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1. வீரமாமுனிவரின் எழுத்துச் சீர்திருத்தம்

முனைவர் செ. ரெஜினா,
உதவிப் பேராசிரியை, தமிழ்த்துறை
ஜெயராஜ் அன்னபாக்கியம் மகளிர் தன்னாட்சிக் கல்லூரி,
பெரியகுளம் - 625 601, தமிழ்நாடு, இந்தியா
சந்தையெவையுளையநெதயஉ.யஉ.கெ

ஆய்வுச் சுருக்கம்

தமிழ் மொழியின் எழுத்து மரபில் காலத்திற்கேற்ப சீர்திருத்தங்களைக் கொண்டு வந்தவர் வீரமாமுனிவர். எகர, ஓகர எழுத்துகளுக்கிடையிலான உச்சரிப்பு மற்றும் பொருள் குழப்பங்களைத் தெளிவுபடுத்தும் வகையில் வீரமாமுனிவரின் எழுத்துச் சீர்திருத்தம், தமிழின் வாசிப்பு மற்றும் எழுத்து நடைமுறைகளில் பெரும் முன்னேற்றத்தை ஏற்படுத்தியது. தொன்றுதொட்டு நடைமுறையில் இருந்த பழைய எழுத்து மரபை மாற்றி, புதிய விதிகளை நிறுவியதன் மூலம் மொழியின் கட்டமைப்பில் தெளிவும் ஒழுங்கும் உருவானது. மொழிகள் தங்களது நிலைபெறுதலுக்காக சமூக, பண்பாட்டு மற்றும் அறிவியல் மாற்றங்களுடன் இணைந்து வளர வேண்டும் என்பதற்கான சிறந்த எடுத்துக்காட்டாக வீரமாமுனிவரின் சீர்திருத்தங்கள் திகழ்கின்றன. இன்றைய நவீன காலத்தில் அறிவியல் தமிழ், கணினித் தமிழ் போன்ற வளர்ச்சிகளுக்கு அடித்தளமாக அமைந்துள்ள இவ்வெழுத்துச் சீர்திருத்தங்கள், இளைய தலைமுறையினர் தமிழை எளிமையாகவும் துல்லியமாகவும் கற்றெழுத உதவுகின்றன. ஆகவே, நவீன சூழலுக்கு ஏற்ற வகையில் தமிழ் எழுத்து வடிவத்தை மேம்படுத்திய வீரமாமுனிவரின் பங்களிப்பு, தமிழ் மொழியின் தொடர்ச்சியான வளர்ச்சிக்கும் பெருமைக்கும் அடிப்படையாக அமைந்துள்ளது.

கடவுச்சொற்கள்:-

எழுத்துச் சீர்திருத்தம்	- Script Reform
எகர, ஓகர வேறுபாடு	- A-O vowel distinction
ஒலி, எழுத்து தொடர்பு	- Sound-Symbol Relationship
புள்ளி குறியீட்டு முறை	- Dot Marking System
உச்சரிப்பு தெளிவு	- Phonetic Clarity
எழுத்து ஒழுங்கமைப்பு	- Script Standardization
எழுத்து விதிமுறை	- Writing Rules
எழுத்தியல்	- Writing Systems

முன்னுரை:-

ஐரோப்பாவில் இருந்து தமிழகத்திற்கு சமயப் பணிக்காக வந்தவர்களுள் மிக முக்கியமானவர் வீரமாமுனிவர். அவர் தமிழ் மொழியைக் கற்றுக்கொண்டதோடு மட்டுமல்லாமல் தமிழில் இலக்கண இலக்கியங்களைப் படைக்கும் அளவிற்குப் புலமை பெற்றவராகத் திகழ்ந்தார். அவர் தமிழ் எழுத்துச் சீர்திருத்தத்தின் முன்னோடியாகக் கருதப்படுகிறார். வீரமாமுனிவரின் எழுத்துச் சீர்திருத்தப் பணிகளை இக்கட்டுரை விவரிக்கிறது.

வீரமாமுனிவர்:-

வீரமாமுனிவர் 1680 ஆம் ஆண்டில் இத்தாலியில் பிறந்து, 30வது வயதில் தமிழ்நாடு வந்து ஏறக்குறைய 37 ஆண்டுகள் தமிழகத்தில் தங்கி மதப்பணியுடன் மொழிப் பணியும் ஆற்றிய கத்தோலிக்கப் பாதிரியாரே வீரமாமுனிவர். இவரது இயற்பெயர் ஜோசப் கான்ஸ்டன்டைன் பெஸ்கி. சந்தா சாகிப்பால் பெரிதும் பெருமைப்படுத்தப்பட்டவர். இத்தாலி, கிரேக்கு, இலத்தீன், எபிரேயம் ஆகிய மொழிகளில் சிறந்த தேர்ச்சியுடையவர். தமிழ் மொழியில் ஆழ்ந்த புலமை பெற்றவர். அவர் தமிழ் மொழிக்கு ஆற்றிய தொண்டு பல திறப்பட்டதாகும். இலக்கிய மரபில் தமிழராக வாழ்வதை அவரின் படைப்புகள் பறைசாற்றுகின்றன. உரைநடை, அகராதி, இலக்கணம், உரைகள், சுருங்கக் கூறின் வீரமாமுனிவர் செய்யுள் மொழிபெயர்ப்பு போன்ற பல்வேறு படைப்புகளோடு, எழுத்துச் சீர்திருத்தமும் செய்து புகழ்மிக்கவராகத் திகழ்ந்தார். தமிழ்த்தாயின் மேல் தணியாத தாகமும், தீராத பற்றும் ஒருங்கே கொண்டதால்தான் தமிழனையும் மிஞ்சிச் செயல்பட்டுள்ளார் என்பதை அறிந்துள்ளோம்.

எழுத்துச் சீர்திருத்தம்:-

முற்காலத்தில் எகர, ஓகரத்திற்கு வேறுபாடு தெரியாமல் இடப்பட்டனர். வீரமாமுனிவர் தமிழ் எழுத்துக்களின் எகர, ஓகர ஒலியியல் தெளிவிற்காகச் சில சீர்திருத்தங்களைச் செய்தார். பண்டைக் காலத்தில் எகர ஓகரக் குற்றெழுத்துக்களும், அவற்றின் நெட்டெழுத்துக்களும் ஒன்று போலவே எழுதப்பட்டன. ஆகவே, குற்றெழுத்துக்கும் நெட்டெழுத்துக்கும் உள்ள வேறுபாட்டை அறிவதற்காக, எகர ஓகரங்களின் மேல் புள்ளி வைத்தும் ஏகார ஓகார நெட்டெழுத்துக்களின் மேல் புள்ளி வைக்காமலும் எழுதி வந்தனர். ஏ, ஓ, கே, கோ என்னும் புதிய வடிவங்களைத் தந்து அல்லவை நீக்கி நல்லவை ஆக்கி எளிய முறையில் எழுதும் வகையினைச் செய்தார். இவர் செய்த எழுத்துச் சீர்திருத்தம் இன்று வரை சமூகப் பயன்பாட்டில் சிறந்து விளங்குகின்றது.

குற்றெழுத்தும் நெட்டெழுத்தும்:-

குற்றெழுத்தாவன: எ, ஒ, கெ., கெர் ஆகும்.

நெட்டெழுத்தாவன எ, ஓ, கெ, கொ ஆகும்.

இதனை,

“மெய்யி னியற்கை புள்ளியொடு நிலையல்இ”

“எகர ஓகரத் தியற்கையு மற்றே”

(தொல்., எழுத்து., சூத்திரம்.15,16)

“எகர ஓகர மெய்யிற் புள்ளி மேவும்.”

(வீரசோழியம், சூத்திரம் 6,)

என்ற நூற்பாக்களின் வழி தமிழ் எழுத்துகளில் குறிலாகிய எகர, ஓகரங்களுக்கு புள்ளி இருந்தது. குறிலுக்குப் புள்ளி இல்லாமலும், நெடிலுக்கு மாறுதல் செய்தும் அமைத்தவர் வீரமாமுனிவர் ஆவார்.

புது விதியை உருவாக்குதல்:-

வீரமாமுனிவர், தொன்று தொட்டு வந்த இப்பழைய முறையை மாற்றிப் புது விதியை ஏற்படுத்தியுள்ளார். அது எகர ஓகரக் குற்றெழுத்தின் மேல் நீண்ட புள்ளியும், மெய் எழுத்துக்களின் மேல் சுழிந்த புள்ளியும் வைக்க வேண்டும் என்பதுதான் அவ்விதி ஆகும். இதற்கு இவர் கூறிய சூத்திரம்,

“நீட்டல் சுழித்தல்

குறின்மெய்க் கிருபுள்ளி”

(தொன்.,விளக்., நூற்பா.,)

எ, ஓ, ஆகிய எழுத்துக்களுக்கும் சீர்திருத்தத்தை உருவாக்கினார்.

(எ.கா.,) எரி, ஒதி, மண், கண்

வீரமாமுனிவர் இயற்றியமைத்த இவ்விதியைப் பின்பற்றியே 19ஆம் நூற்றாண்டில் சில அச்சுப் புத்தகங்கள் நீண்ட புள்ளியும் சுழித்த புள்ளியும் அமைத்து அச்சிடப்பட்டன. ஆனால் இக்காலத்தில் எகர ஓகரக் குற்றெழுத்துக்கள், வீரமாமுனிவரின் தொன்னூல் விளக்கத்தில் கூறியபடி நீண்ட புள்ளி பெறாமலும் நன்னூல் முதலிய இலக்கண நூல்களின்படி சுழித்த புள்ளி பெறாமலும் எழுதப்பெறுவதோடு, ஏகார ஓகார நெட்டெழுத்துக்கள் முறையே நீண்ட புள்ளியும் சுழித்த புள்ளியும் கீழே அமைக்கப்பட்டு எழுதப்படுகின்றன. இந்த மாறுதல் யாரால் எப்போது உண்டாக்கப்பட்டதென்று தெரியவில்லை.

உயிர்மெய் எகர ஓகரங்களில் வீரமாமுனிவர் இன்னொரு திருத்தத்தையும் உண்டாக்கியிருக்கிறார். எகர ஓகர குற்றெழுத்துக்களுக்கு மேலே புள்ளிகொடுத்து எழுதியதைப் போலவே, எகர ஓகர உயிர்மெய்க் குற்றெழுத்துக்களுக்கும் மேலே புள்ளி வைத்து எழுதப்பட்டன.

(எ.கா.,) கெ, பெ, செ - புள்ளி பெற்ற இவை குற்றெழுத்து

கெ, பெ. செ - புள்ளி பெறாத இவை நெட்டெழுத்துக்கள்

இவை கே, பே, சே என்று வாசிக்கப்பட்டன. கொம்பு பெற்று வருகிற இந்த எழுத்துக்கள் குற்றெழுத்துக்கும் நெட்டெழுத்துக்கும் ஒன்று போலவே எழுதப்பட்டபடியால், அவற்றின் வேறுபாட்டை எளிதில் தெரிந்து கொள்ளும் பொருட்டு, நெட்டெழுத்துக்குக் கொம்பை மேலே சுழித்தெழுதும் சீர்திருத்தம் படிப்பதற்கும் எழுதுவதற்கும் தெளிவாக இருக்கிறபடியால், வீரமாமுனிவர் அமைத்த முறைப்படியே இப்போது வழங்கி வருகிறோம். இதைப்பற்றி வீரமாமுனிவர், இலத்தீன் மொழியில் எழுதிய “கொடுத்தமிழ்” இலக்கணத்தின் முதல் அதிகாரத்தில் கீழ்க்கண்ட விதம் எழுதியிருக்கிறார்.

எகரக் குற்றெழுத்தும் ஏகார நெட்டெழுத்தும், ஓகரக் குற்றெழுத்தும் ஓகார நெட்டெழுத்தும் (குறில் நெடில் வேறுபாடுகளைக் காட்டும் அடையாளம் இல்லாமல்) ஒரே விதமாக எழுதப்படுவதால், அவர்கள் (தமிழர்) குற்றெழுத்து நெட்டெழுத்தென்னும் வேறுபாட்டினைப் பிரித்தறியும் பொருட்டு, நெட்டெழுத்துக்களின் மேல் புள்ளி இல்லாமலும், குற்றெழுத்துக்களின் மேல் புள்ளி வைத்தும் எழுதும்படி பிள்ளைகளுக்குக் கற்பிக்கிறார்கள். ஆகவே மெய் என்னும் சொல்லின்மேல் உள்ள (ெ) கொம்பின் மேல் புள்ளி வைக்காதபடியால் மெய் என்று வாசிக்கப்படுகிறது. ஆனால், மெய் என்னும் சொல்லில் கொம்பின் மேல் புள்ளி வைக்கிறபடியால் அது மெய் என்று வாசிக்கப்படுகிறது. அப்படியே பொய் என்னும் சொல்லில் கொம்பு புள்ளி பெறாதபடியால் பொய் என்றும் பொய் என்பதில் கொம்பு புள்ளி பெற்றிருக்கிறபடியால் பொய் என்றும் வாசிக்கப்படுகிறது.

எழுத்துக்களின் வேறுபாட்டை எளிதாக அறிதல்:-

இந்த எகர ஓகரக் குற்றெழுத்து நெட்டெழுத்துக்களின் வேறுபாட்டை எளிதாகத் தெரிந்துகொள்வதற்கு மற்றொரு வகையையும் கண்டறிந்திருக்கிறார். குறிலுக்கும் நெடிலுக்கும் ஒரே மாதிரியாக எழுதப்பட்டு வருகிற ஒற்றைக் கொம்பு என்று சொல்லப்படுகிற (ெ) இந்தக் குறியைக் குற்றெழுத்து எனவும், இக்கொம்பையே மேலே சுழித்து இரட்டைக் கொம்பு (ஃ) எழுதினால் நெட்டெழுத்து எனவும் மாற்றி

அமைத்துள்ளார்.

(எ.கா.,) மெய், மேய், பொய், போய்

இச்சொற்களில் கொம்பு மேலே சுழிக்கப்படாதவை குற்றெழுத்து என்றும், மேலே சுழிக்கப்பெற்றவை நெட்டெழுத்து என்றும் வழங்கப்பட்டு வருகின்றன.

புள்ளி இல்லாச் சொற்களில் ஐயம்:-

தொல்காப்பியம், வீரசோழியம், நன்னூல் போன்ற இலக்கண நூல்கள் அனைத்தும் எகர ஓகரங்கள் புள்ளி பெறுமெனக் குறிப்பிடுகின்றன. இதன்படிதான் அக்காலத் தமிழர்கள் எழுத்துக்களைப் பயன்படுத்தியிருக்கிறார்கள். ஆனால், அவர்கள் ஓலைச் சுவடிகளில் எழுதியதால் புள்ளிகளைப் பயன்படுத்தும் வழக்கம் குறைவாக இருப்பதையே அறிய முடிகிறது. கல்களிலும் செப்பேடுகளிலும் எழுதப்படும் எழுத்துக்களில் கூட புள்ளி இடாதது பரவலாகத் தெரிகிறது. புள்ளி வைக்காமல் எழுதப்படும் எழுத்துகளைப் படிப்பதில் இன்றைய ஆய்வாளர்களுக்கு ஐயப்பாடுகள் தோன்றுகின்றன.

(எ.கா.,)

எரி, ஒதி என்னும் சொற்களில் எகரமும் ஓகரமும் புள்ளி பெறாமல் இருப்பதால் இலக்கண முறைப்படி இவற்றை ஏரி என்றும் ஒதி என்று படிக்க வேண்டும். எகரம், ஓகரம் இவற்றிற்கு புள்ளி பெற்றிருந்தால் எரி, ஒதி என்று படிக்க வேண்டும். ஆனால் நடைமுறையில் எழுதுவோர் எகர ஓகரங்களுக்குப் புள்ளி வைக்க வேண்டியதை மறந்து விடுவது வழக்கம். அப்போது, அச்சொற்களை எரி என்று படிப்பதா ஏரி என்று படிப்பதா ஒதி என்று படிப்பதா ஒதி என்று படிப்பதா என்னும் ஐயப்பாடு நிகழும். இச்சொற்களைக் குறித்து

“நேரிழையார் கூந்தலினோர் புள்ளிபெற நீண்மரமாம்

நீர்நிலையோர் புள்ளி பெறநெருப்பாம் - சீரளவும்

காட்டொன் றொழிப்ப இசையா மதனளவு

மீட்டொன் றொழிப்ப மிடறு” (சொல்., மா.சு.,15)

என்று அணியியலில் மாத்திரைச்சுருக்கம் என்னும் சொல்லணிக்கு எடுத்துக்காட்டாக்கி இடம்பெற்றுள்ள வெண்பாவைக் கூறலாம். பொருள் உணர்த்தும் சொல்லின் எழுத்தில் உள்ள மாத்திரை குறைக்கப்படுவதால், அச்சொல் வேறொரு சொல்லாகி வேறுபட்ட பொருளை உணர்த்துவதுதான் மாத்திரைச் சுருக்கமாகும். இவ்வெண்பாவில் நேரிழையார் கூந்தல் என்பது ஒதி ஆகும். (ஒதி - கூந்தல்) ஒதி என்னும் சொல்லின் ஒரு மாத்திரை சுருக்கினால் (ஒரு புள்ளி வைத்தால்) ஒதிமரம் என்று பொருள்படும். ஒதிமரம்

என்பது மரங்களில் ஒருவகை. மற்றொரு வெண்பா,

“நீண்மரத்தி லொன்றேற நேரிழையார் கூந்தலாம்

பூநெருப்பி லொன்றேறப் பூங்குளமாம் - பேணுங்

கழுத்திலொன் றேற இசையா மிசையின்

எழுத்திலொன் றேறவாங் காடு” (சொல்., மா.வ.,16)

என்று அணியியலில் மாத்திரை வர்த்தனம் என்னும் சொல்லணிக்கு எடுத்துக்காட்டாகக் கூறப்படுகிறது. இதில் நீண்மரம் என்றது ஒதி மரத்தை. ஒதி என்பதில் ஓகரம் ஒரு மாத்திரை அதிகம் பெற்றால் (புள்ளியை எடுத்துவிட்டால்) ஒதி என்றாகி கூந்தல் என்று பழைய பொருள்படும். பூ நெருப்பு என்பது ளி. ஏரி என்பதில் பழைய இலக்கணப்படி எகரத்தின்மேல் இருக்க வேண்டிய புள்ளியை எடுத்துவிட்டால் எகரம் நீண்டு ஏகாரமாகி ஏரி என்றாகும். சென்ற நூற்றாண்டிலே புதிய வழக்கம் இருந்ததாகத் தெரிகிறது. இதனை,

“தொல்லை வடிவின எல்லா எழுத்தும் ஆண்டு

எய்தும் எகர ஓகரமெய் புள்ளி” (நன்.,நா: 98)

என்னும் சூத்திரப்படி எகர ஓகரக் குற்றெழுத்துக்கள் புள்ளி பெற்றிருந்ததை நீக்கி, அதற்கு மாறாக ஏகார ஓகாரங்களுக்குப் புள்ளி கொடுத்து எழுதினார்கள். இந்த வழக்கத்தைக் கண்ட இயற்றமிழாசிரியர் இராமநுசுக்கவிராயர் அவர்கள், தம் நன்னூலுக்கு எழுதி வெளியிட்ட இராமாநுசு காண்டிகை உரையில்,

“தொல்லை வடிவின வெல்லா வெழுத்துமாண்

டெய்து மேகார மோகார மெய்புள்ளி”

எல்லா வெழுத்தும் தொல்லை வடிவின என்பது எல்லா எழுத்துக்களும் பல்வேறு வகைப்பட எழுதி வழங்கும் பழைய வடிவையே உடையனவாம். அவ்வாறு வழங்குமிடத்து, ஏகார ஓகார மெய் என்பது ஏகார ஓகாரங்களும் தனி மெய்களும், புள்ளியெய்தும் என்பது பழைய புள்ளியைப் பெறும். இவ்வாறு கூறுதலால் பிற்காலத்தார் அந்தப் புள்ளியை நீக்கிச் சந்தேகப்பட வந்தனரென்பதாயிற்று. இதன் வரலாறானது, எ ஏ, ஒ ஓ, கெ கே, கொ கோ, க்க, ந்ந என வரும். மற்ற உயிர்மெய்களும் தனி மெய்களும் இவ்வாறே புள்ளிபெறும். தொல்லாசிரியர் முதலாயினோர்,

“பழையன கழிதலும் புதியன புகுதலும்

வழுவல கால வகையி னானே” (நன்.: 462)

எனவும்,

“இறந்தது விலக்கல் எதிரது போற்றல்” (நன்.: 14: 8வது வரி)

“இறந்தது காத்தல் எதிரது போற்றல்”

(தொல்., மரபியல். நூ: 660: 12வரி)

எனவும் கூறினமையால் எகர மொகர மெய் புள்ளிபெறும் என்ற இச்சூத்திரத்தை ஏகார ஓகார மெய் புள்ளிபெறும் எனத் திருப்ப வேண்டியது என்னவெனின், இக்காலத்தார் ஏகார ஓகாரங்களுக்கே புள்ளியிட்டெழுவது பெரு வழக்காயின என்பதேயாகும்.

முடிவுரை:-

வீரமாமுனிவர் தமிழ் எழுத்துக்களில் எகர ஓகரங்களுக்கு திருத்தத்தைக் கொண்டு வந்து, வேறுபாட்டை அறியச் செய்தி, தொன்று தொட்டு வந்த இப்பழைய முறையை வீரமாமுனிவர் மாற்றிப் புது விதியை ஏற்படுத்தி, எழுத்துக்கள் சீர்திருத்தம் பெற்றது படிப்பதற்கும் எழுதுவதற்கும் ஒரு தெளிவைக் கொடுத்து தமிழுக்குப் பெருமை சேர்த்துத் தந்தவர் ஆவார். காலந்தோறும் சூழலுக்கு ஏற்ப மொழிகளும் தம்மை வளர்த்துக் கொள்ள வேண்டும் அவ்வாறு தன்னை வளர்த்துக் கொள்ள இயலாத மொழிகள் அழிந்து போய்விடும். அவ்வகையில் தமிழ் மொழியும் தனது நெடுங்கணக்கில் எத்தனையோ மாற்றங்களை சந்தித்து வந்துள்ளது. நவீன உலகத்திற்கு ஏற்ற வகையில் தமிழ் எழுத்து மரபில் மிக முக்கியமான மாற்றங்களை செய்தவர் வீரமாமுனிவர். இன்று இளைய தலைமுறையினர் தமிழை மிக எளிமையாக எழுதுவதற்கு வீரமாமுனிவர் கொண்டு வந்த எழுத்துச் சீர்திருத்தம் மிக முக்கியமானதாக உள்ளது. இன்று அறிவியல் தமிழ், கணினி தமிழ் என்ற பல்வேறு வகை தமிழில் வளர்ந்துக் கொண்டு உள்ளது. இந்த நவீன சூழலுக்கு ஏற்ற வகையில் தமிழ் எழுத்து வடிவில் மாற்றங்கள் செய்வது அவசியமாகும்.

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2. DIGITAL LITERACY IN TEACHER EDUCATION: CHALLENGES, PRACTICES, AND POLICY CONTEXT

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Abstract

Digital literacy is increasingly recognised as a central professional competence for teachers operating in technology-mediated learning environments. This paper critically examines how digital literacy is conceptualised, embedded, and sustained within teacher education programmes, with particular reference to UNESCO’s ICT Competency Framework for Teachers and India’s National Education Policy (NEP) 2020. Adopting a rigorous conceptual review methodology, the study synthesises policy texts, peer-reviewed international scholarship, and practitioner-oriented literature published between 2018 and 2024. Moving beyond descriptive policy alignment, the paper situates digital literacy within contemporary theoretical frameworks such as multiliteracies and critical digital pedagogy. It identifies structural, pedagogical, and institutional challenges that limit effective digital integration, including uneven infrastructure, fragmented professional development, and curriculum–practice gaps. The study advances a pedagogically embedded and ethically grounded model of digital literacy for teacher education and offers analytically framed implications for curriculum design, institutional governance, and continuous professional development. The paper contributes to ongoing debates in digital education by strengthening the theoretical positioning of digital literacy within teacher preparation, particularly in Global South contexts.

Keywords: digital literacy, teacher education, critical digital pedagogy, ICT competencies, NEP 2020, curriculum integration

The rapid expansion of digital technologies has significantly reshaped

contemporary educational practices. Teaching and learning are no longer confined to physical classrooms but increasingly rely on digital platforms, online resources, and blended modes of instruction. The global shift towards online and hybrid learning, particularly in the aftermath of large-scale disruptions to traditional education, has further underscored the need for teachers to possess strong digital competencies.

Within this context, digital literacy extends beyond the acquisition of basic technical skills. It involves the ability to critically evaluate digital information, design meaningful technology-enhanced learning experiences, communicate effectively in virtual environments, and engage ethically and responsibly with digital tools. Teacher education programmes therefore occupy a crucial position in preparing future educators to navigate these complex professional demands.

International and national policy frameworks strongly emphasise the importance of digital competence in teacher education. UNESCO's ICT Competency Framework for Teachers (ICT-CFT) provides a structured model for integrating technology into pedagogy, professional practice, and institutional development. Rather than promoting technology use in isolation, the framework highlights the progressive development of teachers' digital competencies across different stages of their careers, linking technological skills with pedagogical knowledge and educational values.

At the national level, India's National Education Policy (NEP) 2020 places considerable emphasis on digital education and teacher professional development. The policy advocates the use of digital platforms for pre-service training, in-service development, and lifelong learning. Initiatives such as DIKSHA and SWAYAM aim to expand access to quality digital resources and encourage continuous professional growth among teachers. However, existing research suggests that while these initiatives have increased exposure to digital tools, many teachers continue to face challenges in translating technological familiarity into effective pedagogical practice.

This study adopts a systematic conceptual review approach. Policy documents, peer-reviewed journal articles, and practitioner-oriented studies published between 2018

and 2024 were identified through targeted database searches (Scopus-indexed journals, ERIC, and UNESCO repositories). Sources were selected based on relevance to teacher education, digital pedagogy, and policy implementation. The analysis involved thematic synthesis to identify dominant conceptual patterns, theoretical orientations, and recurring challenges related to digital literacy in teacher education. To strengthen its analytical foundation, the discussion is informed by broader theoretical perspectives on digital literacy, including multiliteracies and critical digital pedagogy.

From this perspective, digital literacy is understood as a socially situated practice that encompasses not only technical competence but also critical awareness, cultural sensitivity, and ethical responsibility. In teacher education, this implies that digital competence should be developed in relation to subject pedagogy, learner diversity, and socio-cultural contexts, rather than as a set of decontextualised technical skills.

Digital literacy in teacher education can be viewed as comprising three interrelated dimensions: technical competence, pedagogical application, and ethical responsibility. Technical competence involves familiarity with digital tools, platforms, and basic technological operations. Pedagogical application refers to the ability to integrate these tools meaningfully into teaching, learning, and assessment processes. Ethical responsibility includes issues such as data privacy, academic integrity, inclusive digital practices, and the promotion of responsible digital citizenship among learners. Meaningful development of digital literacy requires its systematic integration across the teacher education curriculum. Embedding digital tasks within coursework, micro-teaching sessions, practicum experiences, and assessment practices enables student teachers to engage with technology in authentic and contextually relevant ways. Activities such as designing digital lesson plans, creating instructional videos, developing online assessments, and reflecting on digital teaching experiences help bridge the gap between theory and practice.

Despite strong policy support, several challenges continue to hinder effective digital

integration in teacher education. Access to digital infrastructure remains uneven across regions and institutions, particularly in rural and economically disadvantaged contexts. Limited connectivity, inadequate availability of devices, and insufficient technical support affect both teacher educators and student teachers.

In addition, professional development opportunities related to digital pedagogy are often fragmented or short-term in nature. One-time training programmes, without sustained mentoring or follow-up support, are insufficient for developing long-term digital competence. These challenges are not uniform and vary significantly across institutional and socio-economic contexts, underscoring the need for context-sensitive and data-informed approaches to digital integration.

The findings of this conceptual review suggest that digital literacy should be treated as an integral component of teacher education rather than an add-on skill. Teacher education institutions need to adopt holistic curricular models that embed digital competencies within subject pedagogy, assessment practices, and professional ethics. Blended models of professional learning, peer collaboration, and reflective practice can support sustained digital competence among both pre-service and in-service teachers.

As a conceptual review, this study does not include empirical data or field-based case studies. While it draws on existing research and policy frameworks, future studies could strengthen the evidence base by incorporating empirical investigations, comparative institutional analyses, or practitioner narratives to deepen understanding of digital literacy practices in teacher education.

Digital literacy constitutes a core component of effective teacher education in the twenty-first century, not merely as a technical skill set but as a pedagogical, ethical, and socio-cultural practice. Preparing teachers for digitally mediated classrooms requires more than technical training; it demands systematic curricular integration, strong theoretical grounding, institutional support, and opportunities for continuous professional learning. Aligning policy frameworks with classroom practice and

addressing issues of access, equity, and context are essential for strengthening digital competence in teacher education and enhancing the quality of teaching and learning.

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**3. WHEN THE MARGINS SPEAK: LANGUAGE AND GENDERED
MARGINALIZATION IN IMAYAM'S ARUMUGAM**

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Abstract

Language is not merely a tool of communication; it is an embodiment of identity, a source of culture, and a marker of social belonging. The words people speak, the dialects they use, and the silences they keep are deeply intertwined with their histories, power relations, and lived realities. For marginalized communities, language can become a way to fight back against injustice. In *Arumugam*, (2006) Imayam gives voice to sex workers and the marginalized ones, who use strong, sometimes abusive words and shout at men who mistreat them. This rough language is not used for shock alone but it shows the pain and struggles they face because of caste, gender, and poverty. Speaking in a “normal” way is difficult for them, as their lives are marked by constant hardships and discriminations. This article argues that by keeping the natural, unpolished speech of these women, Imayam challenges the idea that literature should use only polite or refined Tamil. Instead, he shows that such voices, even when fierce or “ugly,” carry truth and power, and deserve to be heard. In doing so, the novel not only preserves the linguistic identity of women at the margins but also exposes the deep gendered marginalization they endure, where oppression is experienced both through their caste location and their womanhood. The title, *When the Margins Speak*, reflects this dual struggle—where language becomes both a record of suffering and an act of resistance.

Keywords: *Dalit literature, language politics, caste, vernacular Tamil, sex work narratives*

Language is not just a way to talk; it carries the weight of a person's identity, history, and place in society. As *The Routledge Language and Cultural Theory Reader* reminds us, "Language, any language, has a dual character: it is both a means of communication and a carrier of culture" (436). For people on the margins, language can be a tool for survival and a weapon against injustice.

In Tamil literature, the voices of the marginalized, especially Dalit and poor women, have often been softened, polished, or left unheard. Imayam's *Arumugam* breaks this pattern. The novel crafts a narrative in which the voices of sex workers erupt into the literary space, raw and unapologetic. Their words are often sharp, peppered with curses, and hurled like weapons at people who demean or exploit them. This is not done for shock value but to show the conditions that shape their language: poverty, caste discrimination, violence, and gender-based humiliation. In the world of *Arumugam*, language is deeply tied to gendered marginalization.

Women like Chinnapponnu, Vasantha, and Dhanabagiyam speak in ways that reflect their daily fight for dignity, making it clear that their words are rooted in pain as much as in defiance. This article, titled *When the Margins Speak: Language and Gendered Marginalization in Imayam's Arumugam*, explores how Imayam uses language to reveal the lived experiences of these women and why it is important to hear them as they are, without refinement or censorship. This article argues that in *Arumugam*, Imayam's deliberate use of raw, colloquial Tamil functions as a political and aesthetic strategy through which the intersecting oppressions of caste, gender, and poverty experienced by marginalized women, especially sex workers are exposed, resisted, and reclaimed as forms of linguistic and social agency.

In *Arumugam*, the women use rough and direct speech as a kind of protection. Their words come from a life shaped by caste discrimination, violence against women, and poverty. Speaking in this way is not just a habit but a way to survive in a world that constantly tries to silence or shame them. By keeping their natural, unpolished Tamil, Imayam refuses to clean up or soften their voices for the sake of politeness. Instead, he

lets them speak in the way they truly do, with all the rhythm and style of their everyday lives. This language may sound “ugly” to some, but in the novel it becomes a strong way for the women to show who they are, hold on to their identity, and push back against the social forces that try to control them.

Dalit writers often express their experiences in the most realistic way by using their native speech. As Amar Nath Prasad and M. B. Gaijan observe, “their language as well as images come from their own experiences instead of from their observation of nature” (p. 5). While Imayam is not identified as a Dalit writer, in *Arumugam* he adopts a similar linguistic strategy, employing the unfiltered idioms and speech patterns of the marginalized. When Bhagyam cries after the death of Chinnaponnu, “My daughter is gone... Aren’t there so many fellows about who live on urine and deserve a worse fate? Why couldn’t death have taken them away instead of her? Ah, she’s gone and left me an orphaned corpse” (Imayam162), her words are raw, straightforward, and deeply rooted in personal grief. This is not the polished sorrow of elite literary Tamil but a grief-laden fury shaped by a life marked by caste oppression, gender-based violence, and economic deprivation. By giving space to such voices, Imayam aligns himself with the subaltern tradition, using the language of the margins not as a stylistic device, but as a mode of truth-telling inseparable from lived reality.

The sexual exploitation of lower-caste women by upper-caste men is, as Joshil K. Abraham and Judith Misrahi-Barak observe, “a familiar trope located in the structure of caste” (p. 184). In *Arumugam*, this exploitation reaches its most brutal form in the death of Chinnaponnu, a sex worker whose body is found in a drain the next morning. Vasantha recounts that, according to the Chekkumedu women, “the marks caused by fingernails around her neck resembled a wound inflicted by a sharp instrument,” (Imayam160) revealing the violence she endured during sex. The scene makes visible the intersection of sexual desire and caste entitlement where the woman’s body becomes a disposable object, discarded once it has served its purpose. By narrating such incidents through the voices of the marginalized women themselves, Imayam refuses to sanitize

their reality; the language remains raw, unembellished, and deeply political, transforming personal tragedy into a stark condemnation of structural oppression.

As Joshil K. Abraham and Judith Misrahi-Barak note, “patriarchal oppression within the Dalit community is not the only type of oppression experienced by Dalit women. They are also constantly vulnerable to sexual harassment and abuse at the hands of men belonging to other castes” (p. 254). In *Arumugam*, Imayam shows that this vulnerability does not end even in death. When Chinnappону’s body is found in a drain after a violent encounter, the women around her face not compassion but contempt from the authorities. The police investigating the scene hurl abuse: “Get lost, you whores. Look at them come, displaying their Things. Why don’t you people hang yourselves? Lock them up for six months. Let’s see if these brazen harlots know their place at least then” (Imayam156). This exchange exposes how castism and patriarchal prejudices are embedded in the very institutions meant to uphold justice. The women’s grief is met with public shaming, turning an act of investigation into an act of oppression. Imayam’s choice to preserve such raw speech makes visible the structural hostility Dalit women face, where verbal humiliation becomes an extension of the physical and sexual violence inflicted on them.

Imayam focuses on colloquial language as a powerful tool to convey the lived realities of sexual workers and other marginalized individuals, refusing to smooth over the rough edges of their speech for literary politeness. Chinnappону’s angry command to *Arumugam* -“Go outside and stand guard. Thrash any cur that walks in with your chappals... Their mother’s also have what they want. Tell them to get it there” (Imayam116) - is not mere vulgarity, but the voice of a woman hardened by physical exhaustion, unhygienic living conditions, and degrading encounters. The uncleanness of their living spaces deepens this bitterness: “The hut was barely big enough for just two to lie down and yet it leaked in twenty different spots; they had to place tumblers, plates and bowls in strategic positions, to hold the water dripping from leaks” (Imayam121). As Abraham and Misrahi-Barak observe, “the connection between

female sex, caste and pollution is persistent” (278), and it is precisely this entanglement that shapes the bitter, defensive speech of women like Chinnapponnu. The insult “thoomappayya,” used by Dharmamoorthy (85, 108), emerges from this same socio-economic and emotional landscape, where language becomes both a weapon and a shield. Imayam’s choice to retain these raw, colloquial voices preserves the emotional truth of his characters, making their speech a living record of oppression and pent-up rage.

Imayam’s *Arumugam* exposes how women from marginalized communities become perpetual victims of a deeply entrenched patriarchal order, where their bodies are sites of control, exploitation, and humiliation. Dhanabagiyam’s abuse at the hands of Jerry Albert and Vasantha’s harassment by the manager of the Ram industry reveal how power operates through sexual dominance, reducing women to objects of male gratification.

As Rekha observes, “all issues related to sex and sexuality become the extension of male authority and power and get replicated as relations of dominance and submission” (157). This holds equally true for Chinnapponnu, Abi, and other sex workers in the novel, who, stripped of autonomy, become mere toys in the hands of men who exploit their vulnerability. Imayam refuses to sentimentalize these experiences; instead, he presents them in stark realism, showing how caste, gender, and economic oppression intersect to perpetuate this unbroken cycle of domination.

Dalit women are often described as “thrice-alienated,” facing layered oppression due to their caste, class, and gender. As it is highlighted in the book *Women Reinventing Development: The Odisha Experience*, “Scheduled Caste women face a triple layer of discrimination of caste, class, and gender.” (Hans 4), women in Dalit community undergo three layers of discrimination. In *Arumugam*, Imayam vividly illustrates this compounded marginalization through characters like Chinnapponnu, Vasantha, and Dhanabagiyam. Their caste identity determines the kind of degrading work they are forced into, their economic poverty keeps them trapped in exploitative environments,

and their gender subjects them to relentless sexual harassment and violence. Chinnapponnu's life as a sex worker is dictated not by choice but by the crushing constraints of poverty and caste stigma; Vasantha's harassment at the Ram industry shows how workplace exploitation targets women's gendered vulnerability; and Dhanabagiyam's abuse by Jerry Albert underscores how patriarchal power disregards the humanity of women from oppressed communities. Together, their stories prove that these women's alienation is not singular but multiplied by intersecting systems of discrimination as said by Hans, "Dalit feminist thoughts put forth that a Dalit woman undergoes three tiers of discrimination namely, gender, class, and caste." (22)

In *Arumugam*, Imayam shows how the lives of marginalized people are shaped by both small opportunities and constant humiliations. As Satyanarayana notes, "Dalit writings in Indian languages have praised the arrival of colonial modernity for introducing new principles and institutions that enabled Dalits and other marginal groups to participate in the public space" (p. 20). But even with these openings, the characters in *Arumugam* still face what Still calls "structural humiliation" that "is continually reinforced in daily life" (p. 54). This is clear in the way sex workers like Chinnapponnu and Vasantha are treated—not only by clients and police, but also by doctors, nurses, neighbors, and even people from their own caste. They may be able to step into public spaces, but those spaces often bring new forms of insult and mistreatment. Imayam's story makes it clear that while modern times promised inclusion, Dalit women still live with the daily struggle of being seen and yet being constantly disrespected.

In *Arumugam*, Imayam reveals how Dalit women's oppression is compounded by the intersection of patriarchy and caste hierarchy, echoing Abraham and Misrahi-Barak's observation that "patriarchy and imperialism intersect in ways similar to patriarchy and caste hierarchy – as a context where women's bodies have been taken up as the only evidence they may give" (275). Chinnapponnu's encounters with the healthcare system expose this entrenched contempt: "Doctors and nurses usually treated

women like Chinnapponnu with a condescension laced with heavy contempt... medicines were usually flung into their faces... injections... administered with merciless, hard pricks” (Imayam132). The humiliation intensifies with verbal abuse from female medical staff: “Why have you come here?... Why don’t you people just die?... Oh! Look at her, the slut” (Imayam133). These moments illustrate that Dalit women are not only excluded socially and economically but are also denied dignity in spaces meant for care. Their bodies are reduced to markers of pollution and moral judgment, reinforcing a cycle where both their caste identity and womanhood make them targets of systemic violence. Imayam’s unfiltered portrayal forces the reader to confront the brutal normalcy of this dehumanization in patriarchal, caste-bound society.

Conclusion

Imayam’s *Arumugam* clearly shows how women suffer when caste, poverty, and patriarchy come together. Using everyday speech and realistic scenes, he gives voice to sex workers, widows, and poor women who face insults, exploitation, and neglect every day. In the novel, gendered oppression is not only about sexual violence or lack of money—it also happens in public places, at work, in hospitals, and even at home, where women’s dignity is constantly attacked. Characters like Chinnapponnu, Vasantha, and Dhanabagiyam show that for women in these situations, simply staying alive is a struggle against humiliation, hard work, and being treated as less than human. By showing their lives without softening the harsh truths, Imayam makes readers face the reality that gendered marginalization is not rare, but a normal part of caste-based society. His choice to keep the rough, raw language of the characters reminds us of the importance of truly listening when voices from the margins speak.

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4. KORKAI: AN IMPORTANT PORT CITY OF THE SANGAM PANDYAS

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Abstract

South India has a long history and rich cultural heritage, yet till the arrival of the Britishers in South India, the people have no clear idea about the glory of their past and the achievements of their predecessors. After the coming of the Britishers, they realized the glorious past of the South Indians and through archaeological excavations they started to bring the hidden past to light. For instance, the first archaeological excavation was held at Pallavaram near Chennai by a British Geologist named Robert Bruce Foote in 1863. It confirmed the existence of the Palaeolithic settlements in South India. Similar excavations were conducted at Korkai, Adichanallur and Arikamedu. It revealed the trade contact of the ancient Tamils with the foreign countries and so it added more glory to South India among the countries across the world. Following that, innumerable excavations were conducted in South India far and wide. After India's Independence, through the Archaeological Survey of India, the government undertook many excavations in order to bring back the buried antiquity of South India. This article entitled "Korkai: An Important Port City of the Sangam Pandyas", is going to remind the great antiquity of South India to the current generation.

Key Words: Archaeological Survey of India, Artifacts, Excavation, Remains, Unearthed.

Introduction

Archaeological excavation is the process of unearthing material remains from the past to study the human past. In short, excavation is the way to obtain material

remains by digging the earth for study in archaeology. Archaeological excavation was not born overnight. It evolved through the centuries and blossomed into what we call archaeological excavation today. South India has a long history and rich cultural heritage. In the political field it witnessed the emergence of so many great dynasties like Chera, Chola, Pandya, Pallava, Imperial Chola etc. In society, it gave due importance to the social values like chastity, family etc. Similarly, it has a glorious economic history, because it had trade relations with the foreign countries.

For the cultural development it produced three Sangams. But till the arrival of the Britishers in South India, the people have no clear idea about the glory of their past and the achievements of their predecessors. After the coming of the Britishers, they realized the glorious past of the South Indians and through archaeological excavations they started to bring the hidden past to light. For instance, the first archaeological excavation was held at Pallavaram near Chennai by a British Geologist named Robert Bruce Foote in 1863. It confirmed the existence of the Palaeolithic settlements in South India. Similar excavations were conducted at Korkai, Adichanallur and Arikamedu. It revealed the trade contact of the ancient Tamils with the foreign countries and so it added more glory to South India among the countries across the world. Following that, uncountable excavations were conducted in South India far and wide. After India's Independence, through the Archaeological Survey of India, the government undertook many excavations in order to bring back the buried antiquity of South India. This article entitled "Korkai: An Important Port City of the Sangam Pandyas", is going to remind the great antiquity of South India to the current generation.

The Sangam Pandya

The Pandyas were one of the oldest dynasties having the privileges of having a continuous history upto 16th century A.D. The name Pandya is derived from the word Pandu which means ancient. The ancient epics, the Ramayana and the Mahabharatha refer to them. The earliest Pandya ruler was Vadimbalambaninra Pandya also called

Nediyon. Their emblem was fish. The Pandyas were credited with the establishment of three Sangams. Since the Pandyas ruled the Tamil country, they were called Thennavan.

Geographical Location

Korkai was an important port city and also the initial capital of the Ancient Pandyas. It is at present situated as an insignificant village in the Thoottukudi district of Tamil Nadu. It is located on the northern side of river Tamiraparani and is in the north east of Srivaikundam by 20 Kms and by 15 Kms from Adichanallor. It is also positioned about 6 Kms from the shore of Bay of Bengal. The place Korkai has so many historical references.

Historical References

Korkai has been invariably referred to by so many people. Periplus refers to it as 'Comari', which was a cape and a harbour. He states that this region from Comara to Colchi(Korkai) had pearl fisheries, which were worked by sentenced criminals and the region was owned by the Pandyas. Ptolemy refers to the place as 'Kolkhai' and says that it was an emporium. Pliny has also attested this and gave it a very high position among all valuables exported from Tamil country to the west.

Similarly Sanskrit literature also refers to this city. Arthashastra refers to this city located on the bank of river Tamiraparani and was famous for pearl fishing. In Arthashastra, Kautilya relates that pearls were found in Kavata of the Pandyan country (here Kavata may be identified with Korkai) on the banks of river Tamiraparani. Kalidasa in his Raghuvamsa also attests the obtainability of pearls in abundance in the mouth of river Tamiraparani. The Hathigumpha inscription of Kharavela of Kalinga states that the King Kharavela received from the Kings of South India among other things rich presents of pearls. This information affirms the fact that Korkai served as an important pearl fishing city of the ancient Pandyas.

Ancient Tamil literature offers much information regarding the city of Korkai and its international links. Historian and retired Professor A. Sivasubramanian said that Korkai has been referred to in various ancient Tamil literatures including

Silapathikaram, Kalithogai, Akananuru and Aingurunuru. It was called 'Pandya-Kavada' in Kalithogai. Ahananuru mentions that the city Korkai was situated within a fort and it was famous for pearl fishing. It further states that the pearls fished from Korkai were very famous and had a good name for it. Silappadikaram refers to this city as one of the popular ports of the time.

The First Historical Excavation

Korkai has an antiquity of its own having urn burials and megalithic objects. Excavations were also done in this site to trace its history. In 1876 Caldwell did excavation in Korkai and its adjoining places. He found an urn burial which was eleven feet in circumference and contained objects such as human bones, small black polished wares etc. in most of the urns. Finally, he concludes that the ancient level of Korkai was about eight feet below its present level which itself is proof of its great antiquity. In addition to that the department of Archeology also conducted excavations, where a large number of shells, rings, potsherds etc. were found which all belonged to the coarse variety of the medieval period. A large number of inscribed potsherds bearing Tamil characters assignable to the period from 3rd century B.C. to 2nd century A.D. were also noticed in the layers. In some other trenches, bone pieces and black and red potsherds, inscribed potsherds etc. were also found.

Other Excavations

After 52 years of the first historical excavations at Korkai, again it was excavated. The Tamil Nadu Department of Archeology had surveyed the region back in 1968 under the headship of Director, Mr. R. Nagaswamy and it is said to be the first survey by the state in Tamil Nadu. His excavation unearthed a structure with nine courses of bricks in six rows at the depth of two- and- a half feet from surface level and three large sized rings placed one over the other, below the brick course. The artifacts collected from Korkai in 1968 were initially stored at a museum in Korkai village, however, it was shifted to Madurai and Chennai when the museum was closed in late 90's.

Because of these excavations so many hidden facts were brought into light. These excavations also proved the historicity of Korkai that is mentioned in the ancient literature. Through this article, it tries to recap once again the glory of Korkai in various aspects in those days. It is believed that this article will create an idea about the antiquity of Korkai among the current generation.

As a Centre of Political Power

Korkai was the center of political activities. In the early historical period Korkai was the capital of the early Pandyas. By virtue, the king's palace and fort establishments were situated there. The Sangam literature such as Madurai Kanchi, Silapadikaram, Manimekalai, Natrinai etc. refers about the political history of Korkai and they say that the Pandyan Kings assumed titles such as Korkai Vendan, Korkai Koman, Korkai Porunan etc. which testifies the importance of Korkai. In the beginning of the Christian Era, Korkai was the capital and an important port city of the Pandyas. But in due course, as the Pandyas shifted their capital to the present-day Madurai, subsequently, Korkai lost its importance. However, Korkai remained to be their subsidiary capital and they appointed a crown prince or an heir apparent to the throne who resided at Korkai to control the important affairs by camping there. It shows the political importance of Korkai during the period of the ancient Pandyas.

As a Trade Centre

Foreign Travelers like Strabo, Pliny, Ptolemy, the author of Periplus of Erythraean Sea mentioned about the international trade of the Pandyas with the Roman empire through the port at Korkai. Strabo says that embassies were sent to the court of Augustus Caesar of Rome from the Pandyan kingdom to promote trade. He further says that he himself saw 120 ships loaded with pearls and other articles. Periplus and Ptolemy agree that Korkai was the headquarters of Pearl fishery by the time. It is stated that the Greek and the Roman ladies increasingly used Pandyan pearls for their personal adornment. Pliny says that the Egyptian Queen Cleopatra was very fond of using Pandyan pearls. It seems likely that Roman trade in pearls was increased after the

discovery of Hippalus due to the heavy demand of the Greek and Roman ladies for their personal adornment. Apart from literary evidence, through archeological excavations, researchers have found Roman ware and Rouletted ware from Korkai. This evidence testifies to the fact that Korkai was an internationally reputed trade centre of the time.

As a minting Industry

For the purpose of corroborating the international trade with the city of Korkai, a large number of coins both indigenous and foreign were found at Korkai. Prof. R. P. Sethupillai feels by taking into account numerous coins that the Pandya kings had their akkasalai (mint) at Korkai. Among them the copper and silver punch marked coins were collected from different places around Korkai in large numbers. These coins bear the symbol of stars, wheels and other small marks and are irregularly punched here and there. They are commonly called punch- marked coins. The gold coins of the Pandas bear the distinguishing Pandya figure of the fish with ancient Nagari letters. In order to prove this, there was a reference in Sangam Literature, when Pandyan Nedumchezhiyan died out of grief in the Kannaki Kovalan episode, his younger brother Vertivelchezhiyan, the crown Prince of Korkai ordered the massacre of one thousand goldsmiths. It proves the prevalence of gold smith in and around Korkai. In addition to that, thirty Arabian coins and one Spanish coin were also unearthed from Korkai. The availability of these varieties of coins clearly attests the prevailing of a minting industry at Korkai.

As a Religious Centre

Korkai was also a religious centre. Peripulus records the southern extremity of the Indian Peninsula where people used to come here and lead a pious life. It was a center of festivals also. It is stated that every year on a full moon day they celebrate the Korkai festival after the sunset by decorating the city. Ahananuru states that during the time, the city looked like a ship and ladies worshiped God by offering pearls and conches. In order to prove this literary evidence, there was archaeological evidence found through the excavation of 1968. In that excavation found the ruins of conch- shell cutting

factories and centres for splitting open pearl oysters. It proved the religious importance of Korkai during the period of the early Pandyas.

Decline of Korkai

A close study of the above, it is known that Korkai was an important port city that flourished during the early centuries of Christian Era. Because of its pearls, foreigners came and settled there and traded with the Tamil people. As a result of it, Tamil Kings acquired more and more wealth. By dint of this wealth the Tamil kings established a stable government, maintained a standing army, patronized religion and promoted arts and culture. But unfortunately, while the Roman empire collapsed in the 3rd Century A.D. its trade with Korkai also collapsed. In the meantime, the Roman Emperor Nero passed an Act to prevent the use of gold as medium of exchange as it drained the Roman economy. As international trade declined, the importance of Korkai also lost its importance. At the same time due to natural calamity Korkai port might have submerged and became unfit for use. Therefore, the Pandya kings shifted their capital to Madurai after the 5th Century A.D. Subsequently, the people involved in trade and commerce also shifted their residence to Madurai.

Conclusion

Korkai is one of the ancient archaeological sites in South India. The first excavation at Korkai was undertaken by Caldwell and following that innumerable excavations were held at the place. All these continuous findings have made clear the antiquity of South India and the existence of a fine civilization for a long time. A systematic exploration and excavation in that area will yield rare antiquities which will throw new light to rewrite the history of Ancient Tamil Nadu in proper perspective. But nowadays because of our busy life we are forgetting the antiquity of our land and so it is the duty of every historian to recap the excavations of Korkai. Likewise, there is a chance to find the hidden facts of Thoothukudi region to further uncover Tamil Nadu's maritime legacy. It is believed that through this kind of attempts one can remind the great antiquity and the glory of our land to the current generation.

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5. MONOPHONIC COVER PEBBLING NUMBER OF ALGEBRAIC GRAPHS

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ABSTRACT.

Given a connected graph G and a configuration D of pebbles on the vertices of G , a pebbling transformation takes place by removing two pebbles from one vertex and placing one pebble on its adjacent vertex. A monophonic path is considered to be a longest chord less path between two vertices u and v which are not adjacent. A monophonic cover pebbling number, $\gamma_\mu(G)$, is a minimum number of pebbles required to cover all the vertices of G with at least one pebble each on them after the transformation of pebbles by using monophonic paths. In this paper we determine the monophonic cover pebbling number of k -coprime graphs.

Keywords: cover pebbling, monophonic pebbling, monophonic cover pebbling and k -coprime.

1. Introduction

Lagarias and Saks [6] contributed for the development of research on graph pebbling. Chung gave further developmental ideas using graph pebbling concepts to solve the number theory problems in [7]. A pebbling move is defined as extracting two pebbles from one vertex and keeping one pebble on the adjacent vertex and eliminating the other pebble. Crullet.al.[5], defined the cover pebbling number γ

(G), as follows: It is the minimum number of pebbles needed to cover all the vertices with at least one pebble however we place pebbles in the initial configuration. Lourdasamy et al. defined detour pebbling number [2], monophonic pebbling number [1] and monophonic cover pebbling number [3]. A monophonic cover pebbling number, $\gamma_\mu(G)$, is a minimum number of pebbles require to cover all the vertices of G with at least one pebble each on them after shifting of pebbles by using monophonic paths which is chord less and the longest [4]. The application of this concept plays a vital role in the supply of goods and transportation problems. This is also applied in the network transmission of the information from one node to the other. The application of monophonic cover pebbling number decides the equal distribution of goods on every customer by using the monophonic path. For the basic terminologies of graphtheory, the readers can refer to [9] and [8]. In this paper we determine the monophonic cover pebbling number of some graphs. To prove the worst condition, we use the stacking the orem [5]. It is stated as: Let D be the initial configuration of pebbles. When the initial configuration D is placed on a single vertex v such that the dist (v) is a maximum. Such a way $s(v) = \sum_{u \in V(G)} 2^{dist(u,v)}$. Do this for every vertex $v \in V(G)$. Then $\gamma(G)$ is the largest $s(v)$.

Although cover pebbling and its variants have been studied for several classes of graphs, the concept of *monophonic cover pebbling number* has received comparatively less attention, particularly for algebraic graphs arising from number-theoretic constructions. In this context, *k-coprime graphs* form an important class with rich structural properties and potential applications in network distribution problems. The main objective of this paper is to determine the monophonic cover pebbling number for k -coprime graphs and to establish exact values for specific cases. This study not only extends existing results in monophonic pebbling theory but also contributes to a deeper understanding of resource distribution along longest chordless paths in algebraic graph structures.

Theorem 1.1. [3] For the path P_n , $\gamma_\mu(P_n)$ is $2^n - 1$.

Theorem 1.2. [3] For the fan graph F_n , $\gamma_\mu(F_n) = 2^{n-1} + 1$.

Theorem 1.3. [3] For the star graph $K_{1,n}$, $\gamma_\mu(K_{1,n}) = 4n - 1$.

Theorem 1.4. [3] For the cycle graph C_n , $\gamma_\mu(C_n)$ is

$$\begin{cases} 2 \sum_{k=\frac{n}{2}+1}^{n-2} 2^k + 2^{\frac{n}{2}} + 5, & \text{if } n \text{ is even} \\ 2 \sum_{k=\lfloor \frac{n}{2} \rfloor} n - 2 + 5, & \text{if } n \text{ is odd} \end{cases}$$

Result 1.5. [5] Let G be a connected graph. The monophonic distance between u and v is 0 if and only if $u=v$ and 1 if and only if $u-v$ is an edge of G .

Definition 1.6. [10] Let $v \in V(G)$. Then v is called a key or source vertex if $\text{dist}(v)$ is maximum.

Notation 1.7. Through out this article we denote

1. β as the source vertex.
2. M_i is the monophonic path and M_i^\sim contains the vertices which are not on M_i .
3. We use MCPN for monophonic cover pebbling number.
4. $N(v_0)$ is the neighbourhood of v_0 .

2. Monophonic cover Pebbling number for k-coprime graphs CPG(k,n)

In this section, we compute the monophonic cover pebbling number of some k-coprime graphs.

Theorem 2.1. For $CPG(1,2)$, $\gamma_\mu(CPG(1,2))$ is 3.

Proof. Let $V(CPG(1,2))$ be $\{v_1, v_2\}$. Then $E(CPG(1,2)) = \{v_1v_2\}$. Now $CPG(1,2) \cong P_2$ and by Theorem 1.1, $\gamma_\mu(CPG(1,2))$ is 3.

Theorem 2.2. For $CPG(1,3)$, $\gamma_\mu(CPG(1,3))$ is 5.

Proof. Let $V(CPG(1,3))$ be $\{v_1, v_2, v_3\}$. Then $E(CPG(1,3)) = \{v_1v_2, v_1v_3, v_2v_3\}$. Now $CPG(1,3) \cong C_3$ and by Theorem 1.4, $\gamma_\mu(CPG(1,3))$ is 5.

Theorem 2.3. For $CPG(1,4)$, $\gamma_\mu(CPG(1,4))$ is 9.

Proof. Let $V(\text{CPG}(1,4))$ be $\{v_1, v_2, v_3, v_4\}$. Then $E(\text{CPG}(1,4)) = \{v_1v_2, v_1v_3, v_1v_4, v_2v_3, v_3v_4\}$. Now $\text{CPG}(1,4) \cong F_4$ and by Theorem 1. 2, $\gamma_\mu(\text{CPG}(1,4))$ is 9.

Theorem2.4. For $\text{CPG}(1,5)$, $\gamma_\mu(\text{CPG}(1,5))$ is 11.

Proof. Let $V(\text{CPG}(1,5))$ be $\{v_1, v_2, v_3, v_4, v_5\}$. Then $E(\text{CPG}(1,5)) = \{v_1v_2, v_1v_3, v_1v_4, v_1v_5, v_2v_3, v_2v_5, v_3v_4, v_3v_5, v_4v_5\}$. The resulting graph is $K_5 - v_2v_4$. Therefore v_2 and v_4 are non-adjacent vertices. Let $p(v_4) = 10$ and $N(v_4) = \{v_1, v_3, v_5\}$. Now to cover the vertices in $N(v_4)$ it will cost 6 pebbles; to cover v_2 which is at the monophonic distance 2 it will cost 4 pebbles and there are zero pebbles to cover v_4 . Thus, $\gamma_\mu(\text{CPG}(1,5)) \geq 11$. Now we prove $\gamma_\mu(\text{CPG}(1,5)) \leq 11$.

Case 1: Let v_1 be the source vertex.

$N(v_4) = \{v_1, v_3, v_5\}$. To cover the vertices in $N(v_4)$ it will cost 8 pebbles and one pebble is used to cover v_1 . By symmetry the proof follows for the source vertices v_3, v_5 .

Case 2: Let v_2 be the source vertex.

$N(v_2) = \{v_1, v_3, v_5\}$. To cover the vertices in $N(v_2)$ it will cost 6 pebbles; to cover the vertex v_4 which is at the monophonic distance 2 it will cost 4 pebbles and one pebble is used to cover v_1 . By symmetry the proof follows for the source vertex v_4 .

Hence, $\gamma_\mu(\text{CPG}(1,5)) = 11$.

Theorem2.5. For $\text{CPG}(1,6)$, $\gamma_\mu(\text{CPG}(1,6))$ is 17.

Proof. Let $V(\text{CPG}(1,6))$ be $\{v_1, v_2, v_3, v_4, v_5, v_6\}$. Then $E(\text{CPG}(1,6)) = \{v_1v_2, v_1v_3, v_1v_4, v_1v_5, v_1v_6, v_2v_3, v_2v_5, v_3v_4, v_3v_5, v_4v_5, v_5v_6\}$. If $p(v_6) = 16$ then to cover the vertices v_2, v_3, v_4 which are at distance 2 it

will cost 12 pebbles and to cover v_1 and v_5 it will cost 4 pebbles. Then we are left with zero pebbles to cover v_6 . Thus, $\gamma_\mu((\text{CPG}(1,6))) \geq 17$. Now to show $\gamma_\mu((\text{CPG}(1,6))) \leq 17$.

Case 1: Let v_6 be the source vertex.

There are 2 vertices at monophonic distance 1 and 3 vertices at distance 2. Therefore, the number of pebbles need to cover $\text{CPG}(1,6)$ is 17.

Case 2: Let v_1 be the source vertex.

The remaining vertices are adjacent to v_1 . Thus, to cover the 5 adjacent vertices with v_1 it will cost 10 pebbles and one pebble is used for the source vertex. By symmetry the proof follows for the source vertex v_5 .

Case 3: Let v_3 be the source vertex.

Except v_6 which is at distance 2, the remaining vertices are adjacent to v_3 . Thus, to cover v_6 it will cost 4 pebbles; to cover the 4 adjacent vertices it will cost 8 pebbles and one pebble is used for v_3 . Therefore, with a configuration of 13 pebbles we can cover all the vertices.

Case 4: Let v_2 be the source vertex.

There are 2 vertices at distance 2 which cost 8 pebbles to cover; 3 adjacent vertices which cost 6 pebbles to cover and one pebble is used for v_2 . By symmetry the proof follows for the source vertex v_4 .

Thus, $\gamma_\mu((\text{CPG}(1,6)))$ is 17.

Theorem 2.6. For $\text{CPG}(2,2)$, $\gamma_\mu((\text{CPG}(2,2)))$ is 3.

Proof. Let $V(\text{CPG}(2,2)) = \{v_2, v_3\}$. Then $E(\text{CPG}(2,2)) = \{v_2v_3\}$. Now $\text{CPG}(2,2) \cong P_1$ and by Theorem 1.1, $\gamma_\mu(\text{CPG}(2,2))$ is 3.

Theorem 2.7. For $\text{CPG}(2,3)$, $\gamma_\mu((\text{CPG}(2,3)))$ is 7.

Proof. Let $V(\text{CPG}(2,3)) = \{v_2, v_3, v_4\}$. Then $E(\text{CPG}(2,3)) = \{v_2v_3, v_3v_4\}$.

Now $CPG(2,3) \cong P_2$ and by Theorem 1.1, $\gamma_\mu(CPG(2,3))$ is 7.

Theorem 2.8. For $CPG(2,4)$, $\gamma_\mu(CPG(2,4))$ is 9.

Proof. Let $V(CPG(2,4)) = \{v_2, v_3, v_4, v_5\}$. Then $E(CPG(2,4)) = \{v_2v_3, v_2v_5, v_3v_4, v_3v_5, v_4v_5\}$. Now $CPG(2,4) \cong F_4$ and by Theorem 1.2,

Theorem 2.9. For $CPG(2,5)$, $\gamma_\mu(CPG(2,5))$ is 15.

Proof. Let $V(CPG(2,5)) = \{v_2, v_3, v_4, v_5, v_6\}$. Then $E(CPG(2,5)) = \{v_2v_3, v_2v_5, v_3v_4, v_3v_5, v_4v_5, v_5v_6\}$. The resulting graph is like a fan graph of order 4 together with an additional pendent edge at v_5 . Consider the monophonic path $M_1: v_2, v_5, v_6$. If $p(v_6) = 14$ then By Theorem 1.1, to cover $V(M_1)$ it will cost 7 pebbles and to cover v_3, v_4 which is at distance 2 it will cost 8 pebbles; but we are left with only 7 pebbles. Hence, $\gamma_\mu(CPG(2,5)) \geq 15$. Now to show $\gamma_\mu(CPG(2,5)) \leq 15$.

Case 1: Let the source vertex be v_6 .

Consider the monophonic path $M_2: v_6, v_5, v_4$. By Theorem 1.1, to cover $V(M_2)$ it will cost 7 pebbles and to cover v_2, v_3 which is at the monophonic distance 2 it will cost 8 pebbles. Thus, with a configuration of 15 pebbles we can cover all the vertices. Similarly, we can prove for the vertices v_2, v_3, v_4 .

Case 2: Let the source vertex be v_5 .

Note that $\deg(v_5) = 4$. There are 4 vertices at monophonic distance 1. Therefore, with a configuration of 9 pebbles we can cover all the vertices.

Thus $\gamma_\mu(CPG(2,5)) = 15$.

3. Conclusion

This paper determines the monophonic cover pebbling number for several k -coprime graphs using properties of monophonic paths and the stacking theorem. The results extend existing work on monophonic pebbling to algebraic graph structures and highlight the influence of graph topology on pebble distribution. These findings contribute to the study of efficient resource allocation in networks and provide a basis

for further research on monophonic pebbling in algebraic graphs.

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6. A COMPARATIVE STUDY OF PICTURE FUZZY SOFT GRAPHS AND ANALYTIC HIERARCHY PROCESS FOR MULTI-CRITERIA DECISION MAKING

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Abstract

Multi-Criteria Decision-Making (MCDM) techniques play a vital role in solving complex decision problems involving uncertainty, imprecision, and multiple conflicting criteria. In recent years, fuzzy-based models have gained significant attention due to their ability to handle vagueness inherent in real-world problems. This paper presents a comprehensive comparative analysis of two prominent MCDM approaches: Picture Fuzzy Soft Graphs (PFSG), and Analytic Hierarchy Process (AHP). The theoretical foundations of picture fuzzy sets, soft sets, and graph theory are integrated to construct PFSG-based decision models. Furthermore, AHP method is systematically applied to the same decision-making scenario to evaluate their effectiveness. A medical decision-making problem involving patient prioritization is used as a case study to demonstrate the applicability of these methods. The comparative results indicate that while PFSG effectively handle uncertainty and ranking, AHP provides greater consistency and interpretability.

Keywords: *Picture Fuzzy Sets, Analytic Hierarchy Process, Multi-Criteria Decision Making.*

1 INTRODUCTION

Decision-making is a crucial activity in many real-world domains such as engineering, healthcare, management and economics, where selecting the most appropriate alternative often involves multiple and conflicting criteria. Such problems are known as Multi-Criteria Decision-Making (MCDM) problems. In practical situations, decision-makers frequently face uncertainty, imprecision and incomplete information, making classical mathematical decision models insufficient for effective analysis. To overcome these limitations, fuzzy set theory has been extensively used to model vagueness and human judgment in decision environments. **Picture Fuzzy Soft Graphs (PFSGs)**, introduced by Chellamani et al. (2022), provide a powerful mathematical framework that integrates picture fuzzy sets, soft sets, and graph theory. The Analytic Hierarchy Process (AHP), as introduced by Saaty and further elaborated in Taherdoost (2017), provides a systematic framework for multi-criteria decision making by converting subjective judgments into a quantifiable scale.

Among the various extensions of fuzzy sets, Picture Fuzzy Sets (PFSs) provide a more expressive framework by incorporating positive, neutral and negative membership degrees, enabling simultaneous representation of acceptance, hesitation and rejection. In addition, soft set theory offers a parameterized structure for handling uncertainty, while graph theory effectively models relationships among alternatives. The integration of these concepts leads to Picture Fuzzy Soft Graphs (PFSGs), which offer a powerful tool for addressing complex decision-making problems involving uncertain attributes and their interconnections.

2 PRELIMINARIES

Definition 2.1

Let Y be a non-void set. A picture fuzzy set (PFS) P of Y characterized by positive (PM), neutral (NM) and negative membership (NEM) functions denoted by μ_P , γ_P and σ_P respectively are given by:

$\mu_P: Y \rightarrow [0, 1], \gamma_P: Y \rightarrow [0, 1], \sigma_P: Y \rightarrow [0, 1]$ such that
 $0 \leq \mu_P(c) + \gamma_P(c) + \sigma_P(c) \leq 1$ for all $c \in Y$.

Definition 2.2

A Picture fuzzy set O is a subset of another picture fuzzy set T if for all $y \in Y, \mu_O(y) \leq \mu_T(y), \gamma_O(y) \leq \gamma_T(y), \sigma_O(y) \leq \sigma_T(y)$.

Definition 2.3

The union of two picture fuzzy set O and T is a picture fuzzy set denoted by $O \cup T$, where the PM, NM and NEM functions are defined as:

$$\mu_{O \cup T}(y) = \max\{\mu_O(y), \mu_T(y)\}, \gamma_{O \cup T}(y) = \max\{\gamma_O(y), \gamma_T(y)\}, \sigma_{O \cup T}(y) = \min\{\sigma_O(y), \sigma_T(y)\}, \forall y \in Y.$$

Definition 2.4

The inter section of two picture fuzzy subsets O and T is a picture fuzzy set denoted by $O \cap T$ where the PM, NM and NEM functions are defined as:

$$\mu_{O \cap T}(y) = \min\{\mu_O(y), \mu_T(y)\}, \gamma_{O \cap T}(y) = \min\{\gamma_O(y), \gamma_T(y)\}, \sigma_{O \cap T}(y) = \max\{\sigma_O(y), \sigma_T(y)\}, \forall y \in Y.$$

Definition 2.5

A picture fuzzy graph is $G=(V, E)$ with $V=\{v_1, v_2, \dots, v_n\}$ such that μ_P, γ_P and σ_P respectively are given by: $\mu_1: V \rightarrow [0, 1], \gamma_1: V \rightarrow [0, 1]$ and $\sigma_1: V \rightarrow [0, 1]$ which denote PM, NM and NEM functions, respectively and $0 \leq \mu_1(a) + \gamma_1(a) + \sigma_1(a) \leq 1 \forall a \in V$, and

$$E \subseteq V \times V \text{ with } \mu_2: V \times V \rightarrow [0, 1], \gamma_2: V \times V \rightarrow [0, 1] \text{ and } \sigma_2: V \times V \rightarrow [0, 1]$$

$$\mu_2(ab) \leq \min\{\mu_1(a), \mu_1(b)\}, \gamma_2(ab) \leq \min\{\gamma_1(a), \gamma_1(b)\}, \sigma_2(ab) \leq \max\{\sigma_1(a), \sigma_1(b)\}, \forall ab \in E.$$

3 Picture Fuzzy Soft Graph

Let V be the universe, E the set of all parameters and $P(V)$ be the collection of all Picture fuzzy soft set of V . Let A be a subset of V . These to fall picture fuzzy sets of V & E are denoted by $P(V)$ and $P(E)$.

3.1 Algorithm

An algorithm for decision making using the proposed Picture fuzzy soft graphs. The notation A denote the attributes, F and K are the mapping from A to $P(V)$ and $P(E)$ and S_e denote the Picture fuzzy softgraph. The algorithm proposed for this PFSG is as follows:

Step1: Consider the picture fuzzy softsets (F,A) and (K,A) according to the attributes in A .

Step2: Draw the PFSG S_e corresponding to each attribute $(e \in A)$ for the considered problem.

Step3: Calculate the result ant PFSG $(S(e))$ by taking intersection of the PFSG's S_e for each attribute and the adjacency matrix of the result antmatrix $S(e)$.

Step4: Calculate the score values for the $S(e)$ using the score function.

$1 + \text{positive} - 2(\text{neutral}) - \text{negative}$

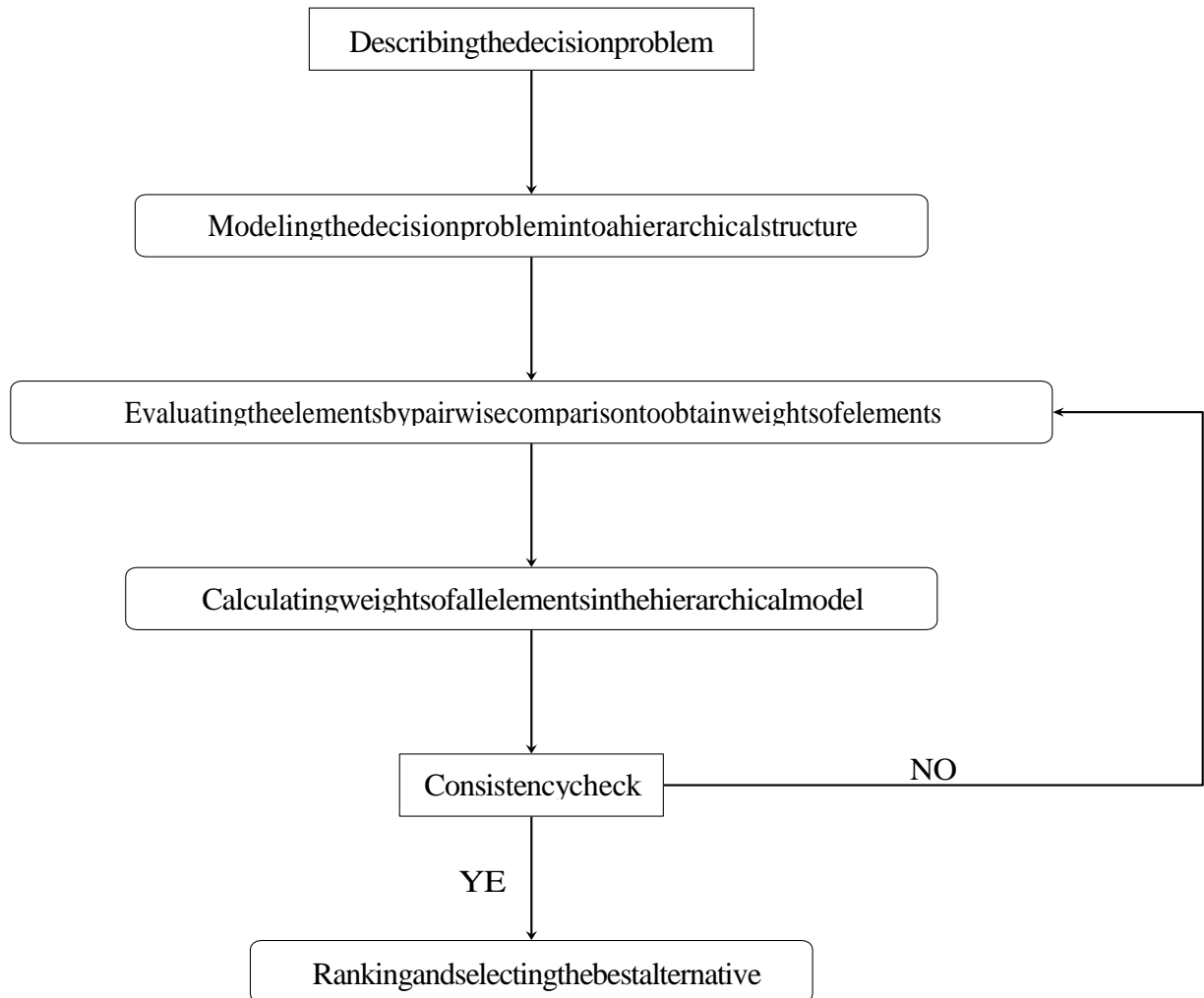
2 and choice value by adding the score values of a particular element of the universal set.

Step5: Obtain the optimal decision by choosing the maximum of the calculated choice values.

4 AHP Method (Analytic Hierarchy Process)

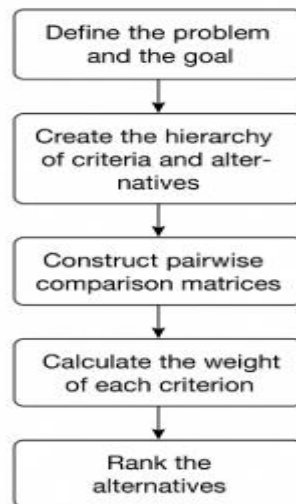
Within the broad spectrum of MCDM methods, the Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty in the late 1970s, stands out as one of the most structured, flexible, and widely applied techniques. AHP offers a rational framework for modelling complex decision problems by decomposing them into a hierarchical structure consisting of a goal, criteria, sub-criteria, and alternatives. This hierarchical representation not only simplifies the decision process but also enables decision-makers to focus on one level at a time, thereby enhancing clarity and reducing cognitive burden. The advantage of this method is that it handles both qualitative and quantitative data effectively. AHP method breaks down the complex decision problem into smaller and simpler decision problems that are more understand able. These smaller decision

problems consist of multi-level hierarchical structure of goals, criteria, sub-criteria and alternative.



4.1 Methodology

The Analytic Hierarchy Process (AHP) is a systematic, mathematics-based decision-making methodology designed to evaluate and rank alternatives when multiple, often conflicting criteria must be considered. The method consists of a series of structured steps that guide the decision-maker from problem formulation to the final ranking of alternatives. This section explains each step of the AHP methodology in detail.



5 Numerical Example

Let us consider a set of six patients. Since it is a difficult process and consumes time to choose them ost affected individual. Let $V = \{P_1, P_2, P_3, P_4, P_5, P_6\}$ be the set of six persons considered as the Universal set and let $A = \{e_1, e_2\}$ be these to fparameters that characterize the risk for patients, the attributes e_1 and e_2 stand for the symptoms and the illness they already have in their system.

Consider the picture fuzzy soft set (F, A) over V which describes the “Impact of the virus on patients” corresponding to the given parameters. (K, A) is a picture soft set over

$$E = \{P_1P_2, P_1P_3, P_1P_4, P_1P_5, P_1P_6, P_2P_3, P_2P_4, P_2P_5, P_2P_6, P_3P_4, P_3P_5, P_3P_6, P_4P_5, P_4P_6, P_5P_6\}.$$

describe the degree of positive, neutral & negative of the relation between patients corresponding to parameters e_1 and e_2 . The PFSG's S_{e_1} and S_{e_2} corresponding to attributes ‘symptoms’ & ‘illness’ respectively.

$$F(e_1) = \{P_1(0.6, 0.2, 0.1), P_2(0.5, 0.2, 0.3), P_3(0.3, 0.4, 0.3), P_4(0.4, 0.3, 0.2), P_5(0.7, 0.1, 0.1), P_6(0.8, 0.1, 0.1)\}$$

$$K(e_1) = \{P_1P_3(0.3, 0.2, 0.2), P_1P_4(0.4, 0.2, 0.2), P_1P_5(0.6, 0.1, 0.1), P_3P_6(0.3, 0.1, 0.2), P_4P_2(0.4, 0.2, 0.3), P_4P_6(0.4, 0.1, 0.2),$$

$$P_2P_6(0.5,0.1,0.2), P_2P_5(0.5,0.1,0.3), P_5P_6(0.7,0.1,0.1)\}$$

$$F(e_2)=\{P_1(0.8,0.1,0.1), P_2(0.7,0.2,0.1), P_3(0.5,0.3,0.2),$$

$$P_4(0.4,0.2,0.4), P_5(0.3,0.3,0.3), P_6(0.6,0.2,0.2)\}.$$

$$K(e_2)=\{P_1P_2(0.7,0.1,0.1), P_1P_5(0.3,0.1,0.3), P_1P_4(0.4,0.1,0.4),$$

$$P_1P_6(0.6,0.1,0.2), P_2P_5(0.5,0.2,0.2), P_2P_4(0.4,0.2,0.3),$$

$$P_3P_4(0.4,0.2,0.4), P_3P_5(0.3,0.2,0.3), P_4P_6(0.4,0.1,0.3), P_6P_5(0.3, 0.1, 0.3), P_5P_4(0.3, 0.2, 0.4)\}$$

AHP Method (Analytic Hierarchy Process)

Alternatives	Score by AHP	Rank
Person1	0.3683375	1
Person2	0.226725	2
Person3	0.0916	4
Person4	0.06575	5
Person5	0.0617625	6
Person6	0.1858375	3

Picture Fuzzy Soft Graph

Persons	Choice value by	Rank
Person1	2.55	1
Person2	2.45	2
Person3	2.3	3
Person4	2.3	3
Person5	2.3	3
Person6	2.45	4

6 Comparison of Picture fuzzy soft graph & AHP

Feature	Picture Fuzzy Soft Graph (PFSG)	AHP
Type	Advanced Fuzzy MCDM (Multi- Criteria Decision- Making)	MCDM (Multi- Criteria Decision- Making)
Mathematical Basis	Graph Theory + Picture Fuzzy Sets	Pairwise Comparisons + Eigen values
Data Handling	Fuzzy data with neutrality	Crisp, pairwise comparisons
Uncertainty Handling	High (captures Hesitation and neutrality explicitly)	Low (requires precise pairwise comparisons)
Computational Complexity	High (Graph-based calculations and fuzzy logic)	High (Eigen value calculations and consistency checks)
Strengths	Better uncertainty representation Handles complex and vague information Graph-based relationships	Structured decision-making Ensures consistency Works well for hierarchical problems
Weaknesses	Computationally intensive Requires deep understanding of fuzzy logic	Time - consuming pair wise comparisons Prone to Inconsistency if criteria increase

7 Conclusion

In this study, we compared Picture Fuzzy Soft Graph and AHP for solving a multi-criteria decision-making problem. While each method has its strengths and weaknesses, our analysis demonstrates that AHP provides the best solution due to its structured approach,

ability to ensure consistency and capacity to handle complex decision hierarchies effectively. PFSG is useful in scenarios where uncertainty and hesitation play a significant role, making it ideal for vague or imprecise data. However, AHP excels in providing an optimal ranking by systematically weighting criteria and ensuring logical consistency in decision-making. From the results obtained in prioritizing six patients based on their symptoms and illnesses, AHP demonstrated higher reliability and accuracy, reinforcing its suitability for medical decision-making and other complex problems requiring a structured evaluation of multiple factors.

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7. ANALYSIS AND EFFECTS OF CONTAMINATED SOIL NEAR COFFEE AND TANNERY INDUSTRIES USING SINGLE LINK TECHNIQUE

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ABSTRACT

The present study on Physio-chemical parameters such as pH, nitrogen, phosphorous, potassium, electrical conductivity and heavy metal from the outlet of industrial effluents contaminated soil was analyzed using statistical method. The predictions on the industrial effluents make a complex situation to the soil-microbe of adapting themselves to the changing conditions. An integrate knowledge on physical, chemical and biological environment as well as the accumulation of physio-chemical characteristics of contaminated soil is higher than the permissible values, the protective measures to reduce pollution.

KEYWORDS: Physio-chemical, Industrial effluents, Single Link Technique.

INTRODUCTION

India's ecology has grown vulnerable, and pollution is one of the unfavourable results of these factors. Even though industrialisation and agricultural advancement are essential to provide people with their basic needs, environmental preservation is as crucial. Due to the nation's increasing industrialisation, industrial waste pollution has significantly increased in the environment. (Tiwari, 1994; Muthuswamy and Jayabalan, 2001; Noorjahan, 2011). Water bodies and soil are contaminated by the wastewater discharged from many businesses, including tanneries, pulp and paper, textile, petroleum, and chemical ones. One of the main issues in human life is the buildup of

heavy metals in the environment, which causes toxicity and harm. (Singanan, 2011). Through eating, heavy metals may accumulate in tissue. More heavy metals harm the brain, cause cancer, and are toxic. (Al-Garni, 2005). As a result of the growing industrialization, water bodies are the main source of heavy metal inclusion. In fact, the purpose of sustainable heavy metal management in agrosystems is to guarantee the long-term preservation of soil fertility and the quality of agricultural output. (Moolenaar et al., 1997). Through root uptake, the soil's characteristics are impacted by the atmospheric deposition of hazardous metals, which also raises plant metal levels. The worst damaged lands by this issue are those used for peri-urban agriculture. (Kaur and Rani, 2006). With definite chemical, physical, mineralogical, and biological properties, soil is a dynamic natural body that forms as a result of pedogenic processes through weathering of rocks.

It has a variable depth over the surface of the earth and acts as a medium for plant growth. (Thakre et al., 2012). Raskin et al. (1997) suggested that soil and water contaminated with metals pose a major environmental and human health problem; that is still in need of an effective and affordable technological solution. Most metals are poisonous, do not degrade through microbial or chemical processes, and their overall concentration in soil lasts for a very long time after introduction. (Kirpichtchikova et al., 2006). Both constructive and negative processes can result from soil formation. In addition to being crucial for agriculture, soil is also beneficial to all living things.

The variances in runoff, erosion, and deposition processes that affect soil genesis are typically blamed for the variations in soil characteristics related to landscape position. (Dengđz, 2010). One of the most common drinks drunk worldwide is coffee, which is a member of the Rubiaceae family. On an area of 0.354 million hectares of land, an average yearly production of 0.291 million tonnes is produced. Either the wet or the dry method is used to process coffee. When compared to the dry method, the wet method produces coffee of higher quality. Currently, the wet method is used in India to prepare roughly 75–80% of Arabica and 15-20% of Robusta.

Environmental pollution, particularly industrial waste, is a major concern on a worldwide scale because it causes ecosystems to become unstable and unhealthy disordered due to toxins in the environment. Pollution is the introduction of contaminants chemical substances like heat, light, or noise into the environment that injure other living things and cause them to feel uncomfortable. The flow of industrial waste across agricultural land causes to environmental damage. The impacts of pollutants, whether they are discharged from industries in solid, liquid, or gaseous form, vary according to their quantity, potential for harm, and fragility in the environment. These contaminants can originate from either human or natural sources, which causes organic damage, regardless of the sources of the pollutants. Although they may not be the primary cause of the ongoing harm caused by humans to the environment, industries play a significant role. There is still much that needs to change on our planet, despite the efforts made by governments around the world to decrease the pollution that these industries pump into the atmosphere.

The physio-chemical parameters such as pH, nitrogen, phosphorous, potassium electrical conductivity and heavy metal from the outlet of industrial effluents contaminated soil was analyzed using statistical method. The predictions on the industrial effluents make a complex situation to the soil-microbe of adapting themselves to the changing conditions. The soil was collected from dumping site of coffee effluent and tannery industries were analysed. The value of electrical conductivity was higher than the permissible limit. The amount of available nitrogen, phosphorous and potassium concentration was also high. Heavy metals such as Zn, Fe, Cr, Cu, Mg, Pb and Mn were also analyzed. This soil contains high amount of heavy metals where Cu followed by Magnesium was the highest among them and exceed permissible limits. The effluent from the coffee industry was the major source of pollution which will affect the flora and fauna existing in such soil environment. Thus, there is need for treatment of coffee industry effluent before they are discharged into the soil environment.

**PHYSICAL, CHEMICAL AND BIOLOGICAL ASPECTS OF SOIL
BACTERIAL ECOSYSTEMS**

Earth is known as dirt or soil; it is a different environment from other habitats and serves as a life support system. Human life would be exceedingly difficult without soil, which is one of the most important elements of the earth's ecosystem and contains a broad array of microorganisms. Overall, microbial communities' complex spatiotemporal dynamics, which result from interactions with their physical, chemical, and biological surroundings, are a manifestation of the specificity of soil. For a wide array of creatures, soil serves as both a home and a genetic diversity reserve.

Physical Aspects of Soil Bacterial Ecosystems

Less than 1% of the soil's specific surface area, or surface area per unit of mass, is occupied by microbes (Tecon and Or, 2017; Chenu et al., 2002). As a result, there is an uneven distribution of microorganisms and the creation of spatially isolated bacterial microcolonies that are dispersed throughout disconnected areas (Nunan et al., 2003; Young et al., 2008). A tortuous, dynamic pore network that emerges from the intricate arrangement of soil particles regulates connection. How far bacteria can travel to reach their environment is determined by the pore size and geometry. Cell-to-cell contact and bacterial penetration are prevented by tiny holes and pore neck sizes less than 0.2 μm (Chenu et al., 2002).

Chemical Aspects of Soil Microbial Ecosystems

The matric potential is a key factor in determining the soil water potential in unsaturated situations. Nevertheless, the osmotic potential may have a significant role in the water potential in particular circumstances, such as prolonged dry spells, following fertiliser application, at specific places close to the soil surface, or in the rhizosphere (Or et al., 2007). Furthermore, irrigation worsens soil salinity, particularly in dry areas with high evaporation rates (Lambers, 2003). Microbial biomass and activity typically decrease in saline soils (Rietz and Haynes, 2003). Additionally, bacterial motility and

chemotaxis can both be suppressed (Steil et al., 2003). On the other hand, rapid water infiltration can raise the water potential and have an impact on the integrity and survival of cells (Halverson et al., 2000). Modelling studies that take into account how soil salinity affects bacteria are essentially non-existent right now. This might be because the osmotic potential has little effect on convective and diffusive nutrient fluxes and there is little empirical data on its impact on microbial processes (Or et al., 2007; Tecon and Or, 2017).

Biological Aspects of Soil Microbial Ecosystems

Multispecies communities of microbes exist, and they communicate with one another using a variety of ways. Microbial interactions are a key factor in population structure and dynamics at the microscale, in addition to the structural soil qualities already mentioned. According to population dynamics models, cohabitation is globally unstable in populations with significant antagonistic interactions, and competitive exclusion eventually results in the domination of one species (Fukami, 2015). Such interactions in spatially structured systems manifest in the creation of a spatial pattern that permits coexistence. Lowery and Ursell (2019) showed that structured environments encouraged the coexistence of two microbial species that could not live under homogenous conditions using a modified Lotka-Volterra model in a 2-D environment. Portell et al. (2018) used the previously published pore network approach using soil CT images in conjunction with an IBM to mimic the breakdown of organic matter in a community made up of three strains of *Arthrobacter* sp. with various competitive capacities.

PHYSICO-CHEMICAL PARAMETERS OF CONTAMINATED SOIL

S. No.	Physio-chemical parameters in Coffee Industry	Permissible value	Contaminated value
1.	pH	7	7.99
2.	Nitrogen	0.43	2.81
3.	Phosphorous	10.2	16.6

4.	Potassium	165	314
5.	Electrical Conductivity	0	0.21

S. No.	Physio-chemical parameters in Tannery Industry	Permissible value	Contaminated value
1.	pH	7	9.63
2.	Nitrogen	0.43	2.68
3.	Phosphorous	10.2	15.8
4.	Potassium	165	306
5.	Electrical Conductivity	0	0.37

Methodology:

The physio-chemical parameters of soil samples collected from coffee and tannery industry effluent sites were analysed for pH, nitrogen, phosphorous, potassium, electrical conductivity, and heavy metals (Zn, Fe, Cr, Cu, Mg, Pb, Mn). To compare and classify the contamination patterns, a hierarchical clustering approach was applied using the Single Link Technique (nearest neighbour method).

In this method, the Euclidean distance was calculated between each pair of parameters, and the closest members were progressively merged into clusters. The process was repeated until a dendrogram was obtained, illustrating the similarity patterns among physio-chemical variables.

The choice of the Single Link Technique was based on the following reasons:

1. It is an effective method for pattern recognition and grouping when dealing with multi-parameter environmental datasets.
2. The technique is widely used in ecological and soil contamination studies where the objective is to identify relationships and similarity structures rather than to test a statistical hypothesis.
3. Since industrial effluents exhibit multi-dimensional variation, clustering provides a clearer picture of how different parameters (e.g., nitrogen, potassium,

heavy metals) relate to one another and which parameters dominate pollution characteristics.

It is acknowledged that the Single Link Technique is descriptive in nature and may form chained clusters; however, in this study it served the purpose of identifying contamination linkages between the soil parameters influenced by coffee and tannery effluents. Future work may extend the analysis using ANOVA, PCA, or discriminant analysis for hypothesis testing and stronger statistical validation.

CLUSTERS USING SINGLE LINK TECHNIQUE – METHOD DESCRIPTION

The given dataset can be clustered by using single link technique of statistical method. Using Euclidean Distance, we can draw the dendrogram.

Algorithm:

Step 1: Compute the difference matrix.

- We have to find the Euclidean Distance between each and every points.
- Let $A(x_1, y_1)$ and $B(x_2, y_2)$ are two points. Then Euclidean Distance between is given by $d(A, B) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$

Step 2: Merging the two closest members.

- Find the minimum value in the difference matrix and hence we combine corresponding row and column.
- Delete the row and column of the minimum value.
- Now, from clusters of elements corresponding to the minimum value and update the difference matrix.

Step 3: Repeat the step 2 until we get the 2 x 2 matrix.

Step 4: Draw the dendrogram for the cluster formed.

Example 1: Coffee Industry

Step 1: The difference matrix for the given dataset.

$$d(C1, C2) = \sqrt{(0.43 - 7)^2 + (2.81 - 7.99)^2} = 8.36$$

$$d(C1, C3) = \sqrt{(10.2 - 7)^2 + (16.6 - 7.99)^2} = 9.18$$

$$d(C1, C4) = \sqrt{(165 - 7)^2 + (314 - 7.99)^2} = 344.39$$

$$d(C1, C5) = \sqrt{(0 - 7)^2 + (0.21 - 7.99)^2} = 10.46$$

$$d(C2, C3) = \sqrt{(10.2 - 0.43)^2 + (16.6 - 2.81)^2} = 16.90$$

$$d(C2, C4) = \sqrt{(165 - 0.43)^2 + (314 - 2.81)^2} = 352.02$$

$$d(C2, C5) = \sqrt{(0 - 0.43)^2 + (0.21 - 2.81)^2} = 2.63$$

$$d(C3, C4) = \sqrt{(165 - 10.2)^2 + (314 - 16.6)^2} = 335.27$$

$$d(C3, C5) = \sqrt{(0 - 10.2)^2 + (0.21 - 16.6)^2} = 19.30$$

$$d(C4, C5) = \sqrt{(0 - 165)^2 + (0.21 - 314)^2} = 354.52$$

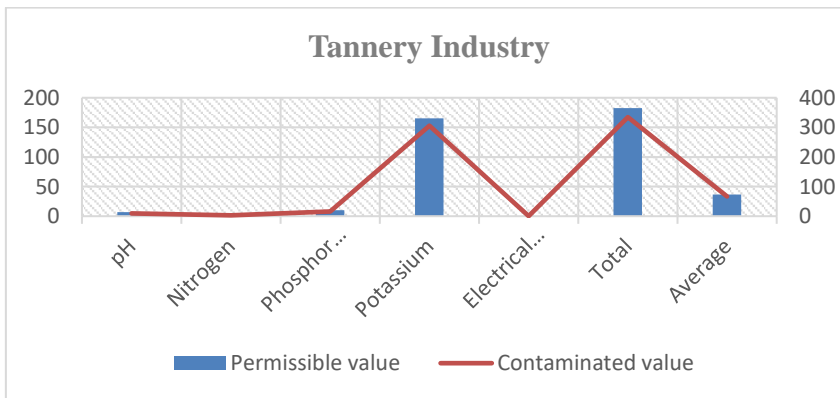
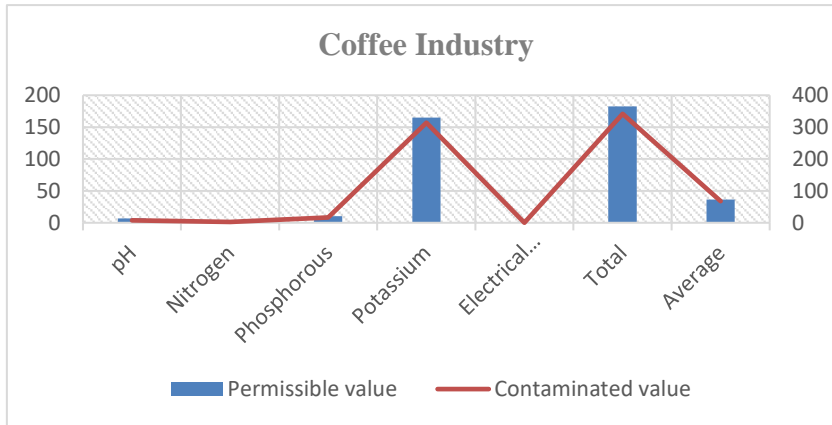
Step 2: Merging the two closest members.

The first minimum value is 2.6 corresponding to C5 row and C2 column.

Delete C5 row and column. Cluster C2 and C5, update the difference matrix.

Coffee Industry						Tannery Industry					
	C1	C2	C3	C4	C5		C1	C2	C3	C4	C5
C1	0					C1	0				
C2	8.4	0				C2	9.6	0			
C3	9.2	16.9	0			C3	6.9	16.4	0		
C4	344.4	352.0	335.3	0		C4	335.9	345.1	328.9	0	
C5	10.5	2.6	19.3	354.5	0	C5	11.6	2.3	18.5	347.3	0

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CONCLUSION

The study revealed that soils collected near coffee and tannery industries contained physico-chemical parameters and heavy metals exceeding permissible limits. Application of the Single Link Technique helped identify clear clustering patterns, showing strong relationships between nutrient enrichment (such as nitrogen and potassium) and heavy metal accumulation. Although this approach effectively provides a pattern-based comparison of contamination, future studies should incorporate complementary statistical methods such as ANOVA or PCA for stronger validation. Overall, the discharge of untreated effluents presents serious ecological risks, and proper treatment measures are crucial to reduce long-term soil and water pollution.

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8. EFFECT OF MODIFIERS ON THE STRUCTURAL, OPTICAL AND SPECTROSCOPIC PARAMETERS OF DYSPROSIUM IONS DOPED BORO-TELLURITE GLASSES FOR WHITE LED APPLICATION

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Abstract

A series of different modifiers incorporated Dy^{3+} ions doped boro-tellurite glasses were synthesized [via classic melt-quenching process and characterized](#) through mandatory analyses like optical absorption and photoluminescence measurements. The absorption spectra exhibit eight diverse spectral peaks originating from the ground level ${}^6H_{15/2}$ to several excited levels. [The bonding nature between dopant ion and ligand field is analysed with the bonding parameters which detected the ionic nature of the \$Dy^{3+}\$ metal ligand bond in the glasses.](#) The CIE color coordinates were calculated for the all the prepared glasses and these coordinates are found to be near to the ideal white light illumination. Zn containing glass possesses the highest spectroscopic quality factor (Ω_4/Ω_6) indicating its potential application in advanced optical glasses, white light applications as well as yellow laser medium and x-ray scintillator applications.

Keywords: Borate glasses, Judd-Ofelt parameter, Luminescence spectra, bonding parameter.

1. Introduction

For the past few decades throughout the world considerable laboratories concentrate on rare earth (RE) ions doped materials due to their potential applications in various fields like optoelectronics, fiber amplifiers, next generation solid state lighting (SSL) systems, solar energy collectors, under sea optical communications, optical data

storage devices, Q-switching devices, X-ray imaging and laser technology [1]. The doping of rare earth ions into glass host found number of advantages like broad inhomogeneous band width, large doping capability, possibility of tuning the emission wave length, low production cost, less preparation time and easy to fabricate in different shapes compared to the crystalline materials. Over the past few decades, many researchers focus on the development of rare earth doped glasses based on different hosts such as silicates, borates, phosphates, fluorides and tellurites through optical absorption and luminescence spectral measurements to examine their suitability for various photonic applications. Among the glass formers, Borate (B_2O_3) based glasses possess good transparency, thermal stability and good rare earth ion solubility but it has higher phonon energy ($1200\text{--}1600\text{ cm}^{-1}$) which reduces the rare earth emission intensity due to their higher non-radiative decay.

Among the rare earth ions, Dysprosium is the best choice for white light applications because of its two dominant emission bands such as $^4F_{9/2} \rightarrow ^6H_{15/2}$ and $^4F_{9/2} \rightarrow ^6H_{13/2}$ energy levels transition in the visible region. The $^4F_{9/2} \rightarrow ^6H_{15/2}$ emission band is due to the magnetic dipole transition and the $^4F_{9/2} \rightarrow ^6H_{13/2}$ emission band is due to the electric dipole transition and this transition is highly affected by the host matrix and the intensity of the yellow emission band can be modified by the ligand field around the RE ion site. White light can be stimulated from the Dy^{3+} doped glass materials by adjusting the yellow to blue (Y/B) intensity ratio by varying the glass composition, RE ion concentration and excitation wavelengths [2,3]. The better white light can be stimulated from the Dy^{3+} doped glass materials at suitable Y/B intensity ratio by selecting the different ligand field strengths.

The present work reports the studies made on Dy^{3+} doped boro-tellurite glasses prepared via melt quenching technique and the results obtained on their spectroscopic properties. The aim of the present study is to (i) synthesize Dy^{3+} doped boro tellurite glasses by varying modifiers to (ii) calculate the bonding ($\bar{\beta}$ and δ) parameters from the

absorption spectra (iii) record the excitation and emission spectra and finally (iv) calculate the color chromaticity coordinates from the luminescence spectra to explore its suitability for white light applications.

2. Experimental

The high purity analytical grade (99.99%) chemicals such as H_3BO_3 , TeO_2 , Na_2CO_3 , Li_2CO_3 , CaCO_3 , SrCO_3 , ZnO , BaCO_3 and Dy_2O_3 were used as precursors for synthesizing Dy^{3+} ions doped boro tellurite glasses with the chemical composition $49\text{B}_2\text{O}_3-25\text{TeO}_2-10\text{MO}-15\text{Na}_2\text{O}_3-1\text{Dy}_2\text{O}_3$ ($\text{MO} = \text{Li, Ca, Sr, Ba and Zn}$) following the melt-quenching technique, and labelled as BTND-Li, BTND-Ca, BTND-Sr, BTND-Ba and BTND-Zn. The mixtures of starting reagents were grounded thoroughly in an agate mortar and the mixture was taken in to the porcelain crucible, and then melted in an electric furnace at $900\text{ }^\circ\text{C}$ for 1 hour. Subsequently, the molten flux was quenched on to a brass plate pressed with another brass plate preheated at $300\text{ }^\circ\text{C}$ and annealed for 10 hours to remove the thermal shocks and to increase the mechanical stability. The prepared glasses were allowed to reach room temperature gradually and the glasses are polished on both sides to obtain smooth surface before further optical measurements. The UV-Vis-NIR absorption spectral measurements were made by using JASCO 500, UV-Vis-NIR spectrophotometer in the wavelength range 350–2400 nm with a spectral resolution of ± 0.1 nm. Fluorescence spectra were recorded using JASCO FP-8500 spectrofluorometer with a spectral resolution of ± 0.1 nm. All these measurements were carried out at room temperature (RT) only.

3. Results and discussion

3.1. Absorption analysis

3.1.1. Bonding parameters

Optical absorption spectra of the title glasses have been recorded in the spectral region 350–1800 nm and as a representative case, absorption spectrum of the BTND-Ba

glass is shown in figure 3.1. The spectrum exhibit eleven broadened absorption bands centred at 362, 385, 424, 450, 471, 750, 799, 894, 1085, 1263 and 1667 nm corresponding to the transitions which originates from the ${}^6\text{H}_{15/2}$ ground state to the various excited states ${}^6\text{P}_{5/2}$, ${}^4\text{I}_{13/2}$, ${}^4\text{G}_{11/2}$, ${}^4\text{I}_{15/2}$, ${}^4\text{F}_{9/2}$, ${}^6\text{F}_{3/2}$, ${}^6\text{F}_{5/2}$, ${}^6\text{F}_{7/2}$, ${}^6\text{F}_{9/2}$, ${}^6\text{F}_{11/2}$ and ${}^6\text{H}_{11/2}$ respectively. The absorption band at around 1263 nm corresponds to the ${}^6\text{H}_{15/2} \rightarrow {}^6\text{F}_{11/2}$ transition which possess higher intensity compared to the other transitions and obey the selection rules $|\Delta L| \leq 2$ and $|\Delta J| \leq 2$ [3].

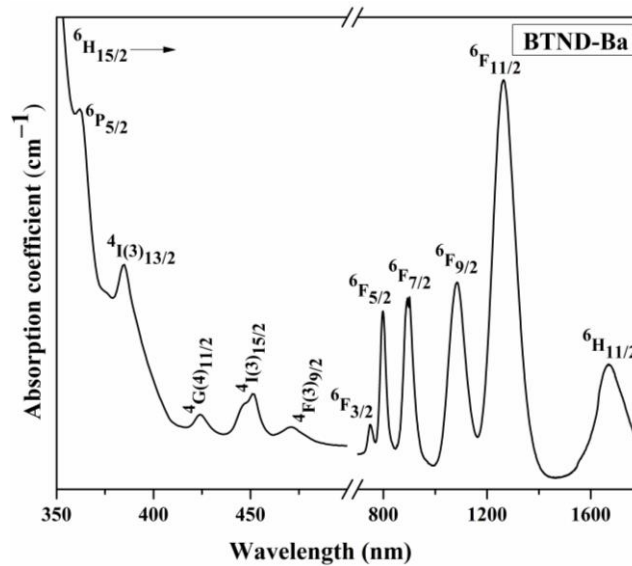


Figure 3.1: Absorption spectrum of the Dy^{3+} doped barium boro-tellurite glass

Also, these observed absorption band positions were used to investigate the nature of the metal-ligand bond present in the Dy^{3+} doped boro-tellurite glasses using nephelauxetic ratio and bonding parameters. “Nephelauxetic effect” is the reason behind the energy level shift of the host matrix when RE ions are incorporated into it. The nephelauxetic ratio represents the ratio of the inter-electronic repulsion (Racah parameter) in the complex to that in the free metal ion. The parameters are calculated to quantify the reduction in inter-electronic repulsion when a free metal ion forms a complex, indicating the degree of covalency in the metal-ligand bond. Hence the nephelauxetic ratio (β) is given by

$$\beta = \frac{\nu_c}{\nu_a} \quad (3.1)$$

where ν_c is the wave number (in cm^{-1}) of a particular transition for an ion in the host under investigation and ν_a is the wave number (in cm^{-1}) of the same transition for the aquo ion. The aquo ion reference is taken from the literature by Carnall et al [4]. From the average values of β , (taken as $\bar{\beta}$) the bonding parameter, δ can be calculated by an expression

$$\delta = \frac{(1 - \bar{\beta})}{\bar{\beta}} \times 100 \quad (3.2)$$

Table 3.1: Nephelauxetic ratio ($\bar{\beta}$) and bonding parameter (δ) of the Dy^{3+} doped borotellurite glasses

Parameter	BTND-Li	BTND-Ca	BTND-Sr	BTND-Ba	BTND-Zn
$\bar{\beta}$	1.0137	1.0108	1.0099	1.0097	1.0082
δ	-1.3594	-1.0697	-0.9857	-0.9666	-0.8229

The metal-ligand bond will be covalent or ionic depending upon the positive or negative sign of δ . The bonding parameter values of the prepared Dy^{3+} doped borotellurite glasses are presented in table 3.1. It is observed from the table that the negative sign of δ for the prepared glasses indicate the ionic nature of the Dy^{3+} metal ligand bond in the glasses.

3.1.2. Oscillator strength and JO analysis

The measurement of intensities of the optical absorption bands of RE^{3+} ions play a major role in understanding their optical properties. The oscillator strengths (f_{exp}) of the absorption bands are determined experimentally using the following formula

$$f_{\text{exp}} = 4.318 \times 10^{-9} \int \epsilon(\nu) d\nu$$

$$(3.3)$$

where $\varepsilon(\nu)$ is the molar extinction coefficient at a wave number cm^{-1} . The experimental oscillator strengths (f_{exp}) of the titles glasses were evaluated by measuring the integrated areas of the observed absorption transitions and are used in the frame work of Judd–Ofelt (JO) theory [5, 6]. The calculated oscillator strengths (f_{cal}) of an electric dipole transition from the ground state to excited state have been calculated using the following equation

$$f_{\text{exp}}((\Psi J, \Psi' J')) = \frac{8\pi^2 mc\nu}{3he^2 (2J+1)} \frac{(n^2+2)^2}{9n} S_{ed}(\Psi J, \Psi' J') + n^3 S_{md}(\Psi J, \Psi' J') \quad (3.4)$$

where, n is the refractive index of the glass, $(n^2+2)^2/9n$ is the Lorentz local field correction accounts for dipole-dipole correction. J is the total angular momentum of the ground state, $(2J+1)$ is the degeneracy of the ground state $^{2S+1}L_J$. The intensities of the magnetic dipole transitions which are weak are relatively independent of the chemical environment around the RE ions. The experimental and calculated oscillator strengths for various transitions by taking all the observed levels ($N= 6$) along with the JO parameters of the prepared glasses are presented in table 3.2.

Table 3.2: The Experimental and calculated oscillator strengths ($\times 10^{-6}$) and Judd–Ofelt ($\times 10^{-20} \text{ cm}^2$) parameters of Dy^{3+} doped boro-tellurite glasses.

Transition from ${}^6\text{H}_{15/2}$ →	BTND-Li		BTND-Ca		BTND-Sr		BTND-Ba		BTND-Zn	
	f_{exp}	f_{cal}	f_{exp}	f_{cal}	f_{exp}	f_{cal}	f_{exp}	f_{cal}	f_{exp}	f_{cal}
${}^6\text{F}_{3/2}$	0.09	0.15	0.14	0.13	0.13	0.15	0.12	0.13	0.15	0.08
${}^6\text{F}_{5/2}$	1.12	0.81	1.10	0.71	0.85	0.79	0.76	0.70	0.82	0.47
${}^6\text{F}_{7/2}$	1.62	1.67	1.47	1.53	2.43	1.65	1.98	1.48	1.20	1.06
${}^6\text{F}_{9/2}$	1.88	1.87	1.89	1.88	1.68	1.87	1.58	1.71	1.34	1.39
${}^6\text{F}_{11/2}$	6.52	6.51	7.97	7.96	8.38	8.34	8.17	8.14	7.31	7.29
${}^6\text{H}_{11/2}$	1.08	1.114	1.10	1.16	0.92	1.27	0.96	1.19	0.77	0.92
Ω_2	7.55		9.10		9.58		8.05		9.23	
Ω_4	1.25		1.55		1.26		1.20		1.15	
Ω_6	1.92		1.64		1.78		1.02		1.56	
Ω_4/Ω_6	0.653		0.946		0.708		1.170		0.737	

Among the JO parameters Ω_2 is more sensitive to the local structure of the RE ion and in turn depends strongly on the ${}^6\text{H}_{15/2} \rightarrow {}^6\text{F}_{11/2}$ transition and the higher value of Ω_2 is due to the relatively higher value of the oscillator strength of the ${}^6\text{H}_{15/2} \rightarrow {}^6\text{F}_{11/2}$ transition. The JO parameters in general provide information about the nature of bond between RE ion and the surrounding ligands and also the symmetry of the environment around the RE ions [7]. It is observed from Table 3.2, Ω_2 is higher when compared to other two values Ω_4 and Ω_6 for all the glasses and follows the trend as $\Omega_2 > \Omega_6 > \Omega_4$. The Ω_4/Ω_6 ratio is called the spectroscopic quality factor which is observed to be higher for BTND-Zn glass indicating its high optical quality.

3.2. Luminescence spectral analysis

Figure 3.2 shows the luminescence spectra of the prepared Dy^{3+} doped borotellurite glasses recorded in the wavelength region 420–650 nm. The spectra exhibit two intense emission bands at 482 nm (blue) and 574 nm (yellow) corresponds to the magnetic dipole (${}^4\text{F}_{9/2} \rightarrow {}^6\text{H}_{15/2}$) and electric dipole (${}^4\text{F}_{9/2} \rightarrow {}^6\text{H}_{13/2}$) transitions respectively. Further, they exhibit feeble red emission at around 666 nm due to the ${}^4\text{F}_{9/2} \rightarrow {}^6\text{H}_{11/2}$ transition for all the studied glasses. Among the observed emission bands, ${}^4\text{F}_{9/2} \rightarrow {}^6\text{H}_{13/2}$ transition is having high intensity and its intensity is strongly influenced by the ligand field around the Dy^{3+} ion site. The emission intensity of the electric dipole transition is found to be higher compared to the magnetic dipole transition for all the prepared glasses. It is observed from figure 3.2 that the luminescence intensity is high for BTND-Zn glass and low for BTND-Li glass.

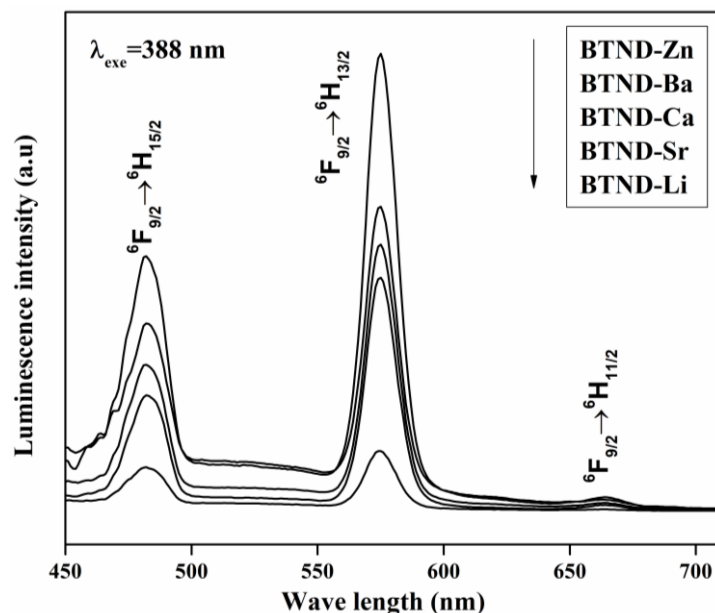


Figure 3.2: Emission spectrum of the Dy³⁺ doped boro-tellurite glasses.

3.3. CIE color coordinates

In order to identify the dominant emission color of the present Dy³⁺ doped title glasses, their emission spectra are characterized through CIE (Commission International d’Eclairage) 1931 color chromaticity diagram [8]. The calculated (x, y) values are found to be (0.415, 0.399), (0.423, 0.412), (0.404, 0.435), (0.392, 0.372) and (0.399, 0.358) corresponding to the BTND-Li, BTND-Ca, BTND-Sr, BTND-Ba and BTND-Zn glasses respectively. Figure 3.3 shows the x, y coordinates of the present Dy³⁺ doped boro tellurite glasses which are positioned very close to the standard equilibrium energy points (x=0.33, y=0.33) situated at the centre of the white light region in the CIE 1931 chromaticity diagram [9]. The correlated color temperature (CCT) values signify the appearance of light as ‘cool’ or ‘warm’ in nature. According to McCamy’s approximation, the CCT values of the present glasses can be obtained using the below given expression

$$CCT = -449n^3 + 3525n^2 - 6823n + 5520.33 \quad (3.5)$$

where $n = (x - x_e)/(y - y_e)$ is the inverse slope line and $x_e = 0.332$, $y_e = 0.186$ is the

epicentre. In the present work, CCT values of all the prepared glasses are found to be more than 3200 K which reveals the fact that the studied Dy^{3+} doped boro-tellurite glasses can emit cool white light which are useful for lighting in schools, hospitals, living houses and offices etc., The intensity ratio (Y/B) is engaged with the hypersensitive transition (yellow band) it is influenced by the ligand field of the Dy^{3+} ion. The BTND-Zn glass is noticed to hold higher Y/B ratio as it varies depending on the modifier of the system. The mixture of blue and yellow bands to produce white light is tuned by, significantly changing the structural surrounding of the Dy^{3+} ion with modifiers. The intensity modulation of yellow and blue bands (Y/B) are 2.29 for BTND-Zn, 1.93 for BTND-Ba, 1.75 for BTND-Ca, 1.65 for BTND-Sr and 1.42 for BTND-Li glasses.

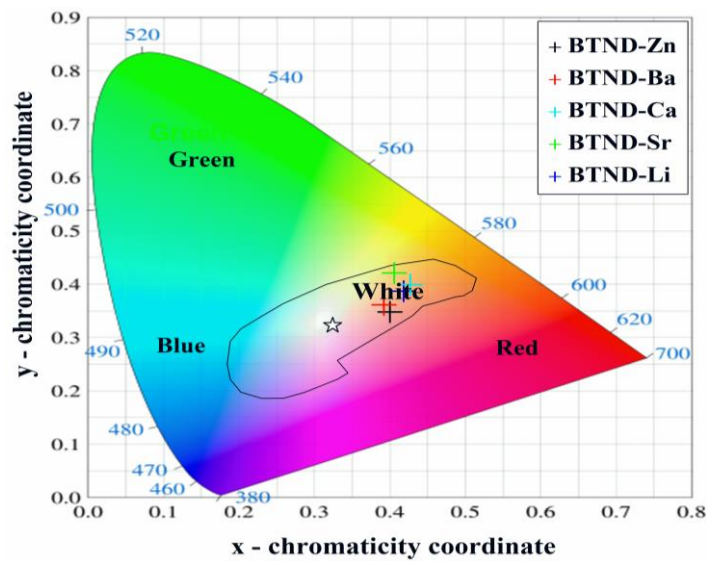


Figure 3.3: CIE color chromaticity diagram of the Dy^{3+} doped boro-tellurite glasses.

4. Conclusion

Synthesis processes of the Dy^{3+} doped boro-tellurite glasses were done by following conventional melt quenching technique. The bonding parameter studies indicate the ionic nature of the metal–ligand bond in the prepared glasses. The higher Ω_2 values indicate the fact that the ligand field environment around the RE ion site possess higher asymmetry in the glass structure. BTND-Zn glass possesses the highest

spectroscopic quality factor (Ω_4/Ω_6) indicating its potential application in advanced optical systems. The CIE color coordinates were calculated for the all the prepared glasses and these coordinates are found to be near to the ideal white light illumination. The studied Dy³⁺ doped boro tellurite glasses are analysed to emit cool white light which are useful for white light applications as well as yellow laser applications.

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9. ECO- FRIENDLY CORROSION INHIBITOR FOR CARBON STEEL IN ACID MEDIUM

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ABSTRACT

*Plant-based corrosion inhibitors are gaining increasing attention as sustainable and environmentally friendly alternatives to conventional synthetic inhibitors. In this study, the corrosion inhibition performance of an ethanolic root extract of *Acalypha indica* (AIRE) on carbon steel in 0.5N hydrochloric acid was investigated using weight loss measurements and potentiodynamic polarization techniques. The active phytochemical constituents of the extract were identified by Gas Chromatography-Mass Spectrometry (GC-MS) analysis, while surface morphological changes were examined using Scanning Electron Microscopy (SEM). Weight loss results revealed that the corrosion rate decreases with increasing inhibitor concentration, leading to enhanced inhibition efficiency, with a maximum efficiency of 96% achieved at 200 ppm of AIRE. Potentiodynamic polarization studies indicated that AIRE acts as a mixed-type inhibitor, effectively suppressing both anodic and cathodic reactions. SEM analysis confirmed the formation of a protective adsorbed film on the carbon steel surface in the presence of the inhibitor, resulting in a significantly smoother surface compared to the uninhibited system. The results demonstrate that AIRE is an efficient green corrosion inhibitor for carbon steel in acidic media and holds promise for practical industrial applications.*

Keywords: Corrosion, carbon steel, hydrochloric acid, *Acalypha indica*, protective film.

1. INTRODUCTION

Corrosion is an ongoing challenge owing to its thermodynamic spontaneity, as it proceeds with a reduction in free energy. This naturally occurring phenomenon causes significant material degradation, resulting in substantial maintenance and replacement costs in various industries, including boilers, water storage facilities, infrastructure systems, and petroleum pipelines [1]. Corrosion control can be achieved through the selection of appropriate construction materials for specific applications or by employing protective coatings that isolate the metal surface from the surrounding environment, thereby reducing chemical and physical interactions responsible for degradation [2].

Carbon steel alloys are widely used due to their low cost compared to other metallic alloys. However, they are highly susceptible to severe corrosion under diverse service conditions. Corrosion manifests in various forms, each governed by specific mechanisms influenced by factors such as metal composition, temperature, and environmental exposure [3]. Acidic media, particularly hydrochloric acid, are frequently employed to investigate the corrosion behaviour of carbon steel. Acids are extensively used in industrial operations including metal pickling, boiler descaling, oil well acidification, and ion-exchange resin regeneration. These acidic environments significantly accelerate metal dissolution, leading to pronounced material degradation [4].

Although synthetic organic compounds exhibit high corrosion inhibition efficiency, their application is often limited by high cost and significant toxicity. Increasingly stringent environmental regulations have further restricted their industrial use, prompting the search for safer alternatives. In recent years, plant-derived extracts have attracted considerable attention as cost-effective and environmentally benign corrosion inhibitors [5]. Green inhibitors interact with metal surfaces through π -electron systems and heteroatoms such as sulfur (S), phosphorus (P), and oxygen (O). Their adsorption onto the metal surface may occur via physical adsorption, chemical adsorption, or a synergistic combination of both mechanisms. The formation of an

adsorbed protective film effectively isolates the metal from the corrosive environment, thereby mitigating corrosion processes [6].

2. EXPERIMENTAL SECTION

2.1. Preparation of carbon steel specimens

Carbon steel specimens of composition (Sulphur 0.034%, Phosphorous 0.06%, Manganese 0.610%, Carbon 0.271% and remaining percentage of iron) of the dimensions $1.0 \times 4.0 \times 0.2$ cm and the density 7.84 g/cm^3 were polished to mirror finish and degreased with acetone and used for all the studies.

2.2. Preparation of the inhibitor extract

An ethanolic extract of *Acalypha indica* root (AIRE) was prepared by refluxing 10 g of root powder with 100 mL of ethanol for 3 h. The refluxed mixture was filtered, and the filtrate was concentrated by evaporating the solvent. Subsequently, 1 g of the dried extract was accurately weighed and dissolved in double-distilled water, and the volume was made up to 1000 mL in a standard volumetric flask. The resulting solution was used as the corrosion inhibitor in the present study [7].

2.3. Bioactive compound analysis

Gas Chromatography-Mass Spectrometry (GC-MS) analysis of AIRE extracts was performed using a Shimadzu AOC-20i system equipped with an Elite-5 capillary column. The analysis was carried out at an injection temperature of $280 \text{ }^\circ\text{C}$ under split injection mode, with a carrier gas flow rate of 1.20 mL min^{-1} . The resulting mass spectra were interpreted by comparing the detected compounds with reference spectra available in the NIST 2020 mass spectral library, enabling the identification of unknown constituents.

2.4. Weight loss method

The weight loss techniques are the conventional and simplest of all corrosion techniques. Carbon steels were completely immersed in 100 ml of the solution of acid medium of normality 0.5N HCl containing various concentrations of the inhibitor (AIRE) for a period of 1, 3 and 5 hours. After various hours of immersion the specimens

were taken out, washed in running water, dried and weighed. The corrosion inhibition efficiency (IE) was then calculated using the equation

$$IE = 100 \left[1 - \left(\frac{W_2}{W_1} \right) \right] \%$$

where,

W_1 is the corrosion rate in the absence of the inhibitor

W_2 is the corrosion rate in the presence of the inhibitor

Corrosion rate is calculated assuming uniform corrosion over the entire surface of the coupon. Corrosion rates (CR) are calculated from weight loss method using the formula

$$CR = \frac{534 W}{DAT} \text{ Mils per year (mpy)}$$

where,

W = weight loss in milligrams

D = density of specimen g/c

A = area of specimen in square inches

T = exposure in hours

2.5. Effect of temperature

The polished and accurately pre-weighed specimens were immersed in 100 mL of the test solution in the absence and presence of varying concentrations of AIRE for duration of 3 hours at temperatures ranging from 303 to 318 K using a thermostatically controlled water bath. After the exposure period, the specimens were withdrawn, rinsed with distilled water, dried, and reweighed. The inhibition efficiency was subsequently determined from the measured weight loss values.

2.6. Potentiodynamic polarization study

Polarization studies were carried out in a CHI electrochemical work station with impedance model 608 E. A three – electrode cell assembly was used. The working

electrode was carbon steel. A SCE was the reference electrode. A Platinum as the counter electrode. Both cathodic and anodic polarization curves were recorded in the absence and presence of the flower extract. From polarization studies, corrosion parameters such as corrosion potential (E_{corr}), corrosion current (I_{corr}), Tafel slopes anodic = β_a and cathodic = β_c were calculated and a linear polarization study done. The scan rate (V/S) was 0.01. Hold time at $E_f(s)$ was zero and quiet (s) was two.

2.7. Scanning Electron Microscopy (SEM)

Surface morphological analyses were carried out for freshly polished, inhibited, and uninhibited carbon steel specimens. After immersion in the blank and inhibitor-containing solutions for 3 hours, the specimens were withdrawn, rinsed with double-distilled water, dried, and examined to assess surface morphology. SEM observations were performed using a computer-controlled JEOL 6390 scanning electron microscope.

3. RESULTS AND DISCUSSION

3.1 GC-MS analysis

GC-MS spectrum of AIRE is shown in Figure 1, with the recognition of phytochemical components relying on data such as peak area, molecular weight, and molecular formula. The major constituents are listed in Table-1.

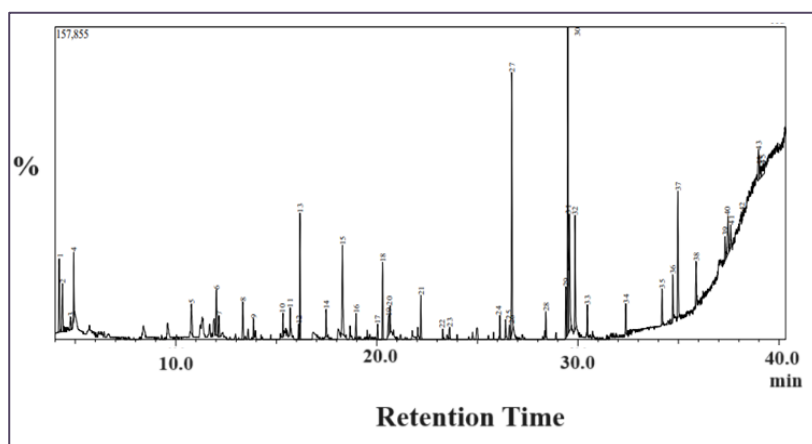


Figure 1: GC-MS spectrum of AIRE

GC-MS analysis revealed 9-octadecenoic acid as the predominant constituent of the extract. The presence of functional groups such as carbonyl and hydroxyl moieties, along with carbon- carbon double bonds, indicates that AIRE effectively inhibits the corrosion of carbon steel through surface interaction and adsorption [8].

Table 1: List of major compounds in AIRE

Peak no	Name of the Chemical Compound Present	Formula / Mol.Wt	Area of the Peak (%)
30	9 - Octadecenoic acid	C ₁₈ H ₃₄ O ₂ /282	13.69
27	n –Hexadecanoic acid	C ₁₆ H ₃₂ O ₂ /256	10.4
31	Palmitoleic acid	C ₁₆ H ₃₀ O ₂ /254	7.37
37	Diisooctyl Phthalate	C ₂₄ H ₃₈ O ₄ /390	5.6
15	Hexadecane	C ₁₆ H ₃₄ /226	4.58

3.2 WEIGHT LOSS ANALYSIS

Figure 2 shows the changes in corrosion rate and inhibition efficiency of carbon steel in 0.5 N HCl with and without the aqueous AIRE inhibitor. The inhibition efficiency increased with increasing inhibitor concentration, reaching a maximum value of 96% at 200 ppm. This enhancement is attributed to increased adsorption and surface coverage of AIRE molecules on the carbon steel surface, which suppresses metal dissolution. The interaction of heteroatoms present in the phytochemical constituents of AIRE with metal ions further contributes to the improved inhibition performance.

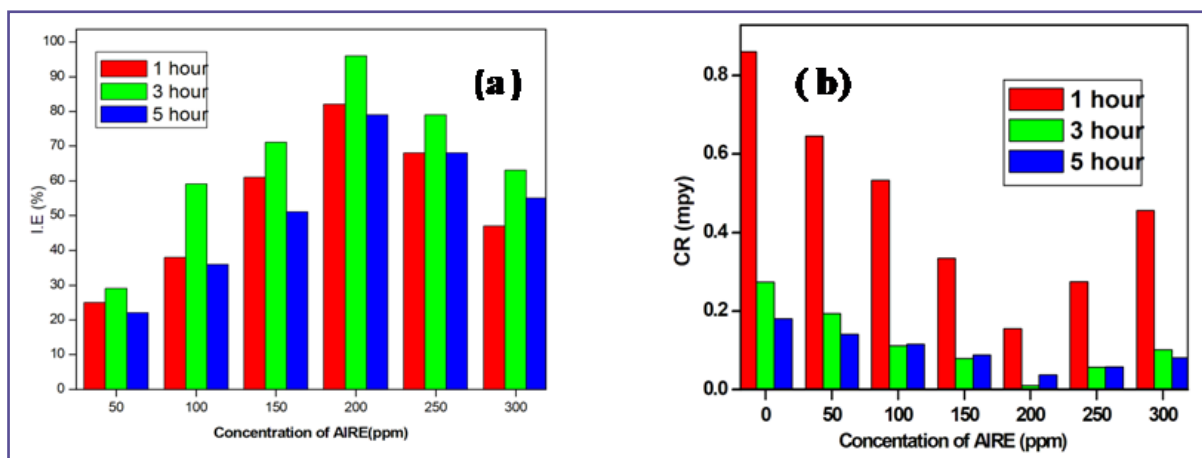


Figure 2: plot of (a) IE% of AIRE at various immersion periods (b) CR of AIRE at various immersion periods.

3.3 EFFECT OF TEMPERATURE

Temperature has a pronounced effect on metal corrosion kinetics. The influence of AIRE concentration on the corrosion behaviour of carbon steel in 0.5N HCl was evaluated at 303, 308, 313, and 318 K for a 3 hours immersion period. The corrosion rate (CR) and inhibition efficiency (IE) values were shown in Figure 3. Figure 3 demonstrates that the presence of AIRE significantly reduces the corrosion rate of carbon steel at all investigated temperatures compared to the blank solution. However, a gradual decline in inhibition efficiency was observed with increasing temperature [8]. This trend is attributed to the decreased stability of the adsorbed inhibitor layer and the progressive desorption of AIRE molecules from the metal surface at elevated temperatures [9]. The reduction in IE with rising temperature suggests that the adsorption of AIRE on carbon steel is predominantly governed by a physisorption mechanism.

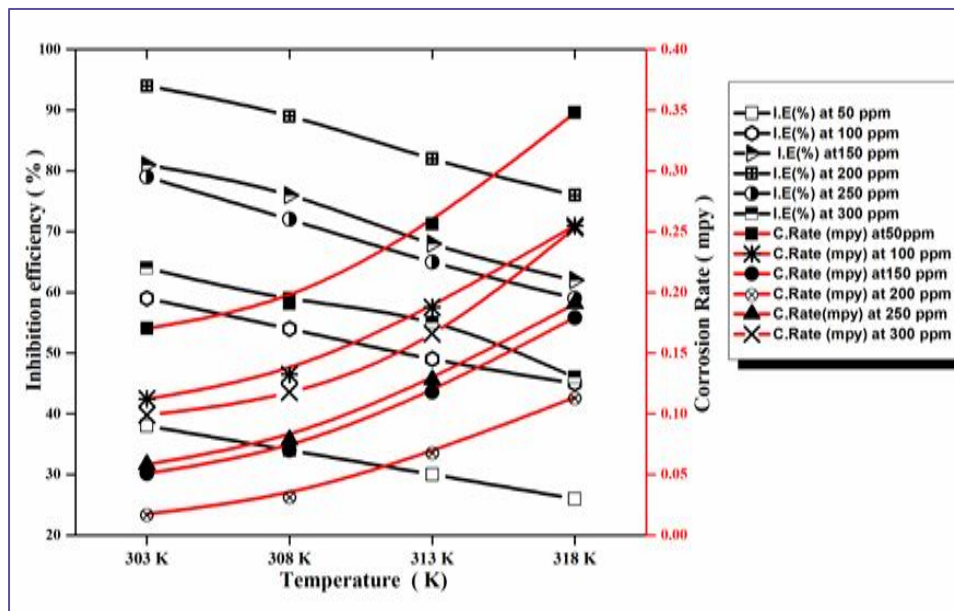


Figure 3: IE and CR of AIRE on carbon steel in 0.5N HCl at different temperatures.

3.4 Potentiodynamic Polarization Study

Polarization study has been extensively used in the corrosion inhibition studies. In the presence of inhibitors, linear polarization resistance (LPR) value increases and corrosion current (I_{corr}) value decreases. The polarization curves of CS electrode immersed in acid medium in the absence and presence of inhibitor (AIRE) system are shown in Figure 4. Electrochemical parameters such as corrosion potential (E_{corr}), Tafel slopes (β_c , β_a), linear polarization resistance (LPR) values and corrosion current (I_{corr}) values are given in Table 2. When mild steel was immersed in acid the corrosion potential was -0.512 V vs. SCE. When 200 ppm of AIRE extract was added to the above system the corrosion potential shifted to the anodic side -0.515 V vs. SCE. This indicates that the anodic reaction is controlled predominantly. However, the shift is within ± 0.51 V [10]. This indicates that the inhibitor behaves as a mixed type inhibitor controlling both anodic reaction and cathodic reaction to an equal extent by forming a protective film. Further, the LPR value increases from $15.0 \text{ Ohm}\cdot\text{cm}^2$ to $79.9 \text{ Ohm}\cdot\text{cm}^2$.

The corrosion current decreases from $2.19 \times 10^{-3} \text{ A/cm}^2$ to $2.80 \times 10^{-4} \text{ A/cm}^2$. Hence, polarization study confirms the formation of a protective film on the metal surface. The inhibition efficiency calculated from corrosion current was found to be 87%. The above inferences indicate that the corrosion rate of the mild steel reduced through the formation adsorbed protective film on the metal surface.

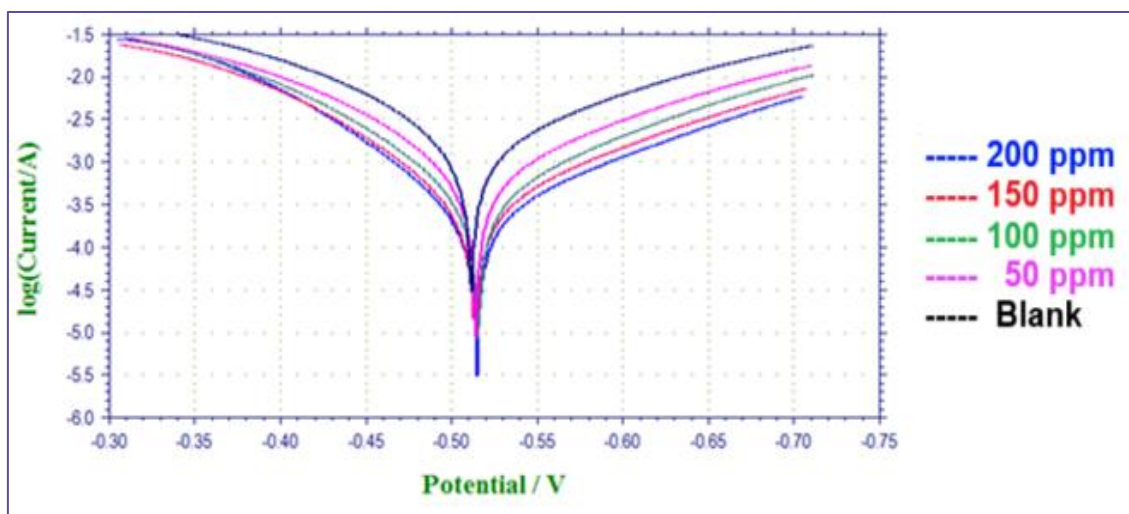


Figure 4: Tafel Plots for carbon Steel without and with AIRE in 0.5N HCl solution

Table 2: PDP values of carbon steel in absence and presence of AIRE in 0.5N HCl solution

Conc. (ppm)	E_{corr} (V)	I_{corr} (A/cm^2)	β_a (V/dec)	β_c (V/dec)	LPR (Ohm/cm^2)	IE (%)
Blank	-0.512	2.19×10^{-3}	7.81	5.84	15.0	-
50	-0.514	9.66×10^{-4}	8.80	5.93	30.6	56
100	-0.515	5.10×10^{-4}	10.35	6.86	49.5	77
150	-0.514	3.81×10^{-4}	10.89	6.72	64.8	83
200	-0.515	2.80×10^{-4}	12.31	7.12	79.9	87

3.5 SEM ANALYSIS OF METAL SURFACE

Analysis of SEM Scanning electron microscopy (SEM) was used to examine the surface morphology of the carbon steel species. The SEM images of magnification (1000x) of carbon steel specimen and carbon steel specimen immersed in acid medium for 3 hours in the absence and presence of inhibitor system are shown in Figure 5 as images (a, b, c) respectively.

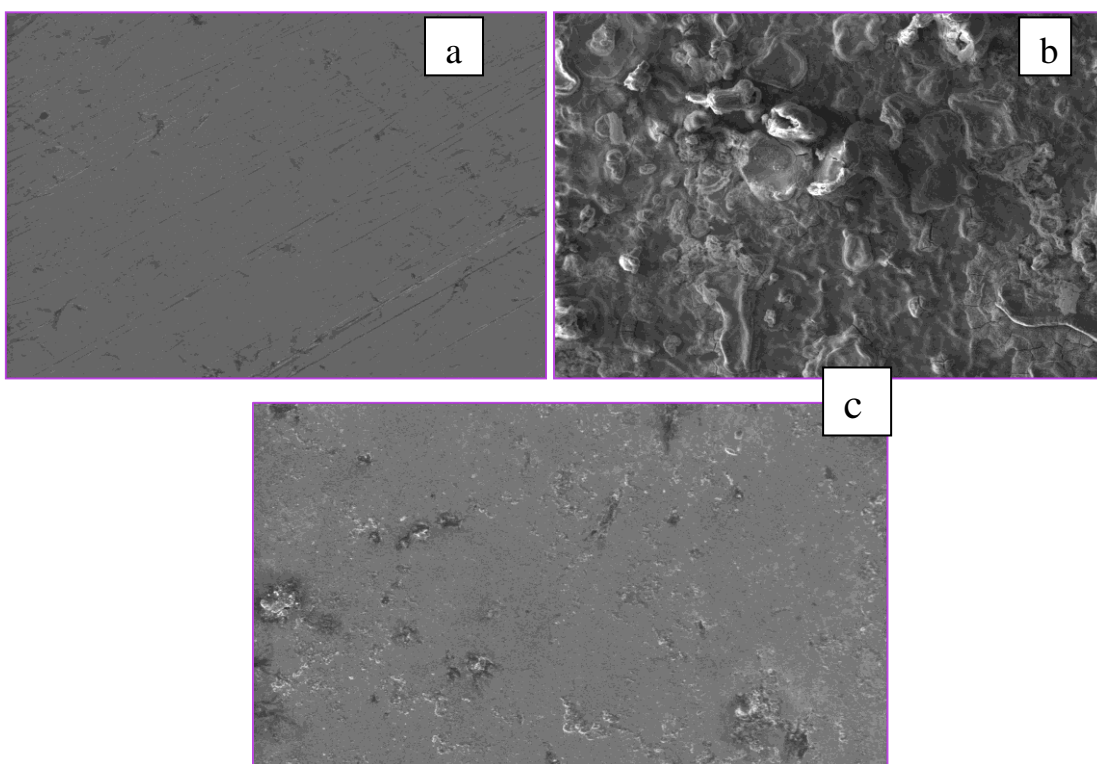


Figure 5: SEM micrographs of

- a) Polished carbon steel (control)**
- b) Carbon steel immersed in 0.5N HCl**
- c) Carbon steel immersed in 0.5N HCl containing 200 ppm of AIRE**

The SEM micrograph of polished carbon steel surface (control) in Figure 5a shows the smooth surface of the metal. The surface is considerably quite good and even.

The SEM micrograph of carbon steel surface immersed in 0.5N HCl (Figure 5b) shows the roughness of the metal surface which indicates the corrosion of carbon steel in 0.5N HCl. The SEM image of the carbon steel surface immersed in 0.5N HCl containing the inhibitor AIRE is shown in Figure 5c. A smooth surface is noticed. This indicates that a protective film is formed by the adsorption of the inhibitor on the metal surface, thus preventing the corrosion. The images confirm that AIRE inhibitor is effective in controlling corrosion by hindering the reactive active sites on the carbon steel surface [11,12].

4. CONCLUSION

AIRE exhibited excellent corrosion protection for carbon steel in 0.5 N HCl medium. GC–MS analysis identified 9-octadecenoic acid as the principal active component of the extract. The inhibitor achieved a maximum inhibition efficiency of 96% at an optimal concentration of 200 ppm after 3 h of immersion. Temperature studies revealed a decrease in inhibition efficiency with increasing temperature, accompanied by a corresponding increase in corrosion rate. Potentiodynamic polarization measurements indicated that AIRE acts as a mixed-type inhibitor. SEM analysis confirmed that the inhibited carbon steel surface was significantly smoother than the uninhibited surface, owing to the formation of a protective adsorbed film.

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**10. GREEN SYNTHESIS OF SILVER, CADMIUM AND ZINC
NANOPARTICLES USING *Euphorbia Hirta* (eaves)
AND THEIR ANTIMICROBIAL ACTIVITY**

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Abstract

Nanotechnology is a fast-growing field that plays an important role in modern medicine. It combines bioelectronics and biochemistry to create new nano-devices using materials inspired by living organisms. Among the many approaches, using plants to produce nanoparticles is gaining attention because it is simple, eco-friendly, safe, and low-cost. Compared to microbial methods that use bacteria or fungi, plant-based synthesis avoids safety risks and the need for complex purification or culture maintenance steps.

*In this study, we developed a simple and rapid method to produce silver, cadmium, and zinc nanoparticles using leaf extracts from *Euphorbia hirta* L. The synthesized nanoparticles were characterized using UV-Visible spectroscopy, Fourier transform infrared spectroscopy (FT-IR), and X-ray diffraction (XRD) techniques. Their antimicrobial activity, as well as their Chemical Oxygen Demand (COD) and*

Biological Oxygen Demand (BOD), was also evaluated. The results show that this plant-based approach provides an effective and environmentally friendly method for synthesizing stable metal nanoparticles.

Keywords: *Green synthesis, Euphorbia hirta, Silver nanoparticles, Cadmium nanoparticles and Zinc nanoparticles*

1. Introduction

Nanotechnology is a rapidly expanding field focused on materials and devices with dimensions between 1 and 100 nm, where unique optical, electrical, and mechanical properties arise due to high surface area and quantum effects.¹In recent years, nanotechnology has found extensive applications in medicine, electronics, energy, environmental remediation, textiles, cosmetics, and the food industry, highlighting its interdisciplinary importance.²Among the wide variety of nanomaterials, metallic nanoparticles such as silver, cadmium, and zinc have attracted special interest because of their antimicrobial, catalytic, optical, and biomedical potentials.³

1.1.Nanotechnology and Nanoparticles

Nanoparticles are particles typically ranging from 1 to 1000 nm, exhibiting properties that differ significantly from their bulk counterparts due to increased surface-to-volume ratio and altered electronic structure.⁴These properties enable enhanced conductivity, catalytic efficiency, tunable optical behavior, and improved performance in applications such as sensors, drug delivery, and imaging. Metallic nanoparticles, in particular, play a key role in consumer products, environmental applications, and advanced therapeutic systems, including targeted drug delivery and biosensing.⁵

1.2.Need for Green Synthesis

Conventional physical and chemical methods for nanoparticle synthesis often require high energy input, toxic reagents, and complex processing, leading to environmental and health concerns. Green synthesis has emerged as a sustainable alternative, utilizing biological systems such as bacteria, fungi, and plants to produce nanoparticles in an eco-friendly, cost-effective, and biocompatible manner.⁶This

approach reduces toxic by-products, lowers energy consumption, and yields nanoparticles more suitable for biomedical and environmental applications.⁷

1.3.Plant-Mediated Nanoparticle Synthesis

Among biological routes, plant-mediated synthesis offers several advantages, including simple experimental setup, easy scalability, and the avoidance of culture maintenance required for microbial methods.⁸Plant extracts contain diverse phytochemicals that act as natural reducing and stabilizing agents, enabling the rapid formation of stable metal nanoparticles without additional hazardous chemicals. Such green-synthesized nanoparticles have demonstrated promising activities in drug delivery, antimicrobial formulations, water treatment, and other nanobiotechnology applications.⁹

1.4.Importance of Silver, Cadmium, and Zinc Nanoparticles

Silver nanoparticles are well known for their broad-spectrum antimicrobial properties and are widely applied in medical devices, wound dressings, textiles, food packaging, and surface coatings.¹⁰Cadmium-based nanoparticles, despite cadmium's inherent toxicity, are valued for their unique optoelectronic characteristics, making them useful in sensors, photocells, LEDs, and imaging-related biomedical applications when handled carefully.¹¹Zinc oxide nanoparticles combine strong UV-absorbing, antimicrobial, and biocompatible properties, leading to applications in sunscreens, textiles, rubber, photocatalysis, and emerging biomedical fields such as anticancer and antidiabetic therapies.¹²

1.5.Eco-friendly Nanoparticle Synthesis Using *Euphorbia hirta* Leaves

Euphorbia hirta L., a medicinal plant from the Euphorbiaceae family, is traditionally used to treat respiratory disorders, gastrointestinal problems, infections, and various inflammatory conditions.¹³The plant is reported to possess antibacterial, antifungal, anti-inflammatory, antioxidant, antimalarial, antiasthmatic, antidiarrheal, anticancer, and other pharmacological activities, indicating a rich phytochemical profile suitable for nanoparticle synthesis.¹⁴In this context, the present work aims to synthesize

silver, cadmium, and zinc nanoparticles using *Euphorbia hirta* leaf extract and to characterize them by UV–Visible spectroscopy, FT-IR, and XRD, along with evaluation of their antimicrobial activity and water quality parameters such as BOD and COD. ¹⁵

2. Experimental Details

2.1. Materials

The following materials and chemicals were used in this study: *Euphorbia hirta* L. leaves, silver nitrate (AgNO_3), cadmium chloride (CdCl_2), zinc sulfate (ZnSO_4), and distilled water. For COD and BOD analysis, potassium dichromate, sulfuric acid with silver sulfate, mercuric sulfate, ferroin indicator, ferrous ammonium sulfate, dilution water, BOD bottles, and an incubator were used, along with standard glassware. All reagents were of analytical grade and distilled water was used for all preparations.

2.2. Preparation of Plant Extract

Fresh *Euphorbia hirta* leaves were collected from the college campus, washed thoroughly with tap water followed by distilled water, and cut into small pieces. Twenty-five grams of leaves were boiled in 100 ml of distilled water for 30 minutes, the mixture was cooled and filtered through Whatman No. 1 filter paper, and the clear extract was stored in a refrigerator for further use.

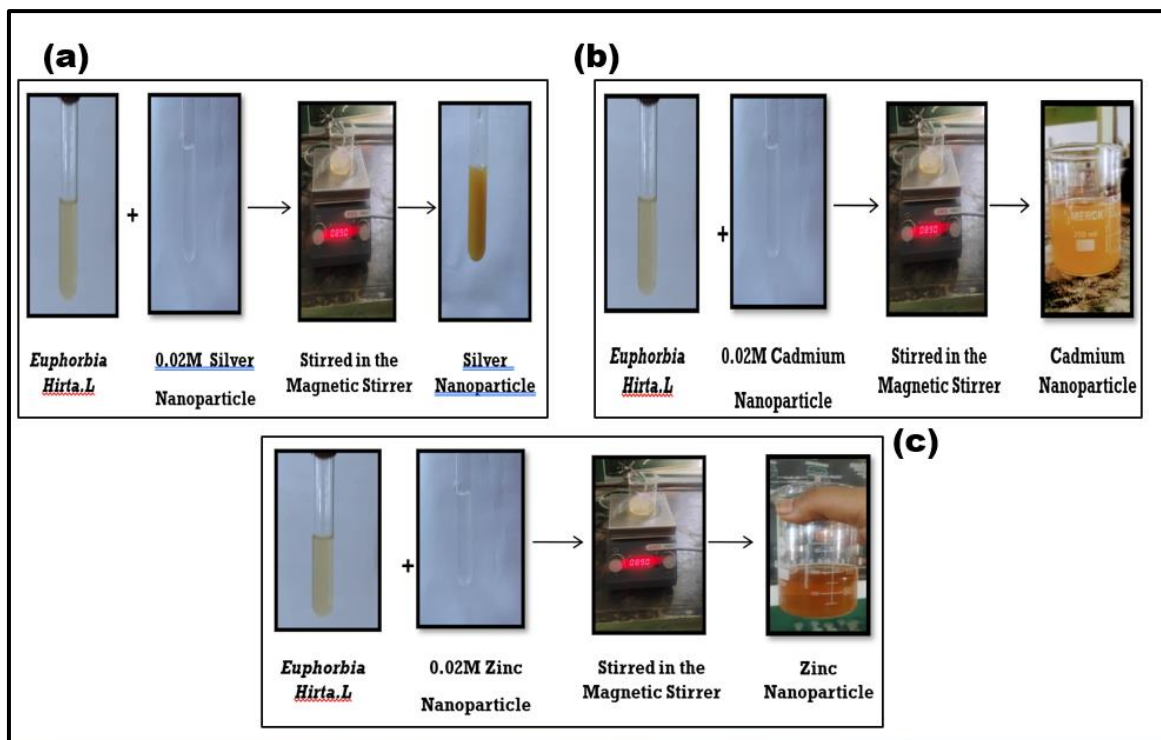


Fig 1. (a), (b) and (c) Silver, Cadmium and Zinc nano particles experimental preparation

2.3.Synthesis of Metal Nanoparticles

For silver nanoparticles, 20 ml of leaf extract was mixed with 50 ml of 0.02 mol/ml silver nitrate solution (ratio 1:5) and stirred until a colour change and precipitate formation were observed, after which the precipitate was collected by filtration. For cadmium and zinc nanoparticles, 20 ml of leaf extract was mixed separately with 20 ml of 0.02 mol/ml cadmium chloride or zinc sulfate solution (ratio 1:1), stirred until colour change and precipitate formation, and the formed nanoparticles were similarly separated using Whatman No. 1 filter paper.

2.4.Characterization of Nanoparticles

The synthesized nanoparticles were characterized using UV–Visible spectroscopy, Fourier Transform Infrared (FT-IR) spectroscopy, and X-ray diffraction (XRD). UV–Vis spectroscopy was used to confirm nanoparticle formation through

surface plasmon resonance, FT-IR to identify functional groups involved in stabilization, and XRD to determine crystalline nature and estimate particle size using Scherrer's formula.

2.5. Antimicrobial, COD and BOD Analysis

Antimicrobial activity was evaluated using agar plate diffusion, where standardized bacterial inocula were spread on nutrient agar plates and discs containing the nanoparticle samples were placed on the surface, followed by incubation at 35–37°C for 16–18 hours and measurement of zones of inhibition.¹⁶ Chemical Oxygen Demand (COD) was measured using the dichromate reflux method, and Biological Oxygen Demand (BOD) was determined by incubating samples in BOD bottles at 20°C for five days and measuring the oxygen consumed, to assess the impact of nanoparticles on water quality.¹⁷

3. Results and Discussion

3.1. Synthesis of Silver Nanoparticles

The formation of silver nanoparticles was visually confirmed by the colour change of the reaction mixture from light green to pale yellow after adding *Euphorbia hirta* leaf extract to silver nitrate solution, indicating reduction of Ag⁺ ions to nanosilver. This colour change is due to surface plasmon resonance of silver nanoparticles, which is characteristic of nanosized metallic silver formed in aqueous plant-mediated systems. The synthesized silver nanoparticles were further subjected to UV–Visible spectroscopy, FT-IR, and XRD to confirm their crystal structure, morphology, and purity, and were then evaluated for antimicrobial activity.

3.2. Synthesis of Cadmium Nanoparticles

In the case of cadmium, the addition of *Euphorbia hirta* extract to cadmium chloride solution led to visible precipitate formation accompanied by a change from light green to pale yellow, suggesting reduction of Cd²⁺ ions and nucleation of cadmium nanoparticles. This observation supports the role of phytochemicals in the plant extract as efficient reducing and stabilizing agents for cadmium nanostructures in aqueous

medium. The obtained cadmium nanoparticles were characterized by UV–Visible spectroscopy, FT-IR, and XRD to study their structural and optical properties and were also screened for antimicrobial potential.

3.3.Synthesis of Zinc Nanoparticles

For zinc, mixing zinc sulfate solution with *Euphorbia hirta* extract produced a pale yellow precipitate, indicating successful reduction of Zn^{2+} ions and formation of zinc nanoparticles. The similar colour change pattern observed for silver, cadmium, and zinc systems confirms that the same plant-derived biomolecules can drive the green synthesis of different metal nanoparticles. The zinc nanoparticles were likewise characterized using UV–Visible spectroscopy, FT-IR, and XRD to determine their crystalline nature and were evaluated for antimicrobial activity.

3.4.Characterization of Plant Extract

The hot aqueous extract of *Euphorbia hirta* was prepared by boiling 20 g of fresh, cleaned plant material in 200 ml of distilled water for 30 minutes followed by filtration. This extract was analyzed by UV–Visible, FT-IR, and XRD to understand its optical features and the presence of functional groups and any crystalline components that might participate in nanoparticle formation and stabilization. Such preliminary characterization of the extract supports its suitability as a green reducing and capping agent in nanomaterial synthesis.

3.5. UV–Visible Spectroscopic Analysis

The bio reduction of silver, cadmium, and zinc ions was monitored by recording UV–Visible spectra of the reaction mixtures in the 200–800 nm range at different time intervals using a double beam spectrophotometer. Silver nanoparticles synthesized using *Euphorbia hirta* leaf extract showed a strong surface plasmon resonance band centered at 400–430 nm, which is typical for spherical nanosilver and confirms successful nanoparticle formation. Cadmium and zinc nanoparticles displayed distinct absorption peaks at 325 nm and 324 nm, respectively, indicating the formation of semiconductor-type nanostructures consistent with quantum confinement effects at reduced particle

size. The blue-shifted, well-defined bands in all three systems suggest that the particles are in the nanometer range and that the plant extract provides effective stabilization against aggregation, which is essential for their intended antimicrobial and environmental applications.

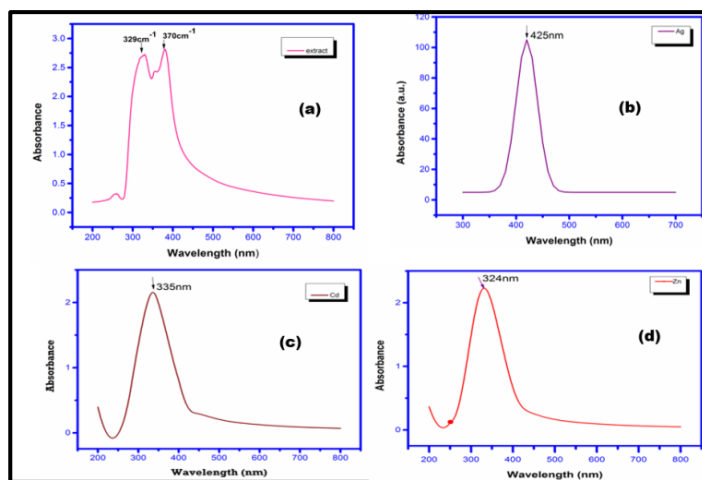


Fig 2. UV-Visible Spectrum of *Euphorbia Hirta*(a)and (b), (c) (d) Ag, Cd & Zn Nanoparticles from *Euphorbia Hirta*

3.5.1. UV–Visible Spectrum of *Euphorbia hirta* Extract

The UV–Visible spectrum of the *Euphorbia hirta* extract shows strong absorbance at 329 nm (2.558), 370 nm (2.570), and 385 nm (2.786). These peaks indicate the presence of phytochemicals such as phenolics, flavonoids, and other conjugated compounds, which are known to act as natural reducing and stabilizing agents in green nanoparticle synthesis. The relatively high absorbance values suggest a rich concentration of these biomolecules, supporting the ability of the extract to reduce metal ions and cap the formed nanoparticles effectively.

3.5.2. UV–Visible Spectrum of Silver Nanoparticles

The silver nanoparticle solution synthesized using *Euphorbia hirta* shows a

prominent absorption band around 420–425 nm with high absorbance values, corresponding to the characteristic surface plasmon resonance (SPR) of silver nanoparticles. An SPR peak in this region confirms the successful reduction of Ag⁺ ions to metallic nanosilver and indicates that the particles are in the nanometer range, typically associated with spherical or quasi-spherical morphology. The sharp, intense peak also suggests good dispersion and relatively narrow size distribution, reflecting effective stabilization of the nanoparticles by plant-derived phytochemicals.

3.5.3. UV–Visible Spectrum of Cadmium Nanoparticles

Cadmium nanoparticles synthesized from *Euphorbia hirta* extract exhibit absorption peaks at 324 nm (2.1282) and 335 nm (2.1896), which are characteristic of semiconductor-type cadmium nanostructures. The position of these peaks in the UV region indicates a widened band gap compared to bulk cadmium compounds, consistent with quantum confinement effects at the nanoscale. The close spacing and relatively high absorbance of these bands imply the formation of stable cadmium nanoparticles with reasonably uniform size and good interaction with the plant matrix.

3.5.4. UV–Visible Spectrum of Zinc Nanoparticles

The zinc nanoparticle samples show strong absorption at 324 nm (2.2678) and 325 nm (2.2608), which fall in the expected region for zinc-based nanoparticles such as ZnO or related zinc nanostructures. These UV-region peaks likewise indicate nanoscale particles with modified electronic structure compared to bulk zinc compounds, again reflecting quantum confinement behavior. The similar wavelengths but slightly higher absorbance compared to cadmium nanoparticles suggest efficient formation and stabilization of zinc nanoparticles by *Euphorbia hirta* extract, with a dense population of particles in the colloidal system.

The UV–Visible results demonstrate that the *Euphorbia hirta* extract itself contains UV-absorbing phytochemicals and can act as both reducing and capping agent for metal ions. The distinct and well-defined absorption peaks for silver (around 420–425 nm), cadmium (324–335 nm), and zinc (324–325 nm) confirm successful green

synthesis of three different metal nanoparticles, each showing spectral features consistent with nanoscale dimensions and good colloidal stability. These findings support the suitability of *Euphorbia hirta*-mediated synthesis for producing metal nanoparticles with potential applications in antimicrobial formulations and environmental remediation.

3.6.FT-IR Analysis

FT-IR analysis is employed to investigate the surface chemistry of the synthesized nanoparticles. It helps identify organic functional groups such as –OH and C=O that are attached to the nanoparticle surface. The FT-IR spectra were recorded using acetone as the solvent. For the analysis, silver, cadmium, and zinc nanoparticle solutions were centrifuged at 20,000 rpm for 20 minutes. The resulting pellets were thoroughly washed three times with 20 mL of deionized water, dried, and analyzed using the IR-Prestige-21 (Shimadzu) at a resolution of 2 cm⁻¹. FT-IR characterization was further carried out for the *Euphorbia Hirta* leaf extract-mediated silver, cadmium, and zinc nanoparticles. The obtained spectra exhibited a strong peak at 3595.31 cm⁻¹, corresponding to O–H stretching vibrations, indicating the presence of hydroxyl groups from phytochemicals involved in nanoparticle synthesis and stabilization. Fourier Transform Infrared (FT-IR) spectroscopy, which operates in the infrared region of the electromagnetic spectrum characterized by longer wavelengths and lower frequencies than visible light is a widely used analytical technique for identifying and studying chemical compounds based on their absorption features

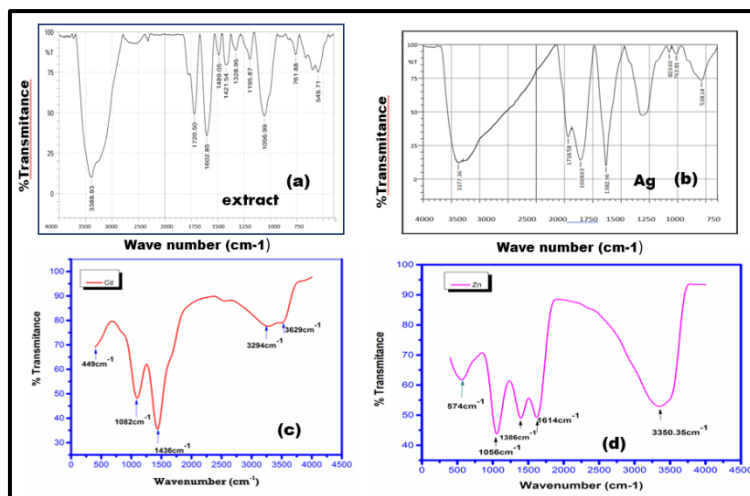


Fig 3.(a)FT-IR Spectrum of *Euphorbia hirta* L. Leaves Extract and Ag, Cd, & Zn Nanoparticles

3.6.1. FT-IR Analysis of Plant Extract and Nanoparticles

The FT-IR spectrum of *Euphorbia hirta* leaf extract showed key peaks at 3388.93 cm^{-1} (O-H stretch), 1720.50 cm^{-1} (C=O stretch), 1602.85 cm^{-1} (N-H bend), 1195.87 cm^{-1} (C-N stretch), 1056.99 cm^{-1} (C-O stretch), and 761.88 cm^{-1} (C-H bend), confirming the presence of phenols, flavonoids, proteins, and aromatic compounds responsible for nanoparticle synthesis.

3.6.2. Silver Nanoparticles FT-IR Results

Silver nanoparticles displayed shifted peaks at 3377.36 cm^{-1} ($\Delta 11.57\text{ cm}^{-1}$), 1718.58 cm^{-1} ($\Delta 1.92\text{ cm}^{-1}$), 1608.63 cm^{-1} , with a new C-F peak at 1382.96 cm^{-1} , indicating O-H/N-H and C=O groups from the extract participated in Ag^+ reduction and formed coordination bonds with nanoparticle surfaces. These shifts provide direct evidence of phytochemical interaction, while N-H bending and C-F stretching confirm protein-flavonoid capping that prevents aggregation and ensures colloidal stability.

3.6.3. Cadmium and Zinc Nanoparticles FT-IR Results

Cadmium/zinc nanoparticles showed O-H, C-H, COO^- bending, C-O, and metal halide vibrations, demonstrating phenolic reduction, terpenoid

coating, carboxylate chelation, and ether stabilization of nanoparticle surfaces. These functional groups create a biomolecular corona essential for biocompatibility and environmental stability.

3.6.4. Zinc Nanoparticles Specific Analysis

Zinc nanoparticles exhibited peaks at 3350.35 cm^{-1} (N-H/O-H), 1614 cm^{-1} (C=C aromatic), 1386 cm^{-1} (hydrocarbon), 1056 cm^{-1} (C-O-C ether), and crucially 574 cm^{-1} (Zn-O stretch), providing definitive evidence of ZnO nanoparticle formation. This metal-oxygen vibration confirms successful green synthesis and bioreduction by *Euphorbia hirta* phytochemicals.

The FT-IR results demonstrate that *Euphorbia hirta* polyphenols (O-H, C=O), proteins (N-H), and terpenoids (C-H, C-O-C) serve dual roles as reducing and capping agents, with characteristic peak shifts and new metal-oxygen bonds confirming stable nanoparticle formation suitable for antimicrobial and environmental applications.

3.7.XRD Analysis

3.7.1. Sample Preparation and Analysis

Silver, cadmium, and zinc nanoparticles synthesized using *Euphorbia hirta* extract were purified by centrifugation at 5000 rpm for 20 minutes, redispersed in deionized water, freeze-dried, and analyzed by XRD using Cu K α radiation ($\lambda = 1.5406\text{ \AA}$).⁴ Crystallite sizes were calculated using the Debye-Scherrer equation: $D = 0.94\lambda / (\beta \cos\theta)$, where β is the full width at half maximum (FWHM) after instrumental correction.

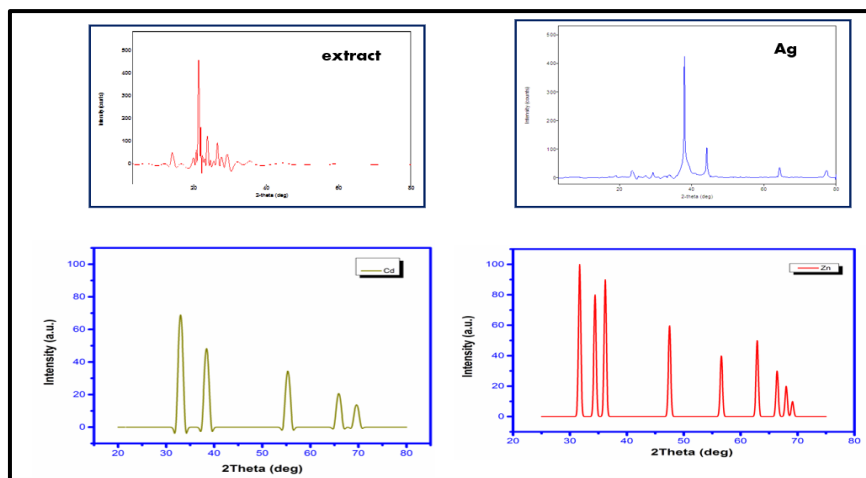


Fig 4. (a) XRD Spectrum of *Euphorbia Hirta L.* Leaves Extract and Ag, Cd, & Zn Nanoparticles

3.7.2. Silver Nanoparticles - Crystallite Size Analysis

Silver nanoparticles showed distinct diffraction peaks at 2θ values of 23.7272° ($D = 6.53$ nm), 29.256° ($D = 7.05$ nm), 18.8597° ($D = 4.07$ nm), and 64.2872° ($D = 3.98$ nm). These multiple peaks confirm the polycrystalline nature of the biosynthesized silver nanoparticles with average crystallite sizes ranging from 3.98-7.05 nm, well within the nanoscale regime. The peak broadening characteristic of nanomaterials further validates the nano-dimensions achieved through green synthesis.

3.7.3. Cadmium Nanoparticles - Crystallite Size Analysis

Cadmium nanoparticles exhibited a sharp diffraction peak at $2\theta = 32.996^\circ$ ($\theta = 16.498^\circ$, $\cos\theta = 0.9588$), yielding a crystallite size of **2.13 nm** using the Debye-Scherrer formula. This extremely small crystallite size demonstrates the high efficiency of *Euphorbia hirta* phytochemicals in controlling nucleation and growth during cadmium nanoparticle biosynthesis.

3.7.4. Zinc Nanoparticles - Crystallite Size Analysis

Zinc nanoparticles displayed a characteristic peak at $2\theta = 31.707^\circ$ ($\theta = 15.8535^\circ$, $\cos\theta = 0.96196$), corresponding to a crystallite size of **3.05 nm**. This size confirms formation of nanoscale zinc oxide (ZnO) particles, consistent with the FT-IR metal-

oxygen vibration observed at 574 cm^{-1} .

The XRD results confirm successful green synthesis of crystalline silver (3.98-7.05 nm), cadmium (2.13 nm), and zinc (3.05 nm) nanoparticles using *Euphorbia hirta* extract. All calculated crystallite sizes fall within the 2-7 nm range, validating the nanoscale dimensions essential for unique plasmonic, quantum confinement, and antimicrobial properties. The consistency between UV-Vis (SPR peaks), FT-IR (functional group interactions), and XRD (crystallite sizes) provides comprehensive evidence of stable nanoparticle formation. These ultra-small, biocompatible nanoparticles demonstrate the efficacy of plant-mediated synthesis for producing application-ready nanomaterials for antimicrobial therapy and environmental remediation.

The *Euphorbia hirta* extract plays a critical role in regulating nanoparticle nucleation and growth. Phytochemicals such as phenolics, flavonoids, proteins, and terpenoids act as both reducing and stabilizing agents. These biomolecules donate electrons for metal ion reduction and form a capping layer on nanoparticle surfaces, preventing aggregation and improving colloidal stability. This bio-capping effect contributes to the nanoscale crystallite sizes observed from XRD and promotes relatively uniform particle dispersity.

3.8. Antimicrobial activity

Silver is a powerful and natural antibiotic and antibacterial agent. Silver nitrate has long been considered a potent and natural antibacterial compound. Similarly, cadmium is recognized for its strong antimicrobial activity, particularly due to its ability to disrupt microbial cell function, while zinc is known for its broad-spectrum antimicrobial and antifungal properties, as well as its role in enhancing immune response. Synthesized silver, cadmium, and zinc nanoparticles were tested for antimicrobial activity against pathogenic microorganisms. The antimicrobial assay was conducted on human pathogens including *Escherichia coli* (*E. coli*), *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Candida albicans* using the Kirby-Bauer

method. Each zone size is interrupted according to the organism by reference to the tables.

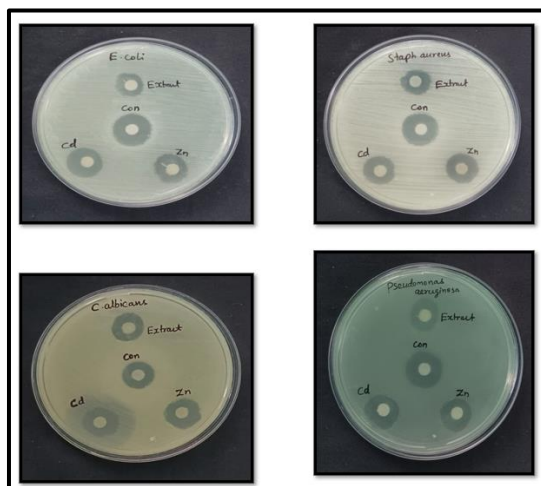


Fig 5. (a)Antimicrobial Characteristics Of Silver, Cadmium and Zinc Nanoparticles

The antimicrobial activity of *Euphorbia hirta* extract and biosynthesized Ag, Zn, and Cd nanoparticles was evaluated against *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus* (bacteria), and *Candida albicans* (fungus) using agar well diffusion method. The zones of inhibition are presented below: table .1

Microorganism	<i>Euphorbia Hirta</i>	Ag NPs	Zn NPs	Cd NPs	Control
<i>E. coli</i>	14 mm	13 mm	15.6 mm	16.2 mm	18 mm
<i>P. aeruginosa</i>	16 mm	18 mm	15 mm	16.3 mm	17 mm
<i>S. aureus</i>	14.6 mm	14 mm	15.8 mm	15 mm	17 mm
<i>C. albicans</i>	14.5 mm	11 mm	16 mm	15.2 mm	14 mm

All nanoparticles exhibited significant antimicrobial activity against tested pathogens, with zone sizes comparable to or better than plant extract alone. Cadmium nanoparticles showed highest activity against *E. coli* (16.2 mm) and *P. aeruginosa* (16.3 mm), while zinc nanoparticles were most effective against *S. aureus* (15.8 mm) and *C.*

albicans (16 mm). Silver nanoparticles demonstrated superior activity against *P. aeruginosa* (18 mm), confirming their well-established broad-spectrum antibacterial properties through membrane disruption and reactive oxygen species generation.

The variation in activity reflects differences in nanoparticle composition, size (2-7 nm from XRD), and surface chemistry (FT-IR confirmed protein/phenol capping), which influence bacterial cell wall interactions. Gram-negative bacteria (*E. coli*, *P. aeruginosa*) showed slightly larger zones with Cd/Zn nanoparticles, possibly due to thinner peptidoglycan layer facilitating nanoparticle penetration. Gram-positive *S. aureus* responded better to Zn nanoparticles, while antifungal activity against *Candida albicans* was highest with Zn nanoparticles, consistent with ZnO's documented antifungal mechanism.

These results validate *Euphorbia hirta*-mediated green synthesis as an effective route for producing multifunctional antimicrobial nanoparticles suitable for biomedical applications, wound dressings, and surface coatings.

3.9. Chemical Oxygen Demand Analysis

COD was determined using standard dichromate reflux method. Twenty ml sample was digested with 0.2N K₂Cr₂O₇, HgSO₄, Ag₂SO₄ catalyst, and concentrated H₂SO₄ at 150°C for 2 hours. After cooling and dilution to 100 ml, titration against 0.1N FAS with ferroin indicator determined oxygen demand. COD calculated as: **COD (mg/L) = [(A - B) × N × 8000] / V**, where A = blank titer, B = sample titer. Result are given in table 2.

Table 2.

Sample	Volume of sample (ml)	Volume of FAS (ml)	COD Result
Blank solution	100	20	Reference
<i>Euphorbia hirta</i> extract	100	ADL	ADL
Ag nanoparticles	100	ADL	ADL

Sample	Volume of sample (ml)	Volume of FAS (ml)	COD Result
Cd nanoparticles	100	ADL	ADL
Zn nanoparticles	100	ADL	ADL

ADL = Above Detection Limit (no significant FAS consumption observed)

All test samples (*Euphorbia hirta* extract and Ag, Cd, Zn nanoparticles) showed "Above Detection Limit" (ADL) results, indicating negligible Chemical Oxygen Demand compared to the blank (20 ml FAS consumption). This confirms that the plant extract and biosynthesized nanoparticles contain minimal readily oxidizable organic matter.

The ADL result for *Euphorbia hirta* extract suggests efficient extraction of reducing phytoconstituents with low residual organic pollutants. More importantly, the nanoparticles themselves exhibit chemically inert/stable nature, as no significant oxidation occurred during harsh dichromate digestion. This stability is attributed to the biomolecular capping layer (confirmed by FT-IR: phenols, proteins coating surfaces) that protects nanoparticle cores from chemical degradation.

These findings demonstrate that *Euphorbia hirta*-mediated nanoparticles are environmentally stable with low oxygen demand, making them suitable for water treatment applications where they can adsorb/degrade pollutants without generating secondary organic load. The chemical inertness complements their antimicrobial efficacy, positioning these green nanoparticles as dual-function nanomaterials for wastewater remediation.

Calculation

$$COD \left(\frac{mg}{L} \right) = \frac{(A - B) \times N \times 8000}{V} \quad (1) \rightarrow$$

Where,

A = Volume of FAS used for blank (mL)

B = Volume of FAS used for sample (mL)

N = Normality of FAS

V = Volume of the sample taken (mL)

8000 = Milliequivalent weight of oxygen × 1000

5.10. Biological Oxygen Demand Analysis

BOD was determined using the Winkler titration method. Water samples containing *Euphorbia hirta* extract and nanoparticles were analyzed for initial and final dissolved oxygen (DO) after 10 days incubation. BOD calculated as **BOD (mg/L) = D₁ (initial DO) - D₂ (final DO)**. Results (BOD) are given in table 3. Comparison table of COD and BOD given in table table 4.

Table 3.

Sample	Volume (ml)	Initial DO (ml)	Final DO (ml)	BOD (mg/L)
<i>Euphorbia hirta</i>	20	0	1	1
Silver nanoparticles	20	0	0	0
Cadmium nanoparticles	20	0	0	0
Zinc nanoparticles	20	0	4	4

Table 4.

Sample	COD	BOD (mgO ₂ L ⁻¹)	Interference
<i>Euphorbia hirta</i>	ADL	1	Good
Silver nanoparticles	ADL	0	Good
Cadmium nanoparticles	ADL	0	Good
Zinc nanoparticles	ADL	4	Good

The BOD results demonstrate extremely low biological oxygen demand across all samples, confirming minimal biodegradable organic content in both *Euphorbia hirta* extract and the biosynthesized nanoparticles. Silver and cadmium nanoparticles

exhibited **zero BOD (0 mg/L)**, indicating complete chemical stability and lack of microbial degradation even after 10 days incubation. *Euphorbia hirta* extract showed minimal BOD (1 mg/L), while zinc nanoparticles had slightly higher but still negligible BOD (4 mg/L).

Combined with ADL COD results, these findings confirm the **environmental stability** of green-synthesized nanoparticles. The biomolecular capping layer (FT-IR confirmed: phenols, proteins, flavonoids) protects nanoparticle cores from both chemical oxidation (low COD) and biological degradation (low BOD), making them suitable for long-term environmental applications.

- **Zero BOD** for Ag/Cd nanoparticles indicates inert nature ideal for water treatment applications
- **Low overall BOD (<4 mg/L)** confirms eco-friendly synthesis with negligible secondary pollution
- **High COD + low BOD ratio** validates stable nanoparticle formation suitable for antimicrobial coatings and wastewater remediation

These water quality parameters complement the confirmed nanoscale dimensions (XRD: 2-7 nm) and antimicrobial efficacy, positioning *Euphorbia hirta*-mediated nanoparticles as sustainable, dual-function nanomaterials for biomedical and environmental applications. **Calculation**

$$\text{BOD (mg/L)} = D_1 - D_2 \quad (\Rightarrow)$$

Where ,

D_1 = Initial dissolved oxygen (mg/L)

D_2 = Dissolved oxygen after 10 days (mg/L)

The findings indicate that both the extract and metal nanoparticles have minimal quantities of biodegradable organic materials and are unlikely to have a high biological oxygen requirement. According to COD and BOD measurements, high COD and low to moderate BOD are ideal conditions for nanoparticle formation.

CONCLUSION

The present study successfully demonstrates the green synthesis of silver, cadmium and zinc nanoparticles using *Euphorbia hirta* leaf extract as a reducing and stabilizing agent. This eco-friendly approach offers a sustainable and cost-effective alternative to conventional chemical and physical methods of nanoparticle synthesis. The phytochemicals present in *Euphorbia hirta* such as flavonoids, tannins, alkaloids, and phenols played a crucial role in the reduction of metal ions and the stabilization of the synthesized nanoparticles. Characterization of the synthesized nanoparticles was carried out using UV-Visible spectroscopy, FTIR, XRD and antimicrobial assays. The UV-Visible spectra confirmed the formation of nanoparticles through characteristic surface plasmon resonance (SPR) peaks at [e.g., 324 nm for ZnNPs, 425 nm for AgNPs, and 325 nm for CdNPs].

FTIR analysis revealed the presence of various functional groups such as hydroxyl, carbonyl, and amine groups, suggesting the involvement of bioactive phytochemicals in nanoparticle stabilization. XRD analysis confirmed average size of the nanoparticles. The antimicrobial activity test demonstrated that the biosynthesized nanoparticles exhibit significant antibacterial and antifungal properties, with cadmium nanoparticles showing the highest efficacy, followed by zinc and silver nanoparticles. Additionally, the impact of these nanoparticles on Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) tests highlighted their potential role in environmental remediation.

Overall, this study validates the potential of *Euphorbia hirta* as a valuable biological resource for the synthesis of metal nanoparticles. The synthesized nanoparticles not only exhibit promising physicochemical properties but also demonstrate notable antimicrobial activity, which could be harnessed in future biomedical and environmental applications. This green synthesis approach contributes to the advancement of sustainable nanotechnology by minimizing the use of hazardous chemicals and promoting the use of plant-based materials.

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**11. GREEN SILVER NANOPARTICLE SYNTHESIS USING
ALLIUM CEPA PEEL EXTRACT AND ANTIMICROBIAL
ACTIVITY AGAINST SELECTED HUMAN PATHOGENS**

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Abstract

Green synthesis of nanoparticles is cost-effective, eco-friendly, and non-toxic, with large-scale production and potential for bioaccumulation into the food chain and environment. The study investigates the synthesis of silver nanoparticles using Allium cepa peel extract as a reducing and stabilizing agent and silver nitrate as a silver precursor. The color changes of the solution were observed when incubated with silver nitrate at different time intervals. The highest silver nanoparticle production was obtained in A1 at 437nm, followed by A4 at 422nm, A3 and A2 at 288nm. The highest UV spectrum absorption was recorded after 1hr incubation, confirming that the synthesis of Allium cepa silver nanoparticles decreased with increasing time duration. TEM analysis confirmed the spherical-shaped particles with a diameter of 100 nm. Researchers are advancing towards sustainable and eco-friendly nanoparticle production with diverse applications by integrating synthesis and characterization techniques with vegetable peel extracts.

Keywords : *Green Synthesis, Silver Nanoparticle, Allium Cepa Peel*

Introduction

Nanotechnology is rapidly gaining importance in a number of areas such as health care, cosmetics, food and feed, environmental health, mechanics, optics, biomedical sciences, chemical industries, electronics, drug-gene delivery, energy science, optoelectronics, catalysis, single electron transistors, light emitters, nonlinear optical devices, and photo- electrochemical applications (Colvin *et al.*,1994; Mansur *et al.*,1995). Generally, metal oxide nanoparticles are inorganic. Various nanoparticles like Gold, Silver, Titanium, Zinc, Iron, Carbon, Copper, etc. are known as enormously accepted magnetic materials for a wide range of applications like various generators, vending machines, medical implants, wristwatches, inductor cores, transformer circuits, magnetic sensors and recording equipment, telecommunications, magnetic fluids, microwave absorbers, etc. They also apply in other high-frequency applications (Snelling, 1969; Willard M *et al.*, 2004).

Silver nanoparticles are one of the promising products in the nanotechnology industry. The development of consistent processes for synthesizing silver nanomaterials is an important aspect of current nanotechnology research. Among the several noble metal nanoparticles, silver nanoparticles have attracted special attention due to their unique properties including appropriate electrical conductivity, chemical stability, catalytic and antimicrobial activities (Vijay Kumar *et al.*, 2014). Because of the high surface-to-volume ratio, silver in a nano-scale has demonstrated completely different properties from bulk particles made from the same material (Thirunavoukkarasu *et al.*, 2013).

Silver nanoparticles are synthesized using various physical, chemical and biological techniques resulting in different shapes and sizes for use in numerous applications. These synthesis methods are categorized into two main categories namely, top-down and bottom-up. In the top-down approach, the size of silver metal in its bulk form reduces mechanically to the nano-scale by using sophisticated methodologies such

as lithography and laser ablation. The bottom-up approach is also known as the self-assembly technique and includes of dissolution of silver salt into a solvent, reduction of silver ions to their element using the addition of a reducing agent and then stabilization of the forming silver nanoparticles using a stabilizing agent to prevent agglomeration of nanoparticles (Tolaymat *et al.*, 2010). This approach leads to nanostructures with fewer defects, more homogenous chemical composition and better short and long-range ordering (Leela and Vivekanandan, 2008).

The biological synthesis of nanomaterial can solve environmental challenges like solar energy conservation, agricultural production, catalysis, electronics, optics and biotechnological areas. Green synthesis of nanoparticles is a cost-effective, easily available, eco-friendly, nontoxic, and large-scale production and acts as a reducing and capping agent (Quang *et al.*, 2013) compared to the chemical method, which is very costly as well as it emits hazardous by-products, which can have some deleterious effect on the environment. Biological synthesis (Kaushik *et al.*, 2013) utilizes naturally occupying reducing agents such as plant extract, microorganisms, and enzymes, polysaccharides which are simple and viable, which is the alternative to complex and toxic chemical processes. Plants and fruit extracts can be described as nano factories that provide a potential pathway to bioaccumulation into the food chain and environment.

Materials and methods

Collection of vegetable and fruit peels:

The *Allium cepa* vegetable peels were collected from the kitchen waste. Collected vegetable peel wastes were washed with tap water followed by double distilled water to remove waste materials. Samples were dried in a hot air oven at 100°C for two days and powdered. 15g of the powdered sample were mixed and boiled with 100 ml of double distilled water for 3 mins. After 10 mins, the extracts were transferred into a conical flask and filtered thrice with Whatman No.1 filter paper to remove the particulate matter to get a clear solution and stored at 4°C refrigerated for further

experiments.

Preparation of Silver nitrate solution:

0.02 mmol aqueous solution of silver nitrate was prepared by adding 0.0338g of the silver nitrate in the 100 mL double distilled water. Usually change in color of the aqueous salt solution of a metal is indicative of metal nanoparticle formation. The distinct color change of the silver nitrate solution from colorless to gray color after the reduction process indicates the formation of silver nanoparticles.

Effect of concentration and reaction period

The different partition ratios of 0.02mmol concentrated silver nitrate and *Allium cepa* peel extracts such as A1 (2ml silver nitrate + 8ml peel extract), A2 (4ml silver nitrate + 6ml peel extract), A3 (6ml silver nitrate + 4ml peel extract) and A4 (90ml silver nitrate + 10ml peel extract) were prepared and used for silver nanoparticles synthesis. The test tubes were sealed using cotton plugs and observed for color change after 1hr, 2hr and 3hr.

Characterizations of silver nanoparticles:

UV-Vis spectroscopy:

Synthesis silver nanoparticles was confirmed by sampling the aqueous component of different time intervals and the absorption maxima were scanned by UV-Vis spectrophotometer at the wavelength of 250-600 nm on (CHEMILINE CL – 1320 Spectrophotometer) are generally used for characterizing various metal nanoparticles in the size range of 2 to 100 nm (Mittal *et al.*,2013).

FTIR spectroscopy:

FTIR is a molecular vibration spectroscopy that dissects chemical functional groups in different absorbance regions between 4000 and 400 cm^{-1} (Mittal *et al.*,2013). FTIR analysis was carried out in order to determine the role of functional groups involved in the stabilization (capping) and synthesis of silver nanoparticles present in the vegetable and fruit peel extract. The powdered sample of the formed silver nanoparticles at 3 hours was subjected to FTIR (Shimadzu, India) analysis at a

resolution of 4cm.

Transmission electron microscope (TEM):

Transmission electron microscope (TEM) technique was used to visualize the morphology of the silver nanoparticles. The 200 kV ultra high-resolution transmission electron microscopes (JEOL, Model No.JEM 2100 HRwith EELS). TEM grids were prepared by placing a 5 μ L of the silver nanoparticle solutions on carbon-coated copper grids and drying them under the lamp. Additionally, the addition presence of metals in the sample was analyzed by energy dispersive spectroscope (EDS) using INCA energy TEM 200 with analysis software (JEOL) was used (Mittal *et al.*,2013).

Effect of different partition ratio on the antimicrobial activity:

The different partition ratio 0.02mmol concentration silver nitrate and *Allium cepa* peel extract such as A3 and A4 were prepared and used for antimicrobial activity.

Antibacterial Activity-Disc diffusion method(N.G. Heatley, 1944)

The *in-vitro* anti-bacterial activity was assayed by the disc diffusion method, for *E.coli*, *Proteus mirabilis*, *Shigella flexneri*, *Entero bactor*, *staphylococcus aureus* and *Pseudomonas aeruginosa*. A 0.3ml amount of synthesized silver nanoparticles was applied to 4mm sterile disc. In the same way for control 0.3ml of amikacin was soaked in sterile disc. Both the discs were allowed to dry at room temperature. Pathogenic bacterial strains were inoculated in sterile broth and incubated at 37°C for 24 hrs. Pathogens were swabbed on the surface of sterile petri dishes in 20ml of solidified nutrient agar. The control and the experimental discs were placed in the sterile solidified nutrient agar petri plates to assess the effect of solvent and extracts on pathogens. These agar plates were incubated at 37°C for 24 hrs and the antibacterial activity was measured accordingly based on the inhibition zone around the disc. Antibacterial activity was expressed in diameter zone of inhibition which was measured with the outer side of the disc to inner side of the inhibition zone. Each synthesis silver nanoparticles were tested thrice for confirmation of activity.

Antifungal activity(Rao et al.,2010)

Pathogenic fungal strains were inoculated in potato dextrose agar medium and incubated at 48 hrs. In vitro antifungal activities of synthesized silver nanoparticles were determined against *Candida albicans*, *Candida tropicalis*, *Aspergillus niger*, *Aspergillus flavus* and *Actinomyces*. Fungal strains were gently swabbed on the surface of the sterile petri dish containing 20 ml Czapek Dox solidified nutrient agar with the help of a sterile cotton swab. The same procedure was followed. Areas of inhibited fungal growth were observed after 48 hrs.

Result

The reduction of silver ions to silver nanoparticles using *Allium cepa* peel extract acted as both a reducing and stabilizing agent. silver nitrate (0.02mmol) as a silver precursor was indicated by color changes of *Allium cepa* peel extract when incubated with silver nitrate at certain time (1hr, 2hr and 3hr). The color of the solution changed from yellow to light brown, and went darker with increasing time (1hr, 2hr and 3hr), at room temperature. It was known that silver nanoparticles colloidal solutions show intense yellow to brown colors, which occur only in nanoparticles, not in the case of bulk materials due to the strong interaction between light and conduction electron of silver in the solution (Figure 1,2 and 3)

The effect of different partition ratios of 0.02mmol concentrated silver nitrate in the production of nanoparticles using *Allium cepa* vegetable peel extract at 3hrs was analyzed. The highest *Allium cepa* silver nanoparticles production was obtained in A1 at 437nm followed by A4 at 422nm, A3 and A2 at 288nm (Table 1 and Figure 4). The effect of time on different partition ratio of 0.02mmol concentrated silver nitrate in the production of silver nanoparticles using *Allium cepa* vegetable peel extract at different time duration was analyzed. Maximum UV spectrum absorption was recorded after 1hr incubation. It confirms the production of *Allium cepa* silver nanoparticles synthesis decreased with increasing the time duration.

FT-IR has become an important tool for understanding the involvement of functional groups in interactions between metal particles and biomolecules. The synthesized silver nanoparticles were confirmed by changes that occurred in the FTIR spectra after 3-hour synthesis (Figure 5). FT-IR analysis was carried out to characterize the silver nanoparticles obtained from *Allium cepa* peel extracts. The prominent bands of absorbance were observed at around 3490 cm^{-1} , 3480 cm^{-1} , 3470 cm^{-1} , and 3495 cm^{-1} corresponding to N-H, O-H stretching vibrations of alkanes, amide, alcohol and H-banded to phenols. So, it proved that the water-soluble phenols, alkanes, amide and alcohol present in the peel extracts are acting as both a capping agent as well as a stabilizing agent. TEM analysis of *Allium cepa* peel silver nanoparticles showed spherical-shaped particles with a diameter of 100 nm (Figure 6),

Discussion

Owing to the applicability of silver nanoparticles in wide sectors, its demand is increasing at an overwhelming rate which has resulted in increased production. Researchers are continuously developing newer methods for the synthesis of highly monodispersed silver nanoparticles which are efficient in terms of synthesis rate as well as energy usage. Biological methods have emerged as an alternative to conventional methods for the synthesis of nanoparticles. The reduction and stabilization of silver ions by the combination of biomolecules such as proteins, amino acids, enzymes, polysaccharides, alkaloids, tannins, phenolics, saponins, terpenoids and vitamins which are already established in the plant extracts having medicinal values and are environmentally benign, yet chemically complex structures.

Synthesizing and characterizing nanoparticles using vegetable peel extracts is a burgeoning field with extensive research supporting its efficacy and potential applications. Vegetable peel extracts are rich in phytochemicals such as polyphenols, flavonoids, and terpenoids, which serve as natural reducing and capping agents for nanoparticle synthesis (Raut et al., 2014). The synthesis process typically involves the reduction of metal salts, such as silver nitrate or gold chloride, in the presence of the

extract under controlled conditions of temperature and pH (Iravani, 2011). Various vegetables, including banana, orange, lemon, and onion peels, have been utilized for nanoparticle synthesis, each imparting unique characteristics to the resulting nanoparticles (Sathishkumar et al., 2013; Castro et al., 2017). UV-Vis spectroscopy is commonly employed to monitor the formation of nanoparticles by observing the characteristic surface plasmon resonance (SPR) peak in the absorbance spectra (Kumar et al., 2018). Transmission electron microscopy (TEM) provides detailed insights into nanoparticle morphology, size distribution, and crystallinity (Mittal et al., 2013). Fourier-transform infrared spectroscopy (FTIR) helps in identifying the biomolecules present in the peel extract responsible for nanoparticle synthesis and stabilization (Philip, 2018).

Nanoparticles synthesized using vegetable peel extracts exhibit promising applications in various fields. In biomedicine, silver nanoparticles have demonstrated antimicrobial activity against a wide range of pathogens, making them suitable for wound healing and infection control (Singh et al., 2020). Catalytic applications include the use of nanoparticles as efficient catalysts for organic transformations due to their high surface area and reactivity (Kumar et al., 2019). Environmental remediation efforts benefit from the ability of nanoparticles to degrade pollutants and facilitate the removal of heavy metals from contaminated water sources (Dwivedi & Gopal, 2010). Additionally, nanoparticles synthesized from vegetable peel extracts are being explored for their potential in food packaging materials to enhance shelf life and safety (Das et al., 2012). By integrating synthesis and characterization techniques with the utilization of vegetable peel extracts, researchers are advancing towards sustainable and eco-friendly nanoparticle production with diverse applications.

Conclusion

In conclusion, the study demonstrates a green and efficient method for the synthesis of AgNPs using *Allium cepa* peel extract, highlighting its potential for various applications in biomedicine, catalysis and environmental remediation.

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**12. EXTRACTION AND CHARACTERIZATION OF
THERAPEUTIC POTENTIAL OF THE INK AND TISSUE
EXTRACT OF *SEPIA BREVIMANA* FROM THE GULF OF
MANNAR**

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Abstract

*The marine environment is a rich source of unique bioactive compounds with promising pharmaceutical potential. Cephalopods, particularly cuttlefish, produce biologically active substances in their tissues and ink that may serve as novel antimicrobial agents. The present study investigates the antimicrobial properties of crude ink and tissue extracts of *Sepia brevimana* against selected pathogenic bacterial strains. Extraction was performed using polar and non-polar solvents, followed by antimicrobial assays, SDS-PAGE protein profiling, and GC-MS analysis to characterize the bioactive constituents. Results revealed significant antibacterial activity, particularly in methanolic extracts, and identified several bioactive compounds, including carveol, phenolic derivatives, steroids, and astaxanthin. These findings highlight the potential of cuttlefish-derived compounds as candidates for novel antimicrobial drug development.*

Key Words

Pharmaceutical, Cephalopods, Cuttlefish, SDS-PAGE and GC-MS.

1. INTRODUCTION

The marine environment covers nearly 70% of the Earth's surface and represents one of the most biologically diverse ecosystems on the planet. Oceans harbor an extraordinary range of life forms, and nearly two-thirds of all known phyla are exclusively marine. This vast biodiversity has made marine ecosystems a prolific source of structurally unique and biologically potent natural products with applications in pharmaceuticals, nutraceuticals, cosmetics, and agrochemicals (Faulkner, 2002). Marine organisms produce diverse secondary metabolites shaped by extreme ecological conditions such as high salinity, pressure, and intense competition, resulting in compounds with remarkable pharmacological activities. To date, thousands of marine-derived natural products, including terpenes, polyketides, alkaloids, peptides, and polyketides, have been reported with antimicrobial, antiviral, antitumor, and anti-inflammatory properties (Blunt *et al.*, 2023).

Among marine organisms, invertebrates, particularly molluscs, have gained attention due to their rich repertoire of bioactive compounds. Molluscs, the second largest invertebrate phylum, possess innate defense mechanisms that yield metabolites with antimicrobial, cytolytic, antitumor, and immunomodulatory activities. Cephalopods, a highly evolved molluscan class including cuttlefish, squids, and octopods, are notable for their advanced nervous systems and effective chemical defenses. In addition to their nutritional value, cephalopods produce ink, a complex secretion composed of melanin, proteins, enzymes, biogenic amines, and antioxidants, which functions in predator deterrence. Cuttlefish ink has been traditionally used in medicine and is known for its antimicrobial, antioxidant, and antitumor properties (Palumbo *et al.*, 2003).

The increasing threat of antimicrobial resistance has intensified the search for novel antimicrobial agents from marine sources. In this context, cephalopods represent an underexplored reservoir of bioactive proteins and peptides. Therefore, the present study evaluates the antimicrobial potential of ink and tissue extracts of the cuttlefish

Sepia brevimana (Ullah et al., 2022). This work aims to contribute to marine natural product research and highlights the therapeutic potential of cephalopod-derived bioactive compounds.

2. MATERIALS AND METHODS

2.1. Collection and Preparation of Extract:

In the present study, the animals *S. brevimana* were collected from the Gulf of Mannar, Thoothukudi coastal region (Long 78° 8" to 79° 30" E and Lat 8° 35" to 9° 25" N) by trawl catch, brought to the laboratory, cleaned and washed with fresh seawater to remove all impurities. The abdomen of cephalopods was cut open and the ink glands and mantle tissue were carefully removed (Plate.1).

2.2. Crude extraction of ink:

The ink was collected by gently squeezing the glands with the spatula and the raw ink obtained from the glands was directly used for extraction. The ink used in the present work was crude and contained almost all the ingredients such as melanin, protein, lipids, glycosaminoglycans, etc.

Extraction was done by using different solvents. 25 ml of the ink was extracted with 75 ml of polar and non-polar solvents (1:3v/v) like hexane, chloroform, benzene, methanol and ethanol in sterile glass bottles. The ink was mixed gently with the solvents using sterile glass rods and was refrigerated at 4°C for 7 days for crude extraction. Each preparation was filtered using Whatman No. 1 filter paper and the crude extracts were concentrated under a vacuum rotary evaporator. Crude extracts were collected and stored at 4°C in glass bottles (Bansemiret *al.*, 2006).

2.3. Crude extraction of tissue:

The skin was removed and the tissues were cut into small pieces. 5g of tissue of cephalopod was weighed and homogenized with 5 ml of different solvents like hexane, chloroform, benzene, methanol and ethanol using a mortar and pestle following aseptic techniques. To this homogenate, 100 ml of solvents were added and incubated at room

temperature for 48 hrs. This extract was centrifuged at 27°C at 10000 rpm for 10 min and the supernatant was collected and concentrated under vacuum in a rotary evaporator at 30°C. The crude extract was analysed for its antimicrobial activity using the standard disc diffusion method (Boscaro *et al.*, 2022).

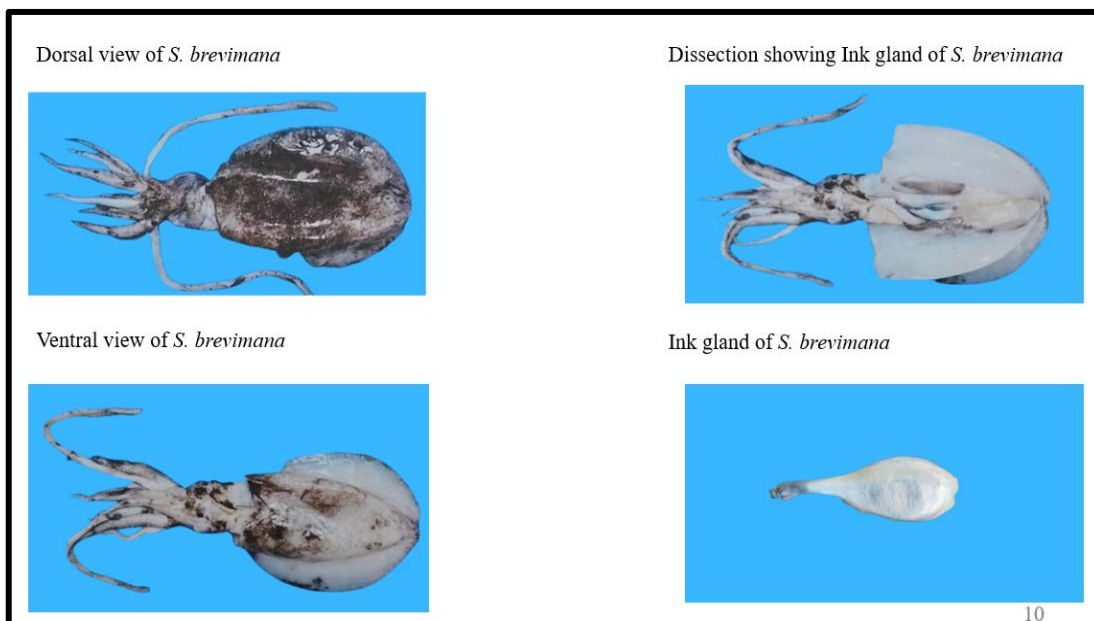
Plate 1. Experimental Animal: *Sepia brevimana*

2.4. Microbial Cultures:

Five bacterial strains, namely *Klebsiella pneumonia*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Streptococcus pneumoniae*, and *Staphylococcus aureus*, were obtained from the Zoology Department of St. Xavier's College (Autonomous), Palayamkottai.

2.5. Inoculum preparation for bacteria:

Nutrient broth was prepared and sterilized in an autoclave at 15lbs pressure for



15 minutes. All five bacterial strains were individually inoculated into the sterilized broth and incubated at 37°C for 24 hours. Nutrient agar was prepared and poured into sterile Petri dishes. The 24-hour-old bacterial broth cultures were inoculated in the Petri

dishes using a sterile cotton swab (Boscaro, 2005).

2.6. Antimicrobial assay:

2.6.1. Agar well diffusion method:

The antimicrobial activity of *S. brevimana* ink was evaluated using the well diffusion method. Mueller-Hinton Agar (MHA) was prepared, sterilized, and poured into sterile Petri dishes, allowing it to solidify. Bacterial *Klebsiella pneumoniae*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Streptococcus pneumoniae* and *Staphylococcus aureus* strains were cultured and adjusted to a 0.5 McFarland standard. Using a sterile cotton swab, the microbial suspensions were evenly spread on the agar surface. Wells of approximately 6 mm in diameter were created using a sterile cork borer. Different concentrations of ink extract were loaded into the wells (25, 50, 100 μ L), along with a control. The plates were incubated at 37°C for 24 hours for bacterial strains and at 25 - 0°C for 24 hours for bacterial strains. After incubation, the antimicrobial activity was assessed by measuring the diameter of the zone of inhibition (ZOI) around each well using a ruler or calliper. The results were recorded, and statistical analysis was performed to determine the significance of the antimicrobial effect of cuttlefish ink compared to the controls (El Masry *et al.*, 2005).

2.6.2. SDS-PAGE:

SDS–polyacrylamide gel electrophoresis (SDS-PAGE) was performed according to the method of Laemmli (1970) to qualitatively analyze protein profiles based on molecular weight. Proteins were denatured with sodium dodecyl sulfate (SDS) and a reducing agent, allowing separation of polypeptide chains solely according to size. A discontinuous gel system consisting of a stacking gel and a separating gel was used (Jayalakshmi *et al.*, 2014).

An 18% resolving gel was prepared using acrylamide, Tris-HCl buffer (pH 8.8), SDS, ammonium persulfate (APS), TEMED, and distilled water, and allowed to polymerize. This was overlaid with a stacking gel prepared in Tris-HCl buffer (pH 6.8).

Protein samples were mixed with sample buffer containing bromophenol blue and glycerol, heated at 95 °C for 3 min, and loaded into the wells along with molecular weight markers. Electrophoresis was carried out in Tris-glycine-SDS running buffer at 50 V until the dye front reached the bottom of the gel. After electrophoresis, protein bands were visualized by Coomassie Brilliant Blue staining.

2.6.3. GC-MS Analysis:

GC-MS analysis was performed using an Agilent 7890 gas chromatograph coupled to an Agilent 7000C mass selective detector in the positive ion electron impact (EI) mode. The separation was achieved using an HP-5MS fused silica capillary column, 30m 0.25 mm i.d., 0.25µm film thickness. GC oven temperature was programmed from 60°C to 285°C at a rate of 4.3°C/m* in Helium was used as the carrier gas; inlet pressure was 25 kPa; linear velocity: 1 mL/min at 210°C Injector temperature: 250°C and injection mode: split 1:50. MS scan conditions: source temperature, 200°C interface temperature, 250°C E energy, 70 eV; mass scan range, 40-350 amu (Melo *et al.*, 2000).

2.6.4. Identification of compounds:

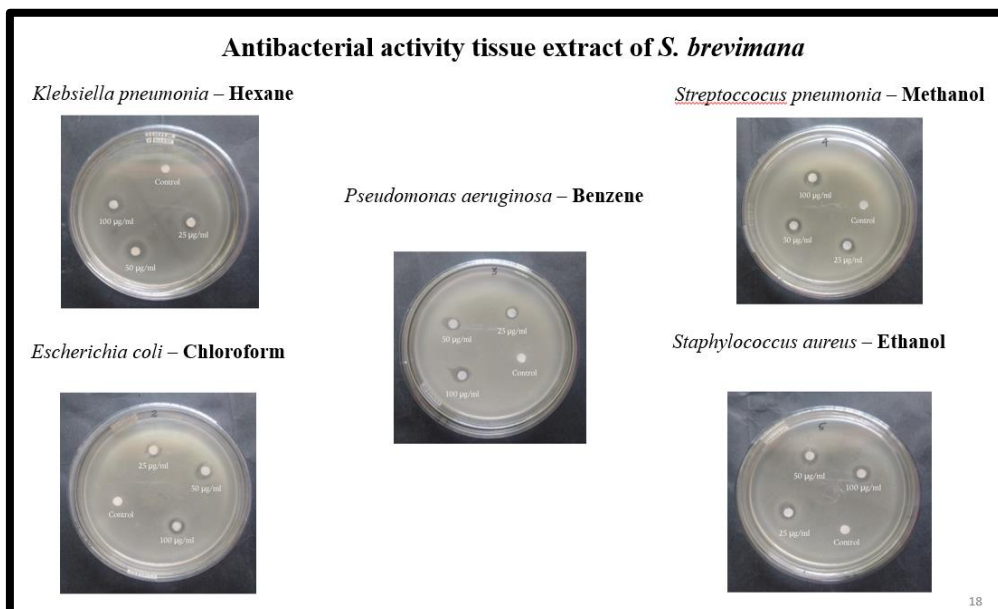
The interpretation of the mass spectrum was conducted using the database of the National Institute of Standards and Technology (NIST) WILEY 8 and FAME, which contains more than 62,000 patterns. The unknown components found in the methanol fraction of the tissue were matched with the spectrum of the known components stored in NIST, WILEY, FAME, and MS library and predicted from Duke's ethno botanical database. The name, molecular weight and structure of the components of the test materials were ascertained (Priya *et al.*, 2006).

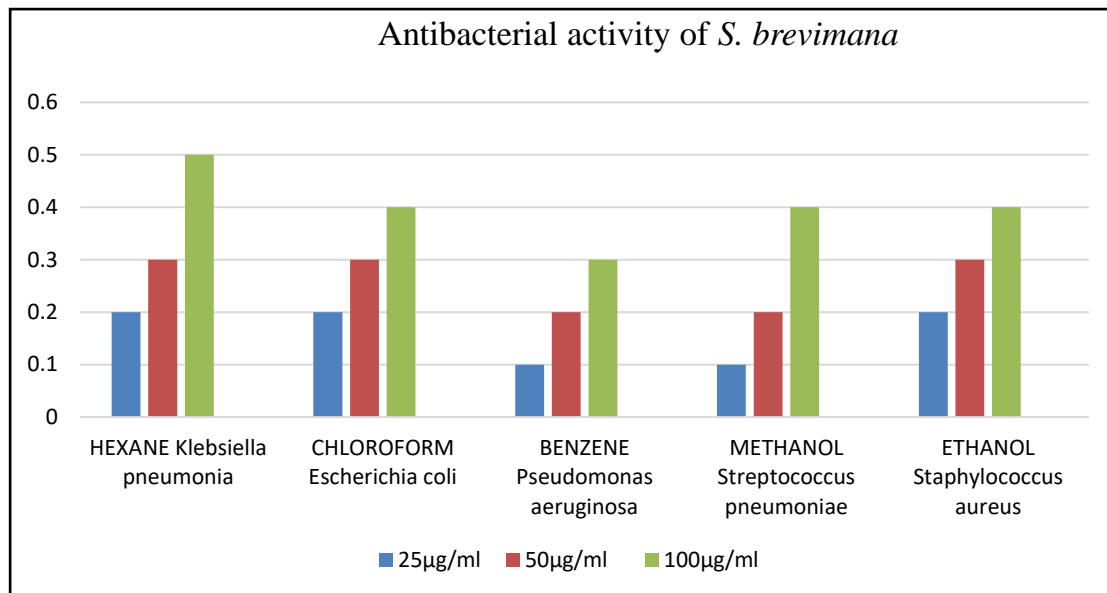
3.RESULTS

3.1. Antibacterial activity of the tissue of *S. brevimana* by agar disc diffusion method:

The antibacterial activity of tissue extracts of *Sepia brevimana* prepared using different organic solvents (hexane, chloroform, benzene, methanol, and ethanol) was evaluated against five clinically important bacterial pathogens, namely *Klebsiella pneumoniae*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Streptococcus pneumoniae*, and *Staphylococcus aureus*. All solvent extracts exhibited measurable antibacterial activity, indicating the presence of bioactive compounds in the cuttlefish tissues.

At a concentration of 25 µg/mL, moderate antibacterial activity was observed, with zones of inhibition ranging from 0.1 to 0.3 mm. The highest inhibition at this concentration (0.3 mm) was recorded against *E. coli*, suggesting greater sensitivity of this organism to the tissue extracts. In contrast, *P. aeruginosa* showed the least susceptibility, with a minimum inhibition zone of 0.1 mm in the benzene and chloroform extracts.





When the concentration was increased to 50 µg/mL, a corresponding increase in antibacterial activity was noted across all extracts and test organisms. The zones of inhibition ranged from 0.2 to 0.4 mm, with the maximum inhibition (0.4 mm) again observed against *E. coli*. The lowest activity at this concentration (0.2 mm) was recorded against *P. aeruginosa* in benzene and chloroform extracts, indicating its relatively higher resistance compared to other bacterial strains.

Figure 1: Antibacterial activity of the tissue of *S. brevimana*

The highest antibacterial activity was observed at 100 µg/mL, demonstrating a clear concentration-dependent response. At this concentration, inhibition zones ranged from 0.3 to 0.5 mm. The maximum zone of inhibition (0.5 mm) was recorded against *K. pneumoniae*, while the minimum inhibition (0.3 mm) was observed against *P. aeruginosa* in hexane and benzene extracts. Overall, *P. aeruginosa* consistently exhibited lower sensitivity across all concentrations and solvent extracts.

These results clearly indicate that the antibacterial efficacy of *Sepia brevimana* tissue extracts is both **concentration-dependent and solvent-dependent**, with higher concentrations producing stronger inhibitory effects. The observed activity suggests that

S. brevimana tissues contain potential antibacterial compounds that could be further explored for pharmaceutical applications (Figure 1).

3.2. Protein Profiling:

SDS - PAGE analysis of the protein extract from *S. brevimana* demonstrated the presence of several clearly resolved protein bands with molecular weights ranging from approximately **53 kDa to 220 kDa**. The presence of multiple distinct bands indicates that the extract comprises a heterogeneous mixture of proteins, highlighting the organism's biochemical complexity.

Proteins in the **lower molecular weight range (53 -70 kDa)** may correspond to enzymes, antimicrobial proteins, or immune-associated molecules that are typically involved in **innate defense mechanisms** in both marine and terrestrial organisms. These proteins are frequently reported to exhibit **antibacterial and antifungal activities** through mechanisms such as disruption of microbial cell membranes, inhibition of essential enzymatic pathways, or interference with protein synthesis (Figure 2)

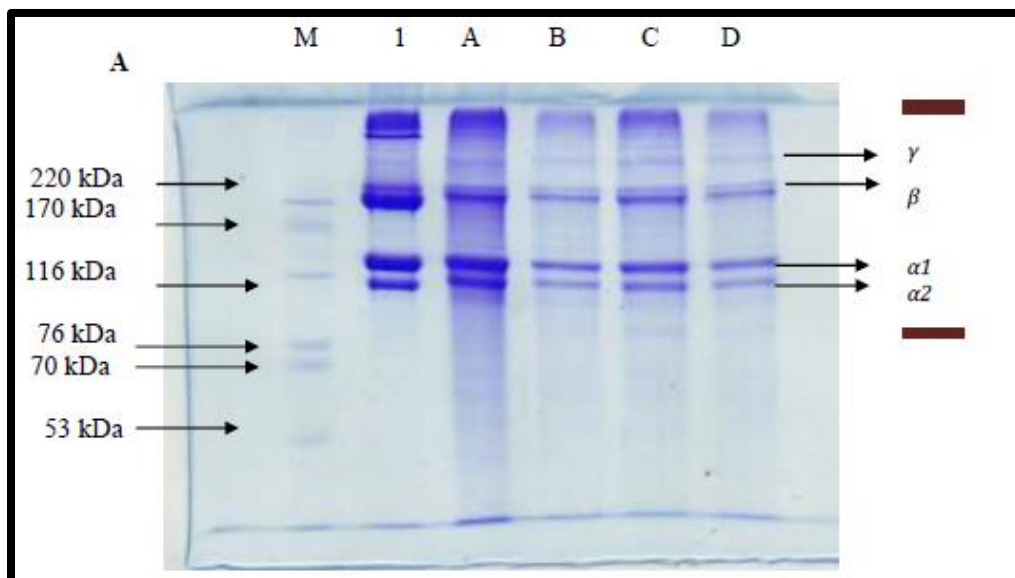


Figure 2: SDS - PAGE analysis of the protein extract from *S. brevimana*

3.3. GC-MS analysis:

The methanol extract of the whole-body tissue of *S. brevimana* showed significant antimicrobial activity. Hence, this fraction was subjected to GC-MS analysis to characterize the compound responsible for antimicrobial activities.

GC - MS analysis of the body tissue of *S. brevimana* exhibited seven peaks (Figure 2), with the retention times ranging from 3.96 to 33.66 min. All seven compounds were characterized as Carveol, Benzenamine, 3-azido N, N-dimethyl-4-nitro-, Phenol, 2-methyl-4-(1, 1,3,3-tetramethylbuty), 1,2-Benzisothiazol-3-amine tbdms, 3 β -Hydroxy-5-cholen-24-oic acid, Ethyl 5,8,11,14-eicosatetraenoate, Astaxanthin. Among the identified compound Carveol, Benzenamine, 3-azido N, N-dimethyl-4-nitro-, Phenol, 2-methyl-4-(1, 1,3,3-tetramethylbuty), 1,2-Benzisothiazol-3-amine tbdms, 3 β -Hydroxy-5-cholen-24-oic acid, Ethyl 5,8,11,14-eicosatetraenoate, Astaxanthin. have the role in Fragrance in cosmetics, Flavor in foods, Anti-inflammatory, Antimicrobial, Antioxidant, Anticancer, Diuretic Hepato protective, Antiasthma, Cardio protective, Natural colorant for food (Table 1,2). These compounds constitute a promising novel class of pharmaceuticals for the treatment of diseases.

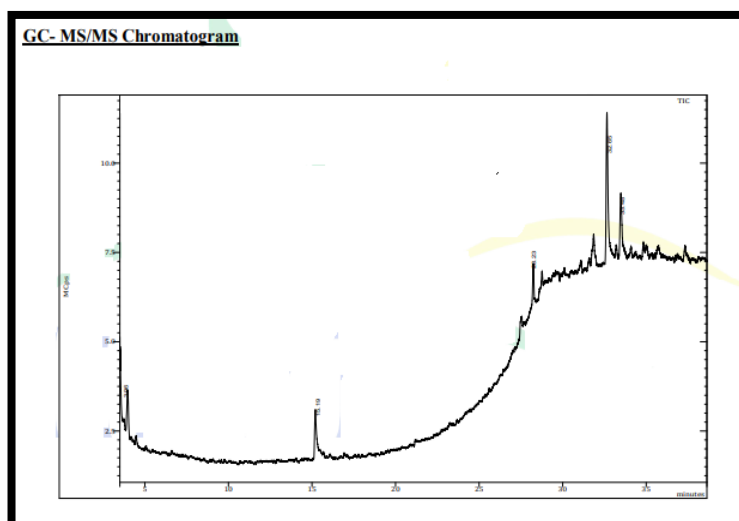


Figure 2: Chromatogram of the column extract of *S. brevimana* by GC-MS

No.	RT	Compound Name	Molecular Formula	MW	Peak area %	Compound Nature	Activity
1	3.96	Carveol	C ₁₀ H ₁₆ O	152	9.78	Monoterpenoid alcohol	Fragrance in cosmetics, Flavor in foods, Anti-inflammatory, Antimicrobial
2	4.48	Benzenamine, 3-azido-N,N-dimethyl-4-nitro-	C ₈ H ₉ N ₅ O ₂	207	0.41	Amino compound	Antimicrobial, Anti-inflammatory
3	15.19	Phenol, 2-methyl 1-4-(1,1,3,3-tetramethyl butyl)-	C ₁₅ H ₂₄ O	220	10.89	Phenolic compound	Antimicrobial, Anti-inflammatory, Antioxidant
4	27.55	1,2-Benzisothiazol-3-amine tbdms	C ₁₃ H ₂₀ N ₂ SSi	264	0.79	Aromatic sulfur compound	Antimicrobial
5	28.23	3β-Hydroxy-5-cholen-24-oic acid	C ₂₄ H ₃₈ O ₃	374	8.70	Steroid	Antimicrobial, Anti-inflammatory, Anticancer, Diuretic, Hepato protective, Antiasthma
6	32.65	Ethyl 5,8,11,14-eicosatetraenoate	C ₂₂ H ₃₆ O ₂	332	4514	Unsaturated fatty acid compound	Cardio protective
7	33.48	Astaxanthin	C ₄₀ H ₅₂ O ₄	596	24.29	Red Color pigment	Natural colorant for food

Table 1: Compounds identified in the methanol extract of the tissue of *S. brevimana* by GC-MS

S.NO	RT	Name of compound	Molecular formula	Molecular weight	Peak Area %
1	3.96	Carveol	C ₁₀ H ₁₆ O	152	9.78
2	4.48	Benzenamine, 3-azido N, N-dimethyl-4-nitro-	C ₈ H ₉ N ₅ O ₂	20	0.41
3	15.19	Phenol, 2-methyl-4-(1, 1,3,3-tetramethylbutyl)-	C ₁₅ H ₂₄ O	220	10.89
4	27.55	1,2-Benzisothiazol-3-amine tbdms	C ₁₃ H ₂₀ N ₂ SSi	264	0.79
5	28.23	3β-Hydroxy-5-cholen-24-oic acid	C ₂₄ H ₃₈ O ₃	374	8.70
6	32.65	Ethyl 5,8,11,14-eicosatetraenoate	C ₂₂ H ₃₆ O ₂	332	45.14
7	33.48	Astaxanthin	C ₄₀ H ₅₂ O ₄	596	24.29

Table 2: Activity of components identified in the methanol extract of the tissue of *S. brevimana* by GC-MS

4. DISCUSSION

The present study demonstrates that the antibacterial and antifungal activities of ink and tissue extract from *Sepia brevimana* are strongly influenced by the solvent used for extraction, concentration, and test organism. Solvent polarity plays a crucial role in extracting bioactive metabolites, which explains the observed variations in antimicrobial efficacy among extracts prepared with hexane, chloroform, methanol, ethanol, and benzene. Similar solvent-dependent variations in antimicrobial activity have been reported earlier, emphasizing that disc diffusion outcomes are influenced by both extract diffusion and intrinsic potency of bioactive compounds (Kelman *et al.*, 2006).

Ink extracts of *S. brevimana* exhibited broad-spectrum antibacterial activity against all tested bacterial strains, with notable inhibition against *Pseudomonas aeruginosa*, *Streptococcus pneumoniae*, and *Staphylococcus aureus* at higher concentrations. These findings are consistent with earlier studies on cephalopod inks, which reported pronounced antibacterial activity against human pathogens (Patterson and Murugan, 2000; Chacko and Patterson, 2005). In *D. singhalensis*, methanolic ink extracts showed comparatively higher activity than non-polar extracts, indicating the presence of polar antimicrobial constituents.

The tissue extracts, particularly methanolic extracts, also demonstrated measurable antibacterial activity in both species. The mantle tissue of *D. singhalensis* and the whole-body tissue of *S. brevimana* showed inhibition against both Gram-positive and Gram-negative bacteria, corroborating previous reports on antimicrobial compounds derived from cephalopod tissue (Mohanraju *et al.*, 2013; Ramasamy *et al.*, 2011). The relatively moderate inhibition zones observed in the present study may be attributed to crude extract composition and diffusion limitations.

SDS-PAGE analysis revealed a wide range of low- to high-molecular-weight proteins (≈ 53 – 220 kDa) in the ink of both species, suggesting the involvement of proteinaceous compounds in antimicrobial activity. Similar protein profiles with antimicrobial and antitumor properties have been reported from cephalopod inks,

including bioactive proteins such as ST94 and Lolduvin-S (Naraoka *et al.*, 2000; Smiline Girija *et al.*, 2011). These findings strengthen the hypothesis that ink proteins contribute significantly to antimicrobial defense mechanisms.

GC–MS analysis of methanolic tissue extracts identified several bioactive compounds, including Carveol, Astaxanthin, Ursodeoxycholic acid, and Desoximetasone, which are known for antimicrobial, antioxidant, anti-inflammatory, and anticancer properties. The detection of such compounds aligns with growing evidence that marine molluscs are rich sources of pharmacologically relevant secondary metabolites (Blunt *et al.*, 2018; Carroll *et al.*, 2023).

Overall, the results highlight the therapeutic potential of cephalopod ink and tissue extracts as sources of novel antimicrobial agents. Further purification, structural characterization, and mechanistic studies are necessary to identify lead compounds and evaluate their efficacy against multidrug-resistant pathogens.

5. CONCLUSION

This investigation confirms that *Sepia brevimana* is a promising source of bioactive compounds with antimicrobial potential. The crude ink and tissue extracts, particularly methanolic fractions, demonstrated significant antibacterial activity and contained diverse bioactive molecules identified via GC-MS. These findings provide a strong basis for developing cephalopod-derived pharmaceuticals and underscore the importance of marine biodiversity in drug discovery.

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**13. AN ASSESSMENT OF TRASH BIVALVE DIVERSITY
ALONG THE FISH LANDING CENTRES OF
KANYAKUMARI DISTRICT**

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Abstract:

In the recent years, the marine science has established much attention in Tamil Nadu coastline, marine molluscs studies are still overseen by many researchers. The commercially important gastropods are present in the region of intertidal and inshore waters and these gastropods received extensive consideration in recent years due to greater demand for meet and ear-rings, bangles, table lamps, spoons cups and saucers etc., and it is also used in Aquarium. Molluscs are having a tremendous impact on Indian tradition and economy and were as ornaments and currency. This has the increasing global demand. Hence the current study was framed to study the diversity of marine trash bivalves as by catch in two landing centres of Kanyakumari District.

Key words: Bivalve, Mollusc, Muttom, Kadiapatnam, Biodiversity.

Introduction

From the beginning of human civilization molluscs have a tremendous role on Indian tradition and economy. They are used as ornaments, currency, medicines and as mascots to wars. Shell handicraft off evil spirit is an age old industry of our country. In very early times the people of all walks were wear rings and bangles carved out of shells. Nowadays, molluscs have great significance in our industrial, technological and aesthetic aspects of life. The molluscs shells are used as a raw material for calcium carbonate- based industries. It is an attractive curio. South India has several industrial cottages export polished shells, utilitarian objects and hand-crafted shells to foreign countries. The shells are also used as a symbol of social status and great pride. Using the

shells of gastropods garlands, eve chains, necklaces, ear rings, studs, rings, bangles, table lambs, bathi stands, ash trays, key chain pendants and curtains are made.

Molluscan species are efficient indicators which indicate the whole ecosystem health and species diversity (Rittschof and McClellan, 2005) and so ideal study of these organism's conservation and biodiversity is indispensable. Gastropods are of particular interest, not only due to their importance in human culture but also because they fill integral ecological roles, from grazers to scavengers and carnivores (Suominen, 2005). They inhabit a range of diverse habitats, from tropical to the deep sea (Sturm, 2006). The lack of basic information such as diversity data and species check list make it impossible to assess the rate of population lost among marine molluscs. During the trawl catch, nearly 70 % of total catch was discarded as by-catch (Hill and Wassenberg, 1990). For many decades molluscan data have been critical to the establishment of the concept of a global-scale increase in species richness from the poles to the equator (Katrin *et al*, 2006).The tropical coastal environments are the most biologically diverse of all marine ecosystems but are being degraded worldwide by human activities potentially leading to numerous extinctions (Eduardo *et al*, 2009). Kanyakumari coastal waters, where the Bay of Bengal transitions to the Indian Ocean and the Arabian Sea, support arich marine fauna including bivalves, along with fish, gastropods and other invertebrates. The region's coast includes sandy shores, rocky substrates and estuarine-influenced zones, all of which can be habitats for different bivalve groups. Hence this study was undertaken to assess the biodiversity of bivalves among the trash fishes in two landing centres of Kanyakumari Coast such as Kadiapatnam (Station I) and Muttom (Station II).

Materials and Methods:

Collection of sample:

The present investigation was carried out for a period of six months (July 2024-December 2024).The bivalves were collected fortnightly among the trash fishes from the two landing centres. The bivalves were brought to the laboratory and cleaned with

fresh water. The bivalves were identified with appropriate manuals and further confirmed with taxonomist.

Diversity indices:

The species diversity (H') of gastropods was calculated using the following Shannon Weiner diversity index (Pielou, 1975).

Species richness index of the gastropods was calculated to find out the richness of the gastropods occurring in the different stations during different months following the formula of Margalef index (Clifford and Stephenson, 1975).

The evenness index of the species of gastropods was calculated to find out the distribution pattern of the gastropods using the formula suggested by Pielou (1969).

Statistical Analysis:

Two-way ANOVA without replication test was carried out using Microsoft Excel.

Result:

The distribution of bivalves was illustrated in Table 1. 6 species of bivalves were collected from two different landing centres among Trash fishes. Among the trash fishes a total of 169 bivalves were collected from Station I and 109 bivalves were collected from Station II. Results of Two Way ANOVA test confirmed that the distribution of mollusc was not significant between stations and between months ($P < 0.05$).

Table 1: Distribution of bivalve species in selected landing centres

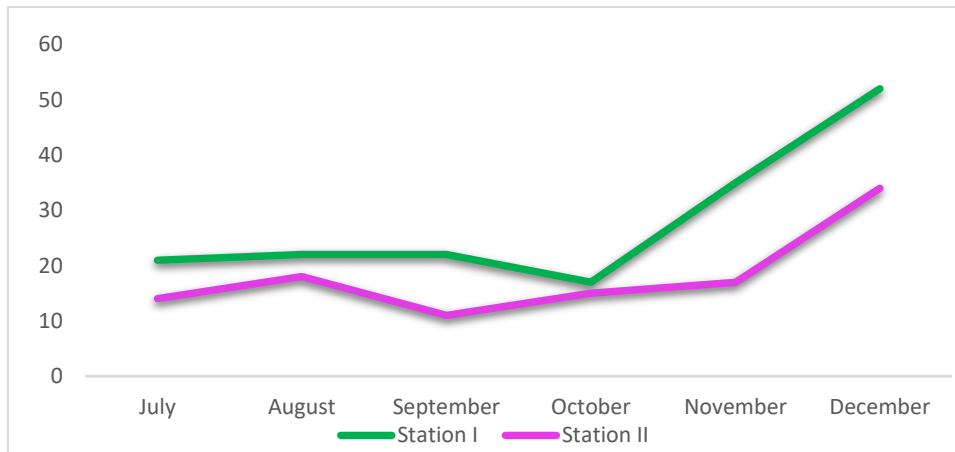
Species	Station I	Station II
<i>Pinctada fucata</i> (Gould, 1850)	+	+
<i>Pinctada chemnitzii</i> (Phillipi, 1849)	+	+
<i>Pinna atropurpureae</i> (Sowerby, 1825)	+	-
<i>Vasticardiummassimile</i> (Reeve, 1844)	+	-
<i>Vasticardium flavum</i> (Linnaeus, 1758)	+	-
<i>Grafrarium divaricatum</i> (Gmelin, 1791)	+	-

Table 2: Two way Analysis of Variance without replication between the occurrence of bivalve in both stations.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	300	1	300	2.504871	0.144577	4.964603
Within Groups	1197.667	10	119.7667			
Total	1497.667	11				

$P < 0.05$ is statistically significant

Fig. 1: Monthly distribution of bivalves in two different stations.



The monthly distribution of bivalves was predicted in Fig. 1. Maximum bivalve contribution was observed during the month of December (52) i.e North East Monsoon followed by November (35) in Station I. In Station II maximum contribution was observed in June (34) followed by July (18) i.e South West Monsoon and least occurrence in November (11) i.e the middle of the North East Monsoon season.

Diversity Indices:

The trends in the regional and seasonal fluctuations of Shannon Weiner diversity index, Evenness index and Richness index were recorded for molluscs were furnished in

Table 3. The highest value of diversity index (2.48) of molluscan population was registered in Station I. The value richness index was highest in Station II (1.07). Evenness index of molluscan population occurring to be high in Station II (38.921).

Table 3: Diversity indices of the bivalve fauna in two stations

Diversity Indices	Station I	Station II
Shannon Weiner diversity	2.48	2.47
Species richness	0.96	1.07
Evenness index	32.45	38.921

Systematic position of Bivalves:

- Kingdom : Animalia
- Phylum : Mollusca
- Class : Bivalvia
- Order : Pterioida
- Family : Pteridae
- Genus : *Pinctada*
- Species : *P. fucata* (Gould, 1850) 1
- Species : *P. chemnitzii* (Phillipi, 1849) 2
- Family : Pinnidae
- Genus : *Pinna*
- Species : *P. atropurpurea* (Sowerby, 1825) 3
- Order : Veneroidea
- Family : Cardiidae
- Genus : *Vasticardium*
- Species : *V. assimile* (Reeve, 1844) 4
- Species : *V. flavum* (Linnaeus, 1758) 5
- Family : Veneridae
- Genus : *Grafrarium*
- Species : *G. divaricatum* (Gmelin, 1791) 6

Discussion:

Trawling in earlier time was not very detrimental to organisms of no commercial value that were trapped incidentally in the trawl, as they were thrown back into the natural system. This practice is disadvantageous as they will finally result in disturbing the stock of several organisms along with shrimps and bottom fishers (Babu, 2009).

The present study revealed that the trash fish (except finfish, shrimp and crustaceans) is composed of gastropods and bivalves. 6 species of bivalves were collected from two different landing centres. Babu (2009) recorded 59 species of gastropods and 11 species of bivalves from Mudasalodai and 57 gastropods and 10 species of bivalves in Cuddalore landing centre. Arjunan Babu *et al* (2012) recorded 21 ornamental gastropods and 5 bivalves among trash fishes from Parangipettai Coast and the results of the present study were in accordance with the above report.

Chinnaiyan *et al* (2012) reported that abundance of trash fish landing was found to be high in the post monsoon and summer and less in monsoon. The poor landing of trash fish was due to the rough weather, and non-conductance of activity was not conducted during the north east monsoon along the southeast coast. The fishing activity was conducted during North east monsoon along the south east coast because of the rough weather. But in our present study, the contribution of molluscs among trash fish was high during North east monsoon of December and Southwest monsoon of June in station I (kadiyapatnam). Whereas it was high during South west monsoon only in Station II (Muttom).

Further the inquiry with the fishermen revealed that the molluscs migrate from deeper waters because of the winds of the southwest and North east monsoon result in abundance in station I. In the case of station II, the abundance of trash fish was mostly associated with the Manangumeen fishery which may be due to the usage of a particular net locally called manangu net. The information regarding the diversity of molluscs assist the researchers to help the taxonomy and towards better understanding in the utilization of bio resources. Although specific detailed surveys focused only on bivalves

for Kanyakumari coast are limited in published literature, bivalve records from Tamil Nadu and adjacent southwest Indian waters, the present study could provide details of the bivalve molluscs diversity among trash fishes in the two landing centres of Kanyakumari District for the better usage of bivalves.

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14. CHATGPT IN ACADEMIC RESEARCH WRITING: OPPORTUNITIES, RISKS, AND ETHICAL CHALLENGES

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Abstract

The emergence of generative Artificial Intelligence tools such as ChatGPT has transformed the academic research ecosystem beyond conventional research writing. ChatGPT is increasingly utilized across multiple stages of the research lifecycle, including problem formulation, literature exploration, data interpretation, methodological support, academic writing, and dissemination of research findings. This study addresses a research gap in systematically analysing both technical and ethical dimensions of ChatGPT usage in academic research. While these capabilities enhance research efficiency and accessibility, they also raise significant risks and ethical challenges related to academic integrity, data reliability, authorship, bias, and responsible AI usage. The paper proposes a conceptual framework for AI-Assisted Research Integrity, and includes actionable recommendations for researchers, institutions, and policymakers.

Keywords : *ChatGPT, Academic Research Writing, Generative AI, Research Ethics, AI Governance, Research Integrity*

1. Introduction

The rapid advancement of Artificial Intelligence transformed many aspects of human life, including academic research. Among these AI innovations, generative AI tools like ChatGPT have emerged as powerful assistants capable of generating human-like text, summarizing literature, and providing methodological suggestions. However,

despite its adoption, there is limited understanding of its responsible use, technical limitations, and impact on research integrity, creating a critical research gap. ChatGPT's influence extends across multiple stages of academic research, including topic selection, literature review, methodology explanation, data interpretation, and manuscript drafting.

2. Literature Review

This study adopts a narrative literature review approach, appropriate for synthesizing emerging and interdisciplinary research on generative AI in academia. Literature published between 2023 and 2025 was reviewed, focusing on peer-reviewed journal articles, conference proceedings, and selected preprints where peer-reviewed evidence remains limited due to the novelty of the field.

Sources were identified using keywords such as ChatGPT, generative AI, academic writing, research ethics, and AI integrity. Priority was given to studies addressing research workflows, ethical implications, and policy discussions in higher education. While preprints (e.g., arXiv) were included to capture cutting-edge debates, their insights were triangulated with peer-reviewed literature to reduce reliability concerns.

Methodology Clarification: This review is a narrative review complemented by targeted peer-reviewed articles (2023–2025). Literature selection included databases such as Scopus, Web of Science, and Google Scholar, with inclusion criteria focusing on empirical studies, reviews, and policy papers on AI-assisted academic writing. Despite this growing body of work, a consolidated framework linking these findings to concrete research practices and ethical governance remains underdeveloped, justifying the present study.

3. Role of ChatGPT in the Academic Research Process

Problem Identification : Assists in brainstorming topics and refining research questions.

Literature Review : Supports summarization and thematic extraction.

- Methodology Planning** : Explains methods but cannot design or validate experiments.
- Data Interpretation** : Helps articulate interpretations without replacing analytical tools.
- Academic Writing** : Enhances structure and language quality.
- Dissemination** : Aids in preparing summaries and presentations.

Technically, these capabilities arise from probabilistic language modeling rather than factual understanding, explaining why hallucinations and citation fabrication may occur. Recognizing these limitations is essential for responsible use.

4. Opportunities of ChatGPT in Academic Research

4.1 Aim of the Study

The primary aim of this study is to systematically examine the role of ChatGPT in academic research writing by analyzing its opportunities, risks, and ethical challenges, and to propose responsible usage guidelines that support research integrity across disciplines.

4.2 Research Design

This study adopts a narrative review research design, which is appropriate for synthesizing emerging, interdisciplinary, and rapidly evolving literature where standardized empirical evidence is still developing. Unlike systematic reviews that aim for exhaustive quantitative synthesis, a narrative review allows for conceptual integration, critical interpretation, and ethical analysis, which aligns with the objectives of this paper.

4.4 Literature Review Protocol

Although the study does not follow a PRISMA-based systematic review protocol, a structured and transparent review process was employed to enhance rigor and reproducibility.

Relevant literature was identified from the following sources:

- Peer-reviewed academic journals
- Conference proceedings
- Publisher policy documents
- Reputed preprint repositories where peer-reviewed literature is still limited due to the novelty of the topic

One of the primary opportunities offered by ChatGPT in academic research is the enhancement of productivity and efficiency. Researchers can use ChatGPT to generate drafts, summarize literature, and structure manuscripts quickly, reducing the time spent on repetitive writing tasks. This allows scholars to focus more on critical thinking, data analysis, and innovation rather than spending excessive time on formatting, grammar corrections, or preliminary drafting. The tool also facilitates multitasking, enabling researchers to handle multiple projects simultaneously with greater ease.

ChatGPT provides significant support in planning and designing research studies. It can explain complex methodologies, suggest suitable experimental designs, and guide researchers through statistical or computational approaches.

Another important opportunity lies in improving accessibility and inclusivity in academic research. Non-native English speakers, students, and researchers with limited resources can leverage ChatGPT to produce clear, well-structured, and grammatically correct content. The tool democratizes access to high-quality academic support, bridging gaps in language proficiency and technical expertise. Additionally, ChatGPT can assist in generating research ideas and simplifying complex concepts, making academic research more approachable and inclusive for a diverse global research community.

Research Ideation & Problem Formulation – ChatGPT can help identify research gaps, suggest topics, refine research questions, and generate innovative ideas.

Literature Review – It can summarize large volumes of academic papers, highlight key trends, and provide concise overviews, making the literature review process faster and more efficient.

Methodology Assistance – ChatGPT can explain research methods, suggest suitable experimental designs, and help with statistical or computational analysis planning.

Data Analysis & Interpretation – While not a replacement for specialized tools, ChatGPT can help interpret data patterns, explain results, and generate initial insights for discussion sections.

Academic Writing & Drafting – It improves clarity, grammar, structure, and coherence in manuscripts, abstracts, and research proposals, particularly benefiting non-native English speakers.

Research Communication – ChatGPT aids in summarizing findings for presentations, posters, or simplified reports for wider audiences.

5. Risks of Using ChatGPT in Academic Research

One of the major risks of using ChatGPT in academic research is the potential for misinformation or inaccuracies. ChatGPT can generate text that appears authoritative but may contain incorrect, outdated, or misleading information. Researchers relying solely on AI-generated content without proper verification risk incorporating errors into their work, which can undermine the credibility of research findings and lead to flawed conclusions.

Another significant risk is over-reliance on ChatGPT, which can reduce the researcher's engagement in critical thinking and independent problem-solving. Excessive dependence on AI for drafting, idea generation, or data interpretation may weaken analytical skills and intellectual rigor. This reliance can result in generic or superficial research outcomes, diminishing the originality and depth of scholarly work. ChatGPT also introduces ethical and accountability challenges. AI-generated content may reflect biases present in the training data, leading to skewed perspectives in research. Furthermore, questions around authorship, transparency, and proper disclosure

of AI assistance remain unresolved in many academic institutions. Misuse of ChatGPT for generating research results, references, or data without oversight can compromise academic integrity and violate ethical research standards.

Despite its growing adoption in academic research, the use of ChatGPT is accompanied by several risks and limitations that may affect the accuracy, integrity, and ethical standards of scholarly work

Misinformation and Hallucination - ChatGPT may generate incorrect explanations, assumptions, or references.

Over-Reliance on AI - Excessive dependence can reduce independent reasoning and methodological rigor.

Data Privacy and Confidentiality - Uploading unpublished or sensitive data poses security risks.

Bias and Fairness Issues - Model biases can influence research framing and interpretation.

Accountability and Authorship Concerns - Determining responsibility for AI-assisted research outcomes remains unclear.

6. Ethical Challenges in AI-Assisted Research

A major ethical challenge in AI-assisted research is maintaining academic integrity and originality. The use of ChatGPT in drafting manuscripts, generating ideas, or summarizing literature can blur the line between the researcher's own contributions and AI-generated content. Undisclosed use of AI tools may lead to inadvertent plagiarism or questions regarding the authenticity of research outputs, undermining trust in scholarly work.

Transparency is another significant ethical concern. Researchers must clearly disclose the extent to which AI tools like ChatGPT have been used in their research process. However, there is currently no universally accepted guideline for AI disclosure in academic publications, leading to inconsistency and potential ethical violations. Lack of transparency can make it difficult for peer reviewers and readers to assess the validity

and originality of the work.

AI models are trained on large datasets that may contain inherent biases, which can inadvertently influence research outputs. This raises ethical concerns about fairness and reliability in AI-assisted findings. Additionally, accountability is ambiguous: when AI contributes to research outcomes, it is unclear who should be responsible for errors or misinterpretations. Responsible and ethical use of AI requires careful oversight, verification, and adherence to institutional and disciplinary ethical standards to prevent misuse.

Issue	Challenge	Mitigation
Integrity	Plagiarism risk	Proper citation
Transparency	Undisclosed AI use	Clear declaration
Bias	Unfair outputs	Human oversight
Authorship	Credit ambiguity	Contribution statements
Evaluation	Peer-review issues	AI-aware policies

7. Best Practices and Ethical

Researchers treat ChatGPT as a supportive assistant rather than an autonomous researcher. All AI-generated content must be carefully verified against credible sources to ensure accuracy, relevance, and scientific rigor. Transparency is essential: researchers should clearly disclose the extent and nature of AI assistance in their publications, including drafts, summaries, or analytical suggestions. Institutions and journals can play a critical role by establishing standardized guidelines for AI usage disclosure, ensuring consistency across disciplines and maintaining research credibility.

Integrating ChatGPT responsibly into the research workflow requires defining clear boundaries for its use. Researchers should avoid using AI to fabricate data, generate results, or replace independent analysis. Instead, ChatGPT can be leveraged for literature summarization, drafting initial outlines, exploring alternative research ideas, or explaining complex methodologies. Combining AI assistance with human critical

thinking ensures that the originality, intellectual rigor, and contextual understanding of the research are preserved. Researchers should also engage in iterative verification, cross-checking AI outputs with empirical data or peer-reviewed literature to maintain accuracy.

Institutions should provide training programs for researchers and students on the ethical and effective use of AI tools. Awareness of biases inherent in AI models, potential security or privacy concerns, and responsible data management practices should be emphasized. Promoting accessibility ensures that early-career researchers, non-native English speakers, and scholars from resource-limited contexts can benefit from AI tools without compromising ethics or quality.

8. Advantages and Limitations of ChatGPT in Research Workflows

8.1 Advantages of ChatGPT in Academic Research Writing

- ✓ Enhances productivity by supporting multiple stages of the academic research process.
- ✓ Assists in literature review by summarizing large volumes of scholarly work and identifying key themes.
- ✓ Organizes research information efficiently, reducing the time required for preliminary review.
- ✓ Improves academic writing quality by enhancing clarity, coherence, and grammatical accuracy.
- ✓ Particularly benefits non-native English speakers and early-career researchers.
- ✓ Supports idea generation and research planning by suggesting research questions, hypotheses, and methodological approaches.
- ✓ Encourages creative and strategic thinking in research design.
- ✓ Promotes accessibility and inclusivity for researchers from resource-limited or linguistically diverse backgrounds.
- ✓ Enables efficient multitasking, helping researchers manage complex research workflows.

- ✓ Serves as a valuable supportive assistant in contemporary academic research environments.

8.2 Disadvantages and Limitations of ChatGPT in Academic Research Writing

- ✓ AI-generated content may contain inaccuracies, outdated information, or misleading interpretations if not carefully verified.
- ✓ Reliance on ChatGPT can pose risks to research validity when outputs are accepted without critical evaluation.
- ✓ Over-reliance on AI tools may reduce independent critical thinking, analytical reasoning, and originality.
- ✓ Excessive AI assistance can lead to superficial or generic research outcomes.
- ✓ Ethical and academic integrity issues may arise when AI usage is not transparently disclosed.
- ✓ Risks include plagiarism, authorship ambiguity, and unclear accountability for research content.
- ✓ ChatGPT may reproduce biases present in its training data, affecting research framing and interpretation.
- ✓ Lack of transparency in AI output generation complicates responsibility for errors or misinterpretations.
- ✓ Limited capability in handling highly specialized or technical content may result in oversimplified suggestions.
- ✓ Strong human oversight is essential when using ChatGPT in academic research writing to maintain accuracy and ethical standards.

9.Future Directions for ChatGPT in Academic Research

Future developments in ChatGPT and AI-assisted research should focus on deeper integration with advanced research tools and platforms. Linking ChatGPT with academic databases, citation managers, and data analysis software could streamline literature reviews, data interpretation, and manuscript preparation. Such integration

would allow researchers to interact with AI in a more dynamic and context-aware manner, improving efficiency while reducing manual effort. Additionally, hybrid systems combining AI with domain-specific analytical tools could enhance accuracy and relevance in specialized research fields.

A critical future direction is improving the reliability, transparency, and explainability of ChatGPT outputs. Research should focus on minimizing biases inherent in AI models and ensuring that generated content is factually accurate and ethically responsible. Explainable AI (XAI) approaches can help researchers understand how outputs are generated, providing confidence in the AI's recommendations and supporting critical evaluation. Continuous updates to training data and contextual learning mechanisms will be necessary to maintain up-to-date and credible information. The long-term adoption of ChatGPT in academic research will depend on the development of robust ethical frameworks and institutional policies. Future research should explore standardized guidelines for AI-assisted research, including disclosure norms, authorship considerations, and accountability measures. Educational programs can be designed to train researchers in responsible AI use, emphasizing critical thinking, ethical decision-making, and transparency.

10. Conclusion

ChatGPT represents a paradigm shift in academic research by supporting multiple stages of the research lifecycle, including idea generation, literature review, methodology guidance, data interpretation, and manuscript drafting. It offers unprecedented opportunities for improving efficiency, enhancing writing quality, and increasing accessibility for researchers across different backgrounds and disciplines. Non-native English speakers and early-career researchers, in particular, benefit from its ability to simplify complex concepts, provide structured drafts, and suggest research directions. However, the misuse or over-reliance on ChatGPT can pose risks, including inaccuracies, bias in outputs, reduced critical thinking, and ethical concerns related to authorship and transparency. To maximize its potential while safeguarding academic

standards, responsible adoption, clear disclosure of AI assistance, verification of outputs, and policy-driven governance are essential.

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**14.A STUDY ON THE ATTITUDE OF BENEFICIARIES
TOWARDS SAVINGS HABITS IN KAMATCHIPURAM
VILLAGE OF NILAKKOTTAI VILLAGE, DINDIGUL
DISTRICT.**

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ABSTRACT:

The standard of living of a household is determined by the family's income, which also influences the purchasing power of its members. Household income is defined as the total earnings received by family members over a specific period, such as a week, fortnight, or month. Income earned by daily wage earners is referred to as wages. According to the National Sample Survey Office (NSSO), household income is the total receipts of a household from all sources during a specified period, usually calculated before the deduction of compulsory payments such as taxes. As per various statistical records, there are still people in India who find it very difficult to fulfil their basic needs such as food, shelter, education, healthcare, fuel and lighting, drinking water, sanitation, transportation, and communication. These basic needs are defined by the National Sample Survey Office. Economic, social, and mental well-being are also influenced by the parameters prescribed by the NSSO. Hence, people strive to fulfil their basic needs according to their economic capacity. However, certain groups are unable to meet all these requirements and therefore attempt to mobilize funds from various sources. They often approach moneylenders rather than banks due to several reasons.

A habit of saving helps individuals during emergencies and difficult times. In earlier days, people commonly saved money at home in earthen pots, clay piggy banks, wooden boxes, or metal containers, believing these to be the safest places for their savings. However, in today's globalized world, with steadily increasing demands, such forms of saving are no longer very effective. Consequently, people prefer banks, Life Insurance Corporation (LIC), post offices, and other private financial institutions. The post office plays a significant role in inculcating the habit of saving among people. Therefore, the present study attempts to examine the attitude of respondents towards post office savings in Kamatchipuram Village of Nilakkottai Taluk, Dindigul District.

INTRODUCTION:

Nilakkottai is one of the taluks of Dindigul District, and Kamatchipuram village is located within it. The primary occupation of the people in this village is agriculture, particularly the cultivation of paddy and pulses. They are also engaged in allied agricultural activities. According to the 2011 Census, the total population of the village is 5,010, comprising 2,503 males and 2,507 females living in 1,433 households. Kamatchipuram has its own post office and three banks, of which two are nationalized banks and one is a private bank. Hence, it can be inferred that the households in the village have access to financial services through both the post office and banks.

STATEMENT OF THE PROBLEM

The Indian family system, influenced by patriarchal values and social norms, often restricts women's economic independence and financial decision-making, particularly in rural areas. Despite various government initiatives aimed at promoting financial inclusion, women's saving behaviour continues to be shaped by family structure, income level, and social constraints. Post offices play a significant role in encouraging small savings among women by offering accessible and secure savings facilities suited to their economic capacity. However, the level of awareness, attitude,

and saving habits of women towards postal savings at the village level is not clearly understood. Hence, the present study is undertaken in the selected village to examine the savings behaviour of women, with special reference to their attitude towards postal savings, without focusing on any specific scheme.

OBJECTIVES:

The main objective of this study is to examine the socio-economic and demographic profile of the respondents, gain knowledge of existing studies, and offer suggestions.

REVIEW OF LITERATURE

The review of literature in any research work helps the researcher to understand the direction in which the study has to proceed, identify the research gap, and select suitable research topics for the proposed study. Hence, this section is considered an essential part of any research work. In the present study, the researchers have reviewed related studies on postal savings, identified the research gap, and developed the framework for the study.

Chinnadorai and Sangeetha (2014) studied the services provided by Axis Bank related to savings schemes. Their study revealed that savings and investment patterns differ according to the income level of customers.

Boaz WamwayiInganga (2014) analyzed customer demand for financial services offered by commercial banks, including various bank accounts, deposit and inventory services, and credit and loan services. The study concluded that customer demand for financial services still has significant potential for growth.

Giri (2014) revealed that post office services need modernization and suggested that technology-driven services should be introduced by the postal department to increase its customer base and improve service quality.

Mahesh Potadar (2015) explored the various challenges faced by the Indian Postal Department. The author suggested providing proper training to employees in technological upgradation, conducting customer awareness programmes, granting managerial autonomy, improving parcel services, and forming tie-ups with major e-commerce players.

Kore Shashikant and Teli (2015) attempted to assess the level of awareness among postal department employees regarding the various financial services offered by the Indian Postal Department. They also analyzed problems faced by postal employees, such as workload issues, and identified major problems encountered by customers availing postal services.

Divyesh Kumar (2015) revealed that developed countries have adopted new practices to improve postal services, which are already being followed by underdeveloped and developing countries. The study concluded that, to strengthen postal services in India, the postal department should expand its network. This expansion would help reduce transportation costs and increase access to credit facilities, non-life insurance, and general insurance, thereby enhancing financial inclusion. Further, the study stated that expanding the rural network would maximize the reach of postal services.

Killare (2015) examined the performance efficiency of postal services, including parcel and mail services. The study stated that the financial services offered by the postal department are satisfactory; however, it emphasized the need to identify new and innovative sources to increase productivity and scale of operations, especially in comparison with private courier services. The study concluded that operational efficiency and sustainability in postal services can be maintained by improving overall performance efficiency.

Rama Chandra Tarai (2016) highlighted financial accessibility through the postal

department, particularly focusing on distance coverage and average population served by a post office. The study reported that the average travel distance to a post office is 4.61 km and noted that the postal department has taken significant steps to create awareness about its financial services. The postal network was found to be widely spread across the country.

Morshed Hasan Khan (2016) conducted a study based mainly on secondary data, focusing on the quality of services offered by the postal department and customer behaviour. The study concluded that customers are satisfied with postal services.

Gayatri (2014) examined various small savings schemes offered by post offices, with special reference to investor attitudes in Cumbum town. The study highlighted issues such as loss of paper records and difficulty in sustaining deposit mobilization. The findings revealed that all 120 respondents were aware of postal savings schemes and were satisfied with post office services, although lack of employee knowledge was identified as a major concern. The study suggested strengthening advertising strategies and incorporating modern technology in post offices.

METHODOLOGY

Research methodology is a vital part of the research work. It includes details of the sample respondents, sources of primary and secondary data, period of the study, and the tools used for analysis.

PrimaryData:

The primary data required for the study were collected through a well-structured interview schedule.

Secondary Data:

Secondary data were collected from various sources such as journals, newspapers, books, and websites.

Sample Size and Sampling Technique

Since the study was conducted during the COVID-19 period at the micro level, 100 respondents were selected using the convenience sampling method from Kamatchipuram village. Though convenience sampling is acceptable in social science research, it largely depends on the availability of respondents. The results and conclusions of the study rely on the respondents' responses. Therefore, the findings cannot be generalized, and the results may be biased. The reliability and validity of the data are also questionable, as the study could not capture diverse opinions through the interview schedule.

Period of the Study:

The present study was conducted during the period from January 2020 to March 2020.

Tools Used in the Study:

Simple percentage analysis was used to study the demographic profile of the respondents. The Chi-square test was employed to analyse the attitude of the respondents towards savings schemes and income level of the respondents.

Limitations of the Study

The study is limited to a particular savings mode, namely post-office savings, and to a specific geographical area. It concentrates on a small sample of respondents over a short period of time; therefore, the results obtained from the study are applicable only for a short period and may not be sustainable in the long run. Further, this article focuses solely on post office savings and does not consider any other savings modes.

ANALYSIS AND INTERPRETATION:

1. Age

Age plays a vital role in leading a family irrespective of income, education, and religion. It reflects an individual's experience, level of awareness, and decision-making power. Hence, age is considered an important demographic variable influencing these factors. Table 1 presents the distribution of respondents based on their age.

Table 1: Age of the Respondents

S. No	Age-wise Classification	Number of Respondents	Percentage
1	Below 25	18	18
2	25–40	48	48
3	Above 40	34	34
	Total	100	100

Source: Primary Data

From the above table, it is inferred that nearly 48 percent of the respondents belong to the age group of 25–40 years, followed by 34 percent above 40 years, and 18 percent below 25 years. Thus, the majority of the respondents fall under the age group of 25–40 years. This group represents productive consumers and income earners. Hence, it is understood that nearly half of the respondents are well aware of postal savings schemes.

2. Religion

Religion is one of the important socio-cultural factors. It reflects the value system, beliefs, and social behaviour of individuals and also influences the attitudes of the respondents towards the research variables. Table 2 presents the religion-wise distribution of respondents in the study area.

Table – 2: Religion of the Respondents

S. No	Religion-wise classification	Number of respondents	Percentage
1	Hindu	42	42
2	Christian	30	30
3	Muslim	28	28
	Total	100	100

Source: Primary Data

From the above table, it is inferred that 42 per cent of the respondents belong to

the Hindu religion, followed by 30 per cent belonging to Christianity and 28 per cent belonging to Islam. The table clearly shows that the majority of the respondents in the study area are Hindus. Hence, the study area is predominantly Hindu in nature.

3. Category

In this study, category is considered as caste. It is one of the important social factors that influences behaviour, lifestyle, and socio-economic conditions, which are highly relevant to social science research. Table 3 presents a comparison of the respondents belonging to different categories.

Table – 3: Category of the Respondents

S. No	Category-wise classification	Number of respondents	Percentage
1	SC	10	10
2	BC	56	56
3	MBC	32	32
4	Others	2	2
	Total	100	100

Source: Primary Data

The above Table 3 clearly indicates that out of 100 respondents, 56% belong to the BC category, followed by 32% MBC, 10% SC, and only 2% from other categories. Hence, the study area is predominantly BC in nature.

4. Marital Status

Marital status is defined as the legally recognized relationship status of an individual. It includes categories such as single, married, widowed, and divorced. Marital status reflects the economic condition, individual responsibilities, and decision-

making ability of a person. Table 4 presents the marital status of the respondents.

Table – 4: Marital Status of the Respondents

S. No	Marital Status	Number of Respondents	Percentage
1	Single	06	06
2	Married	78	78
3	Widowed/Divorced	16	16
	Total	100	100

Source: Primary Data

The above table reveals that out of 100 respondents, 78 per cent are married, 16 per cent are widowed or divorced, and 6 per cent are single. It is evident that the majority of the respondents are married. Hence, they are more likely to be aware of savings and its significance.

5. Education Level

Education is an important socio-economic change agent that fosters the empowerment of individuals. It shapes a person's future, helps them make appropriate decisions, develops critical thinking, and promotes social equality. Furthermore, it serves as a foundation for national development and global progress.

Table 5: Education Level of the Respondents

S. No	Education Level	No. of Respondents	Percentage
1	1 st to 12 th Standard	23	23%
2	Undergraduate	20	20%
3	Postgraduate	15	15%
4	Others	42	42%
	Total	100	100%

Source: Primary data

The above table shows that the highest percentage (42%) falls under the category “Others.” This is followed by respondents educated up to 1st to 12th standard (23%) and those at the undergraduate level (20%). Only 15% of the respondents have completed postgraduate education. It can be inferred from the table that the “Others” category occupies a major proportion among the respondents. This category includes ITI holders, small business owners, tailors, and diploma holders.

6. Income Level

Income is an important economic factor that influences the buying behavior, standard of living, and socio-economic status of an individual. It also plays a vital role in determining purchasing and saving patterns.

Table – 6: Income Level of the Respondents

S. No	Income Level	No. of Respondents	Percentage
1	Rs. 50,000 to 1,00,000	45	45%
2	Rs. 1,00,000 to 5,00,000	37	37%
3	Above Rs. 5,00,000	18	18%
	Total	100	100%

Source: Primary data

It is observed from the above table that 45 percent of respondents fall in the income category of Rs. 50,000 to 1,00,000, which is the highest. This is followed by 37 percent of respondents in the income range of Rs. 1,00,000 to 5,00,000. Only 18 percent of the respondents earn above Rs. 5,00,000 per annum. It is clear from the table that saving and investing may be more challenging for individuals earning between Rs. 50,000 and 1,00,000.

7. Post Office Savings

Saving is the act of setting aside money for future use. People usually save

according to their economic capacity through various institutions such as banks, post offices, LIC, and others. Savings provide financial security and reduce stress about the future.

Table 7: Number of Respondents Who Make Savings in Post Office

S No	Response	Number of Respondents
1	Yes	76
2	No	24
	Total	100

Source: Primary data

It is observed from the above table that 76 per cent of the respondents have stated that they have made savings in a post office under at least one scheme, while 24 per cent of the respondents have not made any savings yet.

CHI SQUARE TEST Chi- square test has been applied to analyse the association between the attitude of the respondents and the following variables the Age, Marital status, Educational Qualification, and Family Income using level of satisfaction (Variables)

The relationship between the attitude level of respondents towards Saving Scheme and the independent variable is studied by means of Chi-square test. It represents a useful method of comparing experimentally obtained data with those expected theoretically

$$\text{Chi-square test } \chi^2 = \sum (O-E)^2/E$$

$$E = \text{Row Total} \times \text{Column Total} / \text{Grand Total (N)}$$

O= Observed Frequency

E= Expected Frequency

Degree of Freedom (R-1) (C-1)

R=Row C=Column

Family Income

To analyse the relationship between the family income of the respondents and the level of satisfaction, the chi-square test is applied by framing the hypothesis such as,

Calculation of chi-square test

Ho-There is no relationship between the family income of the respondents and their level of satisfaction.

Ha- There is a relationship between the family income of the respondents and their level of satisfaction.

Table 13: Level of Satisfaction

S. No	Income	Level of Satisfaction			Total
		High	Medium	Low	
1	Below Rs.50000	20	7	6	33
2	Rs.50000 to 70000	15	5	7	27
3	Rs.70000 to 90000	15	13	12	40
	Total	50	27	23	100

Source: Calculated from the primary data

Table 14: Calculation of chi square

O	E	(O-E)	(O-E) ²	(O-E) ² /E
20	16.5	3.5	12.25	0.742
7	8.91	-1.91	-3.648	0.409
6	7.59	-1.59	-2.528	0.347
15	13.5	1.5	2.25	0.167
5	7.29	-2.59	-6.708	0.920
7	6.21	0.79	-80.3	12.931
15	20	-5	-25	1.25
13	10.8	2.2	4.48	0.415
12	9.2	2.8	7.84	0.852
			X ²	18.033

$$X^2 = \sum (O-E)^2 / E = 18.033$$

$$\text{Degree of Freedom (df)} = (r-1)(c-1)$$

$$(4-1)(3-1) = 6$$

- **Level of significance:**5% (0.05)
- **Degree of freedom:** 6
- **Table χ^2 value:**12.59

Since the calculated chi square value (18.033) is greater than the table value (12.59) the null hypothesis is rejected. Hence it is concluded that the attitude of the respondents toward the Post Office Saving Scheme is significantly dependent on income.

FINDINGS:

- The age range of 25-40 years includes 48 percent of the respondents
- 42 per cent of the respondents follow the Hindu religion.
- 56 per cent of the respondents belong to the Backward Community.
- 78 per cent of the respondents are married.
- 42 per cent of the respondents fall under the “Others” category in education, which includes ITI, small business, and tailoring.
- 48 per cent of the respondents have an income ranging between Rs. 50,000 to 1,00,000.
- There is a significant relationship between the attitude of the respondents and the income level of the respondents.

SUGGESTIONS:

Based on the study and interactions with respondents and employees of the local post office, the researchers suggest the following:

- Technology-based postal services should be increased to improve efficiency.
- Expanding the rural network is necessary to enhance the reach and effectiveness of postal services.
- Providing regular training to postal employees will improve operational efficiency.

- Awareness campaigns and advertisements about the services offered by the postal department should be increased.
- Employee workload should be reviewed and reorganized to reduce inconvenience and stress.
- 76 per cent of respondents reported having made savings in post office schemes.
- The government should raise awareness among rural and underprivileged families about the benefits of these schemes.

CONCLUSION:

Savings play an important role in an individual's life as well as in household financial management. Financial inclusion through various schemes and services offered by banks, LIC, and the post office can significantly support households. This study reveals that the majority of respondents are married, income earners with moderate earnings, and have made savings through post office schemes. The findings also highlight that technological improvements can enhance the operational efficiency of postal employees. However, some groups of people still do not participate in savings through government or private financial institutions. Overall, timely support and technological advancements can improve the quality of postal services at all levels. The selected socio-economic variables such as age, income, occupation, and the availability of financial institutions influence the saving habits of rural people.

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16. AI IN IPR MANAGEMENT

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Abstract

Artificial intelligence (AI) is transforming the legal profession by automating routine activities such as legal research, contract analysis, and document drafting. This allows legal professionals to dedicate more time to complex, value-driven tasks and improve client service. At the same time, AI's growing role in intellectual property (IP) law presents significant opportunities as well as serious challenges, particularly with respect to AI-created works and the datasets used to train these systems. AI technologies are no longer speculative; they are firmly embedded in modern business operations and are expected to reshape industries in the coming years. However, their rapid adoption has also sparked intense debate, especially within IP law, where several high-profile disputes involving AI have already reached the courts. The potential for IP infringement is considerable. When AI systems generate creative outputs—such as music, artwork, or written material—questions arise regarding authorship, ownership, and proper attribution. Similarly, training AI models on large datasets that may include copyrighted material raises concerns about unauthorized use. As AI continues to influence economic and social structures, the relationship between AI and IP law will remain a critical area of legal, ethical, and technological discussion. Legislators, innovators, and legal practitioners must collaborate to design adaptable and forward-looking IP frameworks that both promote innovation and protect creators' rights in an AI-driven environment.

Keywords : *Artificial Intelligence, Intellectual Property Law, Copyright, Patents, Legal Technology would improve academic indexing.*

Introduction

Legal professionals must exercise careful supervision over AI tools, as the lack of transparency in some AI systems can result in breaches of professional and client communication obligations if left unchecked. Laws governing IP infringement in the context of AI use—and determining liability when infringement occurs—are evolving rapidly as courts address new disputes and governments issue guidance or enact legislation to resolve contentious issues.

There is broad agreement that AI systems themselves lack legal personality and therefore cannot hold IP rights. Beyond this consensus, opinions diverge significantly regarding who, if anyone, should own IP rights in AI-generated outputs. Generally, IP protection is more easily obtained for AI-assisted works because of the clear involvement of human creativity. When a human author or inventor employs AI as a supportive tool in the creative process, this is often viewed as comparable to using other technological aids, and thus should not prevent the granting of IP protection.

Applications of AI in Legal Practice**Legal Research :** AI tools can rapidly analyze vast collections of case law, statutes, and regulations to identify relevant precedents, significantly reducing the time required for legal research.

Document Review and Drafting: AI systems assist in examining large volumes of documents, extracting critical information, and generating contracts and legal drafts with improved precision and consistency.

Predictive Analytics: By evaluating historical data, AI algorithms can forecast potential legal outcomes, helping lawyers develop stronger case strategies and provide more informed advice to clients.

Judicial Support : Technologies such as India's Supreme Court Portal for Assistance in Courts Efficiency (SUPACE) help judges manage caseloads by summarizing documents and highlighting essential details.

Compliance and Risk Management: AI can continuously track regulatory updates, notify legal teams of compliance risks, and detect potential legal issues within extensive datasets.

Access to Justice : AI-driven chatbots and legal aid tools offer basic legal guidance, assist with document preparation, and help users navigate court procedures, particularly benefiting individuals who cannot afford traditional legal services.

Use of AI in the Legal Profession

AI has been used by certain legal professionals for many years to analyze data and review documents. However, the emergence of advanced tools such as ChatGPT has accelerated experimentation and adoption across the legal sector. As a result, many law firms and in-house legal teams are now developing internal policies to ensure that AI technologies are used responsibly and ethically in the workplace.

Impact of AI on Intellectual Property

AI presents both advantages and complications for IP law, particularly in relation to AI-generated works and the data used to train AI models. Major concerns include authorship and ownership, as copyright law traditionally requires human creativity; infringement risks arising from training AI on copyrighted materials without authorization; and patent eligibility, since many AI-related inventions are based on abstract algorithms that may not meet patentability standards. Addressing these challenges requires thoughtful policymaking, clear legal guidance, and potentially new regulatory frameworks capable of keeping pace with technological progress.

AI Authorship and Ownership

Absence of Human Creativity: Copyright protection generally depends on human authorship, making it difficult to apply existing laws to content created entirely by AI systems.

Ownership of AI-Generated Works: Determining who owns AI-generated content remains a major challenge, with debates over whether ownership should vest in the developer, the user, or no one at all.

Copyright Infringement Training Data Issues: Generative AI models are trained on extensive datasets that often include copyrighted works, raising concerns about unauthorized use and infringement.

Liability Uncertainty : There is no clear consensus on whether responsibility for infringement lies with the AI developer, the system owner, or the end user.

Patentability of AI Systems Abstract Nature of Algorithms: In many jurisdictions, algorithms are classified as abstract ideas and lack the required “technical character” for patent protection, limiting patent eligibility for AI-based innovations.

Emerging Opportunities in IP and AI Efficient IP Management: AI can streamline the management of IP assets by automating searches, analysis, and administrative tasks.

Innovative Business Models : AI enables new methods of creating, exploiting, and commercializing IP, contributing to economic growth.

Enhanced Innovation : By augmenting human creativity, AI boosts productivity and supports the development of new products and services.

Evolving Legal Frameworks : Governments are considering new legal approaches,

such as the European Union's policies on text and data mining or specialized regimes for AI-generated content.

Clear Regulatory Standards : Establishing transparent rules for the protection of AI-generated data is essential for encouraging responsible innovation.

Technological Safeguards : Tools such as digital watermarking can help monitor the use of AI-generated content and protect copyrighted material.

Human–AI Collaboration : Many experts advocate viewing AI as a collaborative instrument that enhances, rather than replaces, human creativity, thereby preserving IP protection for human-led creations.

IP Protection and AI

IP laws grant rights holders the ability to exclude others from using their protected works without permission. For example, patent owners can prevent unauthorized use of their inventions, while copyright owners can prohibit copying of their works. These rights allow creators to gain recognition and financial returns, providing incentives to invest in innovation.

However, this rationale does not easily apply to AI systems, which do not require incentives to create. This raises the question of whether IP laws should apply to AI-generated outputs in the same manner as they do to human-created works. Patent and copyright law are the areas most significantly affected by AI advancements.

Requirement of Human Involvement

Patent law typically requires the identification of a human inventor; without one, a patent application cannot succeed. Copyright law similarly protects original works of authorship and generally assumes the author to be a natural person. Since copyright duration is often tied to the author's lifetime, applying this framework to AI systems—which are not living entities—would be impractical and could result in perpetual protection.

Although AI systems cannot themselves be inventors or authors, this does not mean that outputs involving AI are automatically excluded from IP protection. A key distinction exists between AI-assisted works, where humans play a significant creative role, and AI-generated works, which are produced with minimal or no human input.

Ownership of AI-generated IP remains a contentious issue. Potential claimants include the AI system owner, developer, trainer, user, or combinations thereof. Ownership may also be allocated contractually, as seen in certain AI service agreements that assign rights in AI-generated content to users.

IP Infringement Risks Associated with AI

The use of AI-generated content raises serious concerns about potential infringement of third-party IP rights. These risks are particularly pronounced given the growing number of legal disputes involving AI systems.

A. Training AI Systems

Generative AI models rely on massive datasets, much of which is sourced from the internet. If copyrighted material is used without permission during training, infringement may occur. While some jurisdictions provide limited exceptions, many do not, meaning that infringement risks persist in a global training environment.

B. Creation and Use of AI Outputs

Infringement can also arise from AI-generated outputs. If generated content is identical or substantially similar to protected works, it may be considered evidence of copying—especially when the AI relies on a narrow set of data sources.

C. Potential Liability

Although AI systems themselves cannot be held legally accountable, various stakeholders may face liability, including:

- AI developers or programmers,

- Owners of AI systems,
- Organizations deploying AI internally, and
- End users who generate and use infringing content.

Liability exposure varies across jurisdictions and among stakeholders, but all participants in the AI ecosystem should remain aware of these risks.

Risk Mitigation Measures

To reduce IP infringement risks, stakeholders may consider:

- Refining AI systems to avoid reproducing existing works verbatim,
- Using plagiarism detection tools on AI-generated content,
- Training employees to avoid improper AI usage, and
- Seeking contractual protections, such as warranties or indemnities, from AI providers.

Conclusion

The continued advancement of AI technologies will bring both opportunities and complexities for IP protection and enforcement. As courts and regulators confront these emerging issues, the legal framework will continue to evolve. Accordingly, all participants in the AI ecosystem should stay informed of legal developments and seek professional guidance to effectively manage the associated risks.

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**17. A CASE STUDY OF CLOUDFLARE'S NETWORK OUTAGE:
TECHNICAL CAUSES AND IMPLICATIONS FOR CLOUD
INFRASTRUCTURE RELIABILITY**

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Abstract

This article presents a case study of the 18 November 2025 Cloudflare global network outage, analyzing its technical causes and implications for cloud infrastructure reliability. Cloudflare, a major provider of content delivery, DNS, and edge security services, experienced a multi-hour disruption triggered by a latent software defect activated by a configuration update. The incident caused widespread service degradation across numerous online platforms, highlighting systemic risks associated with centralized internet infrastructure. Using publicly available post-incident reports and industry analyses, this study examines the failure mechanism, the role of configuration management in large-scale distributed systems, and the cascading nature of outages in shared infrastructure layers. The article also evaluates Cloudflare's post-incident resilience measures and discusses broader lessons for cloud reliability engineering, including validation of configuration artifacts, staged rollouts, observability improvements, and infrastructure diversification. The case demonstrates how non-malicious internal faults can propagate globally in hyperscale environments and underscores the importance of resilience-by-design principles in modern cloud architectures.

Keywords : *Cloud computing reliability, Cloudflare outage, Latent software defect, Distributed systems failure, CDN infrastructure, Configuration management, Cascading failure, Internet resilience.*

Introduction

Cloudflare is a major provider of internet infrastructure services, including content delivery networks (CDN), distributed denial-of-service (DDoS) protection, domain name system (DNS) services, and web security solutions. Its globally distributed network supports millions of websites and online services by improving performance, reliability, and cybersecurity. Because Cloudflare operates at the edge of the internet and handles a significant share of global web traffic, disruptions within its systems can have far-reaching effects on digital communication, business operations, and public services.

The increasing dependence on cloud-based infrastructure has made internet resilience a critical area of academic and industrial research. Prior studies have shown that large-scale cloud systems are highly susceptible to cascading failures caused by software defects, configuration errors, and complex interdependencies (Armbrust et al., 2010). As cloud service providers grow in scale and complexity, ensuring high availability has become increasingly challenging, and even minor internal faults can propagate into widespread service outages.

On 18 November 2025, Cloudflare experienced a major service disruption triggered by a latent software bug that had remained undetected within its infrastructure. Latent bugs are particularly difficult to identify because they often evade routine testing and only manifest under rare operational conditions or specific configuration changes (Yuan et al., 2014). The Cloudflare outage provides a valuable real-world example of how such hidden faults can undermine the reliability of globally distributed systems.

The purpose of this article is to analyze the November 2025 Cloudflare outage as a case study in cloud infrastructure reliability and failure propagation. The study examines the technical causes of the incident, the scale and nature of its impact, and the response and recovery measures undertaken. **This outage is worth academic analysis** because it illustrates how configuration changes in large-scale, centralized infrastructure providers can trigger cascading failures that affect multiple sectors simultaneously. By

examining this incident, the article contributes to broader discussions on fault tolerance, system observability, and risk management in modern cloud environments.

Research Methodology

This study adopts a **qualitative case study methodology** focused on a real-world infrastructure failure event. The analysis is based on secondary data sources, including Cloudflare's official incident reports, technical blog posts, public status updates, and industry commentary published after the November 18, 2025 outage. These sources were examined to reconstruct the sequence of events, identify the technical failure mechanism, and evaluate the systemic factors contributing to the outage.

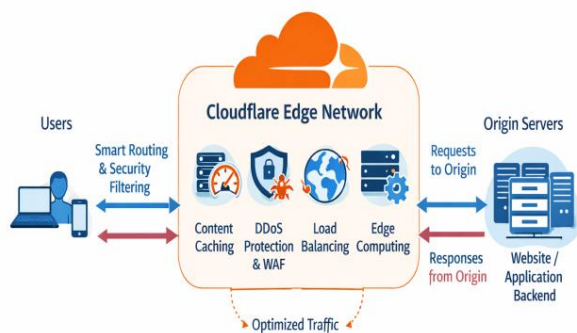
The case study approach is appropriate for investigating complex socio-technical systems where controlled experimentation is not feasible (Yin, 2018). By analyzing this incident as an example of failure propagation in a large-scale distributed platform, the study draws generalized lessons for cloud infrastructure reliability, configuration management practices, and resilience engineering. While quantitative telemetry data was not publicly available, triangulation across multiple credible sources improves the validity of the analysis.

Understanding Cloudflare's Role in Internet Infrastructure

Cloudflare operates as a globally distributed **edge network** that sits between end users and origin servers. Instead of traffic flowing directly to a website's hosting server, user requests are routed through Cloudflare's **Anycast-based network**, where the same IP address is advertised from multiple geographic locations. This routing method directs users to the nearest operational data center, reducing latency and improving reliability. At the edge, Cloudflare performs multiple functions including **content caching, TLS termination, load balancing, traffic filtering, and application-layer security enforcement.**

From a networking perspective, Cloudflare combines **content delivery network (CDN) architecture with edge computing capabilities**. Static content is cached at edge nodes to reduce origin load, while dynamic requests can be processed using serverless edge functions and smart routing algorithms. Security mechanisms such as **DDoS mitigation, Web Application Firewall (WAF) filtering, bot detection, and rate limiting** are applied before traffic reaches the origin infrastructure. This layered model means Cloudflare is not merely an acceleration service but an active participant in **traffic routing, security policy enforcement, and application availability**.

Because this architecture centralizes multiple control and optimization layers within a single distributed platform, it introduces both efficiency and systemic risk. A malfunction within routing logic, configuration management, or edge software deployment can propagate rapidly across the network due to shared control planes and synchronized updates. This characteristic makes large edge platforms important subjects for studying **failure propagation in distributed internet infrastructure**.



Traffic routed through Cloudflare's Edge Network before reaching the origin.

Figure 1 simplified edge-to-origin traffic model

Cloudflare and Cloud-Based Productivity Platforms

Modern productivity environments operate on a multi-layered cloud stack that includes application servers, identity management systems, APIs, and web delivery infrastructure. Many browser-based services depend on **content delivery networks**

(CDNs), **DNS providers, and edge security platforms** to route traffic, terminate TLS connections, and filter malicious requests. These intermediary layers play a key role in ensuring performance, availability, and secure access to cloud applications.

Although major providers such as Microsoft maintain extensive global infrastructure, **web-facing components and third-party integrations may rely on shared internet infrastructure services** for traffic optimization and protection. Prior research on cloud service dependencies highlights that SaaS delivery often involves multiple external network and security layers beyond the core hosting environment [REF]. This layered dependency model means that failures outside the primary application infrastructure can still affect end-user access.

When an edge network provider experiences disruption, the impact is usually **indirect but operationally significant**. Even if backend application servers remain functional, failures in DNS resolution, TLS handshakes, request routing, or caching systems can prevent users from successfully connecting to services. In productivity platforms, this may appear as **authentication delays, API request timeouts, synchronization failures, or inaccessible browser interfaces**.

These scenarios demonstrate that SaaS reliability depends not only on application and data center resilience but also on the **stability of shared internet middleware layers**. Understanding this dependency is important when analyzing large-scale outages, as it helps explain how infrastructure issues outside a provider's core systems can still disrupt user access.

Overview of the November 18, 2025 Cloudflare Outage

On **18 November 2025**, Cloudflare's global edge network experienced a substantial service disruption that affected internet connectivity for numerous websites and cloud platforms. According to official post-incident reporting, the outage began

shortly before **11:20 UTC** and produced widespread HTTP **500-series errors** and connection failures for services that relied on Cloudflare’s traffic-handling infrastructure. These error responses indicated internal server problems within Cloudflare’s network rather than isolated site issues.

Cloudflare later confirmed that the root cause was a **latent software defect in its Bot Management system**, triggered by an internal configuration change to a ClickHouse database. This change inadvertently caused a critical “feature file” — used for both detection and traffic filtering — to grow beyond its expected size, exceeding software limits and causing runtime failures as the oversized file was propagated across the distributed network. The failure occurred within a core traffic-routing component that touches virtually all customer traffic, leading to cascading disruption of numerous services.

Because Cloudflare’s architecture relies on **synchronized deployment of configuration files and routing logic across its distributed data centers**, the faulty configuration rapidly affected multiple regions, transforming what began as a localized defect into a **global outage**. The disruption persisted for several hours: core traffic began stabilizing by approximately **14:30 UTC**, and full restoration of all affected systems was reported by **17:06 UTC**, giving a total major outage duration of around **five hours** before services normalized.

The incident impacted a wide range of online services, with outage reports and monitoring data showing elevated error rates for major platforms including social media, AI services, online retail, and developer tools during the incident window. Because Cloudflare provides CDN, DNS, and security proxy services for a significant portion of the internet, the failure affected both high-traffic public services and enterprise applications alike.

Cloudflare’s post-incident analysis clarified that the outage was **not the result of a cyberattack or malicious activity**, but rather an internal error exacerbated by systemic dependencies in rapid, globally synchronized configuration distribution. The event has since been described as one of the most visible infrastructure failures of 2025, illustrating the challenges of maintaining reliability in hyperscale distributed networks.

The Concept of a Latent Bug

After service restoration, Cloudflare engineers identified a previously undetected defect within the request-processing stack. In software reliability terms, this type of issue is called a **latent defect** — an error embedded in production code that remains dormant under expected workloads and test scenarios but surfaces when unusual system states or input conditions arise. In this incident, the defect did not affect routine operations and therefore escaped earlier validation cycles. A later configuration update introduced operating conditions that interacted with this hidden flaw. Once those conditions appeared in production, the defect disrupted a critical component in the traffic-handling pipeline, initiating a chain reaction across the distributed network.

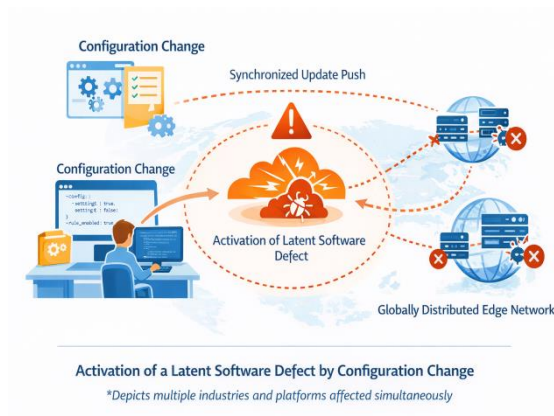


Figure 2 Activation of a latent software defect by configuration change

In this incident, the defect did not affect routine operations and therefore escaped earlier validation cycles. A later configuration update introduced operating conditions that interacted with this hidden flaw. Once those conditions appeared in production, the defect disrupted a critical component in the traffic-handling pipeline, initiating a chain reaction across the distributed network.

Technical Cause of the Outage

Configuration Deployment Trigger

The failure began during a scheduled deployment affecting Cloudflare's **bot mitigation and traffic classification subsystem**. This subsystem depends on continuously updated rule sets and feature datasets that guide how incoming requests are analyzed and filtered in real time.

The updated configuration altered the structure and size characteristics of these datasets beyond values previously exercised in staging environments. A defect in the component responsible for parsing and loading this data caused the process to fail when encountering the new input pattern. Instead of rejecting the configuration safely or reverting automatically, the service crashed.

Failure in the Inline Processing Pipeline

Cloudflare's traffic management systems operate **inline at the edge**, meaning every HTTP request passes through inspection, filtering, and routing stages before reaching the origin server. When the affected component failed, edge nodes could no longer complete request evaluation. As a result, the system returned server-side error responses rather than forwarding traffic.

Because this processing occurs at the entry point of request handling, the failure immediately impacted end-user connectivity. Websites behind Cloudflare appeared unavailable even though their origin infrastructure remained functional.

Why Testing and Safeguards Did Not Prevent the Failure

Several engineering limitations contributed to the defect reaching production:

- **Gaps in Boundary Testing:** Test scenarios focused on expected dataset sizes and normal traffic conditions. They did not simulate extreme or unusual configuration states that could stress memory handling and parsing logic.
- **Limited Configuration Validation:** The deployment pipeline validated syntax and integrity but did not enforce strict constraints on dataset growth, structural limits, or runtime resource impact.
- **Staging Environment Differences:** Pre-production systems did not fully replicate production-scale traffic diversity, which prevented the triggering condition from appearing before release.
- **Canary Evaluation Scope:** Early deployment phases did not run long enough or under sufficient traffic variability to expose the instability before global rollout.

Cascading Failure Across the Global Network

Cloudflare distributes configuration updates through a **centrally coordinated control plane** to maintain consistent behavior across its edge data centers. Once the faulty configuration propagated, multiple locations began encountering identical processing failures. Automated load balancing attempted to reroute traffic, but because the same defective logic existed everywhere, rerouted requests experienced the same errors. This created a **cascading failure**, where redundancy mechanisms could not isolate the fault due to its systemic nature.

Statement from Cloudflare's Chief Technology Officer

Cloudflare's Chief Technology Officer, Dane Knecht, publicly addressed the outage and issued an apology on behalf of the company, acknowledging responsibility for the technical failure. In communications on social and status channels, Knecht stated that the outage was **not caused by a cyberattack, hacking attempt, or any form of external interference**; rather, it resulted from an internal configuration error that triggered a latent defect within Cloudflare's systems. He emphasized that the company had "failed our customers and the broader internet" in this instance, and reiterated Cloudflare's intention to analyze and improve its processes to prevent similar failures in the future.

Knecht also noted the **scale and complexity of Cloudflare's operations**, observing that the platform processes very high volumes of internet traffic. Disruptions within such a pervasive infrastructure provider can therefore have disproportionate visibility, even when the root cause is a localized configuration issue rather than a systemic design flaw. While precise traffic figures were not provided in the statement itself, industry reporting has highlighted the extent to which Cloudflare's network underpins a broad range of digital services worldwide.

Why the Outage Had a Global Impact

The 18 November 2025 service disruption illustrated how a localized technical failure within a central infrastructure provider can translate into widespread internet availability issues. Cloudflare serves as a **gateway for web traffic** for a significant portion of internet destinations by providing CDN, DNS, security proxy, and other intermediary services. When traffic processing components within this gateway fail, end users may be unable to reach otherwise healthy origin servers because their traffic cannot be correctly routed or authenticated.

This architectural role means that an error internal to Cloudflare can manifest externally as simultaneous accessibility failures across thousands of websites and applications. Reporting on the incident identified elevated error rates and service interruptions for numerous platforms — including AI services, social networks, entertainment services, and business applications — during the outage period.

The dependency on Cloudflare for **both performance and security services** further complicated mitigation efforts. Many organizations integrate Cloudflare into their delivery and protection stacks, making it operationally challenging to reroute traffic quickly during an outage without significant reconfiguration. This dependency magnified the user-facing impact of the disruption and highlighted the broader risks associated with reliance on centralized internet infrastructure providers for distributed digital services.

Impact on Businesses and Digital Productivity

The November 18, 2025 Cloudflare outage caused measurable disruption across multiple business sectors because many services depend on Cloudflare's infrastructure for content delivery, security, and DNS resolution. During the incident window, numerous major platforms reported elevated error rates and periods of unavailability, including AI services such as ChatGPT and Claude, social media platforms like X, music streaming services such as Spotify, and e-commerce sites powered by platforms like Shopify.

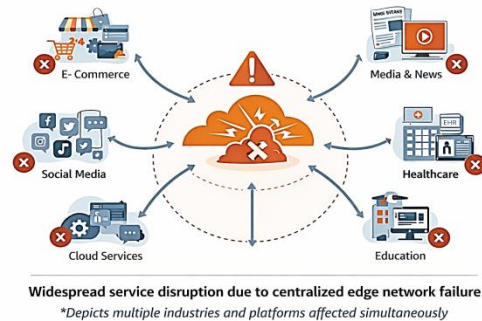


Figure 3 Widespread service disruption due to centralized edge network failure

For organizations reliant on real-time connectivity and web-based applications, even brief interruptions translated into operational challenges. Communication tools, customer-facing portals, and transactional systems failed to respond normally while HTTP 5xx errors persisted, which likely impacted revenue streams, delayed workflows, and degraded user experience during peak business hours. Analytics from independent outage monitors indicated thousands of service degradation reports within minutes of the outage onset, illustrating the interconnected nature of modern digital operations.

The incident underscored the degree to which **digital productivity has become tightly coupled with shared internet infrastructure**. As hybrid and remote work models continue to rely on web-based collaboration, access management, and cloud services, the availability of intermediary network providers becomes a critical factor in maintaining continuity of business operations.

Industry Response and Analysis

Industry analysts characterized the Cloudflare disruption as **a case study in infrastructure interdependence and systemic risk**. Commentary from technology research outlets highlighted that failures within central network platforms can cascade across sectors, particularly when configuration changes propagate rapidly without sufficient validation.

Experts emphasized that configuration updates — similar to software code changes — merit **rigorous testing, semantic validation, and staged deployment safeguards** because they can alter runtime behavior in complex, distributed systems. The outage reignited discussions around architectural diversification, including using multiple CDN/DNS providers or isolation strategies to mitigate reliance on a single intermediary network layer.

Furthermore, some analysts noted that the Cloudflare incident, together with recent outages at other major providers, illustrated broader trends in cloud infrastructure risk where **single subsystem failures can have disproportionate global effects**, encouraging enterprises to rethink resilience strategies beyond traditional high-availability assumptions.

Post-Outage Improvements by Cloudflare

In the aftermath of the November 18, 2025 outage, Cloudflare publicly outlined a set of targeted measures to improve the resilience of its global network. The company launched an initiative internally referred to as “**Code Orange: Fail Small**”, under which engineering efforts are being prioritized to strengthen configuration handling and reduce systemic risk from human or automated changes.

The resilience plan includes multiple concrete actions:

- **Configuration validation enhancements:** Cloudflare intends to enforce stricter checks on configuration artifacts (including size limits and format constraints) before deployment to prevent malformed or oversized files from being propagated.
- **Global kill switches and fallback mechanisms:** The plan calls for the ability to disable problematic features across the network instantly, minimizing error propagation when faults occur.

- **Improved observability and failure-mode handling:** Revising debugging and monitoring logic to avoid excessive resource consumption during incidents and to provide earlier anomaly detection.
- **Expanded training and process reviews:** Cloudflare is reviewing internal break-glass procedures and reducing circular dependencies that could slow response during critical incidents.

By implementing these measures, Cloudflare aims **to reduce the blast radius of configuration changes** and to strengthen safeguards against latent defects causing widespread outages. These improvements reflect a broader industry shift toward **resilience-by-design**, where infrastructure changes are treated with the same rigor as code updates.

Conclusion

The Cloudflare outage of **18 November 2025** was a significant infrastructure event that exposed the fragility inherent in highly centralized components of the modern internet. A deeply embedded software defect — benign under typical conditions but triggered by a routine configuration update — led to failures in a core traffic-processing pipeline, temporarily disrupting access for a large portion of the internet.

While service was restored within hours, the outage demonstrated how **dependency on shared intermediary services** can amplify the impact of internal failures beyond a single organization's boundaries. Cloudflare's public post-mortem and resilience plan represent important steps toward addressing the technical and procedural weaknesses that contributed to the incident; however, as the December 5 2025 outage also showed, such improvements take time to implement fully.

Limitations

This analysis is based on public reports, official post-mortems, and industry commentary. It does not include primary data from Cloudflare's internal telemetry, customer impact logs, or economic loss assessments, which were not publicly disclosed at the time of writing. As a result, the quantitative estimates of impact and recovery timelines rely on secondary sources and may not capture the full extent of operational effects on individual businesses.

Lessons and Principles for Future Infrastructure Resilience

The events of late 2025 reinforce several general principles applicable to cloud and distributed systems engineering:

1. **Treat configuration and metadata changes with the same rigor as code updates**, including semantic validation and rollback controls.
2. **Implement multi-layered safeguards** such as kill switches, controlled rollouts, and observability systems capable of early anomaly detection.
3. **Consider diversification of critical infrastructure dependencies** to mitigate single points of systemic failure.
4. **Prioritize transparent communication and post-incident analysis** to support community learning and to maintain stakeholder trust after outages.

In an ecosystem where cloud services, productivity tools, and online platforms are increasingly interdependent, the **stability of shared internet infrastructure remains a central challenge** for both practitioners and researchers. Resilient design, rigorous validation, and robust operational practices are essential to preventing isolated technical faults from disrupting global digital activity.

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