 8°59′ N and 37°51′ E. After being cut off from other components, the root and inflorescence were thoroughly cleaned with tap water multiple times to get rid of dirt, dust, and other contaminants. It was repeatedly cleaned with distilled water. After the separated root and inflorescence were chopped into tiny pieces, they were dried for a week in the sun and then for 24 hours at 105 °C in an oven to get rid of any moisture.

The inflorescence and enset root were chosen f or the activated carbon preparation process. For future research, the dried materials were kept in a sterile area in sealed plastic bags.

Figure 1. Pretreatment of enset root and inflorescence

Preparation of Activated Carbon

Before carbonization, the dried samples were oven-dried for 12 hours at 105 °C to eliminate any remaining moisture (Figure 1). Phosphoric acid was added to the samples after they were taken out of the crucible and cooked in the electrical furnace. For fifteen minutes, the oven was kept at 300 °C, during which time carbon was produced. Once the activated carbon had cooled to room temperature, it was carefully cleaned with distilled water until the pH of the effluent, or supernatant, stabilized at a value close to neutral. The samples were then dried for 12 hours at 105 °C (Figure 2). Lastly, the inexpensive activated carbon made from the root and inflorescence was crushed and kept in a ready-made sample holder until needed for next steps.

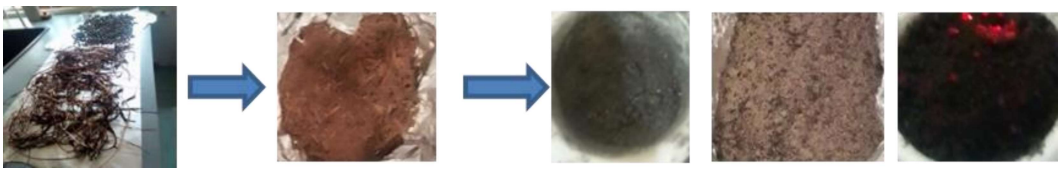

Figure 2. Enset root and Inflorescence stem activation

Characterization of Prepared Activated Carbon

FT-IR Spectroscopy

Enset root and inflorescence, low-cost ACs, and metal-loaded Enset root and inflorescence prepared ACs treatment experimental were performed differently and FTIR absorption for different functional groups scanned in the spectral range of 400 – 4000 cm^{-1} region.

FTIR of Enset Root and Inflorescence Activated Carbon

For the enset root and inflorescence activated carbon transform FT-IR, spectrum analyses were performed. The sample disks were filled with a tablet form of the sorbent for this investigation, and the activated carbon spectra were recorded. Using a screw and a pair of metal dies, the sample was squeezed into a pellet on a 7-mm collar. With the use of a screw, the collar holding the pellet was taken out of the metal die and put inside a cuvette. After turning on the device, the samples were scanned. Distinct linkages in various functional groups were found to correspond to distinct bands in the spectrum

FTIR of Metal Loaded Enset Root and Inflorescence Activated Carbon

After adsorption and filtering, the enset root and inflorescence waste were dried at 105 ^0C in an oven for 24h to eliminate any moisture. 0.5 grams of dry metal-loaded fractions using a mortar and pestle, the enset root and inflorescence were mashed into a powder. Using a mortar and pestle, the fine powder was combined with 1.0 g of analytical-grade KBr. The blend was ground finely. The sample was positioned on a 7-mm collar and compressed using a screw and a series of metal dies to create a pellet. After being taken out of the metal dye and set on the sample container, the collar holding the pellet was replaced. After turning on the equipment, the sample was analyzed. The spectra of enset root and inflorescence of ACs were recorded in specified region.

Preparation of Adsorbate Solution

To ensure accurate results, 1.6 g of $Pb(NO_3)_2$ was dissolved in 1L of distilled water using a volumetric flask to prepare a stock Pb(II) solution with a concentration of 1 g/L. This stock solution was then diluted using double deionized water to obtain the required concentrations. Serial dilutions of the stock solution were performed to produce the working solutions. These working solutions were prepared in 250 mL Erlenmeyer flasks by adjusting the stock solution with deionized water to achieve the desired concentrations.

The adsorbate solutions were prepared at four specific concentrations: 20, 30, 40, and 50 ppm. The dilution equation was applied to calculate the concentrations of these working solutions based on the original stock solution.

Calibration of Pb(II) Absorbance

The amounts of metals in the activated carbon were measured using an Agilent Technologies 200 series atomic absorption spectrophotometer. Prior to the sample determination, the instruments were calibrated using the standards. Both the regular functioning solution and the approaches have blank solutions ready. 10 mL of the standard $Pb(NO_3)_2$ were calibrated appropriately as per needed in order to prepare 100 ppm. Distilled with deionized water at the end, and the mixture was well combined. By pipetting the 100 ppm standard working solution into calibrated flasks and adding deionized water to fill the capacity, the solution was made ready.

Batch Adsorption Experiment

The batch experiment was conducted at ambient temperature by introducing a measured amount of sample powder into 250 mL conical flasks containing Pb(II) solutions. Each mixture was then shaken at a constant speed of 200 rpm for designated time intervals. Following agitation, the solid material was separated through filtration using Whatman No. 1 filter paper. The experiment involved varying the initial metal ion concentrations, pH levels, and the quantity of Enset root and inflorescence applied for adsorption. After the adsorption process, each suspension was filtered, and the resulting filtrates were analyzed to determine the concentration of the respective metal ions.

The removal efficiency of Pb(II) ions from aqueous solution calculated as equation 3.1

$$\%\text{Removal} = (Co - Cf)/Co \times 100 \quad \ldots\ldots\ldots 3.1$$

Where Co and Cf ; initial and final concentration (mgL^{-1}) of metal ion respectively

Batch adsorption experiment of Pb(II) performed to determine the adsorption degree of enset root and inflorescence at different metals concentrations.

The initial and final concentrations of the solutions were measured and quantified using AAS at λ_{max}, and the adsorption capacities of the adsorbents were calculated accordingly. The adsorption capacities of the adsorbents used in this study were quantified using the following equation:

$$q = \left(\frac{Co - Ct}{W}\right) V \qquad 3.2$$

Where V is volume (L), C_o and C_e are initial and equilibrium concentrations (mg/L), and W is adsorbent weight (g).

The influence of solution pH, Pb(II) concentration, adsorbent dosage, and contact time on the adsorption efficiency of the synthesized ACs was systematically examined using central composite design to identify the optimal adsorption conditions.

Factors Affecting the Batch Equilibrium Studies

Effect of Contact Time

To determine the adsorption rate of Pb(II) ions using low-cost activated carbon derived from enset root and inflorescence, 50 mL of standard solutions were used, and the amount of metal ions adsorbed was measured at different contact times: 30, 60, 90, and 120 minutes. During the experiment, temperature, initial concentration, and pH were maintained constant (Shan *et al.,* 2007).

Effect of Activated Carbon Dosage

The effect of adsorbent dosage on metal ion removal was investigated by adding 0.5, 1.0, 1.5, and 2.0 grams of activated carbon into separate 250 mL Erlenmeyer flasks, each containing a metal ion solution with a concentration of 40 mg/L. The adsorption efficiency for each dosage was then evaluated under constant temperature, contact time, and pH conditions.

Effect of pH

To assess how solution acidity affects adsorption efficiency, the pH of Pb(II) solutions was adjusted between 1 and 10 at two-unit intervals. During these experiments, temperature and metal ion concentration were kept constant. Pavasant *et al*., 2006). Adsorption experiments were carried out by temperature and concentration remains constant.

Effect of Initial Concentration of Adsorb Ate

This stage evaluates how different metal ion concentrations impact the removal efficiency of the adsorbent (low-cost activated carbon from enset root and inflorescence). The effect was tested using metal ion concentrations of 20, 30, 40, and 50 mg/L, while all other conditions were maintained constant.

Effects of temperature

The impact of temperature on Pb(II) removal was examined by conducting experiments at different temperatures (25, 30, 35, and 40°C) for a duration of one hour. A temperature-controlled shaker was used to maintain the desired temperatures.

The Study of Heavy Metal Adsorption kinetics

Studying adsorption kinetics is essential as it offers insight into the adsorption mechanism and behavior, which are critical for evaluating process efficiency. In this research, pseudo-first-order and second order kinetics model were studied. These models were applied at various concentrations to identify which one best aligns with the experimental adsorption capacity values. This analysis helps determine the sorption model that the system follows. Mathematically pseudo-first order is expressed as

$$\text{Log}\,(q_e\text{-}q_t) = \log q_e - \frac{k1t}{2.303} \qquad 3.3$$

Here, q_e represents the equilibrium adsorption capacity (mg/g), q_t is the adsorption capacity at time t, and k is the pseudo-first-order rate constant (g/mg·h), which can be determined from a plot of $\log(q_e - q_t)$. The pseudo-second-order kinetic model is expressed mathematically as follows:

$$1/qt = 1/k_2qe_2 + t/qe \qquad 3.4$$

Results and Discussions

Characterizations of the Prepared Enset Inflorescence and Root

FT-IR Analysis of Adsorbent

FT-IR spectroscopy was performed to identify the various functional groups present in the adsorbent, as these groups play a key role in the adsorption process. To determine which functional groups in the enset inflorescence are involved in metal ion binding, FT-IR spectra were recorded before (Figure 3a) and after Pb(II) adsorption (Figure 3b) within the range of 4000–400 cm^{-1}. The broad absorption peaks observed at 3331.91 cm^{-1} and 3274 cm^{-1} were attributed to O–H stretching, indicating the presence of intra- and intermolecular hydrogen bonding. The O-H stretching vibrations indicate the presence of free hydroxyl groups and bonded O–H bands of polymeric compounds such as alcohols or phenols, as in pectin, hemicelluloses, cellulose and lignin (Iqbal *et al*., 2008). The peak observed at 2918.17cm^{-1} and 2923.46cm^{-1} was associated with asymmetric C–H stretching vibrations of aliphatic acids (Feng *et al*., 2008).

The peaks observed at 2290 and 2321 cm^{-1} correspond to aliphatic C–H stretching vibrations. The peak at 1153 cm^{-1} is attributed to C–N stretching of amine groups, while the peak at 1041 cm^{-1} is associated with C–O stretching in primary hydroxyl groups. The peak at 1269 cm^{-1} is related to C–O stretching vibrations from alcohols (C–OH). These functional groups are likely involved in the binding of Pb(II) ions.

The corresponding functional groups and the related absorbance peaks data presents in table 1, confirmed the shifting of absorption bands

and the disappearances of absorption bands due to binding with Pb(II) ions in aqueous solutions with the prepared absorbent.

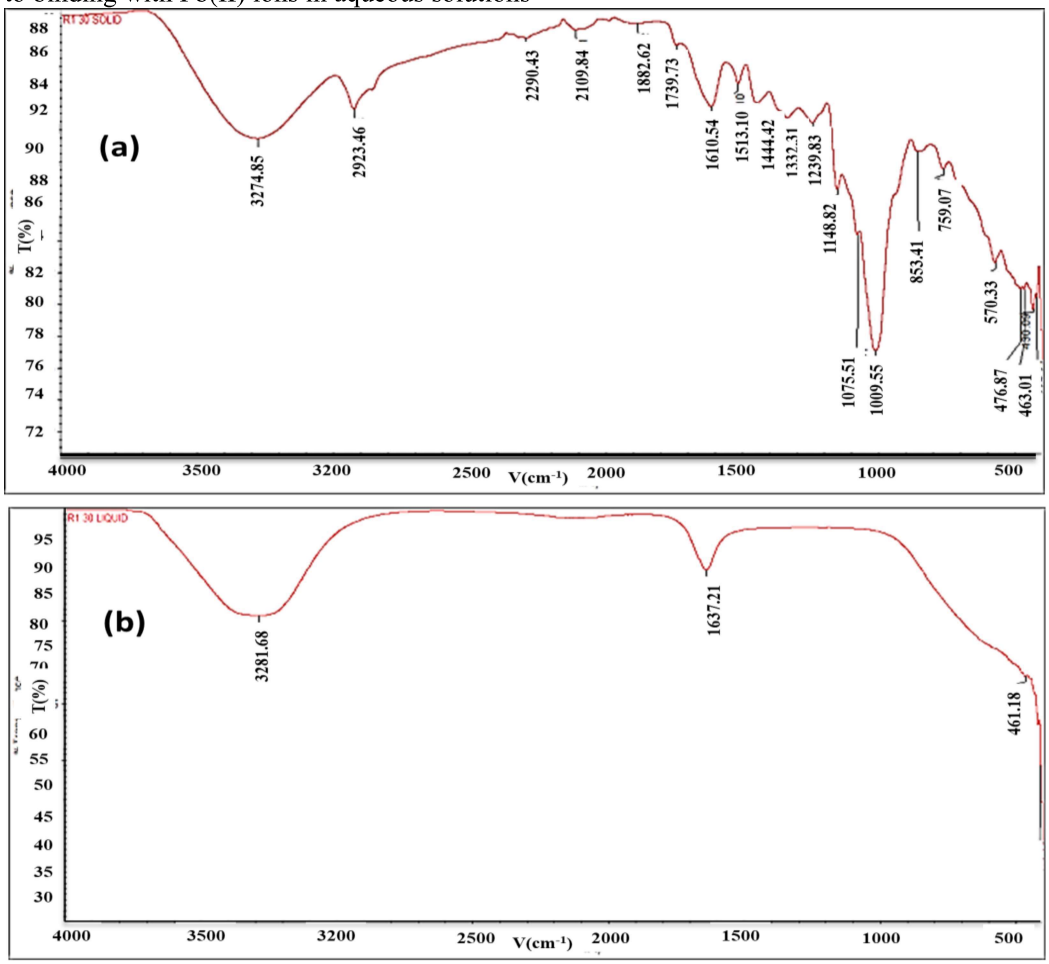

Figure 3. FT-IR spectra of Activate carbon prepared from enset inflorescence (a) before adsorption and (b)after adsorption

Table 1. FTIR spectrum of Enset inflorescence AC before and after adsorption

Frequency(cm^{-1}) before adsorption	Frequency(cm^{-1}) After adsorption	Bond	Functional groups
3274,88	3281	O-H stretching	Hydroxyl
2923.46	--	C-H stretching	Alkanes
1610	1637	C=C stretching	Alkene
1075	---	C-O	Alcohol
1009	--	C-O	Ether

Similar to enset inflorescence the FTIR spectra were recorded in order to quantify which functional groups of enset root responsible for metal uptake, for adsorbent before (Figure 4a) and after Pb(II) binding absorption were scanned (Figure 4b). The broad peak at 3331.91 cm^{-1} and 2918.17 cm^{-1} indicate O-H group presence. The disappearance several absorption peaks from Figure 4b comparing with Figure 4a, confirm the formation of certain binding with Pb(II) and the morphological change of functional group of enset root after treatment

with metal. Similarly, the data presents in table 2, the shifting of absorption bands and the disappearances confirmed the change of functional groups after binding with Pb(II) ions in aqueous solutions.

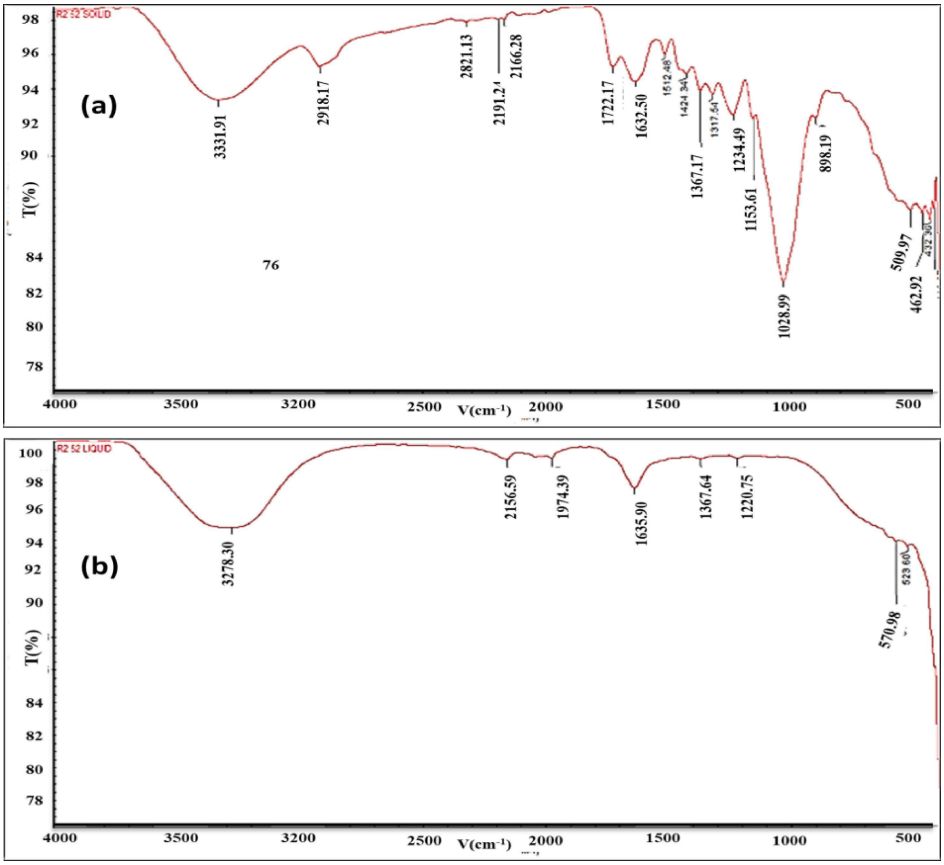

Figure 4. Adsorption spectra of Enset root AC (a) before adsorption and (b) after adsorption

Table 2. FTIR spectrum of root AC before and after adsorption

Frequency(cm^{-1}before adsorption	Frequency(cm^{-1})after adsorption	Bond	Functional groups
3331.5	3278	O-H stretching	Hydroxyl
2918,5	2914	C-H stretching	Alkanes
1635	1632	C=C	Aromatic
1029.99	----	S=O	Sulfoxode

Calibration of Pb(II) Absorbance

An AAS was employed to measure the metal concentrations in the activated carbon samples. Prior to analysis, the instrument was calibrated using standard solutions (Figure 5). A 100 ppm stock solution of each metal was used to prepare a 10 ppm intermediate solution, which was then diluted to create working standards based on the sensitivity of each specific lamp in

the AAS. Calibration was performed using these working standards, resulting in a strong correlation coefficient. Once proper calibration was confirmed, the metal concentrations in the samples were measured. The calibration curves for each metal, showing absorbance versus concentration (mg/L), are presented in Figure 5.

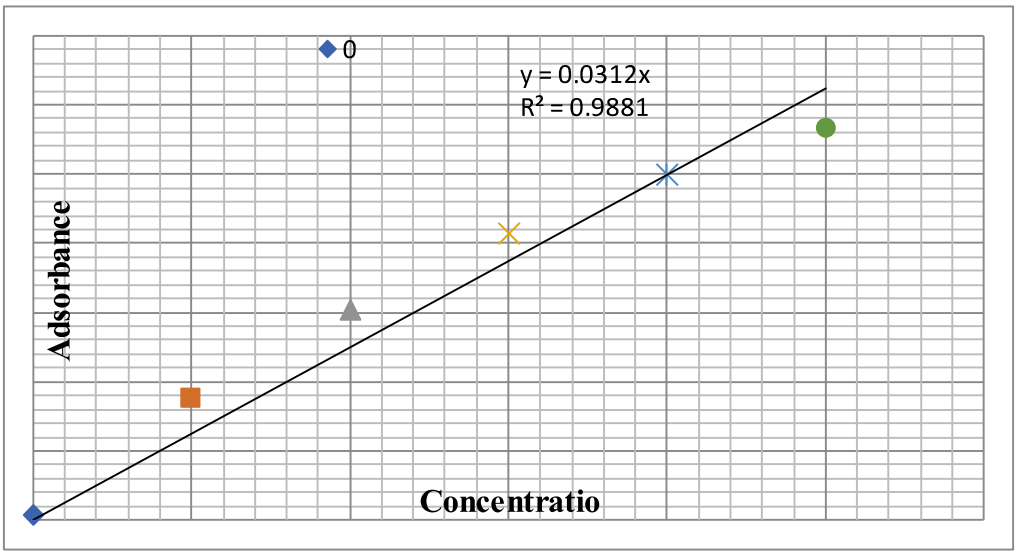

Figure 2. Calibration Curve for Pb(II) ion versus Absorbance

Factors Affecting the Adsorption of Pb(II)

Effect of contact time

In the figure 6a, the influence of contact time for absorption of Pb(II) via keeping other parameters constant at pH 7, Con = 40 mg/L, dose = 0.5 g, agitation speed = 120 rpm) was presented. In order to find out the time required for equilibrium adsorption, the contact time for Pb(II) ions on the enset inflorescence and root were varied as (30, 60, 90, and 120 min) at a fixed Pb(II) ions concentration of 40 ppm, a dosage of adsorbent of 0.5 g per 40 mL solution, at room temperature.

The adsorption reaches a maximum, (99.9 %) at 60 min, but decreases with further elapse of time due to desorption. For enset root the maximum removal efficiency of the metal ions (84.7%) occur at 30 min and decrease with increasing time and percentage removal of enset inflorescence is higher than enset root (99.9% > 84.7%). Hence, the optimum contact time (60 and 30 min) was selected for further experiments.

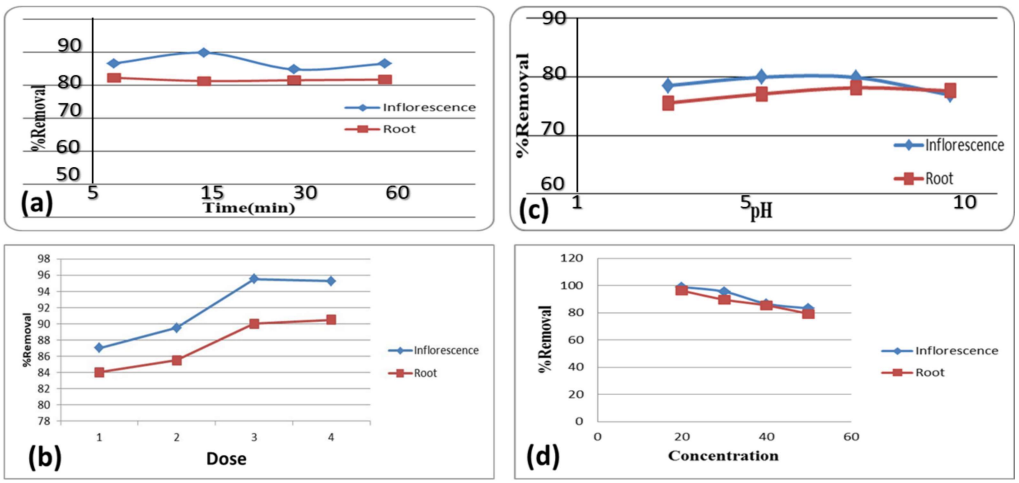

Figure 6. (a) Influence of contact time on the removal efficiency of Pb(II) at different time intervals; (b) Influence of adsorbent dosage on the removal efficiency of Pb(II); (c) Influence of pH on the removal efficiency of Pb(II) at varying pH levels; (d) Influence of initial metal ion concentration on the removal efficiency of Pb(II) from aqueous solution.

Effect of Activated Carbon Dosage

Figure 6b demonstrates how varying the adsorbent dosage influences the adsorption of Pb(II) ions when using activated carbon produced from enset inflorescence and root.

For the activated carbon derived from enset inflorescence, the adsorption of Pb(II) ions initially increased from approximately 87.0% at Dose 1 to 89.5% at dose 2, before subsequently increasing to a maximum of approximately 95.5% at dose 3. This maximum adsorption was observed under the conditions of a fixed Pb(II) ions concentration of 40 ppm, a contact time of 60 min, and a temperature of 25 °C. The most significant increase in percent adsorption (from 89.5% to 95.5%) occurred when the adsorbent dose from dose was increased from dose 2 to dose 3. However, , above this optimal dose 3, the percent adsorption of Pb(II) ions slightly decreased to approximately 95.0% at dose 4.

This non-linear trend observed for the enset inflorescence activated carbon, with an initial increase followed by a subsequent slight decrease in adsorption efficiency with increasing adsorbent dose, warrants further investigation. Potential explanations for this behavior may be agglomeration of adsorbent particles; this means at higher doses beyond the optimum, the activated carbon particles might agglomerate, leading to a reduction in the effective surface area available for adsorption. Additionally, at certain dosages, the activated carbon might release some impurities that compete with Pb(II) ions for adsorption sites, or that the surface chemistry evolves with increasing mass in a complex way.

In contrast, the adsorption of lead ions onto activated carbon derived from enset root exhibited a more typical trend, increasing with the adsorbent dose from approximately 84.0% at Dose 1 to 90.5% at dose 4. This increase was continuous throughout the studied range of doses (1 to 4) under the same fixed conditions of Pb(II) ions concentration (40 ppm), contact time (60 min), and temperature (25 °C). The maximum adsorption within the observed range was achieved at the highest tested adsorbent dose of dose 4, suggesting that within the studied range, more adsorbent consistently provided more available binding sites.

The study indicates that increasing the dose of the enset root-derived adsorbent up to Dose 4 was effective in absorbing a higher number of ions within the experimental parameters. This observation aligns with the general principle that an increased adsorbent dose provides a greater number of active sites, leading to higher

removal efficiency. The peak removal for inflorescence was approximately 95.5%, while for root it reached approximately 90.5%.

Effect of pH

pH plays a crucial role in the adsorption of Pb(II) ions. To realize this, the removal efficiency was examined at different pH values (3, 5, 7, and 9) while keeping the initial Pb(II)ions concentration (40 ppm), adsorption time (60 min), agitation speed (120 rpm), and adsorbent weight (0.5 g) constant for both enset inflorescence and root activated carbons.

Figure 6c illustrates that the adsorption efficiency of Pb(II) ions onto both adsorbents generally increased as the solution pH rose. However, the maximum adsorption wasn't at the highest pH tested. For the enset inflorescence activated carbon, the peak removal efficiency of 99.7% was observed at pH 5, while for the enset root activated carbon, the maximum of 90.7% occurred at pH 7. Beyond these optimal pH values, the adsorption efficiency decreased for both materials.

This suggests that slightly acidic to neutral conditions were most favorable for Pb(II)ions adsorption onto these activated carbons under the tested conditions. Specifically, Figure 6c indicates that the enset inflorescence activated carbon exhibited a better Pb(II)ions removal efficiency than the enset root activated carbon within this slightly acidic to neutral pH range.

Figure 6d shows the impact of varying initial Pb(II) concentrations on the removal efficiency of both enset inflorescence and root activated carbons. These experiments were conducted under consistent conditions: an adsorbent dose of 0.5 g, a pH of 7, a contact time of 60 min, and an agitation speed of 120 rpm for each adsorbent material. The removal efficiency of Pb(II) by the enset inflorescence activated carbon decreased as the initial Pb(II) concentration increased. Specifically, the removal efficiencies were 98.9% at 20 mg/L, 95.5% at 30 mg/L, 86.6% at 40 mg/L, and 83.2% at 50 mg/L. This shows a clear inverse relationship: higher initial Pb(II) concentrations led to a lower percentage of Pb(II) removed by the inflorescence-based adsorbent. A similar trend was observed for the enset root activated carbon (Figure 6d). The removal efficiencies were 96.2% at 20 mg/L, 89.6% at 30 mg/L, 85.4% at 40 mg/L, and 80% at 50 mg/L. This also indicates that increasing the initial Pb(II) concentration resulted in a reduction in the percentage of Pb(II) removed by the root-derived adsorbent.

This observation aligns with findings reported by Ragheb (2007) and others absorbent listed in table 3, regarding Pb(II) ions removal in aqueous solution as adsorbents. Notably, at the lowest initial Pb(II) concentration tested (20 mg/L), the removal efficiency was high for both adsorbents, with the inflorescence-based activated carbon achieving 98.9% removal while the root-based activated carbon achieved up to 96.2% removal efficiency.

Table 3. Comparison of adsorption % Pb(II) ion onto enset inflorescence and root with other different adsorbents found in literatures

Name of adsorbent	%Removal of Pb(II)	Adsorbent dose	References
Alfagrass (stipaTenacissima)	92.39	3.8 g/L	Taziroutand amarani,2009
Need leaves	85	8g/L	Pandhran andNimbalkar,2013
Potato peels	96	4g	Mutungoetal.,2014
Acid treated banana peel	99.53	0.2g/L	Kumarand majumder,2014
Modified orange peel	41.4	4g/L	Mandinaetal.,2013
Raw rice husk	66	70g/L	Nasim et al.,2004
Activated bagasse carbon	99.97	0.8g/L	Nasim et al.,2004
Activated enset inflorescence	95.3	1.5g/L	Present study
Activated enset root	90.3	2g	Present study

Effects of Temperature

Figure 7 indicates that temperature has a noticeable effect on the adsorption of Pb(II) ions onto both types of activated carbon. The inflorescence-based adsorbent shows a trend consistent with an exothermic adsorption process, while the root-based adsorbent displays more intricate temperature dependence, possibly involving a combination of kinetic and thermodynamic factors. The inflorescence adsorbent appears to be more efficient in removing Pb(II) ions across the studied temperatures.

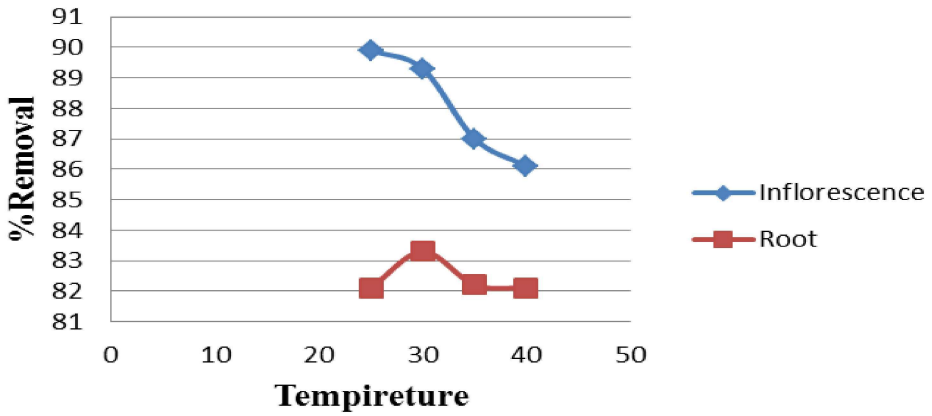

Figure 7. Effect of Temperature removal efficiency of lead at various temperatures

Calculation of Thermodynamic Parameters

To assess energy changes during Pb(II) adsorption, thermodynamic parameters (ΔH, ΔS, and ΔG) were calculated. ΔH and ΔS were obtained from the slope and intercept of the Van't Hoff plot (ln Kd vs. 1/T).

A graph of the natural logarithm of the distribution coefficient (Kd) versus the inverse of temperature (1/T)), using the equation

lnKd = −RTΔH + RΔS. The distribution coefficient (Kd), representing the ratio of adsorbed Pb(II) to the concentration in solution at equilibrium, was calculated. The change in Gibbs free energy (ΔG), which indicates the spontaneity of the adsorption process, was then calculated using ΔG = −RTlnKd. From the Van't Hoff plot Figure 8, although it was previously identified as the Freundlich isotherm plot, this context suggests it's a different figure), the calculated ΔH values were -2.17 kJ mol^{-1} for enset inflorescence and -2.18 kJ mol^{-1} for enset root, while the ΔS values were 32 kJ mol^{-1} and 34.48kJmol^{-1}, respectively, as summarized in Table 4 (a) and (b), which present the adsorption of Pb(II) ions on both activated carbons at different temperatures.

Table 4. Thermodynamic Parameters for enset inflorescence and root at Various Temperatures

(a)						
T(K)	1/T(K^{-1}x10^{-3}	k_d(mLg^{-1})	Lnk_d	ΔH (kJmol)	ΔS (JK1mol)	ΔGkJmol^{-1})
298	3.36	119.7	4.78			-12.2
303	3.3	119.066	4.779			11.8
308	3.25	116	4.75	-2.17	32.409	-11.9
313	3.19	114.8	4.74			--12.3
(b)						
T(K)	1/T(K^{-1}x10^{-3}	k_d(mLg^{-1})	Lnk_d	ΔH ($kJmol^{-1}$)	ΔS ($JKmol^{-1}$)	ΔG ($kJmol^{-1}$)
298	3.36	109.46	4.69			-12.18
303	3.3	111.06	4.71			-12.04
308	3.25	109.6	4.69	-2.18	34.48	-11.6
313	3.19	1106.26	4.666			11.5

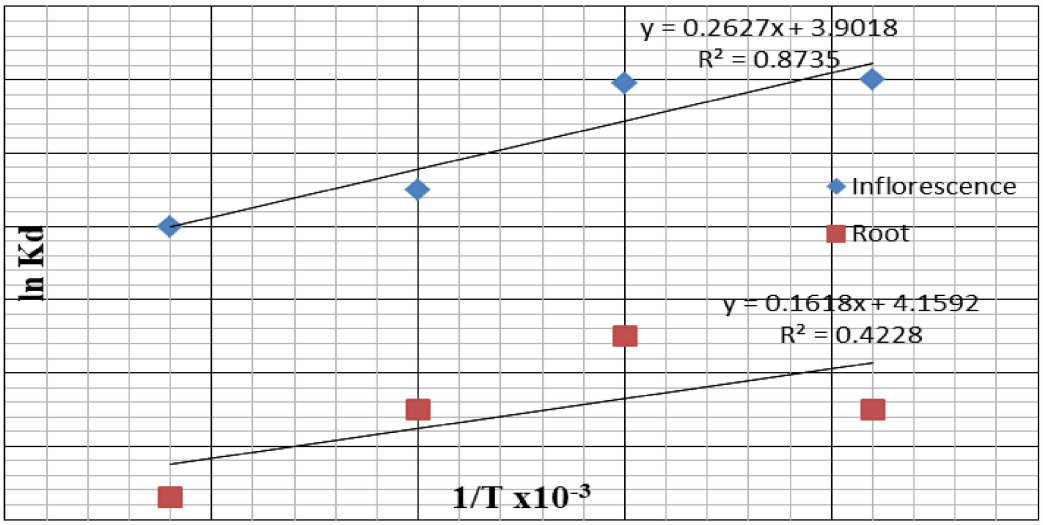

Figure 8. Plot of L kd vs 1/T (pH = 5 and 7 initial concentration = 20mg/L)

The calculated negative enthalpy change (ΔH) indicates that the adsorption of lead ions onto both adsorbents is an exothermic process, meaning it releases heat. The negative values of the ΔG across the tested temperatures, as shown in Table 4, confirm that the adsorption process is spontaneous. Furthermore, the trend of ΔG becoming less negative with rising temperature suggests that the adsorption of lead ions onto these activated carbons is more thermodynamically favorable at lower temperatures. The positive ΔS suggests an increase in randomness at the solid-solution interface as lead ions are adsorbed onto the active sites

Adsorption Isotherm Studies

The equilibrium adsorption of Pb(II) was studied at optimum conditions (pH = 5 and 7 and contact time of 60 min at different concentrations ranging from 20 to 50 mg/L and adsorbent doses of 0.5, 1, 1.5, and 2 g for the metal ions and adsorbent, respectively. The adsorption isotherm can be used to optimize the use of an adsorbent by describing how the solute interacts with the adsorbent (Moreno-Piraján and Giraldo, 2012).

Langmuir Isotherm

The first theoretical model that assumes adsorption will occur at specific homogenous active sites of the sorbent is Langmuir isotherm (Moghadam *et al.,* 2013).

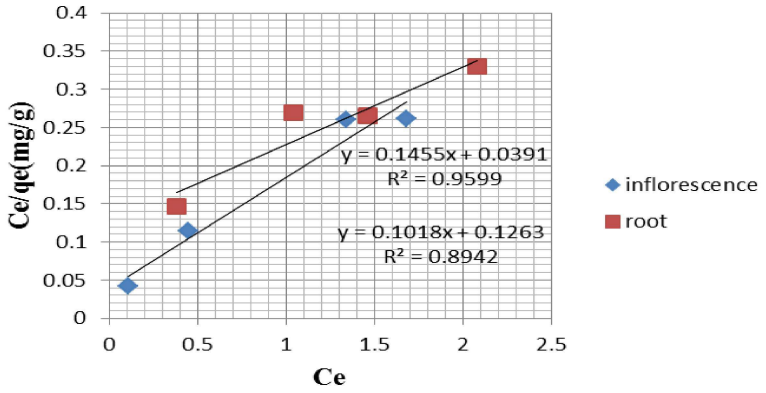

Figure 9. Langmuir isotherm plot for adsorption of Pb(II) ion by Enset inflorescence and Root

The graph plotted between Ce/qe and Ce produces a straight line, where the slope equals 1/qmax and the intercept equals 1/(b × qmax). From this plot, the values of qmax and b can be determined (Figure 9). R^2 values for Pb(II) (0.959 and 0.89 respectively) of enset inflorescence that are greater than 0.90 compared to enset root indicate that the adsorption of these ions onto enset inflorescence follows the Langmuir mode more than enset root.

Freundlich Isotherm

This model describes adsorption occurring on heterogeneous surfaces with varying energy levels, where interactions between adsorbed molecules take place. It assumes that the adsorption sites have an exponential distribution of adsorption energies. The model is described by the following equation (Freundlich, 1907):

$$\text{Log } q_e = \log K_f + 1/n \log C_e$$

Where: q_e is the amount of metal adsorbed by inflorescence and root (mg/g), Ce is the equilibrium adsorbate concentration in mg/L, K_f is the adsorbent capacity measure, and n is the adsorption intensity that can be determined from the linear plot.

The values of the correlation coefficients show that the Freundlich isotherm is appropriate to characterize the adsorption of all the studied metal ions onto inflorescence and root Pb(II) ions, with R^2 = 0.976 and 0.9738 (Figure 10), respectively. The R^2 values of the Freundlich isotherm are somewhat higher than those obtained by the Langmuir isotherm, indicating that this model has better applicability than the Langmuir isotherm model.

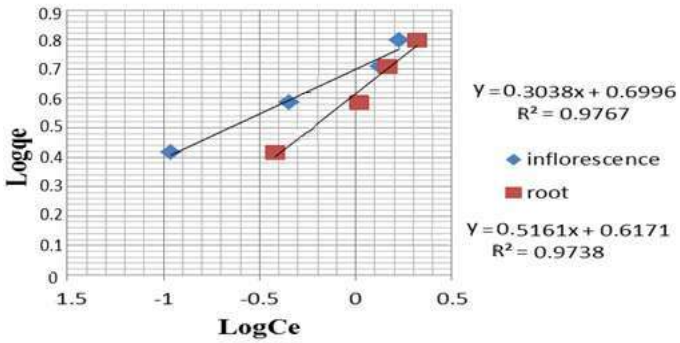

Figure 10. Freundlich isotherm plot for adsorption of Pb(II) ions by enset Inflorescence and root

Table 5. Parameters of Langmuir and Freundlich isotherm on adsorption of metal ions using enset Inflorescence and root adsorbents

Metal	Langmuir		Freundlich	
Pb(II)	b =3.7,1.2 qmax = 25.57,7.9	R^2 =0.959,0.89 RL=0.71,0.68	1/n= 0.308 , 0.516 n = 2.7 , 1.93	K_f = 1.36 ,1.675 R^2=0.973 ,0.978

The Freundlich isotherm's 'n' value provide insights into the favorability of adsorption: values between 2 and 10 indicate good adsorption, 1 to 2 suggests moderately difficult adsorption, and less than 1 implies poor adsorption (Renge *et al*., 2012). For the enset inflorescence, the calculated 'n' value of 2.7 for Pb(II) adsorption (Table 5) falls within the good adsorption range. However, for the enset root see (Table 5), the 'n' value of 1.9 suggests moderately difficult adsorption. Comparing the correlation coefficients (R^2) of the linearized forms of adsorption isotherms ,the Freundlich model demonstrated a better fit (R^2) for Pb(II)

= 0.973 for inflorescence and 0.978 for root) to the experimental equilibrium data for Pb(II) adsorption by both materials, making it the most suitable model to describe this equilibrium. The high R^2 values indicate a good agreement between the experimental data and the Freundlich model. The applicability of the Freundlich model suggests a multilayer adsorption process on the heterogeneous surfaces of both the inflorescence and root activated carbons, implying a non-uniform distribution of adsorption sites with varying energies.

To investigate the controlling mechanism for Pb(II) ion adsorption by enset inflorescence and root activated carbon, the experimental data from this study were analyzed. The pseudo-first-order model, widely recognized for predicting metal adsorption kinetics in both solid and liquid systems, was also applied. (as equation 4.3):

$$\text{Log } (q_e\text{-}q_t) = \log q_e - K_1/2.303\ (t) \qquad 4.3$$

The adsorption rate constant can be determined by plotting $\log(q_e - q_t)$ against time (Figure 11).

Adsorption Kinetics

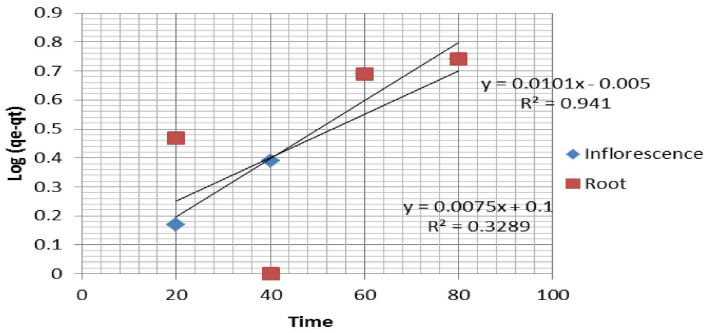

Figure 11. Enset inflorescence and root pseudo 1st order kinetic plot for adsorption of Pb(II) ions

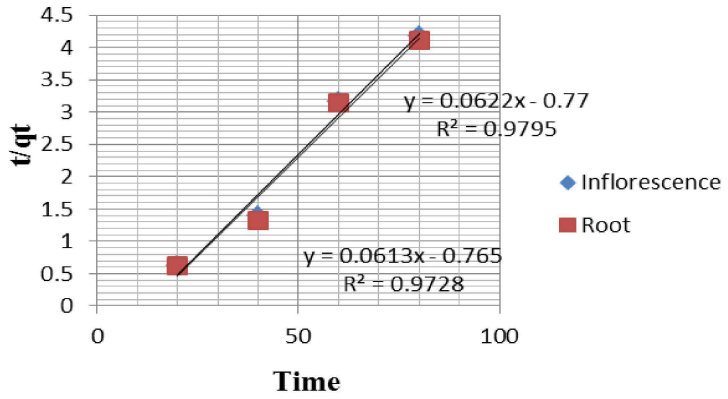

Figure 12. Enset inflorescence and Enset root pseudo 2nd order kinetic plot for adsorption of Pb(II) ion

As shown in Figure 12, R^2 for Pb(II) adsorption using the pseudo-first-order and pseudo-second-order models are 0.941 and 0.328, and 0.979 and 0.972, respectively. Based on these values, the pseudo-second-order model was identified as the best fit for the adsorption process. Using this model, the adsorption capacities and rate constants (k_2) were determined to be 0.003, 0.002, 14.2, and 12.14, respectively.

Conclusion and Recommendation

Activated carbons obtained from freely available enset inflorescence and root, exhibiting alcohol and carboxylic acid functional groups demonstrated significant potential for removing Pb(II) from contaminated water. Under optimized conditions, these materials achieved high removal efficiencies up to 95.3% and 90.3%, for enset inflorescence and root respectively, with a thermodynamically favorable, spontaneous, and exothermic process characterized by increased entropy. The adsorption behavior aligned with the Freundlich isotherm and pseudo-second-order kinetics, suggesting their viability as low-cost adsorbents for broader heavy metal remediation applications.

Conflict of Interests

The author affirms that there are no competing interests or conflicts of interest associated with this publication.

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RESEARCH PAPER

Synergetic Effect of Ni-CuO Nanocomposites with Activated Carbon Synthesized from Zeamays Bark for the Removal of Methylene Blue Dye

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Abstract

In this study, nanomaterial adsorbents including CuO, Ni-CuO, Ni-CuO/activated carbon (AC), and Ni-CuO/zeamays bark (ZB) were synthesized and evaluated for the removal of methylene blue (MB) dye from wastewater discharged by Anmol Paper Production PLC. Structural and surface characterizations were performed using X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FT-IR), scanning electron microscopy (SEM), and UV-visible spectroscopy (UV-Vis). XRD analysis confirmed the formation of a monoclinic CuO phase, with a reduction in crystal size from 34.26 nm (CuO) to 18.06 nm (Ni-CuO/ZB). SEM revealed a porous, hair-like morphology in Ni-CuO nanocomposites. FTIR spectra indicated the presence of OH and CO functional groups, enhancing adsorption potential. UV-Vis analysis showed a bandgap reduction from 3.22 eV (CuO) to 2.10 eV (Ni-CuO/AC) and 1.75 eV (Ni-CuO/ZB), suggesting improved visible light absorption. Batch adsorption experiments showed that Ni-CuO/ZB achieved the highest MB removal efficiency of 99.03% under optimized conditions: 110 ppm dye concentration, pH 12, 1.0 g adsorbent dosage, and 120 minutes contact time. The adsorption process conformed to the Freundlich isotherm model and pseudo-second-order kinetics ($R^2 = 0.99$), indicating multilayer adsorption and a chemisorption mechanism. Overall, the Ni-CuO/ZB nanocomposite demonstrated superior performance, making it a cost-effective and sustainable candidate for industrial wastewater treatment.

Keywords: Ni-CuO nanocomposites, Activated carbon, Zeamays bark, Adsorption isotherm, Methylene blue

Introduction

Industrial growth and population expansion are driving the release of significant amounts of organic and inorganic pollutants into the environment, primarily from industries such as textiles, cosmetics, paper, and leather production (Islam *et al.,* 2025). Organic dyes, such as bromophenol blue, methyl blue, methyl orange, malachite green, rhodium B, and crystal violet, are carcinogenic, mutagenic, and toxic organic chemicals (Sharma and Singh, 2021). This heavy reliance on these dyes leads to the production of contaminated water. Methylene blue dye (MB) is a popular cationic dye used in the pulp and paper industry for staining tissues and cells, as well as in medicine as an antiseptic and antifungicide (El Malti *et al*., 2024). However, MB has harmful impacts on humans, including irritation of the mouth, throat, esophagus, stomach, skin irritation, nausea vomiting, dizziness, headache, and fever (Suryowati, 2024).

Several wastewater treatment techniques have been employed, such as coagulation, photo-degradation, filtration, adsorption, and electrochemical oxidation. For example, (Kamani *et al*., 2024) investigated the degradation of Reactive Red 198 (RR198)

using NZVI nanoparticles via the Advanced Sono-Nano-Fenton hybrid method. Accordingly, the Author achieved 97% degradation efficiency within 60 minutes whereas the degradation process followed pseudo-first-order kinetics and best fitted Langmuir-Hinshelwood model (Andreucci *et al*., 2014). However, photodegradation has limitations due to the demand for specific light sources, high energy consumption, and generation of harmful byproducts (Veisi *et al.,* 2016). Adsorption presents a more attractive alternative due to its simpler operation, high efficiency in removing pollutants, eco-friendly, and cost-effective nature. TiO_2–ZnO/biochar NCs using the sol-gel method engaged for the degradation of furfural in an aqueous solution resulted in 96 % removed capacity at an optimal degradation conditions of pH 3, catalyst dosage of 1 g/L, and pollutant concentration of 10 mg/L within 15 min (Hasanzadeh *et al.,* 2023). Adsorbents such as metal oxides, activated carbon, and silica exhibit exceptional affinity and binding capacity towards dye molecules (Hasanzadeh *et al*., 2023).

Currently, commercial activated carbon (CAC) is being utilized as an adsorbent for organic materials, but its high cost, limited adsorption capacity, and slow uptake rates have led to its decline (Sharma *et al*., 2022). Agro-waste-based adsorbents are promising due to their high surface area, good recyclability, and enhanced adsorption capacity, rate, and efficiency. Maize cobs are being used as an adsorbent for pollutant removal due to their abundance and eco-friendly nature (Fu *et al*., 2022). Salix babylonica leaves powder (SBLP) has been successfully used for the removal of methylene blue (MB) from aqueous solutions through an adsorption process (Opeolu, 2009).

Previous report indicated that MB has been treated using graphene oxide adsorbent and efficient adsorption was recorded as the dye is electrostatically attracted toward the negatively charged adsorbent. Adsorbents like AC, GO, and CNTs have been effectively employed for the removal of MB, demonstrating impressive adsorption capacities of 270.27 mg/g, 243.90 mg/g, and 188.68 mg/g, respectively (Luong *et al*., 2024). Besides to the above studies, nano-adsorbents were successfully utilized for the treatment of heavy metal (Cu^{2+}) using GO nanosheets modified with Fe_3O_4 nanoparticles. It is supposed that nanoparticles likely create additional pores within the graphene structure, enhancing its ability to adsorb pollutants. This increased porosity improves access to pollutants, promotes their diffusion into the material, and shortens the diffusion path (Matandabuzo, 2016). Similarly, (Rashed *et al*., 2017) prepared TiO_2 nanoparticle coated with sewage sludge-based AC (ASS) and tested for simultaneous adsorption of methyl orange dye (MO) and Cd^{2+} ions. It was found that high treatment efficiency of MO dye and Cd^{2+} were achieved with TiO_2/AC. In their finding, the adsorption of TiO_2/ASS NC led to significantly faster and higher degradation of MO compared to ASS alone (74.14% vs. 94.28% removal efficiency at pH 7). Despite the previously reported results apparently promising, the efficiency and cost effectiveness of the adsorbents for pollutants removals with the aid of NC remains unsatisfactory. Therefore, developing more efficient, simple, and cost-effective adsorption techniques is crucial for environmental remediation (Rashed *et al*., 2017).

Therefore, this study intended to explore adsorption techniques using Ni doped CuO nanomaterials modified AC for effective treatment of wastewater containing MB dye discharged from Anmol paper products PLC (Ginchi, Ethiopia). As this industry uses different coloring agents in particular MB, it is found discharging effluents to the environment without pretreatment. Recently, (Alemu *et al.,* 2024) investigated the wastewater treatment discharged from the same site using photodegradation technique. Ag-CdO/PANI NC was employed and the most effective photodegradation of BPB dye in the wastewater samples is achieved 98.64% at pH 8, 0.16 g of catalyst dose and 180 min light irradiation time which agree with the finding of (Lakkaboyana *et al*., 2019). Taking the drawback of photodegradation methods into consideration, the researchers have applied the adsorption method to remove organic pollutant (in particular MB) from Anmol Paper Product PLC

with the aid of nanostructured materials since they possess sufficient surface area and easy tailoring of surface properties. Furthermore, surface modification of nanomaterials with activated carbon derived from zeamays bark was carried in order to enhance the activity of adsorbents (Alemu *et al.*, 2022).

ZB stands out as a promising material for adsorption due to its non-toxic, readily available and highly porous structure (Igwegbe *et al*., 2021). Copper oxide nanoparticles (CuO NPs) are a perfect complement due to their well-understood surface chemistry, which can be customized through doping techniques. Additionally, their narrow band gap makes them ideal for applications involving both light activation (photoconduction) and adsorption. To improve the adsorption capacity of CuO nanostructures for pollutant removal, the research have strategically introduced nickel (Ni) as a dopant so as to effectively tailor its band gap, resulting in Ni-CuO NCs with enhanced capabilities for removing MB from wastewater (Chowdhury et al., 2021). This approach resulted in Ni-CuO NCs with enhanced capabilities for removing MB from wastewater. A comprehensive literature review indicates that there is lack of research investigating Ni-CuO NCs modified with agro-waste-based activated carbon for the targeted removal of organic pollutants present in the wastewater stream generated by Anmol Paper Product PLC (Shah *et al*., 2020).

The research aims to develop a novel adsorbent, Ni-doped CuO NPs modified with AC from locally available resources, for treating wastewater containing MB pollutant of MB pollutant containing wastewater discharged by Anmol Paper Products PLC. Advanced characterization tools like XRD, SEM, FTIR, and UV-Vis spectroscopy were used to analyze the material's structure, morphology, functional groups, and band gap. The optimal conditions for pollutant adsorption were also being investigated.

Materials and Methods

Experimental Sites

Zeamays Bark (ZB) was collected from Jibat District, Oromia Region, Ethiopia. The synthesis of CuO NP, Ni-CuO NC, Ni-CuO/AC NC, and Ni-CuO/ZB NC, preparation of activated carbon (AC) from ZB, optical properties was analyzed using UV-Vis spectrophotometer, batch adsorption experiments and optimization were conducted at Ambo University, Chemistry Research Laboratory. The elucidation of functional group has been conducted at Addis Ababa Science and Technology University, the measurement of crystalline structure and morphology were done at Adama Science and Technology University, Ethiopia.

Apparatus and Instruments

The UV-Vis spectrophotometers (UV-Vis, Sunny ultraviolet-visible spectrophotometer, model Uv-7804C Print), Fourier-transform infrared (FTIR, JASCO FT/IR-6700), scanning electro-microscope (SEM, JCM-6000 PLUS Bench Top SEM, JEOL, and Japan) and x-ray diffraction (XRD, D2, Phaser, Bruker) are instruments used in this research work. Microplant grinding machine (NM-8300, Nima, 220x80mm, Japan), filter paper (Whatman 41), plastic funnel, graduated cylinder, electronic analytical balance (A160, Denver), magnetic starrier (Model № 690/21), centrifuge (Model 80-2, China), refrigerator (MRF451), pH meter (CPI501), drying Oven (DHG-9070A), muffle furnace (PYRO THERM FURNACES, SLAB12/5) and common laboratory apparatus were used in this study.

Chemicals and Reagents

The AC prepared from ZB was used as adsorbent and wastewater containing MB dye is employed as adsorbate. Analytical grade (AG) chemicals/reagents such as sulfuric acid (H_2SO_4, UNI CHEM, 98%), nitric acid (HNO_3 , LOBA CHEM, ACS, 69-70%), potassium hydroxide (KOH, AR, ≥85%), sodium hydroxide (NaOH, AR, 99.8%), hydrochloric acid (HCl, LOBA CHEM PLC, 35%), hydrogen peroxide (H_2O_2, UNI CHEM, 30%), nickel nitrate monohydrate ($Ni(NO_3)_2.H_2O$, UNI CHEM, 98%), copper chloride dehydrate

($CuCl_2.2H_2O$, UNI-CHEM CAS, 99.5%), and ethanol (CH_3CH_2OH, Alpha Chemika, AE754, 95%) are chemicals used to prepare pristine and modified CuO based NP and NC.

Collection of Wastewater Sample

Wastewater sample was collected from Anmol Paper Products PLC (Ginchi, Ethiopia) in March 2023 following US-EPA sampling guideline (US-EPA, 2009). Anmol Paper Products PLC is one of the paper production plant located in Ginchi Town, Dendi Woreda (IFPRI, 2012), West Shoa Zone, Oromia Regional State, Ethiopia. Though it produces high quality papers, Anmol Paper Products PLC release organic pollutants to the environment without pretreatment (Alemu *et al.*, 2024). The wastewater sample contains MB was collected in triplicate (n = 3) into 1 L volume glass container. The samples were stored in an ice-cooled box, promptly transported to the Chemistry Research Laboratory, and kept at 4 °C until the adsorption experiments were carried out.

Collection of ZB and Preparation of AC

The collected ZB has been washed with DI water to get rid of unnecessary impurities. Then, it was exposed to sunlight for several days and dried in oven at 105 ^{o}C, milled by Microplant Grinding machine till the size of ZB is 1 mm and finally sieved. It was activated by carbonization process in furnace at 400 ^{0}C for 2 hr. The activated material was cooled for few a minute and kept in desiccators (Matandabuzo, 2016).

Synthesis of CuO NP

CuO NP was prepared through a co-precipitation method. In this process, 15 g of $CuCl_2.2H_2O$ was taken and dissolved in 50 mL DI water. The mixture was then stirred for 1 hr using magnetic stirrer. 20 mL NaOH was added to the above solution and kept for 1 day to form the gel. The gel was filtered and dried at 110 °C in oven followed by calcinations at 400 °C for 2 hr. The black colored material was formed indicating the formation of CuO NP (Satari et al., 2021).

Synthesis of Ni-CuO NC

In a typical synthesis procedure, a stoichiometric amounts of 5 g Ni $(NO_3)_2.3H_2O$ and 15 g $CuCl_2.2H_2O$ was dissolved in DI water. The mixture was stirred at temperature of 80 °C till the gel was formed. The formed gel is washed 2-3 times with CH_3CH_2OH in order to avoid any contaminations. Subsequently, the cleaned and dense precipitate was formed and heated at 110 °C for 1 hr in oven. Finally, it was grinded and calcinated at 400 °C for 2 hrs while the crystalline phase of Ni-CuO NC was achieved (Xie *et al.,* 2020).

Synthesis of Ni-CuO/AC NC and Ni-CuO/ZB NC

5 g of as-synthesized Ni-CuO NC was added to 250 mL volumetric flask to which each 10 g of AC and ZB was added. Ni-CuO NC was mixed with AC and ZB upon stirring at 200 rpm for 3 hr at 60 ˚C. Then, Ni-CuO NC was homogenized with AC and ZB, followed by filtration and washing by DI water. After drying at 70 ˚C for 24 hr the Ni-CuO/AC and Ni-CuO/ZB NC were formed and kept in dissector (Chesman *et al.,* 2013).

Characterization

The FT-IR was employed to reveal the chemical environment of CuO NP, Ni-CuO NC, Ni-CuO/AC NC and Ni-CuO/ZB NC via scanning the sample between 4000 to 400 cm^{-1} (Hi, 2021). Morphology of as-synthesized materials were investigated using SEM (Yang and Yang, 2018). It was scanned by 10 kV on 20 μm electron beam at X1500 magnification power. XRD was measured between 10 - 80 in order to determine crystal structure of as-synthesized nanomaterials. The crystalline size of the adsorbents were calculated as in follow (Sukumar *et al*., 2020).

$$D = \frac{k\lambda}{\beta \cos \theta} \quad \text{.....1}$$

Where D represent the average particle size, *k* - Scherrer constant (0.9), λ - wavelength (0.15406 nm), B - full width at half-maximum (FWHM) in radians, and θ - diffraction angle.

UV-Vis spectrometry was also used to investigate the optical characteristics of adsorbents between 200 to 800 nm (Khan *et al*., 2022). The band-gap energy was calculated using eq. 2 below:

$$E_g = \frac{hc}{\lambda_{max}} eV \quad \text{.....2}$$

Where h - Planck's constant, c - speed of light, λ - cut off wavelength and E_g - optical band gap (Gomathi *et al*., 2016).

The organic contaminant percentage removal efficiency from wastewater sample can be determined as indicated in eq.3 below:

$$\%R = \frac{c_o - c_e}{c_o} \times 100 \quad \text{.....3}$$

Where R - removal rate, C_o and C_e - liquid-phase concentrations of adsorbate (mg L^{-1}) at initial and equilibrium position, respectively (Al Ani and Al Amri, 2015).

Study of Operational Parameters

Effect of initial concentration of MB in wastewater: In this study, the initial concentration of wastewater containing MB was determined using calibration curve and after determined, the actual concentration was varied from 80 to 120 ppm in adsorption time of 0-120 min, pH 12 and 0.8 g adsorbent dose. The absorbance values of the dyes were recorded at λ_{max} (Medhat *et al*., 2021).

Effect of irradiation time: The effect of irradiation time on decolourization of wastewater sample was studied at contact time of 0, 20, 40, 60, 80, 100 and 120 min. using 0.8 g of the adsorbents load, pH 12 and 110 ppm concentration of wastewater sample.

Effect of adsorbent dosage: the adsorbent dosage of 0.20, 0.40, 0.60, 0.80 and 1.00 g was taken and added to 110 ppm wastewater sample while pH solution was adjusted to 12 and adsorption was undertaken for 120 min.

Effect of pH: 110 ppm concentration of MB containing wastewater with pH value fixed to 2, 4, 6, 8, 10 and 12 were prepared using 0.80 g adsorbent doze and adsorption lasts for 120 min.

Adsorption of Wastewater Sample

The adsorption was conducted by taking 80 to 120 ppm concentration of MB containing sample, 2 to 12 pH of the solution, 0.20 to 1.00 g of adsorbents conducted for 120 min at 25 °C. The amount of dye adsorbed to the unit weight of adsorbent at equilibrium and time t was evaluated (Raut *et al*., 2021):

$$q_t = v\frac{(c_o - c_t)}{m} \quad \text{.....4}$$

Where, q_t - amounts adsorbed (mg/g) at time t, C_t - concentration of MB in the sample (mg/L) at time t; V - volume of the sample (L) and m - dry weight of adsorbent (g).

Langmuir Isotherm

The Langmuir adsorption isotherm follows the principles of forming monolayer at adsorbent surface and determined as follow (Shahmohammadi-Kalalagh *et al*., 2011).

$$\frac{C_e}{q_t} = \frac{1}{K_L q_{max}} + \frac{C_e}{q_{max}} \quad \text{.....5}$$

Where q_e - amount of adsorbed MB (mg/g) at equilibrium, C_e - equilibrium concentration (mg/L) of MB, q_{max} - monolayer adsorption capacity (mg/g) and K_L - Langmuir adsorption constant and measure the adsorption affinity of organic pollutant to adsorbent active sites.

Freundlich Isotherm

This adsorption isotherm follows the principles of forming layers at heterogeneous surface and is commonly determined as (Ayawei *et al*., 2017):

$$log q_e = \log K_f + \frac{1}{n} \log C_e \quad \text{.....6}$$

Where, q_e - amount of MB adsorbed at equilibrium (mg/g), C_e - equilibrium concentration of dye in sample (mg/L) and K_f and n - Freundlich isotherm constants incorporating factors affecting adsorption capacity and intensity of adsorption, respectively.

Adsorption kinetics

Pseudo first-Order Kinetics

This kinetic model is used to describe adsorption of wastewater sample as follow (Hii, 2021):

$$\ln(q_e - q_t) = \ln q_e - \ln k_1 t \quad \text{.....7}$$

Where q_e and q_t (mg/g) - amounts of adsorbate adsorbed at equilibrium and time, t respectively and k_1 - adsorption rate constant.

Pseudo Second-Order Kinetics

The pseudo second-order kinetic model can be determined as follow (Ersali *et al.*, 2013):

$$\frac{dq_t}{d_t} = k_2 (q_e - q_t)^2 \quad \text{.....8}$$

Where, k_2 - rate constant ($gmg^{-1}.min^{-1}$) for pseudo second-order adsorption and q_e - equilibrium adsorption capacity (mg/g).

Re-usability of Adsorbent

The Ni-CuO/ZB adsorbent was confirmed as the best adsorbent and the adsorption experiment was studied once the adsorbent is dried at 60 ºC in oven its re-usability tests (the overall activities are designed as shown in Fig. 1. After drying the catalyst; the adsorbent was collected, measured and prepared for the consecutive five experimental cycles. In this test followed the optimum operating conditions of 110 ppm initial concentration of wastewater sample, 0.80 g of adsorbent dose, pH 12 and 120 min contact time **(**Sravanthi *et al.*, 2016**).**

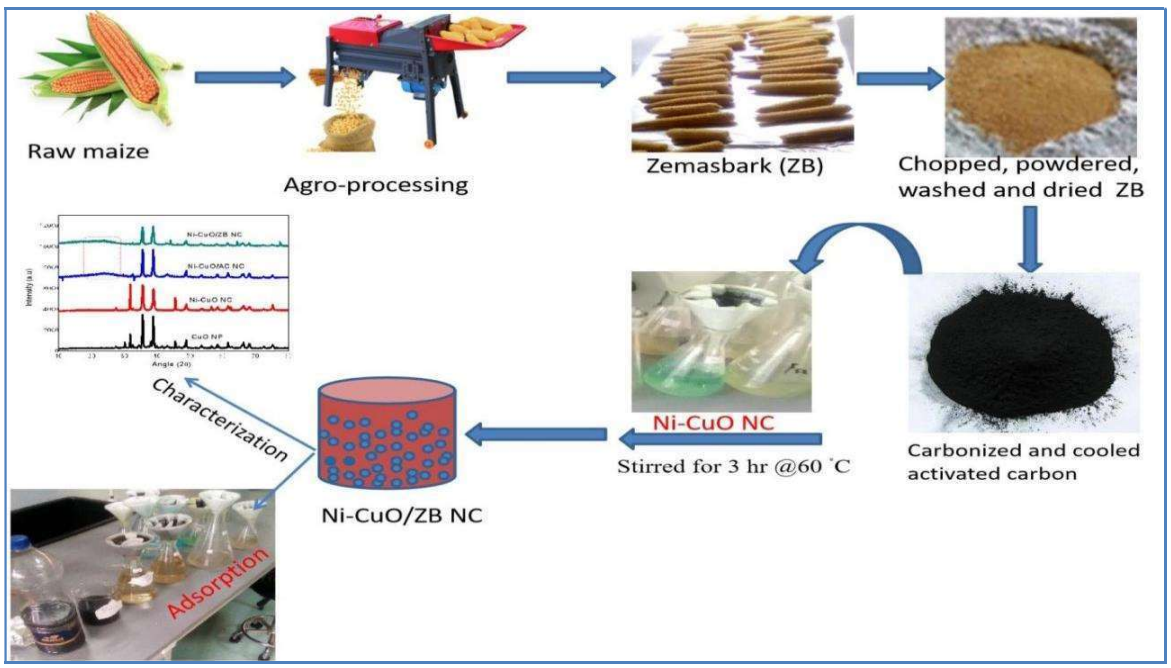

Figure 1. Schematic representation of Ni-CuO/ZB NC preparation, characterization and adsorption activities

Results and Discussions

Characterizations of As-Synthesized Nanomaterials

Analysis of surface morphology: The SEM analysis revealed distinct morphologies for the as-synthesized nanomaterials. Accordingly, Fig. 2(A), shows the crystalline and aggregated structures, suggesting a tightly packed arrangement of CuO NP. Fig. 2(B), reveals an interconnected particle with varying shapes and sizes which indicate the successful Ni incorporation into the CuO lattice, potentially disrupting the original crystal structure. On the other hand, shiny and uniformly distributed small particles compared to CuO and Ni-CuO in Fig. 2(C), suggests the effective anchoring of Ni-CuO nanoparticles onto the AC substrate (Robertson et al., 2010). In Fig. 2(D), a network of pores and hair-like structures with smaller particle sizes and a higher surface area have been observed. This implies that the successful embedding of ZB within the metal oxide structure, lead to the formation of numerous porous cavities and a reduction in particle size. Notably, the interconnected with hair-like structures suggest potentially novel properties for this particular nanocomposite. Such a distribution of particles and the presence of an interconnected, hair-like nanostructure could impart unique properties to this particular nanocomposite (NC) (Morsy *et al*., 2019).

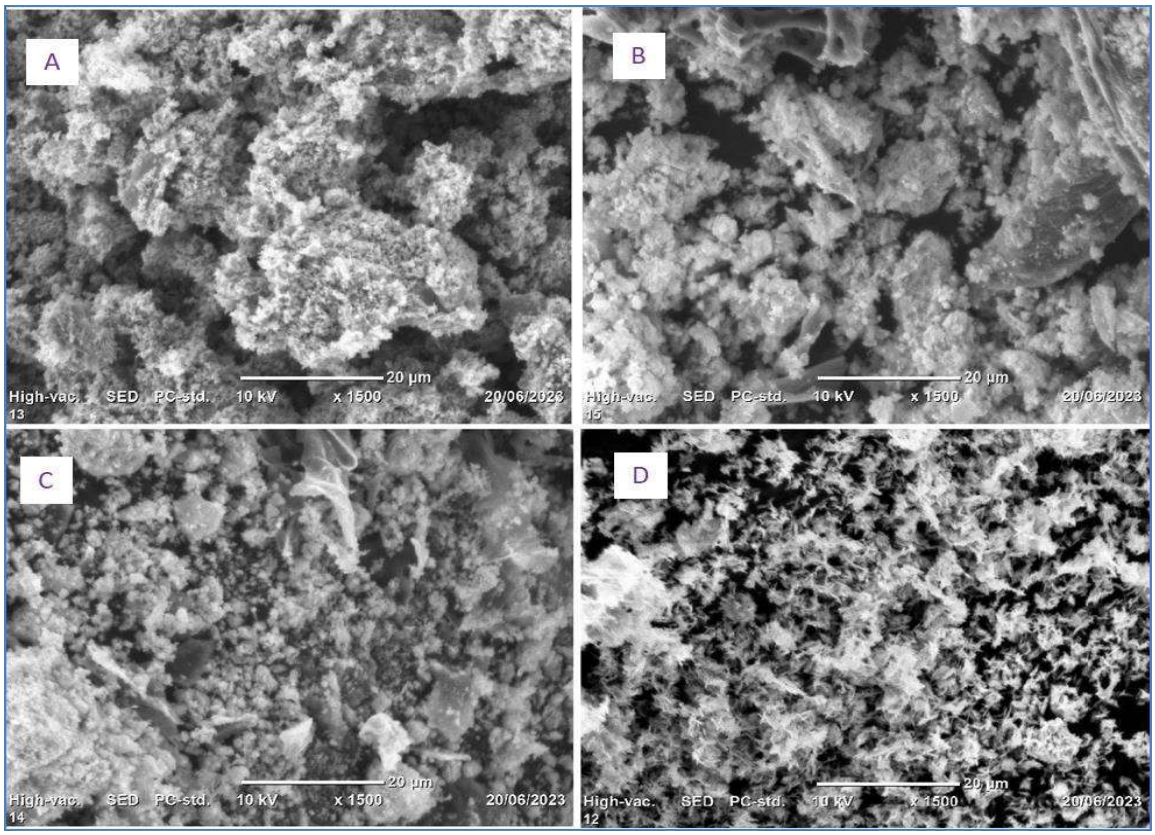

Figure 2. SEM image of (A) CuO NP, (B) Ni-CuO NC, (C) Ni-CuO/AC NC, (D) Ni-CuO/ZB NC

Study of functional group: Fig. 3, presents the FTIR spectra of CuO NP, Ni-CuO NCs, and NC modified with CAC and ZB. The spectra reveal distinct absorption peaks for CuO NP at 486.20, 596.85 and 878.90cm^{-1} correspond to the characteristic stretching vibrations of the Cu-O bond. This confirms the successful formation of CuO NP in the initial material (Suteu *et al*., 2011). Spectral analysis revealed distinctive absorption bands at 534.17, 816.21,

1380.30, and 3309.57 cm^{-1} in the Ni-CuO nanocomposite (NC). The first two peaks represent the stretching vibrations of Cu-O and Ni-O bonds in the copper oxide structure while the latter two peaks indicate the presence of OH groups, likely due to surface adsorbed water molecules or residual hydroxyl groups from the precursor materials (Suteu *et al*., 2011). This characterization tool also provided a unique fingerprint for Ni-CuO/AC NC. For instance, the peaks around 596 and 784 cm^{-1} denoted the Cu-O bonds, possibly influenced by the incorporation of Ni metal. Similarly, other peaks provide insights into the vibration of C-O-C in the AC component, Cu-O-H bending vibrations, and O-H associated with both Ni and AC. In essence, the FTIR analysis offers a detailed picture of the chemical environment within the NC, supposed the integration of Ni-CuO with AC (Al-Amri *et al*., 2015). The near-identical absorption peaks between Ni-CuO/ZB and Ni-CuO/AC suggest a close resemblance in their chemical makeup, with only minor intensity variations. This strongly indicates successful anchoring of the Ni-CuO NC onto the ZB surface. Interestingly, a small, distinct peak appears at 1004.24 cm^{-1} in the ZB spectrum, potentially attributable to in-plane deformation of aromatic C-H bonds and C-O stretching vibrations within the ZB structure itself. The peak at 1400 cm^{-1} indicated aromatic rings likely from the organic precursor. Additionally, the broad peaks between 2900 -3400 cm^{-1}, suggested the presence of both aliphatic C-H bonds and O-H groups from water molecules or surface hydroxyls. Importantly, these results confirmed the presence of metal-oxygen (M-O) bonds, possibly from CuO and Ni-CuO, within the NC structure. Even more significant, the FTIR analysis highlighted the abundance of functional groups such as O-H, C-O, C=C, C-H, C-O-C, Ni-O, Cu-O, and potentially Ni-O-Cu bonds, act as potential binding sites for organic dye molecules during the adsorption process in Ni-CuO/AC and Ni-CuO/ZB NC (Shah *et al*., 2020).

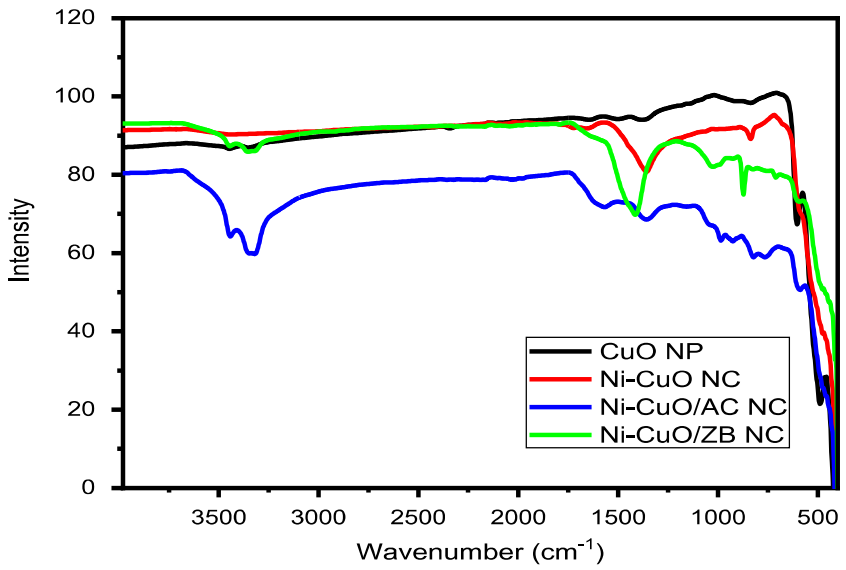

Figure 3. FTIR spectra of CuO NP, Ni-CuO NC, Ni-CuO/AC NC and Ni-CuO/ZB NC

Determination of crystal structure: Fig. 4, represents the XRD pattern of CuO NP, Ni-CuO NC, Ni-CuO/AC NC and Ni-CuO/ZB NC. The peak position for CuO NP generated at 2θ (unit of degree) = 32.02, 35.60, 38.82, 45.49, 48.73, 53.01, 58.311, 61.55, 66.30, 68.03, 72.40 and 75.30^0 correspond to (110), (-111), (111), (200), (-202), (020), (202), (-113), (-311),

(220), (311), and (004) planes, respectively. These diffraction peaks are confirmed the formation of the monoclinic CuO phase which agrees the pattern with standard JCPDS card no. 05-0661. Interestingly, the peaks observed in the analysis don't show any major shifts in position. They are also relatively sharp and intense. This suggests a high degree of crystallinity in the as-synthesized nanomaterials. Furthermore, the peak intensities corresponds to (110), (-111) and (111) are so strong as compared to the others which signifies a favorable orientation of nanoparticles along these directions. The XRD analysis did not identify any separate peaks corresponding to metallic Ni in the Ni-CuO NC. However, the existing peaks became more intense, suggesting that Ni atoms have likely replaced Cu sites within the crystal structure of the pure CuO NP, without causing a significant change in the overall crystal structure. However, the XRD peaks are observed at 35.55, 38.78, 43.20, 48.73, 61.53, 66.11, 68.01 and 75.27^0 are assigned to (-111), (111), (200), (-202), (202), (-113), (-311) and (004) planes for Ni-CuO/AC NC. The X-ray diffraction (XRD) patterns of both Ni-CuO/AC and Ni-CuO/ZB NCs displayed a series of diffraction peaks at similar angles. These peaks are characteristic of the well-established monoclinic crystal structure typically observed in CuO-based nanomaterials. However, a notable difference emerged. Both NCs exhibited an additional weak peak at 2θ values of 23.52 and 43.00 degrees. This suggests the presence of an amorphous phase, potentially arising from the AC substrate. This is due to the fact that Ac is known by its components such as cellulose, hemicellulose, and lignin which are inherently amorphous.

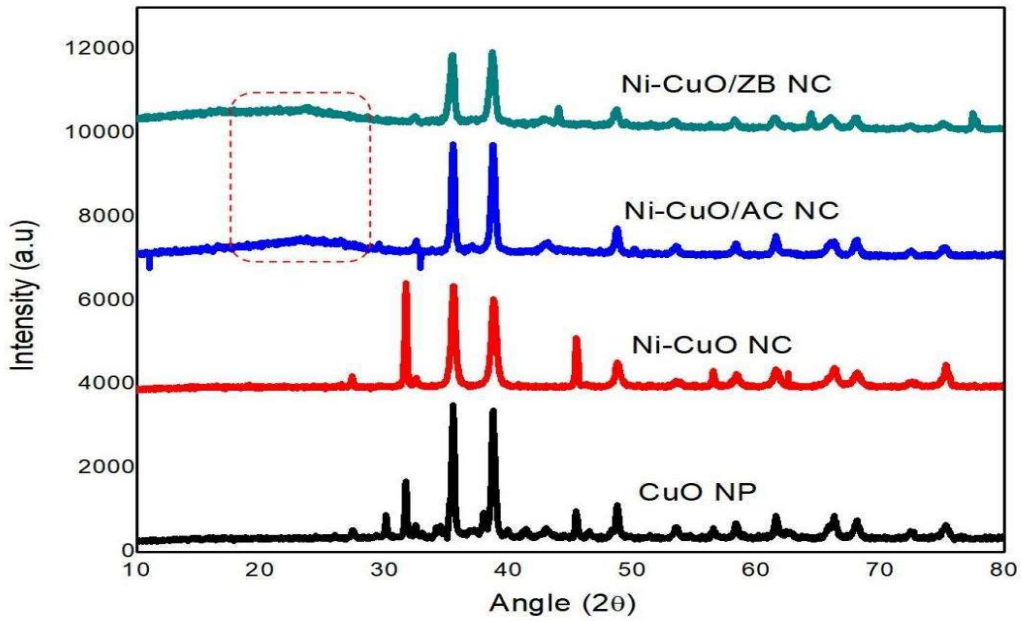

Figure 4. XRD patterns of CuO NP, Ni-CuO NC, Ni-CuO/AC NC and Ni-CuO/ZB NC

This finding aligns with the standard reference pattern (JCPDS 5-667) for AC. Eq. 1 was used to calculate the average crystallite size of the synthesized nanomaterials and the results are summarized in Table 1. Interestingly, the average crystallite size of pristine CuO has progressively decreased from 34.26 nm to 26.09, 22.46 and 18.06 nm corresponding to the sizes of Ni-CuO, Ni-CuO/AC, and Ni-CuO/ZB NC, respectively.

Table 1. Calculated crystallite sizes for as-synthesized nanomaterials

Adsorbent	**2θ**	**θ**	**Cosθ**	**FWMH**	**in rad**	**size/nm**	**Aver/nm**
CuO NP	35.6	17.8	0.9523	0.2956	0.005	30.25	34.26
	38.82	19.41	0.9433	0.2969	0.005	30.4	
	31.92	15.96	0.9619	0.2101	0.0036	42.14	
Ni-CuO NC	31.73	15.87	0.9618	0.4059	0.0069	21.81	26.09
	35.55	17.78	0.9522	0.3847	0.00654	23.25	
	38.78	19.39	0.9431	0.2718	0.0046	33.22	
Ni-CuO/AC NC	38.78	19.39	0.9433	0.3638	0.00618	24.81	22.46
	35.55	17.78	0.9523	0.3449	0.0059	25.93	
	48.73	24.37	0.9109	0.562	0.0096	16.63	
Ni-CuO/ZB NC	38.8	19.4	0.9435	0.5096	0.0087	17.71	18.06
	35.55	17.78	0.9525	0.5101	0.0087	17.53	
	43.38	21.69	0.9112	0.4937	0.0084	18.93	

Analysis of Absorption Spectral: Fig. 5, illustrates the UV-Vis spectra of the synthesized nanomaterials. Eqn. 2 is used to calculate their energy band gaps (Eg). As the materials are modified to get multi-component systems, the maximum absorption wavelength increased. As a result the maximum absorption is observed at 385, 485, 590 and 710 nm corresponding to 3.22, 2.55, 2.10 and 1.75 eV for CuO NP, Ni-CuO NC, Ni-CuO/AC NC and Ni-CuO/ZB NC, respectively (Table 2).

Interestingly, the calculated band gaps decreased significantly compared to the theoretical value for CuO NP (3.9 eV). This trend suggests that incorporating Ni and the additional materials (AC and ZB) successfully modified the electronic structure and particle size of the nanocomposites *(Chandrasekar et al.*, 2022). Moreover, treatment with ZB make the NC more effective in transforming the surface properties as compared to the NC consisting AC (Dwivedi *et al.*, 2021). The Ni-CuO/ZB NC exhibited with the peak wavelength increasing from 590 nm to 710 nm contributing to narrowing Eg to 1.75 eV. This reduction in Eg is likely due to a synergistic effect of novel metal as well as agro-waste surface modifier and ultimately enhanced the pollutant adsorption.

Table 2. Absorbance at maximum wavelength and optical band gap energy of CuO NP, Ni-CuO NC, Ni-CuO/AC NC, Ni-CuO/ZB NC

Samples	Absorbance (a.u)	λmax (nm)	Eg (eV)
CuO	0.002	385	3.22
Ni-CuO	0.04	485	2.55
Ni-CuO/AC	0.583	590	2.1
Ni-CuO/ZB	0.704	710	1.75

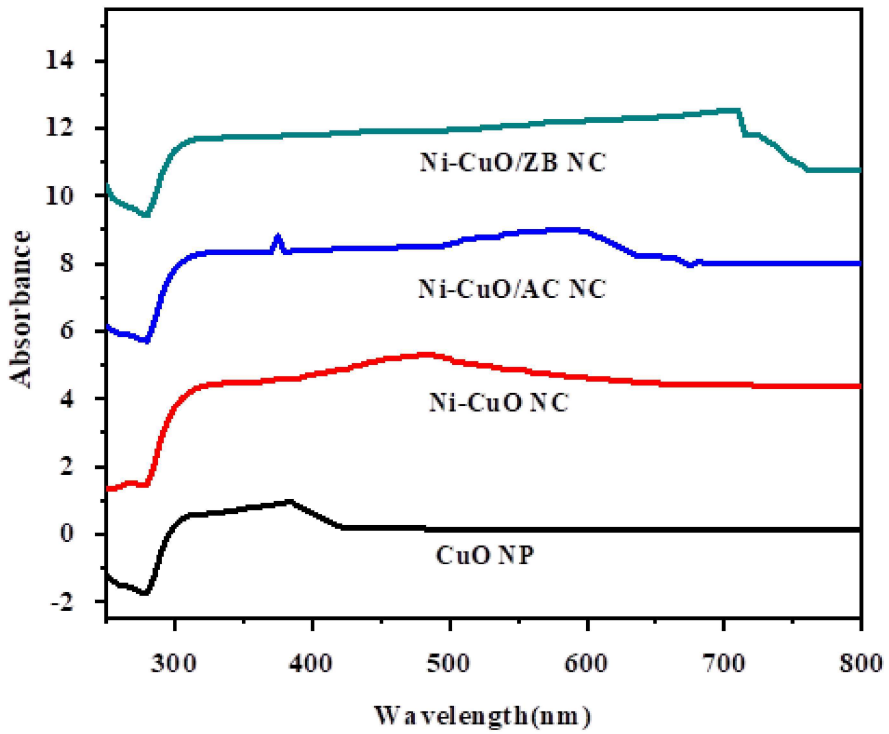

Figure 5. Absorption spectra of CuO NP, Ni-CuO NC, Ni-CuO/AC NC and Ni-CuO/ZB NC

Determination of MB Dye in Wastewater

The concentration of MB in the wastewater from Anmol Paper Product PLC was determined using a standard calibration curve. This involved measuring the absorbance of standard MB solutions at a specific maximum wavelength (665 nm) and plotting it against its known concentrations as indicated in the data summarized in Table 3. Fig. 6 shows a good linear relationship (R^2 > 0.9661) between absorbance and concentration within the tested range of 80-120 ppm. Using the established linear equation (y = 0.002x - 0.133) and the measured absorbance value of the wastewater sample (0.058), the MB concentration was calculated to be 95.5 ppm ± 0.01 ppm. The physicochemical variables of MB in wastewater samples such as pH, dissolved oxygen and its color were determined and

found as 6.67 ± 0.21, 1.10 ± 0.08 mg/L and yellow, respectively (Alemu *et al.*, 2024). The wastewater exhibited a slightly acidic nature (pH below 7), potentially due to the presence of a high organic matter load. Analysis using a calibration curve revealed a mean concentration of MB was 95.5 ± 0.01 ppm.

Table 3. The standard concentration of MBD and corresponding absorbance

	Standard concentration of MBD (ppm)				
Standard Series	80	90	100	110	120
Absorbance (λ_{max} = 665 nm)	0.033	0.038	0.072	0.089	0.108

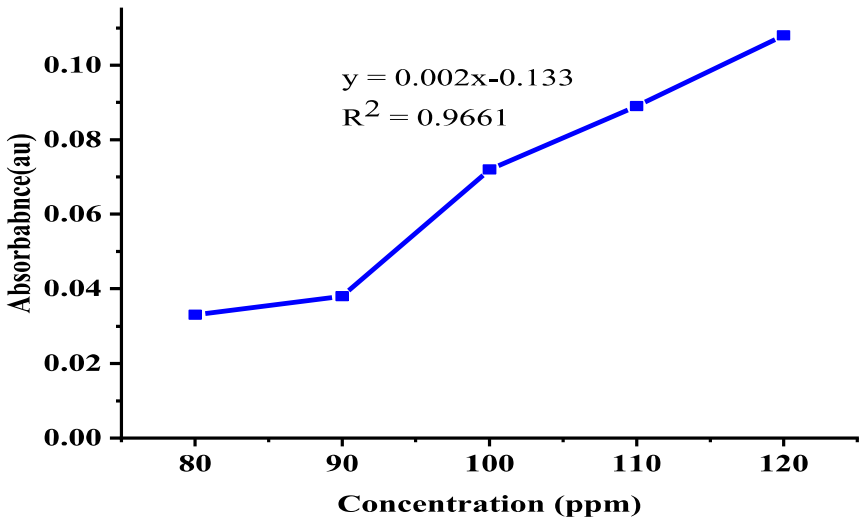

Figure 6. The calibration curve sketched using standard concentrations of MBD (80–120 ppm)

Study of Adsorption Operational Parameters

Effect of adsorbents: The batch adsorption was performed for the removal of MB from wastewater effluent fixing contact time to 120 min, concentration of MB to 80 ppm, adsorbent dose to 0.80 gm, and pH of solution to 12 (Fig. 7). Ni-CuO/ZB NC demonstrated a clear advantage in its initial adsorption rate for MB compared to other adsorbents. This is evident from the sharp rise in the adsorption curve at the beginning of adsorption experiment which can be attributed to the abundant surface area of the Ni-CuO/ZB NC. This adsorbent provide large surface area with greater number of accessible active sites which attract MB molecules at the initial adsorption process (Chakraborty *et al.*, 2020). Smaller particles and a narrower band gap appear to be contributing factors to the faster adsorption rate. The Ni-CuO/ZB nanocomposite (NC) with the smallest crystallite size (18.06 nm) and narrowest band gap (1.75 eV) exhibited a continuously increasing adsorption rate. Impressively, this NC achieved a maximum adsorption efficiency of 99.50% within just 40 minutes. Due to this exceptional performance, the Ni-CuO/ZB NC was chosen as the best adsorbent for further experiments (Juma *et al.,* 2017).

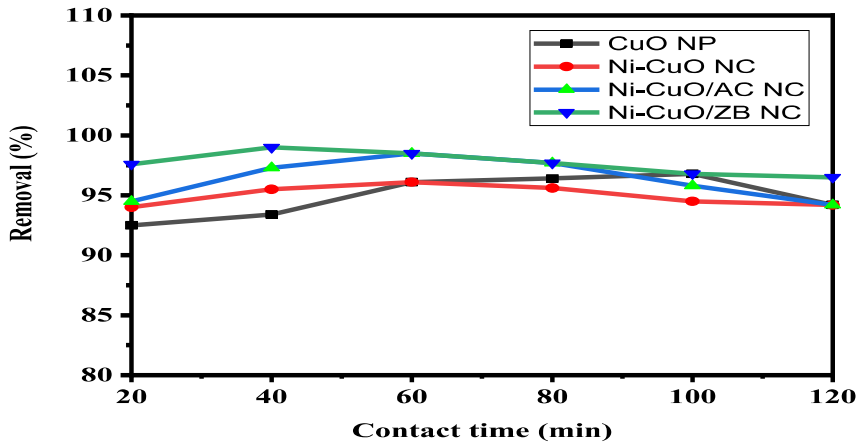

Figure 7. Effect of nature of adsorbent for adsorption of MB from wastewater sample

Effect of MB concentration in wastewater sample: This study examined the effect of initial MB concentration on its removal from wastewater using the Ni-CuO/ZB NC adsorbent. The experiment evaluated MB concentrations ranging from 80 to 120 ppm with a fixed adsorbent dose (0.8 g), pH (12), adsorption time (120 minutes), and room temperature. As shown in Fig. 8, the highest removal efficiency has been recorded at 110 ppm initial concentration of MB and taken as an optimal range for efficient adsorption. The adsorption process was rapid at initial, time and reaching its maximum removal capacity within 120 minutes for all tested MB concentrations (Mousavi *et al.*, 2022). The adsorption efficiency of Ni-CuO/ZB NC was significantly increased with contact time till it reach 120 min (98.98%) which ascribed to the availability of adsorption active sites. This high removal rate and the optimal concentration likely occur because the Ni-CuO/ZB NC has a large number of available and accessible active sites for MB dye adsorption. Regardless of initial concentration, the adsorption rate has initially fast as the positively charged MB is binded to negatively charged adsorbent surface (pH is in alkaline media). These sites become progressively occupied, leading to a steady removal tendency for all concentrations. However, resulted in a slowing down adsorption rate with increasing time as a result of surface saturation (Salih *et al.*, 2022).

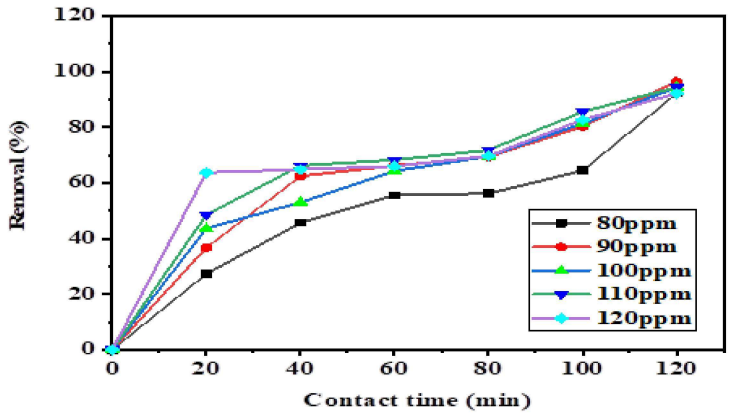

Figure 8. The effects of initial concentration of MB containing wastewater at Ni-CuO/ZB NC surface

Effect of pH: Fig. 9, indicates the adsorption of MB pollutant at Ni-CuO/ZB NC surface via varying pH value from 2 to 12 keeping the adsorbent dose at 0.8 g, dye concentration at 110 ppm and contact time at 120 min. This study revealed that the Ni-CuO/ZB NC is effective at removing MB dye from wastewater samples at various pH levels. Interestingly, the highest removal efficiency (~99%) was achieved at a pH 12. It suggests that the NC's adsorption capacity of MB is strongest when its surface is alkaline (negatively charged). This creates a favorable environment for attracting cationic pollutants (MB), through electrostatic interactions. In contrast, research shows that removing other pollutants, like methyl orange (MO) dye, using agro-waste-based adsorbents is most effective in acidic environments (around pH 4-5) signifying that under acidic conditions, the adsorbent surface becomes positively charged, while MO molecules remain negatively charged. These oppositely charged ions attract each other and enhance adsorption process. However, as the pH increases, the positive charge on the adsorbent weakens, and an abundance of OH^- in the solution repels the negatively charged MO molecules which then reduce its adsorption in basic environments (Tigrine *et al*., 2024).

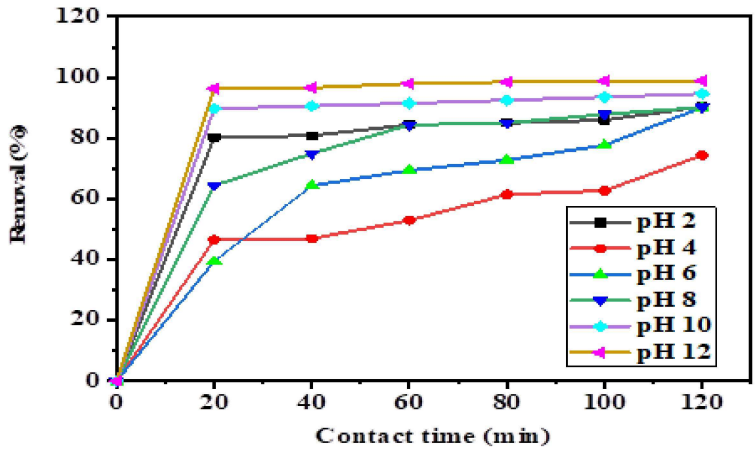

Figure 9. The effect of pH on adsorption efficiency of MBD in wastewater effluent

The effect of adsorbent load: This study investigate the extent of Ni-CuO/ZB NC in removing MB dye from wastewater using different amounts of the nanomaterial vary from 0.07 to 1.00 g while keeping other conditions constant (pH 12, MB concentration 110 ppm, contact time 120 minutes). The study revealed that 1.00 gram of Ni-CuO/ZB NCs was the most effective for removing MB (Fig. 10). This is because a higher amount of adsorbent provides more active sites, which are like tiny hooks that grab and hold onto the dye molecules. As the amount of adsorbent increases, so does the removal efficiency of the MB dye (Bedmohata *et al.*, 2015)**.** Thus, the removal capacity corresponding to 0.20, 0.40, 0.60, 0.80, and 1.00 g of Ni-CuO/ZB NC are 52.54, 49.20, 55.20, 60.48, 86.72 and 98.98%, respectively. Generally, the adsorption experiment for the treatment of MB pollutant using Ni-CuO/ZB NC adsorbent signifies the optimum removal efficiency was retained at adsorbent dose of 1.00 g, pH 12, 110 ppm concentration and 120 min contact time with removal capacity of 99.04%.

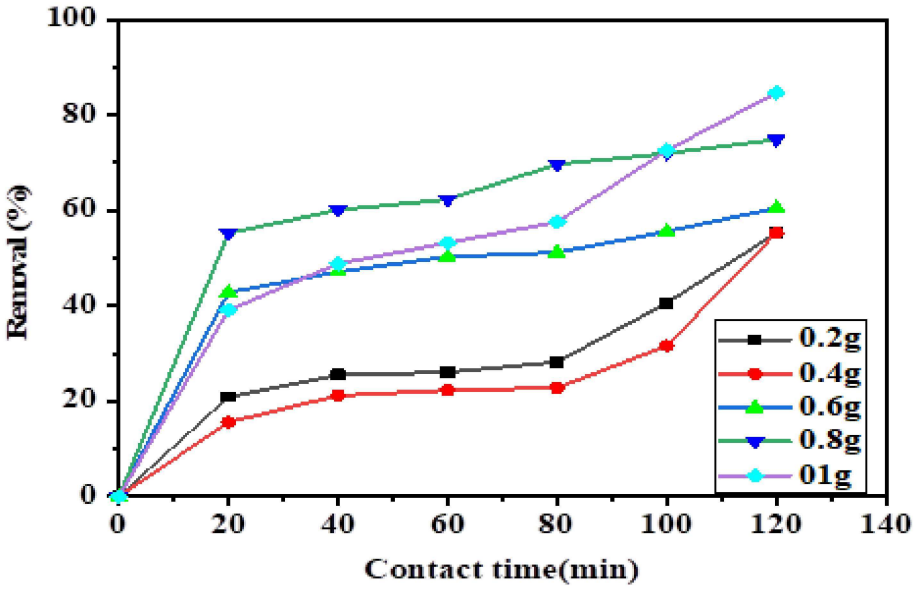

Figure 10. The effect of adsorbent dose on the removal of MB dye from wastewater effluent

Re-usability of Adsorbent

Fig. 11, represent the re-usability of Ni-CuO/ZB NC. It shows significant catalysts stability for efficient adsorption in the five cycles (99.04%, 94.28%, 92.05%, 90.10% and 84.65% respectively) taking 110 ppm concentration of Ni-CuO/ZB NC, 1.00 g adsorbent dose, at pH 12 and adsorption time of 120 min. A previous study using a different adsorbent (DSAC) reported its re-usability for phenol removal over eight cycles. The results showed good performance with removal efficiencies exceeding 96% in the initial cycles, but gradually decreasing with further use (96.12, 94.14, 91.01, 87.65, and 86.10 in the 1st, 2nd, 3rd, 4th and 5th cycles, respectively). This result is more comparable with the current finding and the decrease in adsorption capacity is likely due to the occupation of active sites on the adsorbent by pollutants over multiple cycles (Miri *et al.*, 2016). In the current study, Ni-CuO/ZB NC achieved an impressive adsorption performance of 99% under optimal conditions (110 ppm concentration of dye, 1.00 g of adsorbent dose, pH 12, and 120 min adsorption time). The promise of this technique lies in its reusability, stability, and high pollutant removal efficiency compared to existing methods (as shown in Appendix 1). For instance, a previous study by Tibebu *et al.* (2023) synthesized Ag-CdO/PANI NC for removing BPB dye from wastewater under ultraviolet-visible light irradiation while the effective treatment recorded 98%, this method requires light exposure. Another study by Girmaye *et al*. (2024) developed Ni-TiO_2/PANI NC for removing MG dye using photo-catalysis. This method achieved 99% degradation at optimized conditions, but it also has limitations such as generation of secondary pollutant. In this study, Ni-CuO/ZB NC offers a compelling alternative. It achieves comparable removal efficiency without the need for light or specific operating conditions beyond initial optimization. In general, this study provided a promising nanosorbent derived from agro-waste materials for wastewater pollutant adsorption and anticipated to offer a significant contribution to future environmental management strategies due to its potential for sustainability and effectiveness (Asefa *et al.*, 2024).

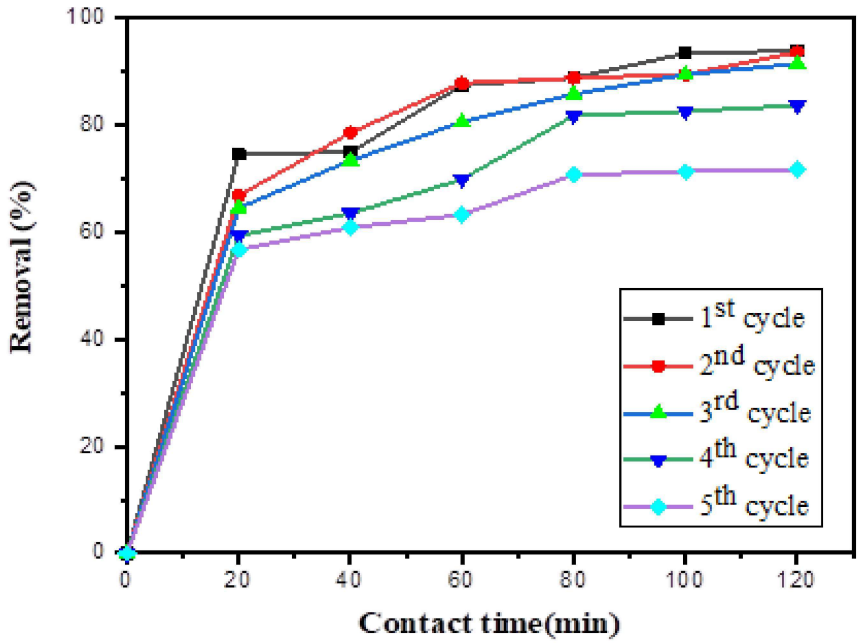

Figure 11.The re-usability of the adsorbent at optimum conditions for five consecutive cycles

Adsorption Isotherm

Langmuir adsorption isotherm: Fig. 12(a) shows the results of a Langmuir adsorption isotherm experiment, where MB molecules interact with the surface of the Ni-CuO/ZB NC adsorbent. The Langmuir isotherm model is often used to analyze the single-layer type of adsorption process. A key parameter in the Langmuir isotherm is the separation factor (R_L), calculated using Eq. 5. In the current study, the R_L value for MB adsorption was 0.0018, indicates a favorable adsorption (Kalaba *et al.*, 2022). Furthermore, the experiment yielded a high correlation coefficient (R^2) of 0.988 using non-linear model. This strong correlation supports the Langmuir isotherm model, suggesting that MB molecules form a single layer on the Ni-CuO/ZB NC adsorbent surface (Mohebali *et al.*, 2018).

Freundlich adsorption isotherm: Fig. 12(b) illustrates the Freundlich adsorption isotherm for MB on Ni-CuO/ZB NC. This isotherm model was used to analyze the favorability of the adsorption process. Using Eq. 6, the calculated value of 1/n was 0.4307, indicates that the MB is favorably adsorbed to Ni-CuO/ZB NC surface as its value fall between 0 and 1 suggesting favorable adsorption. The high correlation coefficient (R^2 = 0.991) from non-linear equation implies that the Freundlich isotherm provides a superior fit for describing MB adsorption at adsorbent compared to the Langmuir model since Freundlich adsorption model accounts for the heterogeneous surfaces with varying binding site affinities which agree with the finding of in particular the adsorption of MB dye on the semiconductor nanoparticles (Kalam *et al.*, 2021). As it was suggested by, Ni-CuO/ZB NC likely possesses a range of adsorption sites with different binding strengths for MB molecules so that it provided a successful adsorption of MB from wastewater sample (Arunkumar *et al.*, 2014).

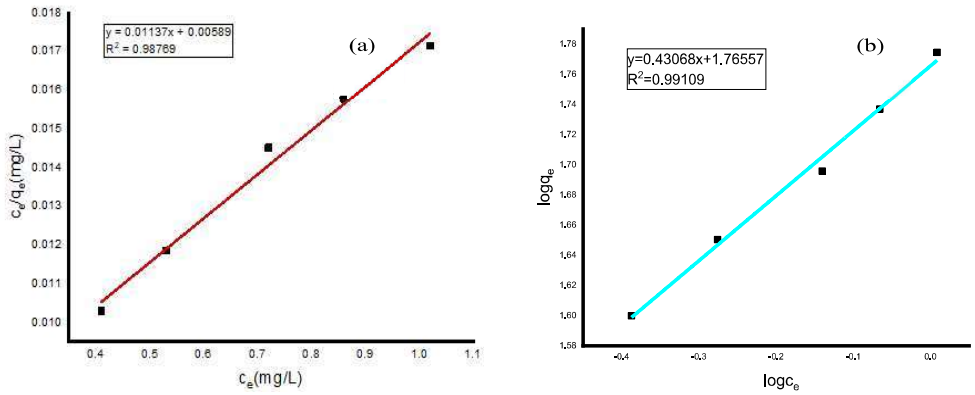

Figure 12. Adsorption model (a) Langmuir isotherm, (b) Freundlich isotherm for Ni-CuO/ZB NC

Adsorption Kinetic

Pseudo first-order kinetic model: Fig. 13(a), analyzes how MB adsorption onto the Ni-CuO/ZB NC surface follows a pseudo-first-order kinetic model. This model is well-suited for the studied adsorption timeframe and suggests that the interaction between MB and the NC primarily involves physisorption (Velusamy *et al.*, 2021). The key parameters which is the correlation coefficient (R^2 = 0.98189) is high value suggesting a strong correlation between the model and the experimental data where as an equilibrium adsorption capacity (q_e = 38.078 mg/g) represents the maximum amount of MB that can be adsorbed per unit mass of the NC under the studied conditions.

Pseudo second-order kinetic model: Figure 13(b), explores the kinetics of MB adsorption onto the Ni-CuO/ZB NC surface using the pseudo-second-order kinetic model. The analysis yielded the rate constant (k_2), equilibrium capacity (qe), and correlation coefficient (R^2). This suggests a slower removal rate at higher dye concentrations which attributed to the reduced diffusion of dye molecules as they encounter more occupied adsorption sites on the NC surface, becoming even more pronounced at high MB concentrations. The equilibrium adsorption capacity (q_e = 41.964 mg/g) and adsorption rate constant (k_2 = 0.0073). The fitting of the data to the pseudo-second-order model resulted in a high R^2 (0.99747), indicating a better fit compared to the pseudo-first-order model. This implies that the adsorption process likely follows a chemisorption mechanism, where valence forces through electron sharing between the NC and MB molecules govern the rate-limiting step (Abd El-Latif *et al.*, 2010).

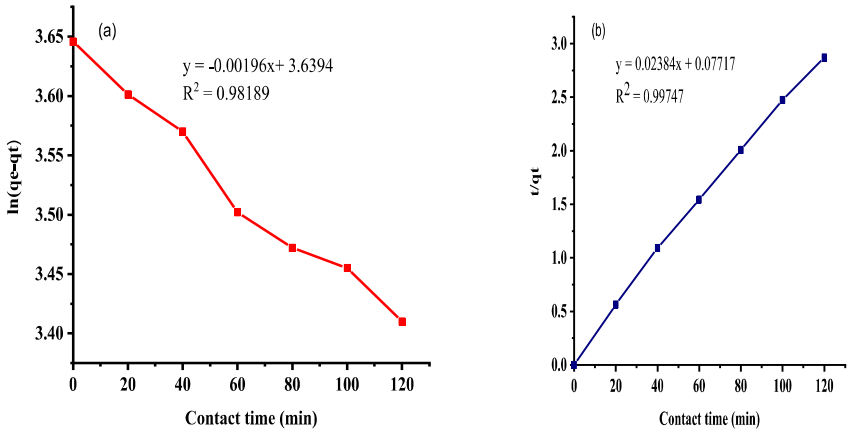

Figure 13. Adsorption Kinetics (a) Pseudo first-order model, (b) Pseudo second-order model

Adsorption Mechanism

The current study reveals the energy band gap (Eg) and particle size has decreased upon surface modification by ZB suggests an enhanced light absorption by Ni-CuO/ZB NC. This aligns with established principles where smaller particle size and lower Eg values typically improve light absorption efficiency. The investigation identified Ni-CuO/ZB NC is one of the most efficient adsorbent, achieving a remarkable 99.03% removal of MB dye under optimized conditions including adsorbate concentration of 110 ppm, pH 12, adsorbent dosage of 1.0 g and adsorption contact time of 120 min. The adsorption kinetic and isotherm model suggest that the adsorption process follows a pseudo-second-order kinetic (R^2 = 0.99), indicating chemisorption as the rate-limiting step. Additionally, the Freundlich isotherm model provides the best fit, implying a heterogeneous adsorption process with multilayer formation on the Ni-CuO/ZB NC surface {Modwi, 2018 #65}. In this work, the exceptional removal efficiency observed at the stated conditions confirmed that Ni-CuO/ZB NC surface exhibits a stronger adsorption capacity for MB dye in an alkaline (anionic) environment which creates a favorable electrostatic interaction toward cationic pollutants. Conversely, in acidic environment (lower pH), it likely leads to a positively charged adsorbent surface, repelling the cationic MB molecules and resulting in a lower adsorption capacity. Therefore, this adsorption process involves the formation of multilayers on the Ni-CuO/ZB NC surface, accompanied by chemisorption as the dominant mechanism.

Conclusion

Water pollution is a global issue that affects both human health and the aquatic habitat. This study aims to create CuO, Ni-CuO, Ni-CuO/activated carbon (AC), and Ni-CuO/zeamays bark (ZB) NCs for the removal of MB from industrial wastewater. The prepared nanomaterials were characterized using FT-IR, SEM, XRD, and UV-Vis analytical tools. FTIR spectra indicated the presence of OH and CO functional groups, enhancing adsorption potential. SEM revealed a porous, hair-like morphology in Ni-CuO nanocomposites. XRD analysis confirmed the formation of a monoclinic CuO phase, with a reduction in crystal size from 34.26 nm (CuO) to 18.06 nm (Ni-CuO/ZB). UV-Vis analysis showed a bandgap reduction from 3.22 eV (CuO) to 2.10 eV (Ni-CuO/AC) and 1.75 eV (Ni-CuO/ZB). The removal of MB exhibited that Ni-CuO/ZB achieved the highest removal efficiency of 99.03% under optimized conditions: 110 ppm dye concentration, pH 12, 1.0 g adsorbent dosage, and 120 minutes contact time. The adsorption process conformed to the Freundlich isotherm model

and pseudo-second-order kinetics (R^2 = 0.99), indicating multilayer adsorption and a chemisorption mechanism. Overall, the Ni-CuO/ZB nanocomposite demonstrated superior performance, making it a cost-effective and sustainable candidate for industrial wastewater treatment.

Data Availability Statement

All necessary data have incorporated within the manuscript and available whenever requested.

Statement of Conflict Of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Summary of previous research report using various pollutant removal methods with key parameters, adsorbents, adsorbent's and findings are highlighted as follows:

Adsorbent used	Focus of the study	Method employed	Target pollutant	Optimum condition and key finding	References
Zero-valent iron (NZVI) NP	The zero-valent iron (NZVI) NPs for the decomposition of Reactive Red 198.	Advanced Sono-Nano-Fenton hybrid method	Reactive Red 198	Degradation efficiency was 97 % achieved by Sono-Nano Fenton process in 60 min and the process follows pseudo-first-order kinetics and the Langmuir-Hinshelwood model.	Hossein K. et al., 2024
TiO_2–ZnO/biochar activator of persulfate	TiO_2–ZnO/biochar NCs as activator of persulfate (PS) for degradation of furfural	Sol-gel method	furfural	Efficiency: 96 % of furfural at pH = 3, catalyst dosage = 1 g/L, persulfate concentration = 1.2 mM, and furfural concentration = 10 mg/L) within 15 min. The experimental data fitted well with the first-order kinetic model	Hasanzadeh, M. et al., 2023
Na_2S_2O/Fe^{2+})	Conducted to Optimize ($UV/Na_2S_2O_8/Fe^{2+}$) process for phthalic acid removal	Response surface method	Phthalic Acid	Removal efficiency: 98% at pH= 11, reaction time=60 min, Fe^{2+} concentration=0.15 mmol/L, persulfate concentration = 0.3 mmol/L and phthalic acid =5 mg. The phthalic acid removal followed by first-order kinetic.	Fallah J. *et al.,* 2018
Desorption from soil	Evaluating the desorption kinetics of phenanthrene	The nonionic surfactant	(PAHs)	The desorption was well described by pseudo-second-order model and fitted well by Freundlich isotherm models	Gharibzadeh F. et. al., 2019
MIL/Cs@Fe_3O_4 NCs	magnetic NH_2-MIL-101(Al)/chitosan NCs for the adsorption of azithromycin (AZT)	Microwave method	Azithromycin (AZT)	At pH= 7.992, adsorbent dose=0.279 g/L, time= 64.256 min and AZT =10.107 mg/L the adsorption efficiency and AZT adsorption capacity were 98.362 ± 3.24% and 238.553 mg/g, respectively. The data well fitted the Langmuir isotherm and Pseudo-second-order kinetics.	Azari, A. et al., 2022
Fe_3O_4@TiO_2 magnetic nanocomposite	Ultrasound-assisted Fe_3O_4@TiO_2 for catalytic oxidation of 2, 4-Dinitrophenol.	RSM-based CCD approach	2,4-Dinitrophenol	Over 91.45% of DNP were removed by Fe_3O_4@TiO_2 /US system (FTU) under optimum conditions within 30 min	Rabiee, F. et. al., 2024
Ni-CuO NCs treated with AC prepared from ZB	Designed for removal of methylene blue (MB) dye from wastewater	Adsorption	Methylene Blue Removal	Ni-CuO/ZB NC showed optimal adsorption at 110 ppm, pH 12, 0.8 g dosage, and 120 min contact time, achieving 99.03% removal efficiency. The process followed Freundlich isotherm and pseudo-second-order kinetics.	This study

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RESEARCH PAPER

Effects of Short Story Instruction on Students' Reading Comprehension, Vocabulary Skills Development and Reading Motivation: The Case of Second Year English Major Students

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Abstract

The objective of this study was to investigate the effects of short story intervention on Ambo University students' reading comprehension, vocabulary skills development and reading motivation. All second year English Language and Literature major students were purposefully selected as the subjects of this study. They participated in six months short story interventions. Quasi-experimental research design was employed. The researchers used a within-subject design where a single group of subjects is exposed to all levels of independent variables, a short story. Next, the students were given intensive training that lasted for six weeks. After the completion of the training, a post-test was administered. Then, the results were collected and recorded. The collected data was analysed by using paired sample t-test and descriptive statistics (mean and standard deviation). The result of the data analysis revealed that short story intervention has a significant effect on the improvement as the paired sample t-test results indicated that a statistically significant improvement in reading comprehension, t (19), 4.41, p <0.001, with the very large effect size (Cohen's d=3.40); vocabulary skills development showed significantly higher score than before the intervention t(19)=11.43, p=0.001, Cohen's' d=0.99, 95%) and level of reading motivation levels from pre-test result to post-test result t(19) = 11.32, p = 0.001). Based on the findings, it was recommended that appropriate short story should be used in the teaching of reading and vocabulary so that it may help students to improve their, reading comprehension, vocabulary skills and motivation to read.

Keywords: Reading comprehension, vocabulary, reading motivation, short story

Introduction

Reading is one of the four essential skills to be mastered, alongside listening, speaking, and writing. Among these English language skills, reading provides students with the greatest access to information. According to Tadros (2014), reading involves the act of deriving meaning from a text that is written. Farha and Rohani (2019) also stated that reading is a language skill that is very important to support success in obtaining knowledge or information. Further, reading is a crucial method for effective learning within an educational environment, and proficient reading involves not just decoding words but also understanding the text (Zaccoletti *et al.,* 2020). In addition, reading plays a significant role in language instruction to enhance the skills that students have developed in listening, speaking, and writing (Van, 2009). Thus, engaging in reading plays a crucial role in forming an individual's personality and enhancing their perspective, which helps them connect with others more effectively.

Like, many English as Second Language or English as a Foreign Language reader, Ethiopian students gain wider access to electronic databases through the Internet.

Indeed, reading is a basic life skill and a cornerstone for learners' success in their careers and throughout their lives (Adcock, 2011). For this reason, the students have to be able to achieve reading competencies that can assist them in grasping necessary input using appropriate strategies of reading. Besides, language educators has given due attention is given on how students can develop their reading skill. Some scholars (Pardede, 2011; Hanadayani, 2013) argued that using short stories to teach reading skill will help students to improve their reading comprehension skill. Hence, the main objective of this study is to examine the effects of short story on the improvement of students' reading comprehension, vocabulary skills and reading motivation.

Robel and Shiue (2011) defined reading comprehension as the ability to read the words and know the meaning of a text. Khatib (2012) also stated that reading comprehension skills are the most important skills for mastery of a foreign language. Reading comprehension skill is a basic skill that any student needs to develop while learning a language. While the students are engaged in real classrooms, teachers of the English Language should use effective ways to improve students' reading comprehension so that the students can easily read and understand what they read in a better way (Nejmeh, 2011).

There are many reading strategies to improve reading comprehension and inferences, including improving one's vocabulary, critical text analysis, actual events and narration of events, and practicing deep reading (Wolf, 2016). Using short stories can help to develop reading comprehension skills and make the students exchange their ideas in the classroom discussion and make a connection between the text and the text from outside the school (Sari, 2013). Pardede (2011) stated that short stories are the most suitable literary genre which can be used in the EFL classes because they are very short, and it is more interesting than the novel, and less trouble when it is compared to the novel and easy to understand. In addition, Hanadayani (2013) pointed out that short stories are authentic materials for learning the English language.

Acquiring and mastering vocabulary is a crucial aspect that educators must instruct in English (Oscarini and Bhakti, 2018; Wulandari, 2019). Learners acquire new vocabulary by reading and understanding various English terms (Bi, 2020). Through reading, individuals can discover the significance of vocabulary (Tager-Flusberg, 2015). This assertion is reinforced by the research carried out by Rahayuningsih (2020), which revealed that in order to grasp the context of a text, students must not only read and articulate some words but also comprehend the meaning of each individual word. In summary, engaging in reading can enhance the vocabulary of students (Yildirim, 2008). A study conducted by Fitria (2019) stated that when students comprehend what they are reading, the more they read, the better they understand each word's meaning in English (Fitria, 2019). Once readers have an extensive vocabulary, they will understand the texts better, as vocabulary plays a crucial role in learning a foreign language (Reynolds et al., 2018). Overall, the enhancement of vocabulary plays a crucial role in advancing students' language abilities (Pezoa *et al.,* 2019; Yousefi and Biria, 2018). So, our students have to learn this basic skill using appropriate strategies to cope with books teaching foreign languages since it has multipurpose benefits. Short stories are very useful in the trials to improve students' vocabulary and reading. Nasreen (2010) stated that "short stories" will create a marked difference in language teaching and improving vocabulary.

Experts have performed numerous previous studies on reading skills. Furthermore, the review of pertinent local empirical studies divulged that some studies were conducted on the issues of students' reading skill and the difficulties associated with it. For example, according to Oromia Education Bureau (2011), the students' overall performance in learning other subjects is affected by their inability to read in English. Different local studies have been conducted in the area of literature in English language classroom teaching learning practices. For instance, Yitagesu (2017) carried out a research study examining the impact of literary texts on enhancing reading comprehension among ninth-grade students in

Addis Ababa. The researchers utilized a correlation design along with both quantitative and qualitative methods for data analysis. Ultimately, the study's results revealed that a majority of the participants viewed the incorporation of literary texts in reading instruction favourably.

Antehun (2020) conducted a second study on the advantages and difficulties of teaching English literature in Ethiopian secondary schools. The researchers employed a descriptive survey research design and purposive and convenient sampling techniques. According to the study's findings, incorporating literary texts into EFL/ESL classes is essential for teaching secondary school students the English language.

Despite the fact that the aforementioned scholars studied the function of literary texts in language instruction, no research has been done to look at how short stories affect students' vocabulary and reading comprehension. Furthermore, the current study's context is different. In this context, the primary goal of the current study was to investigate how short stories can enhance the reading comprehension, vocabulary and reading motivation of second-year English major students at Ambo University.

Methodology

Research Design

The study's goal was accomplished through the use of a quasi-experimental research design. The rationale is that experimental research uses direct manipulation of an independent variable and control of unrelated variables to examine cause-and-effect correlations (Creswell, 2012). Furthermore, by controlling any threats to internal validity, quasi-experimental design procedures can be constructed to draw some conclusions without including all the elements of an actual experiment. According to Patino and Ferreira (2018), internal validity is the degree of assurance that there are no outside factors influencing a cause-and-effect link found in a study. This is the other reason that the researchers used the quasi-experimental design for the current study.

Additionally, this enables the researchers to choose volunteers according to their suitability for the study and convenience (Gray, 2023). Additionally, posttest-only designs with control groups, one group pre-test-post-test designs, and pre-test-post-test designs with control groups are examples of quasi-experimental research designs (Gray, 2023, Harris *et al*, 2006). Because there aren't many responders, the researchers have selected the second one—a one-group pre-test post-test design. Therefore, the current study, which aims to investigate the impact of short tales on second-year students' reading motivation, reading comprehension, and vocabulary skills, is suitable for a quasi-experimental research design.

In particular, a time series design involves using several pre-test and post-test measures created by the researchers to examine a single group over time. The repeated measures design was the most popular time series design, in which each group served as the control and all participants in that group had all experimental treatments (Cresswell, 2012). The researchers compared a group's achievement under one experimental treatment with its performance. This single-subject design involves the study of single individuals, their observation over a baseline period, and the administration of an intervention (Creswell, 2012). In a similar vein, Creswell (2014) also noted that a single-subject design entails tracking the behavior of one person (or a limited number of people) throughout time. Because comparing the effects of treatments entails examining how each participant's performance changed before and after the treatments, the design is known as within subjects.

Research Setting

Ambo University, situated in Ambo town, the capital of the West Shewa Zone of Oromia Regional State, Ethiopia, is where the study was carried out. Ambo is located 114 kilometers to the west of the nation's capital. The University incorporates four campuses,

namely: the main campus at Ambo, Hachalu Hundessa Campus, Mamo Mezemir Campus at Gudar and Woliso Campus. Among the mentioned four, the researchers conducted the study at the main campus since the target groups were found there. The other reason for selecting this particular setting was that while delivering reading courses at different times the researchers' observed students' problems of reading comprehension. Hence, the availability or existence of the problem in this particular setting and its appropriateness to the study were among the other reasons for the selection of this particular research setting.

Participants and Sample of the Study

The study's 19 participants were all second-year English majors at Ambo University. Second year students were believed to be appropriate for this study since they have taken common courses at this level and are also familiar with the environment. The subjects were specifically chosen because they assisted the researchers in conducting experiments on the subject and confirming or refuting the study's concept. Since purposive sampling is a better method for gathering data from students, the researchers employed it. If the objective is description rather than generalization, purposeful sampling are employed (Dawson, 2002).

Research Hypothesis

H1: Students who completed the reading short story training showed a statistically significant difference in their reading comprehension scores before and after the training.

H2: Students who completed part in the reading short story training exhibited a statistically significant difference in the vocabulary skill development scores before and after the training.

H3: The reading motivation levels among the students who completed part in the short story reading training varied significantly in statistical terms before and after the training.

The researchers used description in the case of analysing the collected data for variables in the study through means, standard deviations, and ranges of scores to describe the effect of the treatment. Furthermore, a quasi-experiment was used for the present study by exposing the students' reading skills via different short stories. The effect of the independent variable (short tales) on the dependent variables (the target groups' reading motivation, vocabulary, and comprehension) was attempted to be examined.

Research Questions

1. Is there a statistically significant difference in reading comprehension scores before and after the short story training for the students who participated in it?

2. Is there a statistically significant difference in vocabulary skills scores before and after the short story training for the students who participated in it?

3. Is there a statistically significant difference in reading motivation scores before and after the short story training for the students who participated in it?

Research tools

Pre-test

Pre-tests which are also known as before test was given for all second year English major student respondents to assess their initial level of, reading comprehension, and vocabulary skills and reading motivation before they receive the treatment. It was delivered using different tasks. The question types correspond to the specific objectives of the study. The student respondents were given nearly two and half hours each to complete the given activities. The tests were prepared by the researchers from the selected short stories. Finally, the student respondents' responses were collected and corrected. The method of data analysis used was inferential statistics since it allows the researchers to compare the mean, and P value of the student respondents' result (Lim 2024). .

Post-test

Post-tests which are known as after test were prepared and delivered for all student respondents to know the effects of short stories on their reading comprehension vocabulary skills and reading motivation. The objective was to assess each treatment's effects.

Specifically, it was carried out to assess the effect of dependent variable or the variable being manipulated on the dependent variable or the variable in which the effect of the manipulation of the independent variable is observed. The post-test's objective in this instance was to investigate how the short tale affected the understanding, vocabulary, and reading motivation of the students' responses.The student respondents were given nearly two and half hours each to complete the given activities. The tests were prepared by the researchers and also checked by expert from education institution to ensure the validity. Finally, the respondents' responses were collected and corrected using inferential statistics since it allows the researchers to compare the mean and p value to accept or reject the hypotheses.

Procedures of the Study

The purpose of this study was to investigate how short stories affect, reading comprehension, vocabulary skill and reading motivation. To do so, the selected short stories which were to the level of the learners were adapted from different sources by the researchers and delivered to the student respondents after they were checked by education expert. The level here deals with the age of the students and the theme of the short story. The short stories were mixed in nature since they began from the culture of the students and preceded to the world level. Then after, the provision of a pre-test to identify students' initial level of reading skill was carried out. Next to that, the implementation of the treatment was carried out. The treatment was delivered for six weeks. During this time, the student respondents' were practicing different activities that were prepared from the reading short stories. In particular, the researchers' guidance on applying the three stages of reading—pre-, during-, and post-reading—was given to the students while they read the texts. They were completing the given exercises most of the time in group. The researchers got permission from one of English language and Literature instructors who was assigned to teach reading course. Additional classes were also arranged by the representative of the class.

The prepared short stories for the training were accompanied by various activates and all of them were adapted from different sources of literature by the researchers. The time allotted for reading and performing the followed activities regarding each short story was two and half hours After that, the provision of a post-test to measure the effects of using short stories on students' reading comprehension, vocabulary skills and reading motivation was carried out. The post-test short story's level of difficulty, content and type is the same as that of the pre-test one. The only difference was the topics of the short stories. Hence, the procedure for completing the post-test is the same to that of the pre-test. At last, correcting the post-test was done followed by data analysis using inferential statistics.

Methods of Data Analysis

Following test administration, data was gathered and statistical analysis was performed. The same respondents were given estimation mean of the pre-test and post-test. In particular, the paired sample t-test was used in inferential statistics to analyze the data gathered from student responses at various times. As per the selected approaches in the literature, the statistical tools that were employed were D (mean difference), T (t-value), Df (degree of freedom), and Sig. 2-tailed (p value) (Field, 2024).

Results

The purpose of the pre- and post-tests was to determine whether there was a significant mean difference between the target student respondents' performance on the pre- and post-tests, as well as the impact of short tales on and

reading comprehension, vocabulary skill and reading motivation. The paired sample t-test was used to analyze and interpret the reading comprehension vocabulary skills and reading motivation performance findings from the pre-test and post-test. Here are the analysis's findings.

Table 1. Descriptive statistics on the students' Reading Comprehension

Test	Mean	Standard deviation
Reading comprehension pretest	9.800	7.56
Reading comprehension posttest	12.950	6.11

In the table 1, the result indicated that student's reading comprehension mean score was improved from 9.80 (pre-test) to 12.95 (post-test) (i.e. within difference 3.15). This indicates substantial improvement in reading comprehension after the intervention. Therefore, it can be concluded that the six weeks short story intervention was effective in enhancing the students' reading comprehension.

Table 2. Hypothesis whether statistically significant difference in reading comprehension scores before and after the reading short story training testing

Pre-test and post-test	**T**	**Df**	**p**	**Cohen's Effect size**
Reading comprehension post-test minus reading comprehension pre-test	4.41	19	0.001	3.40

Hypothesis No. 1 'There is a statistically significant difference in reading comprehension scores before and after the reading short story training for the students who participated in it' was accepted. The paired sample t-test results indicated that a statistically significant improvement in reading comprehension, t (19), 4.41, p <0.001, with the very large effect size (Cohen's d=3.40) (Table 2). The effect size of 3.40 is considered as large (Fritz *et al.* (2012). Cohen (1988) also identified small size effect (d=0.2, medium effect size (d=0.5) and large effect size (d=0.8 or greater). This shows that the six weeks short story intervention had positive effect on the students' reading comprehension.

Table 3. Descriptive statistics on the students' vocabulary skill development

Pre-test and post-test	**Mean**	**SD.**
Vocabulary skill development pre-test	11.12	3.39
Vocabulary skill development post-test	17.45	2.07

Table 3 revealed that before the short story intervention, the students' vocabulary skills mean scores M=11.12 (SD. =3.39). However, after the treatment, the mean score increased to M=17.45 (SD = 3.07). The mean difference was 6.33 (17.45-11.12). The increase in the mean scores from pre-test to post-test indicates a substantial enhancement in vocabulary skills (Field, 2018). This suggests that the six weeks short story intervention was effective in improving students' vocabulary skills. Additionally, the reduction in standard deviation from the pre-test (SD=3.39) to the post tests (SD=2.07) indicates that students' vocabulary skills became more consistent following the intervention. This suggests that not only did the average skills level increase, but the variability in scores decreased, which in turn indicates a more uniform improvement among the students.

Table 4. Hypothesis whether statistically significant difference in vocabulary skills development scores before and after the reading short story training testing

Pre-test and post-test	T	df	p	Cohen's Effect size
Vocabulary skills development post-test minus vocabulary skills development pre-test	11.43	19	0.001	0.99

As it can be seen in the Table 3 and 4, participants' vocabulary skills development showed significantly higher score (M=17.45, SD=2.07) than before the intervention (M=11.12, SD=3.39), t(19)=11.43, p=0.001, Cohen's' d=0.99, 95%). This indicates that the hypothesis 'H2: There is a statistically significant difference in vocabulary skill development scores before and after the reading short story training for the students who participated in it' was accepted.

Table 5. Descriptive statistics on the students' on Reading Motivation

Pre-test and post-test results	Mean	SD.
Reading motivation pre-test	3.20	1.34
Reading motivation Post-test	3.84	1.14

The descriptive statistics in the Table 5 shows the increase in the students' reading motivation mean score from post-test (M=3.84, SD=1.14) to pre-test (M=3.84, SD=1.14). The decrease in the standard deviation from 1.34 (pre-test) to 1.14 (post-test) indicates that students' responses became more consistent after the intervention.

Table 6. Hypothesis testing about if there is a statistically significant difference in reading motivation levels before and after the reading short story training

Pre-test and post-test	T	df	Sig.	Effect size
Reading motivation Post-test - Reading motivation pre-test	11.32	19	0.001	1.87

As it can be seen from the table 5 and 6, the paired samples t- test result suggested the increment of the participants' level of motivation from pre-test result (M = 3.20, SD = 1.34) to post-test result (M = 3.84, SD = 1.14), t(19)=11.32, p= 0.001). This shows that the hypothesis No 3 'there is a statistically significant difference in reading motivation levels before and after the reading short story training' was accepted. The effect size of 1.87 is classified as large effect according to the Cohen's (1988) benchmark, which indicates a substantial impact of short story instruction on students' reading motivation. This suggests that the training not only significantly improved students' reading motivation but did so to a considerable extent.

Discussions

The goal of this study was to find out how teaching short stories affected the understanding, vocabulary growth, and reading motivation, of English majors. This study achieved three objectives. Determining the impact of short story usage on reading comprehension was the first specified goal. The second was to look at how pupils' vocabulary skills were affected by short stories. Examining how employing short stories affected the learners' motivation to read was the third goal. The design of this investigation was quasi-experimental. Additionally, the obtained data was analysed using the paired sample t-test.

Data were presented and analysed based on their themes under different headings. Further, the explanation of the reasons why the study has found was provided. Similarly, the results of pre-tests and post-tests were analysed and their means were compared to identify to what extent the intervention affected the participants' motivation to learn reading skills and the effects of using short stories on increasing the

students' achievement. The pre-tests aimed to identify students reading comprehension, vocabulary skills and reading motivation before the treatment. Similarly, the purpose of conducting post-test was to check the effect of the treatment i.e., a short story on the dependent variables i.e., reading comprehension vocabulary skills and reading motivation.

The mean of the learners' scores increased when comparing the pre-test and post-test findings. This suggested that using short stories enhances learners' vocabulary, understanding and reading motivation. According to the results of the paired sample t-test, there was a statistically significant improvement in reading comprehension (t (19), 4.41, p <0.001, with a very large effect size (Cohen's d=3.40); vocabulary skills development showed a significantly higher score (M=17.45, SD=2.07) than before the intervention (M=11.12, SD=3.39) (t(19)=11.43, p=0.001, Cohen's' d=0.99, 95%), and reading motivation levels increased from the pre-test result (M = 3.20, SD = 1.34) to the post-test result (M = 3.84, SD =1.14), t(19)=10.58, p=0.001). In this investigation, all three hypotheses were accepted.

The short stories created for the training included a range of activities and were all adapted from various literary sources by the researchers. These short stories began with elements from the students' own culture and expanded to a global perspective, allowing the participants to explore different cultures around the world. This exposure through literature also helps them reflect on and appreciate the diversity of others' cultures. These can be one of the reasons why these results obtained.

This study's findings align with previous research that demonstrated a positive connection between English literature reading and reading skills. For example, Kazeroon (2013) examined how exposure to literary texts affected students' reading comprehension and vocabulary retention at Khorasgan Azad University in Iran. The study compared literature majors to translation students and discovered that the use of literature increased students' vocabulary. Similarly, Palenfo's (2018) study also found out that the students improved their reading skills as a result of the short story intervention. Hamane and Guetatlia (2022) also stated that using literature in language classes enhances EFL learners' language skills.

Implications drawn from the findings suggested that, for English language teachers, this research could assist them in improving their current teaching techniques. Based on this research work, teaching reading skills through short stories would work best in any language classroom including Ethiopian context if the classroom teacher is given further training on the issue. This study also suggests that teachers need to devote significant class time to teaching reading skills through short stories and encourage students to be engaged in it so that some students' gaps will be addressed. Lastly, the study's findings demonstrated that the student respondents had a favourable opinion of using short stories to improve reading skills. This study also suggests that teachers need to devote additional significant class time to teaching reading skills through short stories and encourage students to be engaged in it so that students can benefit from it especially in their, reading comprehension, vocabulary skills and reading motivation gaps and generally their reading skills can be improved.

Conclusion

As it can be concluded from the above findings, the result indicated that there was a significant effect of the use of short stories in teaching reading skills to improve students', reading comprehension, vocabulary skills and reading motivation. The study also suggested that teachers need to devote significant class time to teaching reading skills through short stories and encourage students to be engaged in it so that some students' gaps can be addressed. Further, the study suggests that teaching reading skills through short stories has a positive effect on student respondents 'reading skills in general and their reading comprehension, vocabulary skills and reading motivation in particular. Moreover, the results of the study can have

practical contributions to designing policy frameworks and curriculum designers.

Recommendations

Based on the drawn conclusions the following recommendations are forwarded: Short stories should be integrated extensively into teaching reading skills so that it can help students' to be better in reading comprehension and vocabulary skills. To maximize the effectiveness of short stories in the English classrooms, teachers need to devote significant class time to teaching reading skills through short stories and encourage students to be engaged in it. Additionally, short stories should get attention since they have positive impact on students' reading skill along with reading comprehension, vocabulary skills and reading motivation. Finally, concerned bodies like designers of policy frameworks and curriculum designers should give due attention on the impact of short stories for students' to teach and reinforce vocabulary acquisition and comprehension skills, vocabulary skills development and reading motivation.

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Conflict of Interest Statement

The authors of this study declare that there are no conflicts of interest regarding the publication of this article.

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RESEARCH PAPER

Occurrence, Associated factors, and Antibiogram Profiles of *Staphylococcus aureus* and *Salmonella* Typhi Among Food Handlers in Restaurants in Hawassa City, Ethiopia

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Abstract

Staphylococcus aureus and Salmonella Typhi are among the most common foodborne pathogens transmitted by asymptomatic food handlers. This study aimed at determining the occurrence and antibiogram profiles of S. Typhi and S. aureus among food handlers in restaurants in Hawassa City, Sidama Regional State, Ethiopia. A cross-sectional study was conducted from August to November 2020, utilizing laboratory analysis of nasal swabs and stool samples from 100 volunteer food handlers working in restaurants in Hawassa City based on standard culture and antibiotic sensitivity tests. Ten (10%) of the 100 food handlers were nasal carriers of S. aureus whereas no S. Typhi was found. Five of the ten S. aureus isolates were resistant to one or more of the seven antibiotics tested. Of the isolates that showed resistance, one showed single resistance to penicillin while four (40%) showed resistance to two or more drugs. Two isolates showed double resistance, and one isolate showed triple resistance. Of the multiple resistant isolates, one belonged to Methicillin-resistant S. aureus (MRSA), which was resistant to penicillin, tetracycline, erythromycin, and oxacillin. All the S. aureus isolates were vancomycin sensitive. This finding implies that food handlers may be a potential source of foodborne disease outbreaks in the community, and the finding of multiple resistant isolates suggests inappropriate use of antibiotics. This highlights the importance of educating food handlers about the necessity of hhygienic food handling and responsible use of antimicrobials.

Keywords: Antibiogram profiles, asymptomatic carriers, food handlers, Salmonella, Staphylococcus

Introduction

Food safety is the conditions and practices that encompasses all measures taken throughout the food chain, from production to consumption, to ensure that food is safe, free from harmful contaminants, and fit for consumption. It is a widespread public health issue in developing countries, where personal hygiene and food safety measures are not well understood and received little attention (Lund and OBrien, 2011). Each year, an estimated 30% of the population in developing countries suffers from foodborne diseases, and up to two million of them die (Steven *et al*., 2019). Foodborne diseases are also common in Ethiopia because of the prevailing high rate of adulteration, poor food hygiene and sanitation practices, inadequate food safety laws, and weak regulatory systems in the production and supply value chains (USAID, 2021). Moreover, the lack of formal education and training of food handlers often results in mishandling and inappropriate hygiene measures that allow contamination of food by pathogenic microorganisms. As a result, food handlers with no formal education or training in food safety and hygiene serve as sources of transmission of foodborne infections (Castro *et al*., 2016; Angelo *et al*., 2017; Beyene *et al*., 2019).

The problem is exacerbated by the existence of food handlers who harbor foodborne pathogens without showing signs and symptoms of diseases. Some opportunistic pathogens are harbored as part of the normal flora of the human body, as in the case of *Staphylococcus aureus,* while others, such as *Salmonella enterica serovar* Typhi, may lead to an asymptomatic carrier state after bouts of typhoid fever in a significant proportion of individuals (Levine *et al*., 1982). Food handlers, who asymptomatically harbor pathogenic microorganisms, make the prevention and control of foodborne disease outbreaks caused by these pathogens difficult because they are unlikely to seek medical care (Smith and Fratamico, 2018). Epidemiological evidence shows that most outbreaks of staphylococcal food poisoning follow contamination of cooked foods by persons carrying enterotoxigenic staphylococci in their nares or skin, and outbreaks of foodborne salmonellosis come from raw or cooked foods not subjected to further cooking after contact with bare hands (Angelillo *et al*., 2000). Food handlers are crucial to safety and prevention of foodborne illnesses, because they may introduce pathogens into foods during production, processing, distribution, and preparation.

This problem is a dire public health issue when foodborne pathogens are multidrug-resistant strains. As is true for many bacterial infections, the evolution and emergence of antimicrobial resistance complicates the problem of foodborne microbial diseases. The emergence of antimicrobial-resistant (AMR) bacteria threatens the effective and successful treatment of infectious diseases worldwide. The World Health Organization (2018) reported that the global consumption of antibiotics by humans has increased in the past two decades, primarily in low- and middle-income countries. Furthermore, there has been a shift towards the use of broad-spectrum and last-resort antibiotics. Over-the-counter sales and inappropriate use of antibiotics are major problems in Ethiopia and have contributed to the emergence of drug resistance in bacterial pathogens (Oumer, 2019). Several studies conducted across Ethiopia have also indicated increasing rates of drug resistance in *Salmonella* species *S. aureus* and several other pathogenic bacteria to commonly prescribed antibiotics (Reta *et al*., 2015; Setegn *et al*., 2016; Bayeh *et al*., 2019; Tadesse *et al*., 2019; Rajiha *et al*., 2019).

Some institution-based studies (mostly university cafeterias) in Ethiopia have reported the presence of *S. aureus* and *S.* Typhi circulating among food handlers (Dagnew *et al*., 2012; Diriba *et al*., 2020). However, there is little published data on the epidemiology of *S.* Typhi and *S. aureus* carrier status among food handlers in public food-catering establishments. The occurrence of foodborne disease outbreaks in public food catering establishments is likely to have far-reaching ripple effects that may have economic repercussions in countries with budding Hotels and Tourism Industry. In the absence of surveillance data and food safety risk management, periodic cross-sectional studies may serve as an early warning system to prevent potential foodborne disease outbreaks by prophylactic treatment of asymptomatic carriers. Therefore, this study aimed to assess the incidence and antibiogram of asymptomatic *S. aureus* and *S.* Typhi carrier status among food handlers working in restaurants in Hawassa City, southern Ethiopia.

Materials and Methods

Description of Study Areas

The study was conducted in Hawassa City, at the Hawassa University Comprehensive Specialized Hospital (HUCSH) Clinical Microbiology Laboratory. Hawassa is located in the Great East African Rift Valley on the shores of Lake Hawassa, 275 km south of Addis Ababa. Hawassa is the administrative center of Sidama Regional State of Ethiopia and situated within the geographic coordinates 7^{o} 3'N - 7.050^{o} N and 38^{o} 28' E - 38.467^{o} E, at an altitude of about 1708 meters above sea level. According to the Ethiopian Central Statistical Agency (CSA, 2017), the estimated population of Hawassa in 2017 was 351,567, and considering the annual growth rate of 2.6% for the country, the current population of

Hawassa can be estimated to be 408,225. The city is a tourist hotspot for both locals and foreigners. Therefore, it is home to scores of international hotels, resorts, and large restaurants that serve both local and international visitors.

Study Population

Food handlers working in different mass-catering establishments/restaurants in Hawassa were enrolled in this study. The study participants were selected from different restaurants.

Study Design

A cross-sectional study, based on microbiological laboratory analysis of nasal swabs and stool specimens, was conducted among volunteer food handlers working in purposively selected restaurants in Hawassa City from August to November 2020. A semi-structured questionnaire was also used to collect the socio-demographic backgrounds of the food handlers to assess possible predisposing factors.

The restaurants for this study were selected purposively, based on a series of circumstantial observations relating to customer service, location, overall cleanliness, and hygienic reputation. We aimed to include a diverse range of establishments to ensure a comprehensive assessment of *Staphylococcus aureus* and *Salmonella Typhi* carriage among food handlers. This targeted approach allowed us to gather data from a representative sample of food handling environments, enhancing the reliability and relevance of our findings.

During the the study, we conducted visits to various restaurants to engage with managers and food handlers regarding our research objectives. The aim of the study was explained clearly, emphasizing the importance of assessing the carriage status of *Staphylococcus aureus* among food handlers and *Salmonella* Typhi among individuals at potential risk. Food handlers who were willing to participate voluntarily in the study were informed about the collection processes, the significance of their participation, and the potential impact on public health. Informed consent was obtained from all participating food handlers, ensuring they understood their rights and the study's implications.

Inclusion Criteria

All food handlers who worked in the selected mass-catering restaurants in Hawassa City, who voluntarily participated after being informed of the objectives of the study, were included in the study until the required sample size was obtained.

Exclusion Criteria

Food handlers who had taken antibiotics within three weeks before the study and those who were not willing to participate were excluded from the study.

Study Variables

Dependent variable: The incidence and antibiogram of *S. Typhi* and *S. aureus* carrier state among food handlers

Independent variable: Socio-demographic data (Age, Sex, educational status, and Service year)

Sample Size and Sampling Procedures

We followed a non-probabilistic convenient sampling method to determine the sample size, considering limited resources and time. A total number of 20 restaurants were purposively selected, consisting of 10 large international hotels and 10 medium-sized restaurants. Five volunteer study participants (food handlers) were included based on their willingness from each, resulting in a total sample size of 100 participants.

Samples Collection and Preparation

Nasal swabs and stool samples were collected from all 100 volunteer food handlers to determine the incidence of *S. aureus* and *S.* Typhi, respectively. For all the study participants, nasal swabs were obtained from

both anterior nares (CLSI, 2020). We conducted nasal swab collections from food handlers using a sterile technique to minimize contamination. Each participant was instructed to tilt their head back slightly. The swabs were initially moistened with sterile distilled water, gently inserted into each nostril, rotated for a few seconds, and then aseptically returned to a labeled (with code), screw-cupped test tube. Following collection, all used materials, gloves, and masks were disposed of in biohazard bags, and hand hygiene was maintained throughout the process. Then specimens were immediately transported, using an ice box, to the clinical microbiology laboratory of Hawassa University Comprehensive Specialized Hospital (HU CSH) for bacteriological analysis. When the specimen could not be processed within 4 h, it was placed in a Stuart transport medium and stored in a refrigerator (CLSI, 2020).

Similarly, stool specimens were collected from each food handler with a suitable, labeled plastic container with a leak-proof lid and a clean wooden applicator stick. The participant was instructed to collect the stool specimen on a piece of toilet tissue and to transfer approximately 1 g of it to the container using two sticks. The lid was sealed once the specimen was placed in the specimen container. When quick delivery (within two hours of collection) of the specimen to the laboratory was not possible, a small amount of the stool specimen was collected on two or three swabs and placed in a tube containing Stuart's transport medium (CLSI, 2020). The stool samples were transported in an ice box to the Hawassa University Comprehensive Specialized Hospital (HUCSH) Clinical Microbiology Laboratory, for bacteriological analysis.

Bacteriological Analysis of Samples for Detection Of Target Organisms

The isolation and identification of *S. aureus* from the nasal swab samples was performed based on conventional methods and according to the standard operational procedure of the HUCSH laboratory (Anyanwu and John, 2013). Upon arrival at the microbiology laboratory, all nasal swab samples were directly inoculated onto Mannitol Salt Agar (Oxoid, UK), and the inoculum was streaked with wire loop. Mannitol Salt Agar (MSA) is a selective and differential medium designed to isolate staphylococci and distinguish *Staphylococcus aureus* based on its ability to ferment mannitol, producing yellow colonies with surrounding yellow zones. After incubation of the MSA plates at 37°C for 48 hours, presumptive colonies were examined by Gram staining, revealing Gram-positive cocci arranged in grape-like clusters. These isolates were further screened using the catalase test, in which a drop of 3% hydrogen peroxide was added to a colony; the immediate release of oxygen bubbles confirmed catalase positivity, consistent with staphylococcal species. Definitive identification of *S. aureus* was achieved using the slide coagulase test, wherein bacterial suspensions were mixed with plasma on a glass slide; visible clumping within 30 seconds indicated the presence of bound coagulase, a hallmark of *S. aureus*. All procedures were performed under aseptic conditions and following standard microbiological protocols (CLSI, 2020).

Likewise, conventional phenotypic methods were followed for the isolation and identification of *Salmonella Typhi* from the stool samples (Srijan *et al*., 2015). Accordingly, a portion of each stool sample was first inoculated into Selenite F broth, a selective enrichment medium that suppresses competing intestinal flora while promoting the growth of *Salmonella* spp., and incubated aerobically at 37°C for 24 hours. Following enrichment, aliquots were streaked onto Hektoen Enteric Agar and MacConkey Agar, both of which serve as differential and selective media for enteric pathogens. Hektoen Enteric Agar facilitates the identification of *Salmonella* through its characteristic production of hydrogen sulfide (black-centered colonies) and non-lactose fermentation, while MacConkey Agar aids in differentiating non-lactose fermenters (colorless colonies) from coliforms (pink colonies). After incubation at 37°C for 24 hours, suspected colonies were subjected to further biochemical screening and confirmed using serological agglutination tests with *Salmonella Typhi*-specific O antiserum, factor

9/group D (Andrews, 2021). This classical workflow remains a reliable approach for the detection of S. Typhi in stool specimens, particularly in resource-limited settings.

Antibiotic Sensitivity Testing

Antimicrobial susceptibility tests were performed using the Kirby-Bauer disk diffusion technique, following standard protocol (CLSI, 2020). The inoculum was prepared by selecting well-isolated colonies of the test organisms with a sterile wire loop and suspending them in sterile normal saline. The density of the suspension was adjusted to 0.5 McFarland turbidity standard using a barium sulfate solution. The test organisms were uniformly seeded on the Mueller-Hinton agar (Oxoid UK) surface and exposed to a concentration gradient of antibiotics diffusing from antibiotic-impregnated paper disks into the agar medium, and then incubated at 37°C for 24-48 h. The antimicrobial disks tested included Penicillin-G (10 IU), Oxacillin (1µg) Tetracycline (30µg), Erythromycin (15µg), Clindamycin (2µg), Cotrimoxazole (25µg) and Vancomycin. The diameters of the zone of inhibition around the discs were measured to the nearest millimeter with a ruler and classified as sensitive, intermediate, or resistant based on a standardized table (Callan and Westblade, 2020). A resistant (ATCC 25923), and susceptible (ATCC 29213) *S. aureus* strains were used in a parallel run as quality controls during identification by biochemical tests (Callan and Westblade, 2020).

Socio-demographic Data

A semi-structured questionnaire was used for collecting information on the demographic characteristics of the food handlers (Age, Sex, educational status, and Service year)

Data Quality Assurance and Analysis

Data quality was maintained throughout the study by adhering to the standard operating procedures of the HUCSH Clinical Laboratory. Culture Media were prepared according to the manufacturer's instructions, and sterility was checked by incubating the representative batch at 37°C overnight and observing growth. A uniform code was used for each sample for both the specimens and the questionnaire.

The data from the laboratory results and questionnaire were recorded in Microsoft Excel 2010 and then exported and analyzed using SPSS version 23. Descriptive statistics (percentages or frequency) were calculated to summarize the information collected during this study in frequency tables and percentages. The incidence of *S. aureus* and *S.* Typhi was calculated as the number of positive isolates divided by the total number of samples examined. The chi-square test ($\chi 2$) was used to compare the incidence among each socio-demographic category. Statistical significance (p) of less than 0.05 was considered. Bonferroni's post hoc test for chi-square was used to make multiple comparisons of the proportions (incidence among the various socio-demographic groups).

Ethical Issues

An ethical clearance letter was received from the Institutional Review Board (IRB) of Hawassa University, College of Medicine and Health Sciences. The participants (food handlers) were given complete information about the objectives of the study. Only volunteer participants were requested to sign an informed consent form prepared in English and Amharic. Signed informed consent was obtained from all the participants before sampling. Participants' confidentiality was maintained throughout the study.

Results

The Occurrence of *S. aureus* Nasal Carriage among Food Handlers

Of the 100 participants, 54 belonged to the 29-39 age group, whereas 31 and 15 belonged to the 18-28 and > 40 age groups, respectively (Table 1). Females accounted for 58% and males for 42%. Based on educational level, the study participants were classified into four categories: illiterate (17%), primary education (49%), secondary education (27%), and tertiary

education (7%). Based on service years, 18% had 1-5 service years, 59% had 6-10 years, and 15% had >11 service years (Table 1).

Of the 100 nose swab samples, *S. aureus* was isolated from 10 samples, resulting in an overall occurrence of 10%. Of these 10 carriers, six were females and four were males. The sex-specific incidence of *S. aureus* carrier status was 9.5% (6/58) among female food handlers and 10.3% (4/42) among male (Table 1). Regarding age, among the 10 carriers of *S. aureus,* six were found in the 29-40 age group, while 3 and 1 were in the 18-28 and >40 age groups, respectively. Therefore, the age-specific incidence of the *S. aureus* carrier state was 11.1% (6/54) among the 29-39 age group, 9.7% (3/31) among the 18-28 age group, and 6.7% (1/15) among those aged >40 years (Table 1). The observed differences in the incidence rate with sex and age of the food handlers were not statistically significant (p.>0.05).

Regarding the educational status of the carriers, five were illiterate, three were at the primary level, one was secondary and one was at the tertiary educational level. Therefore, the educational level-specific incidence rate of *S. aureus* among food handlers was 5/16 among illiterates, 3/49 among those at the primary level, and 1/28 and 1/7 among those with secondary and tertiary educational levels, respectively (Table 1). The observed difference in the incidence of *S. aureus* nasal carrier state among food handlers with different educational statuses was statistically significant ($p< 0.05$). However, the observed differences in the nasal carriage rate of *S. aureus* among the literates with different educational levels were not statistically ($p>0.05$) significant (Table 2).

Based on experience, five of the 10 *S. aureus* nasal carriers had 6-10 years of service, three had 1-5 years and two of them had >11 years of service. The work experience-specific incidence of *S. aureus* was 8.5% (5/59) among food handlers who had 1-5 service years, 3/26 among those with 6-10 service years, and 2/15 among those with >11 service years (Table 1). However, the observed differences in the incidence of *S. aureus* nasal carrier state among food handlers with different service years were not statistically ($p>0.05$) significant (Table 1).

Antimicrobial Sensitivity Pattern of *S. aureus*

The antibiotic susceptibility profiles of the *S. aureus* isolates from the nasal swabs of the food handlers are shown in Table 3. Five of the ten isolates were resistant to one or more of the seven antibiotics tested. Of the isolates that showed resistance, one showed single resistance to penicillin, while four showed resistance to two or more drugs. Of the multiple antibiotic-resistant isolates isolate, HUB2 was found to be MRSA and showed resistance to penicillin, tetracycline, erythromycin, and oxacillin. Two isolates (isolates HUB6 and HUB8) showed double resistance, and one isolate (isolate HUB4) showed triple resistance (Table 3). Resistance to penicillin was the most frequent drug resistance exhibited by five of the ten (50%) *S. aureus* isolates, while all the isolates were sensitive to vancomycin. Resistance to clindamycin, erythromycin, and oxacillin was exhibited by single isolates (1 in 10) whereas resistance to tetracycline and cotrimoxazole was exhibited by two isolates in each case (Table 3).

Table 1. Incidence of *S. aureus* nasal carriage among food handlers of Hawassa City, Ethiopia, from August to November 2020, n=100

Characteristic		Frequency n (%)	Incidence of *S. aureus* (%)	Model test x^2 and p –value
Gender	Male	42 (42)	4 (9.5)	x^2= 0.018
	Female	58 (58)	6 (10.3)	p = 0.893
Total		100 (100)	10 (10)	
Age (years)	18-28	31 (31)	3 (9.7)	x^2= 0.693
	29-40	54 (54)	6 (11.1)	p = 0.707
	>40	15 (15)	1 (6.7)	
Total		100 (100)	10 (10)	
Education level	Illiterate	16 (16)	5 (31.3)	x^2= 10.275
	Primary education	49 (49)	3 (6.1)	p = 0.016
	Secondary education	28 (28)	1 (3.6)	
	Tertiary education	7 (7)	1 (14.3)	
Total		100 (100)	10 (10)	
Service year	5-Jan	26 (26)	3 (11.5)	x^2= 0.567
	10-Jun	59 (59)	5 (8.5)	p= 0.753
	> 11	15 (15)	2 (13.3)	
Total		100 (100)	10 (10)	

Table 1. Post hoc test for multiple comparisons of incidence of *S. aureus* among food handlers of different educational level (Bonferroni's method)

Socio-demographic group		*S. aureus* incidence				
(Educational level)	n	Negative	%	Positive	%	P value
Illiterate	16	11	68.80%	5	31.30%	0.002
Primary	49	46	93.90%	3	6.10%	0.204
Secondary	28	27	96.40%	1	3.60%	0.181
Tertiary	7	6	85.70%	1	14.30%	0.697
Total	100	90	90	10	10	

COR = crude odd ratio; CI = Confidence interval, n = number of study subjects

Table 3. Antimicrobial sensitivity pattern of *S. aureus* isolates from nasal swab samples of food handlers working in some restaurants in Hawassa city, southern Ethiopia

Isolate	Pen	Clind	Tet	Cotr	Ery	Oxa	Vanco	Number of R
HUB1	S	S	S	S	S	S	S	0
HUB2	R	S	R	S	R	R	S	4
HUB3	S	S	S	S	S	S	S	0
HUB4	R	S	R	R	S	S	S	3
HUB5	S	S	S	S	S	S	S	0
HUB6	R	R	S	S	S	S	S	2
HUB7	S	S	S	S	S	S	S	0
HUB8	R	S	S	R	S	S	S	2
HUB9	S	S	S	S	S	S	S	0
HUB10	R	S	S	S	S	S	S	1
Number of R	5	1	2	2	1	1	0	5

R: resistant; S: Sensitive; Pen: penicillin; Clind: Clindamycine; Cotr: Cotrimoxazole; Ery: Erythromycine; Oxa:Oxacilline;Vanco:Vancomycine

Discussion

The Occurrence of *Staphylococcus Aureus* and *Salmonella* Typhi Carrier State

The occurrence rate of the *S. aureus* nasal carrier state in this study (10%) was lower than the average nasal colonization of healthy adults reported from other countries previously (Mehraj et al., 2016; Hu *et al*., 2024). The nasal carriage rate of *S. aureus* among food handlers in the present study was also lower than the 20.5% rate reported for food handlers working in the Gondor University cafeteria, Gondor, northern Ethiopia (Dagnew *et al*., 2012). Other studies also reported higher rates than the present study, including 53% in Kuwait City (Udo *et al*., 2009) and 38.8% in Ekpoma Edo, Nigeria (Eke *et al*., 2015). On the other hand, a slightly lower carriage rate than the present study was reported in a study conducted in Jimma Town, southwest Ethiopia, where the rate of *S. aureus* nasal carriage was 9% (Beyene *et al*., 2019). Another similar study among food handlers in Canton City, Bosnia, and Herzegovina reported a slightly lower rate (7.1%) than the present results (Segalo *et al*., 2020). In contrast, the nasal carriage rate of *S. aureus* among food handlers in this study was significantly higher than the 0.77% reported in a similar study conducted in Turkey (Gunduz *et al*., 2008).

Several factors may explain the differences in the reported incidence rates of nasal carriage among food handlers reported in different studies. These differences might be due to variations in the study design such as sample size, study period, season, and methods of study (Mehraj *et al*., 2016). Furthermore, the results may show variation in different populations living in different geographical areas and their demographics (Sivaraman *et al*., 2009). Likewise,, occupational exposure to raw meat can make food handlers more susceptible to contamination and raise their risk of colonization (Ho et al., 2014). Certain host factors, which can be broadly divided into host genetic and immune factors, are more likely to be associated with nasal carriage; however, robust data on this association are scarce (Mehraj *et al*., 2016; Sivaraman *et al*., 2009).

A statistically significant difference in the incidence of *S. aureus* nasal carriage was observed between illiterate and literate food handlers. However, no significant differences were found in the incidence of nasal carriage among food handlers based on sex, age, or service year. This is contradictory to the study reported in Jimma Town by Beyne *et al.*

(2019), in the Gondar University by Dagnew *et al.* (2012), and in Amassoma City, Nigeria, by Onanuga and Temedie, (2011), who reported no statistically significant difference in the incidence of *S. aureus* nasal carriage among literate and illiterate food handlers.

On the other hand, the findings of this study were concordant with a study conducted among food handlers in the Wollo University student cafeteria by Gashaw (2019), where the observed differences in *S. aureus* incidence rates among educated and uneducated individuals were statistically significant ($P < 0.05$). Likewise, it was also supported by Adugna *et al.* (2018)], who suggested that the lower educational level of food handlers could contribute to higher *S. aureus* contamination. This could be explained by the fact that literate food handlers have better adherence to personal hygiene practices than do illiterate food handlers. The education of food handlers may be crucial in preventing bacterial carriage (Segalo *et al*., 2020). The acquisition of nasal colonization through contaminated hands may have a more significant effect on transient nasal carriers (Saadatian-Elahi *et al*., 2018). The observed discrepancy in these results could be due to differences in study design, population, and demographics.

Regarding *Salmonella* Typhi, none of the food handlers were found to be carriers of the pathogen based on stool culture. This finding was in line with several institutional studies conducted in different parts of Ethiopia. The reported incidence of *S*. Typhi was zero in a study conducted among food handlers at the University of Gondar (Andargie *et al*., 2008) and Hawassa University students' cafeterias by Desta *et al*. (2014). In contrast, the reported incidence of *S*. Typhi is 0.9% among food handlers in Dilla, southern Ethiopia (Misganaw and Williams, 2013), 1.3% among those working in Bahar Dar, northern Ethiopia (Bayeh *et al*., 2010), and 2.7% among food handlers in Ghana (Feglo and Sakyi, 2012). Variations in the incidence of *S*. Typhi among food handlers across different studies may be attributed to differences in personal hygiene, sociodemographic determinants, geographical regions (WHO, 2015), microbiological methods used to detect Salmonella, and study designs (Tadesse *et al*., 2019). While epidemiological risk factors for becoming a persistent carrier have not been throroughly studied, potential risk factors may be influenced by the proportion of the population with gallbladder abnormalities (Gal-Mor, 2019).

Antimicrobial Sensitivity Pattern of *S. aureus*

Considering the drug sensitivity patterns of *S. aureus* isolates, 5 of the 10 (50%) isolates were resistant to penicillin. This was concordant with a study conducted in Gondar, Northwestern Ethiopia, where 51.2% of nasal swab isolates were reported to be resistant to penicillin (Dagnew *et al*., 2012). Similarly, another study in Portugal revealed that 48% of nasal isolates of *S. aureus* were resistant to penicillin (Castro *et al*., 2016). However, the penicillin resistance rate among the *S. aureus* nasal isolates in the this study was significantly lower than the reported penicillin G resistance rate of 97.2 % from Jigjiga University (Wolde *et al*., 2015) and the 90.7% from Jimma town (Beyene *et al*., 2019).

In this study, one in 10 (10%) of the *S. aureus* isolates was resistant to oxacillin (Methicillin-resistant – MRSA) which is in line with studies from other parts of Ethiopia, including the reported oxacillin resistance rate of 9.8 % from Gondar University (Dagnew et al., 2012), the 7% from Jimma town (Beyene *et al*., 2019) and the 13.8% from Debre Markos (Reta *et al*., 2015). However, the incidence of MRSA isolates in this study was higher than that in a study from Turkey, where none of the isolates were found to be MRSA (Vatansever *et al*., 2016). These contradictory results could be due to differences in the methods, sample sizes, populations, and geographical locations in which the study was conducted.

The frequency of *S. aureus* isolates resistant to erythromycin and clindamycin was one in 10 (10%) cases and two in 10 (20%) cases for tetracycline and cotrimoxazole. This resistance frequency was lower than that reported by Dagnew *et al*. (2012) at Gondar University,

where the reported frequencies of isolates resistant to tetracycline, cotrimoxazole, and erythromycin were 31.7%, 26.8%, and 14.6% respectively. Likewise, another study conducted in Jimma Town, southwestern Ethiopia, found that 14.6% of *S. aureus* isolates exhibited resistance to erythromycin (Beyene *et al*., 2019). A similar study conducted in Turkey reported that 9% of *S. aureus* isolates were resistant to tetracycline, 8% to erythromycin, and 0% to clindamycin (Vatansever et al., 2016). A much higher frequency of *S. aureus* isolates was reported from food handlers in Portugal with a resistance rate of 96% to tetracycline and 68% to erythromycin (Castro *et al*., 2016). The variation in the results could be mainly due to sample size and geographical area.

In contrast, all isolates (100%) were sensitive to vancomycin. This was in line with a study, in Gondar, where all isolates of *S. aureus* (100%) were reported to be sensitive to vancomycin (Dagnew *et al*., 2012). A similar finding has been reported in Turkey (Vatansever *et al*., 2016). In contrast, a study conducted in Jimma reported that 93% of *S. aureus* nasal swab isolates from food handlers were sensitive to vancomycin (Beyene *et al*., 2019). These variations could be due to differences in study populations and methods.

A multi-drug resistance (MDR) pattern, (resistance to at least one antimicrobial drug in three or more different categories of antimicrobial drugs) was observed in two of the 10 (20%) *S. aureus* isolates, a frequency that is slightly higher than that reported in a study from Jimma town (Beyene *et al*., 2019) where 14.3% MDR was reported, but lower than the 86.4% reported in Bosnia and Herzegovina (Segalo *et al*., 2020). The emergence of MDR *S. aureus* is attributed to the inappropriate use of broad-spectrum antibacterial drugs over-the-counter sell without the prescription of qualified health workers. This is common in most developing countries where antibiotic use is generally unregulated. Therefore, drug administration authorities and other public health officials should be vigilant to enforce existing regulations and control the prudent use of antibiotics by the public.

Conclusion

The study revealed that 10% of the food handlers were nasal carriers of *S. aureus*, while no *Salmonella Typhi* was detected in any stool samples. Notably, illiterate food handlers were significantly more likely to be nasal carriers of *S. aureus* compared to their literate counterparts. However, no statistically significant associations were found between nasal carriage and factors such as sex, age, or years of service. Among the *S. aureus* isolates, five of 10 exhibited resistance to one or more of the seven antibiotics tested, with one isolate showing single resistance to penicillin and four others demonstrating resistance to multiple drugs. Specifically, two isolates displayed double resistance, and one isolate exhibited triple resistance, including identification as MRSA, which was resistant to penicillin, tetracycline, erythromycin, and oxacillin. Importantly, all *S. aureus* isolates were found to be sensitive to vancomycin. The finding of multiple antibiotic-resistant *S. aureus* isolates from the nasal swabs of food handlers implies the possibility of antibiotic misuse or overuse and the potential risks of foodborne disease outbreaks. This calls for raising the awareness of food handlers about the need for hygienic food handling with an emphasis on illiterate ones, judicious use of antimicrobials, and curbing over-the-counter sell and abuse of drugs without the prescription of qualified physicians.

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Ethics Approval and Consent to Participate

Ethical approval with regards to all experimental protocols for the work was granted by Institutional Review Board (IRB) of Hawassa University, College of Medicine and Health Sciences. All the study participants were informed about the objectives of the study and were included in the study only after they gave their verbal consent to participate.

Competing Interests

The authors have none to declare

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RESEARCH PAPER

Effects of Mediated Learning Experiences for Hard of Hearing Children on Language Development

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Abstract

The present study aimed at determining the effect of an educational intervention in enhancing the Amharic language level of grade one students, particularly focusing on Mediated Learning Experiences (MLE) and instruction strategies from teachers. The intervention was applied in two comparatively equal sized government primary schools with 200 students divided equally between experimental and control groups. All of the students who took part were of low socioeconomic status. The key objective was to determine whether MLE would be able to bring about language development, in hearing impaired and hearing students. To collect data, the research performed audiometric tests for the diagnosis of hearing impairment, the application of sound level meters to ascertain ambient noise in classrooms, and standardized testing for ascertaining language capacity. Results showed that 13.5% of the test participants experienced some form of hearing impairment. Ambient noise in classrooms was found to be a significant auditory impediment to learning. The outcome was that the intervention based on MLE had a very positive impact on the language acquisition of the total group, as well as on both hearing and hard-of-hearing students. The intervention recipients also showed notable improvement in their Amharic language when compared to the control group. Ultimately, the innovative research highlights the accessibility and possibility of the MLE approach. In promoting active participation and cognitive interaction, MLE was a valuable practice to enhance disparate learners. The effective implementation of this approach in this setting reveals that flexibility and accommodativeness could be made. teaching methodologies an intrinsic part of the primary school syllabus to ensure equal and effective learning for all students regardless of their hearing or socio-economic requirements.

Keywords: Language skills, hard of hearing, mediated learning experiences, intervention, dynamic assessment

Introduction

The hard of hearing child typically faces extreme challenges in learning language due to lesser auditory input during critical development stages, which gets in the way of learning vocabulary and grammar. Their ability to participate in meaningful communication as well as academic attainment is also compromised. Fulfilling these developmental requirements requires instructional strategies beyond the traditional method and actively promote cognitive and linguistic growth through specially modified interaction. One such approach is Mediated Learning Experience (MLE), a model of intervention that emphasizes the presence of a human mediator, most frequently a parent, teacher, or caregiver, on a child's learning process through intentional, interactive communication. MLE has been promising in a variety of learning deficit populations, but its influence on language acquisition in hard of hearing children is poorly studied. This research aims to examine the manner in which MLE's intentionality and reciprocity, meaning, and transcendence principles can be most effectively applied to the advancement of

language acquisition in children with auditory impairments. By way of review of theoretical foundations as well as practical applications of MLE to this end, this research aims to contribute evidence toward an emerging body of research focused on inclusive and adaptive pedagogies for children with auditory impairments.

MLE has been used in intervention programs for hard of hearing children to address language delay, behavioral disorders, and psychosocial disabilities by providing enriched and responsive learning environments tailored to the individual child's development level and hearing loss. Because hearing loss can restrict access to spoken language and intellectual stimulation. MLE focus on intentional, mediated interaction serves as a compensatory strategy. The mediator's role is to adjust teaching strategies based on the child's needs, promoting not only scholastic growth but also social-emotional and critical thinking (Teklemariam, 2022). Empirical evidence supports the effectiveness of MLE in these settings. As an example, Teklemariam's (2022) Experimental study of 200 first-grade children from low socio-economic status revealed that teacher-led, MLE-facilitated interventions led to significant behavioral improvements in hearing-impaired and typically hearing children alike, suggesting that formal mediation can overcome most of the developmental deficits associated with hearing impairment.

Language development outcome is also influenced to a large degree by the quality and timing of early intervention. Studies by Yoshinaga-Itano *et al*. (2000) and Tomblin *et al.* (2016) bring to light that hearing loss detection and intervention by the age of 11 months is strongly associated with enhanced vocabulary and verbal reasoning capacity at the age of five. Such outcomes are optimally reinforced through conjunction with the frequent use of hearing aids, active parental involvement, and linguistic environments. Even with the early intervention, however, inequalities in the development of language are not entirely averted. Differences in individual characteristics in the degree and type of hearing loss still impact results, affirming the need for individually adapted intervention strategies that take account both of auditory and contextual factors.

While promising, several outstanding problems exist. Socioeconomic and environmental conditions, for instance, poor acoustic environments in classrooms, continue to impede language learning and academic success among hard of hearing children, especially in poor settings (Teklemariam, 2022). These conditions not only limit access to hearing but also continue to widen educational inequalities, particularly where support services and infrastructure are poor. The success of MLE intervention also depends partly on the teaching skills, indicating the need for expert teacher training and professional development. Teachers in general, particularly in less affluent regions, have no expertise to use MLE methods productively. Family involvement is also an important but often overlooked variable. Increased parental participation leads to increased academic success and generalization of skills beyond the classroom, suggesting that interventions in school need to be followed up with robust family-based components (Yoshinaga-Itano *et al*., 2000).

Aside from language and schoolwork, children who have hearing loss also have difficulties interacting socially and with their self-concept due to communication. MLE approaches try to close these psychosocial dimensions by establishing motivation, affective strength, and peer attachment (Teklemariam, 2022) so vital in language development. But to have lasting impact, interventions need to affect more pervasive system deficits, including socioeconomic disparities, teacher education, and environmental challenges. Challenges are most severe in low-resource settings like Ethiopia, where early hearing detection and intervention services are limited, and schools lack the capacity to handle children with hearing impairments.

Hearing impairment in children has been recognized internationally as a major communication, learning, and social interaction barrier. Early hearing screening and

intervention have been promoted on a widespread scale as best practice to minimize these effects (Yoshinaga-Itano *et al*., 2000). But in the majority of poor countries such as Ethiopia, these services are not yet provided everywhere. The prevalence of restricted newborn screening programs, noisy and overpopulated classrooms, poor socioeconomic status, and an untrained teaching staff significantly contribute to the progress of hard of hearing children. However, evidence from Ethiopian schools also indicates that interventions based on MLE can be successful even in these constrained environments (Teklemariam, 2022).

Despite global recognition of early intervention, hard of hearing children in Ethiopia remain under-served. Institutional barriers in the shape of resource limitation, outdated education data, and inadequate modified pedagogic approaches are some of the contributing factors perpetuating inequalities in development. While several studies have documented the overall benefits of MLE among children with hearing impairments (Teklemariam, 2022; Elemukan *et al*., 2024), the existing body of research lacks substantial evidence on the specific impact of MLE on language acquisition in normal, multilingual Ethiopian elementary schools. Most of the recent research either is on behavioral outcomes or in high-income settings, leaving plenty of contextual and methodological room to investigate language-specific effects in low-resource settings.

Apart from the time delay caused by the application of older data, most research fails to control the unique contribution of MLE for other factors such as hearing aid use or intervention type, leading to their limited application in evidence-based educational planning. Recent studies (Bekele and Tadesse, 2022; Asefa and Haji, 2023) reiterate the ongoing lack of support for hearing loss children, yet again accentuating the urgent need for context-specific research.

This study therefore aims to address these gaps by examining the effect of MLE on first-grade hard of hearing students' language development in Ethiopian primary schools. With focus on an under-represented group in a low-resource learning context, the study aims to provide up-to-date, targeted evidence for the design of inclusive education policy and practice that is locally responsive and globally contextualized.

Theoretical Framework

The Mediated Learning Experiences (MLE) theoretical model is grounded in the original research by Feuerstein (Teklemariam, 2022) and has been developed further by scholars such as Lidz and Jepsen (2021). Cognitive development, and language development as a process heavily enhanced through the active mediation of a caregiver or teacher, are emphasized in MLE. In this model, the mediator is an important bridge between learner and environment through consciously selecting stimuli, organizing learning activities, and managing the learning process to facilitate efficacious cognitive growth. This approach is especially vital for language-delayed at-risk children, since the mediator steps in to provide one-on-one assistance and tools of cognition instead of relying on the learner's receptive passivity to information (Feuerstein Institute, 2024).

Three fundamental principles form the core of MLE: intentionality and reciprocity, mediation of meaning, and transcendence. Intentionality refers to the systematic and goal directed regulation of the learning interaction by the mediator in a way that is intentional and directed to guiding the learner's attention to specific cognitive objectives (Vygotsky, 1978; Van der Veer and Valsiner, 2020). Reciprocity underpins intentionality through the active, open, and cooperative learner's response to the mediator's initiative, with a focus on meaningful learning being an ongoing two-way process (Pino-Pasternak and Sesen, 2021).

Mediation of meaning enhances the learning process by inviting learners to understand sense

of purpose and value of activities, encouraging emotional involvement and facilitating the transfer of knowledge, values, and cultural beliefs via joint discussion (Mercer & Littleton, 2021). Transcendence extends mediation past the here-and-now task by challenging students to transfer principles and strategies to new and dissimilar circumstances, thereby creating intellectual versatility, curiosity, and a desire for continuous learning (Vygotsky, 1978).

While these three principles form the backbone of the MLE framework, other aspects such as self-regulation, goal-setting, and competence support its flexible application according to learner needs (Lutz and Lutsy, 2021). MLE aligns closely with sociocultural theories of learning, highlighting cognition as a socially mediated process. It conceptualizes the teacher's role as an active facilitator who not only transmits knowledge but also scaffolds learners' cognitive and emotional development, enabling autonomy and self-regulation (Mentis and Mentis, 2008). In the context of language learning, especially for Amharic learners at risk of developmental delays, MLE provides a theoretically and practically sound framework for designing interventions that enhance learner engagement and cognitive modifiability through purposeful, meaningful, and reciprocal interactions (Feuerstein Institute, 2024). Thus, applying MLE principles as independent variables in language skill development underscores their practical significance, with effectiveness assessed through curriculum-based language tests that reflect learners' internalization and application of mediated learning. Based on this theoretical framework the present experimental research is to test two hypothesis.

Hypothesis

To guide the study, two quasi-experimental hypotheses were formulated. The first hypothesis speculated that the intervention of Mediated Learning Experience (MLE) through teacher competency would significantly impact the improvement of children's language ability. The second hypothesis was that such an effect of intervention would equally be effective in hearing and hard-of-hearing children, emphasizing its potential in promoting inclusive language development in heterogeneous learners.

Methodology

Study Design

Quasi-experimental design was employed in the present study. Quasi-experimental designs are especially useful in the arena of language development in children who are hard of hearing because they enable researchers to experiment with Mediated Learning Experiences without random assignment, which may be ethically or pragmatically challenging in this population. Quasi-experimental designs are matched on hearing loss severity, communication modality, and intervention timing, and allow for long-term evaluation of language development in natural instructional conditions. The design provides strong evidence of early and extended intervention impact on language development, vocabulary, and phonological knowledge (Tomblin et al., 2015). With the application of quasi-experimental methods, research can ensure ecological validity and yet continue to measure language development in hard-of-hearing children in a manner that is suitable.

Setting and Participants

The study was conducted in two government elementary schools in Addis Ababa's Gulele sub-city, consisting predominantly of low socio-economic, culturally homogeneous communities.

The experimental sample was one school with six first-grade classes and the control sample was another school with four first-grade classes.

480 first-grade children were screened for hearing status by qualified audiologists using calibrated pure tone audiometry. 100 children

from each school were selected from this population and matched between the groups by age, sex, language, parental socio-economic level, and hearing level, using typical matching procedures to minimize confounding variables. The hard of hearing, as well as hearing children, were selected to be able to explore differential intervention effects and adapt inclusive education practices (Alemayehu, 2018; Mojica and McIntyre, 2022).

All grade one teachers of the ten sections were trained in intervention, and home visits were conducted for a randomly selected subset of ten families to ground socio-economic and environmental factors affecting language development.

Intervention Procedures

The study used the pretest-posttest design over an eight-month school term. Both groups were administered baseline measurement (pretest) before the intervention was initiated. The experimental group received 84 hours of structured MLE-focused teacher training and in-class support, while the control group was given regular teaching without additional intervention.

A posttest was administered to both groups at the end of the intervention time to measure changes in language proficiency. This design enables within-group changes across time and between-group differences resulting from the intervention to be quantified (Creswell, 2014).

Equipment and Instruments

Hearing Assessment

Hearing screening was performed by two qualified audiologists utilizing calibrated Pure Tone Audiometers (PTA), frequencies ranging from 250 Hz to 8000 Hz, and sound intensities ranging from -10 to 120 dB, within controlled acoustic environments (Smith *et al*., 2020). Testing took place in teachers' rooms, which had lower ambient background noise levels (around 54.5 dB) than classrooms. Background noise levels in test rooms, classrooms, and school environments were measured by a 93411 Digital Sound Level Meter (SLM), calibrated and certified by Ch. Beha GMbH, Germany to create standard testing environments that minimize auditory distractions and increase hearing assessment reliability.

Language Skills Assessment

The language skill of children was assessed using teacher-administered tests that aligned with Grade One Amharic language classes according to the Addis Ababa City Administration Bureau of Education (2020). Tests covered major aspects of language, vocabulary, syntax, pragmatics, and speech, and were administered privately to give an accurate measurement (Smith and Johnson, 2019; Brown, 2018).

Data Collection Procedures

Prior to data collection, ethical clearance was received from the sub-city education bureau and school principals. There was substantial training of teachers and research assistants in data collection procedures to achieve consistency and accuracy

The Sequence of Data Collection

The participants were first put through a hearing screening to ascertain auditory readiness for study. Both the experimental and control groups were subsequently administered a pretest to establish baseline measurements. The experimental group was then put through the Mediated Learning Experience (MLE) intervention, while the control group was not. Both groups were subsequently tested using a posttest eight months later to ascertain change or improvement. In aside from quantitative information, qualitative information was collected to add richness in the context. These included socioeconomic status information,, teacher ability, and school environment, collected using observation and informal

interviews. Such encounters were documented through video recording, audio recording, and field notes, in adherence to conventional qualitative research protocols (Creswell, 2014)

Data Analysis

Quantitative Analysis

Data were coded and processed using SPSS software (IBM Corp., 2021). Descriptive statistics (means, standard deviations) were employed to summarize language test scores.

Inferential statistics included: A two-way ANOVA was employed to establish the effect of hearing status and group status on language development. A repeated measures ANOVA was also employed to assess within-subject differences over time, as well as the interaction effects of intervention and hearing level (Tabachnick and Fidell, 2013). Alpha was set at 0.05, with results reported using 95% confidence intervals.

Qualitative Analysis

Qualitative data transcribed were thematically analyzed to identify socioeconomic factors, teachers' practice, and influences of acoustic environments on patterns of language development. Observations and interviews were coded, categorized, and triangulated with quantitative data for interpretive completeness (Patton, 2015; Creswell, 2014).

Ethical Considerations

The study adhered to ethical research practices and comprised: The research ensured ethics through several significant measures. Parents' and children's informed consent was taken prior to participation, so everyone understood the purpose and nature of the research. Participants were debriefed prior to data collection in order to provide transparency and manage expectations on procedures of the study. Data collection was securely and confidentially kept in order to protect participants' privacy. Further, to promote equitable access to the potential benefits of the intervention, the control group was offered a deferred Mediated Learning Experience (MLE) intervention following study termination.

Results

Teachers' Competence in the Profession

The teacher competence in inclusive education and MLE was quantified qualitatively pre- and post-intervention using the same MLE checklist. The teachers initially demonstrated several weaknesses: they failed to motivate learners to set learning goals, lacked intentional teaching actions, and did not demonstrate adequate care or engagement. They seldom involved students in activities, were generally unresponsive to student feedback, both written and verbal, and came to class unprepared. Furthermore, they gave little clarification when students were lost and made few efforts to foster motivation or enthusiasm. This resulted in passive learning environments, which were dominated by teacher talk. Overall, their conventional approach to teaching wasn't deliberately designed, interactive, and student-centered in nature, addressing learners' interests, needs, and potential. Student engagement was hardly supported. However, post-intervention observation showed a radical shift. Teachers moved away from the conventional approach and began adopting MLE principles of care, engagement, and inclusivity. Post-intervention developments are clarified further under the results.

This presentation of the result begins by addressing the two central hypotheses guiding our study. First, it was examined whether the Mediated Learning Experience (MLE) intervention, delivered through enhanced teacher competency, would significantly improve children's language abilities. Second, we explored whether this effect would be consistent across both hearing and hard-of-hearing children, highlighting the potential of MLE as an inclusive approach to support language development in diverse learning populations.

Nature of the Sampled Children

The study involved 200 grade one children, 100 in each experimental and control group. These were students from various sections within their respective schools. By the time of post-test eight months later, 10% of the experimental and 13% of the control group had dropped out, mainly due to migration from the sub-city for reasons not specified. This drop-out is a limitation of the study. Among the students who withdrew, 3% of the experimental group and 1% of the control group had been identified as hard of hearing.

Demographically, the two groups were identical in gender distribution (50% male, 50% female) and age distribution. The majority (92%) in the two groups also indicated Amharic as their mother tongue, with the remaining 8% indicating other mother tongues but being proficient in Amharic as a second language. In terms of hearing status, 54% of the children in the two groups were borderline hearing, 13.5% were hard of hearing, and 32.5% had normal hearing.

Parental Socioeconomic Status

A great majority of the 200 interviewed parents were educationally disadvantaged: 44.5% were illiterate, and 16% had not progressed beyond early primary school (grades 1–4). Another 25% had graduated from middle school (grades 5–8), and 17% had graduated from secondary school (grades 9–12). Only 5% of the fathers were college graduates, and none of the mothers had any college education. These findings show that parents' low educational levels are not sufficient to secure stable employment or to provide a home environment that is conducive to children's language growth. Mothers, in particular, suffer from educational and economic disadvantage, limiting their capacity to support their children's learning and overall development.

Employment data also brings to light the low socioeconomic status of the participating families. Nearly 69.5% of the parents were unemployed, and only 13% of them were working in government or NGO sectors. Those who were working were doing small-scale, short-duration work with little job security or income stability. As a result, a majority of the families were living a subsistence life. Teachers also confirmed that a majority of the students belonged to families below the poverty line.

The Acoustic Environment

The experimental school was situated in a highly noisy environment, with main roads and an active traditional clothes market in the vicinity. This created perpetual auditory distractions, which interfered with classroom communication between the teachers and students. The background noise level during the instructional period averaged 79.8 dB, while the noise level dropped to 67.5 dB in empty classrooms. In comparison, the control school had quieter background levels, 74.3 dB when in class and 63.1 dB when empty.

Ten teachers were interviewed and shared a similar concern about these conditions. All of those surveyed reported that poor acoustics significantly affected teaching and learning for students. Environmental noise was consistently described as a barrier to communication and instruction.

Effects of hearing on language skills

Table 1. Mean and SD on hearing language skills

Hearing status	Measurement	Experimental	Control	Total
Normal Hearing	N	28	37	65
	Mean (SD)	54.50 (16.94)	60.41 (18.51)	57.86 (17.95)
Borderline Hearing	N	57	51	108
	Mean (SD)	58.95 (14.05)	57.75 (19.29)	58.37 (16.66)
Hard of Hearing	N	15	12	27
	Mean (SD)	54.93 (12.41)	49.03 (19.34)	52.33 (15.81)
Total	N	100	100	200
	Mean (SD)	57.10 (14.79)	57.69 (19.12)	59.39 (17.02)

Two-way ANOVA test showed that hearing ability was not statistically significant in impacting performance on the Amharic language tests, $F(1, 194) = 0.018$, $p > .05$. This shows that participants' performance on the tests was the same irrespective of their varying levels of hearing. Lastly, the effect of group membership (control vs. experimental) was also not significant, $F(2, 194) = 1.497$, $p > .05$, indicating no differences in performance between groups overall. There was also no significant interaction between hearing level and group, $F(2, 194) = 1.407$, $p > .05$, indicating the effect of hearing didn't vary by group.

These findings mean that neither hearing status nor group membership had any meaningful impact on Amharic test performance. Also, the lack of an interaction effect implies that the relationship between hearing status and test performance was consistent across all groups. This has practical implications: both hearing-impaired and non-hearing-impaired participants performed equally regardless of whether or not they belonged to the experimental or control group.

Effects of the Intervention

This section compares the effects of the intervention on the language development of 177 children in the experimental and control groups. A repeated-measures ANOVA was used to evaluate the impact of MLE on language development. Pretest and posttest mean scores and standard deviations for both groups were analyzed (see the tables following each analysis).

Effects of Intervention on Language Skills

Table 2. Mean and SD on effects of intervention on language skills

Time	Measurement	Experimental group (n = 90)	Control group (n = 87)	Total n = 177
Pretest	Mean	57.23	56.94	57.09
Assessment	SD	14.58	18.45	16.55
Posttest	Mean	62.83	58.01	60.46
Assessment	SD	15.47	16.52	16.13

The within-subject main effect of time on language ability acquisition was statistically

Significant for the repeated-measures ANOVA, $F(1, 175) = 50.774$, $p < .05$, $\eta^2 = .225$, indicating that the effect size was medium. This suggests that overall, children's language abilities improved significantly from pretest to posttest. Also, there was significant time of measurement by group interaction, $F(1, 175) = 23.438$, $p < .05$, $\eta^2 = .118$, which indicates a small effect. This interaction indicates that the experimental group children had greater increases in language development compared to the control group. Nevertheless, the between-subjects effect was insignificant, $F(1, 175) = 1.129$, $p > .05$, $\eta^2 = .006$, suggesting that global group differences, over time, were minimal and of small magnitude.

Table 3. Mean and SD on the Effects of intervention and hearing level on language skills

Time	Hearing status	Experimental Group		Control Group		Total	
		N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
Pre Intervention Assessment	Normal Hearing	25	54.24 (17.68)	34	60.71 (17.88)	59	57.97 (17.930)
	Borderline Hearing	53	59.26 (13.27)	42	55.26 (18.90)	95	57.49 (16.04)
	Hard of hearing	12	54.50 (12.57)	11	51.73 (17.860	23	53.17 (15.03)
	Total	90	57.23 (14.58)	87	56.94 (18.45)	177	57.09 (16.55)
Post Intervention Assessment	Normal Hearing	25	60.08 (16.93)	34	61.88 (15.15)	59	61.12 (15.81)
	Borderline Hearing	53	65.21 (15.08)	42	56.76 (17.30)	95	61.47 (16.56)
	Hard of hearing	12	58.08 (12.90)	11	50.82 (15.74)	23	54.61 (14.48)
	Total	90	62.83 (15.47)	87	58.01 (16.52)	177	60.46 (16.13)

The repeated-measures ANOVA revealed a statistically significant main effect of time on children's language development, $F(1, 171) = 26.27$, $p < .05$, $\eta^2 = .133$. This indicates that, overall, language skills improved across the study period for all participants, regardless of group or hearing level. However, the effect size was relatively small, suggesting that although the improvement was consistent and statistically meaningful, the magnitude of change was modest.

A significant interaction was found between time and group, $F(2, 171) = 16.55$, $p < .05$, $\eta^2 = .016$. This result suggests that the pattern of language improvement over time varied by group, with children in the experimental group showing greater gains than those in the control conditions. This interaction highlights the positive impact of the intervention, indicating that it effectively enhanced language development among the children who received it. On the other hand, there was no significant interaction between time and hearing level. $F(2, 171) = 1.38$, $p > .05$, $\eta^2 = .016$. This shows that hearing level was not an influencer on the rate or level of language learning over time.

Additionally, the three-way interaction between time, group, and hearing level was also non-significant, $F(2, 171) = 0.99$, $p > .05$, $\eta^2 = .000$. This indicates that the combined effect of group and hearing level failed to differentially influence on the children's language development during the study duration.

Finally, the between-subjects effects for group ($F(2, 171) = 0.70$, $p > .05$, $\eta^2 = .004$), hearing level ($F(2, 171) = 1.14$, $p > .05$, $\eta^2 = .013$), and their interaction ($F(2, 171) = 1.97$, $p > .05$, $\eta^2 = .023$) were all non-significant, with small effect sizes. This means that there were no substantial difference in overall language skill among groups or levels of hearing when time was not taken into account.

Overall, while language development improved more for all the children over time, the intervention was particularly effective for those who were in the experimental group. Hearing level, however, played no significant role in predicting language outcomes, or in moderating with the intervention effect. The results show that the intervention was effective irrespective of the hearing ability of the child and promotes its increased application in different populations.

Major Findings

This study answered to teacher incompetence by using a Multilingual Education (MLE) intervention for children's language improvement. The intervention strongly impacted Amharic language development, especially among the recipients. Two-way

ANOVA showed that hearing ability did not affect language development, while repeated-measures ANOVA also testified to overall improvement from pretest to posttest. Control and experimental groups varied, with children with hearing defects benefitting equally from the intervention.

Discussion

This section reports the findings of the study against the two key hypotheses:

1. That teachers' professional capacity, home and school environments, and hearing loss affect children's language acquisition; and

2. That intervention based on an MLE can significantly impact the language growth of both hearing and hard-of-hearing children.

The findings are reported in the context of Ethiopia's education policy and legal frameworks, as well as pertinent international conventions to which Ethiopia is a signatory.

Home and School Environments

The research found that kids of socioeconomically disadvantaged backgrounds tend to have restricted linguistic stimulation and emotional support in the home and experience additional disadvantage in schools that are under-resourced. Parental poverty, low parental literacy, and unemployment (Liu & Sun, 2023) are conditions that create a condition where the language development of children during their early childhood is impacted. This accords with Feuerstein's (200) theory of mediated learning, which emphasizes that children raised in poor environments require mediated and structured learning support.

These findings highlight the difficulties of carrying out Ethiopia's Education and TrainingPolicy (ETP, 1994), which provides for community involvement and fair access to good education. The Education Sector Development Program VI (ESDP VI, 2020–2025) also prioritizes reducing education differentials among disadvantaged groups, such as children from poor backgrounds and children with disabilities. In practice, however, systemic neglect persists in rural and poorly resourced areas.

Besides, Article 36 of the FDRE Constitution (1995) tantalizes that all children are entitled to learn and grow up in their own language and culture. However, when children are denied access to MLE or exposed to overcrowded, noisy classrooms (Kast, 2022), their language learning - particularly for children with hearing impairment is significantly disrupted. Such environmental limitations are contrary to the policy dream of inclusive and equitable education reflected in both ESDP VI and the Inclusive Education Strategy (2022).

The research, however, illustrates that even in disadvantaged settings, collaborative effort between parents, peers, and teachers under the MLE program can enable children's cognitive and language development (Kozulin *et al.,* 2020). This is consistent with Ethiopia's commitments under UNCRC (Article 29) and the African Charter on the Rights and Welfare of the Child that place emphasis on the importance of culturally and linguistically relevant teaching in promoting children's learning outcomes.

Teachers' Professional Competencies

Teachers demonstrated weaknesses in MLE pedagogy before the intervention, consistent with research by Benson (2022) and Kebede and Shiferaw (2023), which indicated systemic shortcomings in Ethiopian teacher preparation. Despite ETP (1994) making allowance for mother tongues to be used as languages of instruction and the Teacher Development Program (TDP III), a considerable majority of teachers have not been trained adequately in MLE methodologies.

After targeted professional development, teachers showed considerable improvement in their knowledge about and confidence in using MLE. This underscores the catalytic role of capacity-development interventions, as contemplated in ESDP VI and the Inclusive Education Strategy, both of which call for the

development of teacher competences in inclusive and multilingual pedagogies.

MLE basically changes the teacher's role from knowledge transmitter to mediator and facilitator of intellectual development. With teaching guided by Vygotsky's Zone of Proximal Development (ZPD), teachers were able to scaffold learning effectively, offering differentiated instruction that catered to the developmental requirements of specific learners (Kim and Hannafin, 2019). These practices are indicative of the learner-centered ideals advocated by Ethiopia's education reform agendas.

By being guided by both Feuersteinian and Vygotskian theories, the intervention was also strongly aligned to Ethiopia's inclusive education policy ambitions, confirming that effective professional development is crucial for improving educational equity and language outcomes.

Effects of Hearing Impairment

Consistent with international evidence (Wang and Paul, 2022), hearing impairment is linked with high risks for social exclusion and language delay due to decreased access to auditory input. Against expectation, no statistically significant language performance differences between hard-of-hearing and hearing children in the control group were identified through the research. This might be due to the shared experience of an overwhelmingly impoverished learning environment, which limited linguistic input for all students regardless of hearing status (Kern *et al*., 2023).

These results make it even more urgent to realize Ethiopia's Inclusive Education Strategy (2017), which recognizes children with disabilities, such as hearing impairment, as priority groups. Although the strategy supports inclusive practices and the provision of adapted educational materials, implementation remains patchy, particularly in rural schools.

Under Article 24 of the CRPD, Ethiopia is obligated to provide persons with disabilities with access to education on an equal basis with others. But the observed behavioral challenges, e.g., attention deficits and absence of peer interaction, among hard-of-hearing children (Alemayehu, 2019) are indicators of unsatisfied communication and emotional needs. Such observations show a gap between policy intention and classroom reality, and underscore the need for more comprehensive support services, such as speech therapy, assistive devices, and specialized teacher training.

Effects of Intervention on Language Development

The second hypothesis was also strongly supported: children who were given the MLE-based intervention developed significantly in language proficiency, both in listening, speaking, and phonological awareness. This demonstrates that well-designed, inclusive, and linguistically appropriate pedagogy can achieve measurable academic improvement, even for children with multiple levels of disadvantage.

Its success is also aligned with national education priorities established in ESDP VI, such as enhancing learning outcomes through mother language education, early grade reading programs, and inclusive education models. The intervention is also aligned with Ethiopia's commitments under SDG 4, particularly Target 4.5, which aims to eliminate inequities in education access for marginalized groups, such as children with disabilities.

Intervention teachers learned to identify each student's ZPD and implement differentiated approaches that facilitated students' progression from concrete to abstract thought (Vygotsky, 1962; Pérez and García, 2021). These practices reflect the inclusive, child-centered principles upheld by both the ETP and the Inclusive Education Strategy.

The application of dynamic assessment methods (Grigorenko, 2020) also permitted the educators to focus on the potential of every learner, rather than a fixed level of aptitude. This formative approach is consistent with Ethiopia's curriculum reform ambitions, which

require competency-based and ongoing assessment mechanisms.

By encouraging transcendence, the ability of the learner to apply acquired skills to new situations, the intervention bridged existing learning gaps (Hadidi and Mowlaie, 2023). The findings corroborate arguments by Alper (2022) that systematic mediation is essential in the formation of higher mental functions in disadvantaged learners.

Conclusion

The results corroborate arguments by Alper (2022) that systematic mediation is crucial in the development of higher mental functions among underprivileged learners.

The study recognizes the critical necessity for more policy coherence and practice realization in Ethiopia's education sector. Despite having a proper legal and policy framework, the Education and Training Policy (ETP, 1994), the Education Sector Development Program VI (ESDP VI), and the Inclusive Education Strategy (2022), these

policies are rarely put into practice, particularly in marginalized and rural areas. The result is an education system in which the majority of vulnerable children, including children with disabilities, are not provided with the support they require to thrive. The findings of this study demonstrate that the language development of hearing and hard-of-hearing children can be significantly improved when they are provided with well-trained teachers, mother tongue instruction, and conducive learning settings. In circumstances where poverty, poor infrastructure, and untrained teaching staff tend to discourage learning, this research demonstrates that such constraints could be circumvented through overt Mediated Learning Experiences (MLE). Through these kinds of interventions, if provided by well-trained teachers, situations for meaningful learning and cognitive progress emerge.

Above all, the study concludes that hearing status itself is not a predictor of language success. Instead, what is crucial is the quality of meditational instruction, how educators facilitate learning, adapt instruction to students' needs, and engage students in culturally relevant conversation. The quasi-experimental evidence reported here shows the revolutionary power of MLE, particularly when implemented by reflective, well-trained teachers. These findings are aligned with Ethiopia's national education objectives and in line with its global commitment under the UN Convention on the Rights of the Child (UNCRC), the Convention on the Rights of Persons with Disabilities (CRPD), and Sustainable Development Goal 4 (SDG 4) to achieve inclusive, equitable, and quality education.

Supporting MLE to its maximum requires system-level commitment to teacher preparation, inclusive classroom practices, and early intervening systems. It entails getting teachers equipped with the tools, strategies, and staff development to serve diverse learners and developing school climates that are physically and emotionally supportive. These steps are not only essential for improving language achievement but also for creating greater educational equity and inclusion.

For the future, further research is needed to examine the long-term impact of MLE on children's language, educational, and psychosocial development. Future studies should examine the impact of parental involvement and home–school collaboration, particularly in poor resource environments, and establish how MLE can be adapted to children with varying hearing impairments, from mild to severe. Some of the other areas of inquiry include the effect of classroom acoustics on learning, the development of scalable models for the training of teachers that integrate MLE and inclusive pedagogies, and how technology-enabled MLE might be leveraged to reach remote or disadvantaged communities.

Finally, this study provides rigorous evidence that culturally responsive MLE taught by teachers is a powerful intervention for continued language expansion among linguistically and culturally diverse student populations. Under the umbrella of supportive policies, ongoing professional development of

teachers, and fruitful community engagement, MLE can serve as an early sign for Ethiopian education reform. Systematic policy attention and research are imperative to ongoing and large-scale replication of these promising outcomes.

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RESEARCH PAPER

Adolescents' Psychological Well-being: The Role of Sex and Family Structure

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Abstract

Adolescents' psychological well-being is a salient factor in fostering their comprehensive psychological, socio-emotional, and physical development, enabling them to thrive during this period of rapid growth. A range of individual and social factors contributes to the perceived level of adolescents' psychological well-being. This study aimed to investigate the influences of family structure and sex on adolescent's psychological well-being. A correlational research design was employed to achieve the purpose of this study. Data were collected from a randomly selected 340 adolescents (158 males and 182 females) through proportionate stratified sampling, by using Ryff's psychological well-being scale. Descriptive statistics (mean, standard deviation), two-ways ANOVA, and multiple regression analysis were employed to examine relationships and differences. The results indicated that Adolescents who participated in the present study exhibited a lower level of psychological well-being. When compared by sex, female adolescents are found better in their psychological well-being than their male counterparts (F (1,339) =8.55, P<.05). Adolescents from intact families (i.e., where both biological parents live together) are found to be better in their psychological well-being than adolescents from non-intact families (F (1, 339) = 12.822, P <.05). Overall, both sex and family structure were identified as significant factors influencing adolescents' psychological well-being. Female adolescents exhibited higher levels of psychological wellbeing than male adolescents. Both female and male adolescents from intact demonstrated higher levels of psychological well-being than those from non-intact families. Given the low levels psychological well-being observed among adolescents, key agents within their immediate ecological systems such as families and schools, bear a critical responsibility to actively foster and enhance their psychological well-being. Thus, all stakeholders involved in adolescent psychosocial development are encouraged to actively contribute to promoting adolescents' psychological well-being. This support serves as a foundation for their positive growth and development.

Keywords: psychological well-being, family structure, sex, adolescents

Introduction

The period of adolescence is a crucial stage in human development marked by the achievement of various developmental milestones. Notable transformations in brain development, hormonal activity, emotions, thinking processes, behavioral, and social interactions characterize this stage (Zaky, 2016). Parallel to the developmental changes, developmental theorists contended that adolescents entertain developmental tasks of establishing one's own identity and strive for achievement of autonomy (Meeus, 2016). The literature also indicates that adolescents engage in developmental tasks such as identifying, evaluating, and choosing roles and values that they will adhere to as adults (Hamman and Hendricks, 2005). Expected developmental milestones during adolescence seem to be

successfully attained by adolescents in a psychologically healthy state. Supporting this notion, a research shows that psychological well-being is an important and salient factor for healthy trajectories from adolescence to adulthood (Hoyt *et al.,* 2012).

Although definitions of psychological well-being vary among scholars, Ryff's (1989) conceptualization is one of the most widely used. According to her, psychological well-being represents optimal human functioning (Diener, 2009). Furthermore, Ryff (1995) further sub-classified the construct into dimensions including self-acceptance, positive relationships with others, environmental mastery, autonomy, purpose in life and personal growth. Chen *et al.* (2018) referred to these dimensions as "health assets" as they affect adolescents' physical and mental health and, ultimately shaping their behavioral development trajectories. In a similar vein, Burns (2015) defined psychological well-being as intra and inter-individual levels of positive functioning that comprises relatedness with others and self-referent attitudes that could be explained in terms of environmental mastery and personal growth. Broadly, Vinothkumar (2015) referred to psychological well-being as representing lives flourishing indicated by range of feeling better and functioning optimally. In summary, the tenets characterizing psychological well-being are associated with positive psychological functioning and one's optimal psychosocial development that would serve adolescents' successful achievement of anticipated milestones during this critical stage of life.

Research indicates that adolescents' psychological well-being positively correlates with several factors, including adaptive decision-making (Páez-Gallego *et al.,* 2020), emotional self-control (Wills *et al.,*2016)), resilience to stressful situation (Konaszewski *et al.,* 2021; Sagone and De Caroli, 2014), life satisfaction, happiness, hopefulness and self-efficacy (Alkhatib, 2020; Heizomi *et al.,* 2018), internal locus of control (Mobarakeh *et al.,* 2015), and positive thinking (Alkhatib, 2020). Conversely, adolescents facing psychosocial health issues are more likely to encounter difficulties in social relationships, engaging in substance abuse, dropping out of school, and attempting suicide (Tayfur *et al.,* 2022; Hetrick *et al*., 2016). Hence, it is essential to investigate factors accounting for desired changes in adolescents' psychological well-being and come up with potential recommendations directed to boost psychological wellness of the young people. Among the various factors influencing adolescent psychological well-being, family structure and sex were found to play a significant impact on adolescents' psychological well-being (Cavanagh and Fomby, 2019; WHO, 2021). For instance, family structure shapes the social and emotional environment in which adolescents develop, affecting their sense of stability, support, and access to resources (Amato, 2010). Similarly, sex differences are crucial, as males and females' adolescents may experience and express psychological well-being differently due to biological, social, and cultural influences (Nolen-Hoeksema, 2001; WHO,2021). Thus, it is critical to consider both the environmental (intact and non-intact adolescent family context) and personal elements (sex of adolescents) that could influence the adolescents' psychological well-being (Santrock, 2018).

Human development, particularly during adolescent, is a dynamic process shaped by various factors contexts, among others, family structure is one of them (Lerner, 2006). Family structure can shape adolescents' psychological health in diverse ways (Cavanagh and Fomby, 2019). However, existing research remain inconclusive regarding the precise impact of family structure on adolescents' psychological well-being. Some studies have found that adolescents from intact families tend to report greater levels of psychological well-being compared to those from non-intact families. For example, Demo and Acock (1996) reported that adolescents living in intact families exhibited slightly higher well-being than those from single-parent or stepfamilies. Similarly, Amato (2005) showed that children raised by continuously married parents are less likely to experience a broad range of cognitive, emotional, and social problems than peers from single-parent households. Amato's study

further confirmed that children raised in stable two-parent families tend to have stronger emotional connections with their parents and experience fewer stressful events than those living in stepfamilies. Conversely, Bass and Warehime (2011) reported that adolescents not residing in nuclear families, particularly those without two parents, experienced more health problems, chronic illnesses, and lower quality of life related to health, along with lower parental assessments of their health.

On the other hand, several studies reported no significant differences in psychological well-being among adolescents from intact and non-intact families. For instance, Vandewater and Lansford (1998) reported no notable variations in well-being among adolescents across different family structures. Similarly, Baeder *et al.* (2009) and Singh and Udainiya (2009) found that adolescents' psychological well-being is not notably affected by their family structure background. Furthermore, Ongaro and Meggiolaro (2012) found that family structure generally had no impact on adolescent psychological well-being, except in the case of young people residing in stepparent families. Given these inconsistent research outcomes, it remains challenging to attribute adolescent psychological well-being solely to family structure. Therefore, this study seeks to contribute to clarifying these mixed findings and deepen the understanding of how family structure relates to adolescent psychological well-being.

Adolescents' sex is the other factor considered for examined in this study to assess its predictive effect on adolescents' psychological well-being. Similar to family structure, there is no conclusive evidence in the literature as to whether male or female adolescents have better psychological well-being. For example, Ryff (1995) suggested that women of all ages scored higher than men on all dimensions of psychological well-being. Another study finding revealed gender differences in three of the six psychological well-being dimensions (purpose in life, positive relationships with others and autonomy), with female adolescents outperforming male adolescents in the latter two dimensions (Perez, 2012). Furthermore, Chraif and Dumitru (2015) reported gender differences in four of the six components of psychological well-being-environmental mastery, self-acceptance personal growth and positive relations with others. Female adolescents scored higher than their male counterparts in three of the components except on the environmental mastery, where males scored higher. Several studies have shown that girls exhibit greater psychological well-being compared to boys (Chen *et al*., 2018; Liu and Zhao, 2016; Tangmun *et al.,* 2019). In contrast, other studies suggested that male adolescents are better in their psychological well-being than female adolescents. Savoye *et al.* (2015) also suggested that female adolescents have lower level of psychological well-being during adolescence than male adolescents. Similarly, Jiang (2020) found that girls experience greater psychological distress compared to boys, while Lucktong *et al*. (2018) found that males had higher psychological well-being than females. On the other hand studies (Francis et al., 2021; Páez-Gallego *et al.,* 2020; Vinayak and Judge, 2018; Chen *et al.,* 2018) have reported no sex difference in adolescents' psychological well-being. The inconsistent or contradictory findings may be attributed to socio-cultural factors, underscoring the need for further study. This study, therefore, aims to investigate the influence of sex and family structure in predicting adolescents' psychological well-being. Based on these considerations, the following study questions are put forward for investigation.

- What is the level of adolescents' psychological well-being in the study area?
- Does adolescents' psychological well-being differ as a function of their family structure and sex?
- Do family structure and sex significantly contribute to predicting adolescent psychological well-being?

Materials and methods

Study Design

The researchers employed a correlational research design, as the primary objective was to investigate the relationships among the study's three key variables: adolescents' psychological well-being, sex, and family structure. Specifically, the study aimed to examine both the unique and combined contributions of sex and family structure in predicting adolescents' psychological well-being.

Study Site

The current research was conducted in Jimma town located in the Oromia region of Ethiopia. Jimma, one of the country's oldest and most historically significant cities, lies approximately 353 kilometers southwest of Addis Ababa, the nation's capital. According to the Central Statistical Agency of Ethiopia (2007), Jimma is home to an estimated population of 195,288 residents, nearly evenly split between males (97,259) and females (97,969). The town is ethnically diverse, predominantly inhabited by the Oromo people alongside Amhara, Yem, Tigre, Gurage, Dawuro, and other groups. Islam and Christianity are the major religions practiced in the area. Adolescents in Jimma face a range of psychosocial challenges, including depression and anxiety, which are shaped by unique socio-cultural and family dynamics distinctive to the region (Girma *et al*., 2021). The psychosocial circumstances of adolescents in Jimma made the town a highly relevant setting for studying adolescent psychological well-being and developing contextually appropriate recommendations.

Participants of the Study

The study sample consisted of adolescent students selected from two randomly selected senior secondary schools in Jimma town. One was a government school (i.e., Sato Senior Secondary School) and the other was a private school (i.e., Catholic Senior Secondary School). Drapper and Smith's (1998) formula for non-single populations for the non- single population was utilized to establish the sample size for this study. Accordingly, the size of sample (n) is a function of the factors (Xi) and categories (Ck) involved in the research, such that a minimum of 10 observations are needed for each category of a factor i.e., n= Cfn1 x Cfn2 x Cf3x… Cfn. Where, n denotes sample size, while Cf1, Cf2, Cf3 through Cfn are the number of categories for factors 1, 2, 3, to factor n. Accordingly, the present study involves four variables: sex, school type, family structure, and grade level. The first variable has two categories (male and female), the second has two categories (private and government schools), the third has two categories (intact and non-intact), and the fourth includes four categories (grades 9, 10, 11, and 12). Hence, a minimum sample size that should be drawn was calculated to be 320 (i.e., 2 x 2 x 2 x 4 x 10 = 320), which is needed for the desired precision in the statistical analysis. Assuming possible non-response rate and potential incomplete responses, the sample size was increased by 10%. Accordingly, the proposed total sample size for the study was 352. They were selected from the aforementioned two secondary schools by using proportionate stratified sampling methods to ensure representativeness of participants in terms of sex, grade level and type of school and followed by systematic random sampling technique to identify adolescents participating in the study. The final analysis was performed using data from 340 participants, after excluding 12 questionnaires from the original 352 due to incomplete or improperly answered responses.

Instruments of Data Collection

Two instruments were employed to collect the required data from the participants. These included socio-demographic information utilized for gathering set of questions and Ryff's Psychological Well-Being Scale (PWB) to collect data about perceived psychological well-being of the study participants. The socio-demographic questionnaire was used to collect data on the socio-demographic characteristics of the respondents including age, sex, grade level, and family structure (intact/ non-intact). To measure psychological well-being in adolescents, an adolescent self-report version of Ryff's Psychological Well-Being Scale (PWB) developed by Ryff (1989) and modified by Ryff and Keyes (1995) was used. The scale

has 42 items. It measures six dimensions of wellbeing and happiness, including self-acceptance, autonomy, environmental mastery, personal growth, positive relationships, and purpose in life. Ryff Psychological Well-Being Scale is a widely used measure of well-being, and it is the most commonly used tool for assessing adolescents' psychological well-being. The participants rated each item on a six-point scale (ranging from 1=strongly disagree to 6=strongly agree) according to how much they agreed or disagreed. The scale includes items such as: (1) Autonomy – "I'm not hesitant to voice my views even if they oppose the majority," (2) Environmental Mastery – "Overall, I feel I have control over my life situation," (3) Personal Growth – "I am uninterested in pursuits that would broaden my perspective," (4) Purpose in Life – "I take life one day at a time without considering the future," (5) Positive Relations – "People generally regard me as warm and affectionate," and (6) Self-Acceptance – "Looking back on my life, I am content with the way things have gone." Negatively stated items were reverse coded during data feeding and analysis.

Psychometrically, the scale shows favorable results. As a tool for measuring specific characteristics of adolescent populations (e.g., Fernandes et al., 2010), it has been found to be reliable and valid. There was good reliability across all dimensions of the scale: Autonomy (0.71), Self-acceptance (0.79), Positive relations with others (0.78), Environmental mastery (068), Purpose in Life (0.82), Personal growth (0.71) and Total psychological well-being scale (0.82). The scale has been widely used across different countries in the world to study adolescents' well-being (Ryff & Keyes, 1995; Gómez-López *et al.,* 2019). Moreover, the scale's internal consistency has been in the acceptable range. Aregash (2010) used the scale to assess psychological well-being and reported a coefficient of internal consistency (Cronbach alpha) of 0.74. Similarly, Berhe (2020) reported a Cronbach alpha reliability of 0.84 for the entire scale.

Instrument Validation

Before using the instrument of data collection, six subject-matter experts checked the content and face validity of the scale. Their review of the instrument found it relevant, appropriate, clear, and conceptually sound. Once the scale items were modified based on the expert comments, it was then translated into to the study participants' native languages (Amharic and Afan Oromo) for the ease of understanding. Data collected from the participants were analyzed using Cronbach alpha (internal consistency reliability) followed by exploratory factor analysis (EFA). The EFA results indicated that some items had low loadings and others cross loaded on more than one factor. Therefore, removing the items with low loadings and those cross loaded on more than one factor was an option to get the items load on a single factor. Accordingly, three items (1, 31 & 37) from Autonomy, three items (2, 26 & 38) from Environmental mastery, two items (33 & 39) from personal growth, one item (40) from positive relationship, two items (23 & 41) from purpose and two items (36 & 42) from self-acceptance were removed. Discarding the aforementioned items yielded six components (fitting to the original underlying factor structure) with eigenvalues exceeding 1.

Table 1. Internal consistency assessment of the Psychological Well-Being Scale and its subscales subsequent to factor analysis

Type of instruments	Number of Items	Cronbach's Alpha
Psychological well-being	29	.89
Personal growth	5	.90
Positive relationship	6	.92
Autonomy	4	.81
Environmental mastery	4	.87
Purpose in life	5	.86
Self-acceptance	5	.88

As indicated in Table 1, the overall internal consistency of the Psychological Well-Being Scale and its six dimensions falls within the acceptable range.

Data Analysis Methods

Data collected from the participants were entered into SPSS version 24. Next, the data were cleaned and edited. Both descriptive statistics (such as mean and standard deviation) and inferential statistics (such as multiple regression analysis and two-way ANOVA) were used in the data analysis process. The study participants' descriptive characteristics and the state of adolescents' psychological wellbeing were summarized using descriptive statistics. Subsequently, prior to using parametric statistics, statistical assumptions for employing inferential statistical tests were tested. Afterwards, to examine variations in adolescents' psychological well-being based on sex and family structure, a Two-way ANOVA was employed. Multiple regression analysis was utilized to investigate the effect of family structure and sex on adolescents' psychological well-being. Prior to conducting ANOVA, all key assumptions for were checked and satisfied. Independence of observations was ensured, residuals were approximately normal, Levene's test confirmed homogeneity of variances ($p > .05$), and no significant outliers were found. Thus, ANOVA was suitable for the analysis. An alpha (α) value of .05 was used for statistical significance tests.

Ethical Considerations

All relevant ethical considerations were addressed during this study. The researchers received approval from the School of Psychology Research Ethics Committee at Addis Ababa University. Following this, adolescents in the selected schools were asked for their consents to participate in the study and gave their approval to proceed. Participants were also made aware that their involvement in the data collection process was completely voluntary and that they could revoke their consent at any moment. In addition, the participants were instructed not to write their names on the questionnaire in order to safeguard their privacy. Furthermore, they were assured that the data collected about them would be kept private and used exclusively for this study.

Results

Demographic Characteristics of the Respondents

Table 2. Demographic Characteristics of the Respondents (N=340)

Variables	Categories	Frequency	Percentage
Sex	Male	158	46.5
	Female	182	53.5
	Total	340	100%
Family structure	Intact	231	67.9
	Non-intact	109	32.1
	Total	340	100%
Grade Level	Grade 9	111	32.6
	Grade 10	81	23.8
	Grade 11	87	25.6
	Grade 12	61	17.9
	Total	340	100%
School type	Government	232	68.2
	Private	108	31.8
	Total	340	100%
Age	14-20	-	$\bar{X}$=17.8 (SD =3.42)

Table 2 presents the demographic details of the study participants. In this study, 340 adolescents, 182 (53.5%) females, and 158 (46.5%) males. Regarding family structure, 67.9% of the respondents were from intact families, whereas 109 (32.1%) were from non-intact families. In terms of grade level, adolescents from grade nine through twelve were represented. The sample encompassed adolescents from grades nine to twelve. Grade nine students formed the largest participants (n = 111; 32.6%), whereas grade twelve students represented the smallest participants (n = 61; 17.9%). The study participants' age falls between 14 to 20 ages, with a mean of 17.8 years old (and standard deviation of 3.42). In terms of the type of school the adolescents attending, the majority (n = 232; 68.2%) were from government schools.

Levels of Psychological Well-Being among Adolescents

The primary focus of this study is to ascertain about adolescents' level of psychological well-being. Adolescents who scored significantly below the expected mean are considered to have a lower level of psychological well-being, whereas those scoring significantly above it are regarded as having a higher level of the measured well-being indicators. When a scale lacks predefined cut-off scores, researchers often recommend a practical method of establishing a threshold by selecting a meaningful minimum response on the Likert scale and multiplying it by the total number of items to derive an overall score cutoff (Hughes, 2018; Barua, 2013). In line with this, given Ryff's six-point psychological well-being Likert scale lacks an established cut-off score, the researchers have set the threshold as aforementioned. Taking four (slightly agree) on the scale as the minimum threshold as an indicator of positive psychological well-being on each item, the researchers multiplied this value by the number of items to obtain the total score on the scale that indicates the minimum threshold of positive psychological well-being (i.e., 4 x 29 = 116). This means for an adolescent to be considered better in their psychological well-being, they must, on average, rate each item at least 4 on a 6-point

scale and achieve a minimum total score of 116.

Table 3. Adolescents' level of psychological well-being

Variables	No of items	Min	Max	obtained Mean	SD	Expected Mean
PWB	29	33	159	96.11	23.7	116

PWB= Psychological well-being; SD=Standard Deviation, Df=Degree of Freedom

In terms of psychological well-being, the obtained result reveal that the observed mean (Mean= 96.11) is below the expected mean (Mean=116). This implies that the study participants exhibit lower levels of psychological well-being.

Variations in psychological well-being of adolescents' as a result of family structure and sex

Table 4. Descriptive statistics on adolescents' psychological well-being by sex and family structure

Sex	Family	Mean	Std. Deviation	N
Female	Intact	103.09	20.78	130
	Non-Intact	91.52	27.58	52
	Total	99.79	23.44	182
Male	Intact	94.64	20.41	101
	Non-Intact	86.95	27.65	57
	Total	91.87	23.49	158
Total	Intact	99.40	21.00	231
	Non-Intact	89.13	27.58	109
	Total	96.11	23.76	340

Table 4 shows that female adolescents from intact families had a higher PWB mean score (M=103.09) than female adolescents from non-intact households (M=91.52). In the same vein, male adolescents from intact families (M= 94.64) had a higher mean score in their psychological well-being than male adolescents from non-intact households (M=86.95). Compared to adolescents from non-intact families, adolescents from intact family backgrounds, both male and female, were found to have superior psychological well-being. This suggests that teenagers raised in two-parent households are more likely to experience better psychological health than teenagers raised in households with a single parent (i.e., the mother, father, stepfather, stepmother, or family members). The effect of sex (male, female) and family structure (intact, non-intact) on adolescents' psychological well-being (in terms of autonomy, positive relations with others, self-acceptance, purpose in life, personal growth, and environmental mastery) was tested by applying two-way ANOVA.

Table 5. Two-way ANOVA results showing how adolescents' psychological well-being varies according to their sex and family structure.

Source	Type III Sum of Squares	df	Mean Square	F	p	Partial Eta Squared
Corrected Model	12436.305[a]	3	4145.435	7.783	.000	.065
Intercept	2603157.928	1	2603157.928	4887.361	.000	.936
Sex	3118.312	1	3118.312	5.855	.016	.017
Family	6829.484	1	6829.484	12.822	.000	.037
Sex * Family	276.454	1	276.454	.519	.472	.002

a. R Squared = .065 (Adjusted R Squared = .057)

As shown in the Table 5, family structure has a statistically significant effect on adolescents' psychological well-being, F (1,339) =12.822, p<.05. Adolescents from intact families exhibited higher levels of psychological well-being (mean = 99.40; see Table 4) compared to those from non-intact families (mean = 89.13). The effect size was small to moderate, with a partial eta squared of .037, indicating that family structure accounts for approximately 3.7% of the variance in psychological well-being among adolescents, highlighting family structure as an important but not exclusive factor in adolescent well-being. This suggests that a stable family environment contributes positively to adolescent psychological well-being.

Table 5 also reveals a statistically significant effect of sex on adolescents' psychological well-being, F(1, 339) = 8.55,p<.05, suggesting that the observed difference is unlikely to have occurred by chance. Female adolescents reported significantly higher psychological well-being (mean = 99.79; see Table 4) compared to their male counterparts (mean = 91.87). The effect size was small, with a partial eta squared of .017, indicating that sex accounts for approximately 1.7% of the variance in psychological well-being among adolescents.

On the other hand, no statistically significant sex by family structure interaction effect was found (F (1,339) = .519, P >.05), indicating that the effect of family status on adolescents' psychological well-being did not differ between males and females. This refers that the way family structure influences adolescents' well-being is consistent for both males and females. Moreover, this suggests that the positive or negative impact of coming from an intact or non-intact family applies similarly across sexes, indicating no moderation by sex in the relationship.

Predictive effect of adolescents' sex and family structure on adolescents' psychological well-being

Table 6. Model summary table

R^2	Adjusted R^2	F	Df_1	Df2	P
.064	.058	7.78	2	337	0.000

Note. The model includes predictors: sex and family structure

Table 6 shows that the overall model was statistically significant, F (2,337) =7.78, p<.001, accounting for about 6.4% of the variance in psychological well-being scores (R^2=.064, adjusted R^2=.058). This indicates that sex and family structure together significantly predict psychological well-being, although a large proportion of variance remains unexplained.

Table 7. Summary of the multiple regression analysis

Model	Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	p
Sex	-7.194	2.516	-.151	-2.860	.005
Family structure	-9.653	2.689	-.190	-3.590	.000

a. Dependent Variable: Psychological well-being

The regression findings shown in Table 7 reveal that both sex (t (337) = -2.86, p = .005) and family structure (t (337) = -3.59, p < .001) are significant predictors of adolescents' psychological well-being. With sex coded as female = 1 and male = 2, the negative unstandardized coefficient for sex (B = -7.19, p = .005) means that transitioning from female to male is linked to a decrease of approximately 7.19 points in psychological well-being. This suggests that, after controlling for family structure, females report significantly higher psychological well-being scores than males by about 7.19 points. Similarly, with family structure coded as intact = 1 and non-intact = 2, the negative unstandardized coefficient (B = -9.65, p < .001) indicates that moving from an intact family to a non-intact family is associated with a decrease of approximately 9.65 points in psychological well-being. This means that, controlling for sex, adolescents from intact-families reported significantly higher psychological well-being than those from non-intact families.

Discussion

Psychological well-being has long-term implications for adolescents' overall life development. Recognizing and prioritizing adolescents' psychological well-being is critical for raising a generation that is not only academically successful but also emotionally resilient, socially adept, and capable of positively contributing to its society. However, contrary to the researchers' expectations, adolescents in the study area were found to exhibit low level of psychological well-being. Supporting this finding, Yasmin *et al.'s* (2015) study also showed that majority of the study participants had low to moderate levels of psychological well-being. Similarly, another study indicated that more than half of adolescents reported low psychological well-being (Arjun *et al.,* 2022). Hadjam and Nasiruddin's (2003) study indicated that such state of psychological wellness characterizes inadequate positive psychological functioning. Ryff and Singer (1998) further explained that this condition may stem from feelings of self-dissatisfaction, difficulties in forming meaningful relationships, dependence on others for success, challenges in managing one's environment, lack of clear life goals, and a sense of stagnation.

Furthermore, low adolescent psychological well-being could be the result of psychosocial influencers such as family instability, gender-induced social pressures, and inadequate opportunity to psychosocial support, which could exacerbate emotional and social difficulties. Additionally, livelihood hardships, educational anxieties, and cultural expectations may contribute to one's struggle for self-acceptance and purpose, ultimately undermining overall psychological health and development (World Health Organization, 2024; UNICEF, 2022).

Adolescence is a stage characterized by rapid physical, social, and psychological growth, which makes the family environment vital in supporting adolescents to reach key developmental milestones. In this study, family structure showed a statistically significant effect on the psychological well-being adolescents, both for male and female adolescents. This indicates that adolescents from families that are intact tend to have a higher levels of psychological well-being than those from non-intact families. This study aligns with the findings of Demo and Acock (1996), who observed that adolescents from intact families exhibit somewhat higher levels of well-being compared to those from single-parent or stepfamilies. Similarly, Amato (2005) demonstrated that children raised by two

married parents are less prone to various cognitive, emotional, and social difficulties compared to those living in households with just one biological parent. Moreover, adolescents from two-parent households, whether biological or blended, were reported to have better mental health outcomes compared to those from single-parent or non-traditional family structures (Carlson, 2006; Amato, 2005).

Being a female or male adolescent raised in a non-intact family has been linked to low psychological well-being. Various causes might be responsible for the poorer developmental outcomes associated with adolescents living in non-intact family environments. Among others, explanations given by ecological theory (Rosa and Tudge, 2013) and parental investment theory (Trivers, 1972) are worth discussing here. Proponents of the ecological perspective suggest that adolescents' psychological well-being is influenced by a variety of factors, and the absence of certain elements (such as belonging to a non-intact family) may adversely affect their psychological well-being. These factors encompass the individual's family relationships (microsystem), their interactions with broader community and social settings (mesosystem and exo-system), as well as cultural and societal influences at the broader societal level (macrosystem). According to parental investment theory, parents allocate resources (such as time and energy) to increase their offspring's chances of survival and reproductive success. Adolescents in non-intact families often face reduced parental involvement owing to fewer resources available after divorce or separation. In sum, according to Amato (2005) and Ganong and Coleman (2004) findings, stepparents may exhibit characteristics such as being more disengaged, less emotionally available, less affectionate, and providing less supervision than biological parents.

Difference in adolescents' psychological well-being also appears to vary between male and female adolescent, which is another variable of interest in this study. In this regard, sex had a statistically significant effect on adolescents' psychological well-being, with females reporting higher levels than males. Supporting this finding, Ryff (1995) found that women across all age groups scored higher than men in positive relationships with others and personal growth, while no sex differences were observed in the other four dimensions of psychological well-being: autonomy, environmental mastery, self-acceptance, and purpose in life. Morermore, Perez's (2012) study demonstrated gender differences in three of the six psychological well-being dimensions—namely autonomy, positive relations with others, and purpose in life—with female adolescents scoring higher than males in the last two dimensions, while males scored higher than females on autonomy. Furthermore, Chraif and Dumitru (2015) reported gender differences in four of the six psychological well-being components—personal growth, positive relations with others, self-acceptance, and environmental mastery—where female adolescents scored higher than males in the first three dimensions, while males outperformed females in environmental mastery. Likewise, some studies have shown that girls exhibit higher levels of psychological well-being compared to boys (Chen *et al*., 2018; Liu & Zhao, 2016; Tangmunkongvorakul *et al.,* 2019).

Conclusion and Implications

The low levels of psychological well-being observed among the adolescent participants in this study suggest they may be struggling to flourish and achieve the developmental milestones typically associated with this stage of life. This necessitates close support and fostering care services from pertinent actors (e.g., parents, siblings, teachers, peers, etc.) that could boost the psychological well-being of the adolescents for their improved positive psychological functioning. In relative terms, the female adolescents' perceived better psychological well-being than their male counterparts would imply that female adolescents are on the path to promising positive development, though they still need extensive psychosocial support to improve their overall low psychological well-being. This bestows a strong social responsibility on the concerned bodies to support female and male

adolescents' positive development in general, particularly that of male adolescents.

Adolescents' family environment characterized by intact family structure has positively impacted their psychological well-being. Conversely, those from non-intact families were found to experience less supportive social conditions, which potentially hinder healthy psychological development. As a result, adolescents from non-intact family settings are more prone to exhibiting lower levels of psychological well-being. Adolescents who are not raised in intact families may lack the warmth and affection of both parents, which can contribute to lower levels of psychological well-being. Given the challenging family dynamics of these days, it is very natural to expect adolescents' leading social life without both biological parents. Hence, whoever is directly influencing the psychosocial development of the adolescents in a non-intact family context (e.g., stepfather, stepmother, relatives, adopting parents, etc.) are socially responsible to provide pertinent parental care and social services to their maximum social capacity.

Overall, the psychological well-being of adolescents, as examined through key features of positive psychological functioning (self-acceptance, purpose in life, positive relations with others, autonomy, personal growth and environmental mastery) is a vital factor that promotes healthy developmental outcomes. All stakeholders involved in adolescent psychosocial development are encouraged to actively contribute to promoting adolescents' psychological well-being, as this support serves as a foundation for their positive growth and development.

The current study specifically focused on investigating how adolescents' sex and family structure influence their psychological well-being. Future research by Ethiopian scholars in family and adolescent psychology is encouraged to explore the resilience capacities of adolescents with low psychological well-being, as well as other potential factors related to adolescent psychological well-being. Such studies would broaden the existing body of knowledge and deepen understanding in this important area of adolescent development. Furthermore, additional research on the psychological well-being of Ethiopian adolescents in areas outside of Jimma town is suggested to either confirm or challenge the external validity of the results obtained in this study.

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Conflict of interest

The authors affirm that they do not have any relevant financial or personal relationships to declare.

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