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MEMBRANE BIOREACTOR FOULING: MECHANISMS, IMPACTS, AND CONTROL TECHNIQUES

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Review Paper

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ABSTRACT

Membrane bioreactor (MBR) technology has gained significant attention in the realm of wastewater treatment. Using membrane bioreactors in wastewater treatment provides numerous advantages, including high-quality effluent, space efficiency, higher treatment performance, flexibility, reduced sludge production, improved process control, and environmental benefits. Membrane fouling, on the other hand, continues to be a major issue, resulting in higher operational costs, a shorter membrane lifespan, and frequent maintenance requirements. Fouling is produced by deposits of suspended particles, colloids, bacteria, and organic materials on the membrane's surface or within its pores, resulting in decreased permeability. This review critically explores the fouling mechanisms in MBR systems. This review provides a comprehensive analysis of membrane fouling in the Membrane Bioreactor (MBR), focusing on the mechanisms that lead to fouling, its impacts on system performance, and the state-of-the-art techniques employed to control fouling. Membrane fouling is one of the most critical challenges in the operation of MBRs, significantly affecting their efficiency and operational costs. This paper provides an overview of fouling phenomena in MBR systems while also highlighting innovative techniques to improve membrane performance and longevity.

No. of Pages: 10 **References: 48**

Keywords: Membrane Bioreactor, Membrane Fouling, Mechanisms, Controlling Techniques, Membrane Performance.

Abbreviations
MBR: Membrane Bioreactor
SMP: Soluble Microbial Products
MLSS: Mixed Liquor Suspended Solids
EPS: Extracellular Polymeric Substances
SRT: Solid Retention Time
HRT: Hydraulic Retention Time
TMP: Transmembrane Pressure
CEB: Chemically Enhanced Backwash
PFS: Polymeric Ferric Sulfate
PFC: Polymeric Ferric Chloride
PAC: Powdered Activated Carbon
GAC: Granular Activated Carbon
CNT: Carbon Nanotube

INTRODUCTION

MBR technology has emerged as a critical advancement in wastewater treatment due to its ability to produce good-quality effluent. Since its inception in the 1960s, MBR technology has undergone significant advancements, making it a viable option for both municipal and industrial wastewater treatment (Drews, 2010). MBRs are a highly effective method for treating domestic and industrial liquid wastes. By integrating biological treatment with physical separation using membranes, MBRs can efficiently remove pollutants (Li *et al.*,

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2019). MBRs are known for their operational simplicity and ability to minimize sludge production, especially when operated by skilled personnel. In densely populated urban areas where space is limited, the compact size of MBRs is highly advantageous. Given the aforementioned benefits, coupled with the declining expenses of membrane materials and the growing demands for high-quality treated effluent, it is evident that MBR technology is being increasingly utilized in wastewater treatment (Abdelrasoul *et al.*, 2018).

Despite its advantages, MBR technology is hampered by membrane fouling, which remains the most significant operational challenge. Fouling leads lower membrane permeability, increased transmembrane pressure, and higher energy consumption, ultimately affecting the cost-effectiveness and reliability of MBR systems (Meng *et al.*, 2009). Effective fouling mitigation is crucial for the sustainable operation of MBR systems. Various strategies have been developed to combat fouling, including physical cleaning methods, chemical cleaning agents, and advancements in membrane material design. However, the complexity of fouling mechanisms makes it challenging to develop universally effective solutions (Le-Clech *et al.*, 2006).

This review aims to provide a comprehensive overview of the current understanding of membrane fouling in MBR systems, focusing on the mechanisms that drive different types of fouling and the strategies employed to mitigate these issues. The review is structured to first explore the various types of fouling encountered in MBR systems, followed by a discussion of the mechanisms underlying these processes. The paper will then delve into the diverse range of fouling mitigation strategies, evaluating their effectiveness and feasibility.

2. Types of Fouling

There are different types of membrane fouling, namely internal, external, and concentration polarization. Internal fouling, also known as pore blocking, occurs when solutes deposit and adsorb on the interior of membrane pores, leading to fouling. External fouling refers to the accumulation of particles, colloids, and macromolecules on the surface of the membrane. The phenomenon of concentration polarization occurs when solutes and ions accumulate in the thin liquid layer near the membrane surface (Du *et al.*, 2020). Membrane fouling has been generally classified into two types: irreversible and reversible, which are determined by the degree to which pollutants are eliminated. Reversible fouling pertains to the portion of the foulants that can be eliminated through backwashing. Non-reversible fouling is characterized by its resistance to physical cleaning methods, necessitating the use of chemical cleaning agents for its removal. Reversible fouling is attributed to the loose deposition of contaminants on the membrane surface, while irreversible fouling is attributed to the membrane pore blockage and the strong adhesion of contaminants (Meng *et al.*, 2009).

Based on the chemical composition of the pollutants, three distinct forms of membrane fouling can be characterized: organic, inorganic, and biofouling. Organic fouling occurs because of the presence of large organic macromolecules. Organic macro-molecular polymer clusters play a significant role as contaminants. The analysis reveals that the diameter of BPCs is less than 50 μm, a notable distinction from the particles found in activated sludge floc (X. M. Wang & Li, 2008). Inorganic foulants refer to a collection of inorganic substances that deposit onto the surface of the membrane or clog its pores, leading to the phenomenon known as membrane fouling. Inorganic fouling occurs when inorganic species chemically precipitate or when inorganic-organic complexes are biologically precipitated (Iorhemen *et al.*, 2016). Biofouling is the most complex due to its association with the unwanted deposition, growth, and flocs on the surface of the membrane and/or within its pores (Guo *et al.*, 2012). The categorization of fouling types typically relies on the approach employed to restore the original permeability. Table 1 presents the classification of fouling. The analysis focuses on the anticipated formation rate of fouling and the timing of cleaning strategies employed to eliminate them.

Table 1: Classification of fouling.

Types of fouling	**Fouling Rate (mbar/min)**	**Time Interval**	**Cleaning Method Applied**
Cake, reversible, or removable fouling	0.1–1	10 min	Physical cleaning (e.g., relaxation, backflush)
Residual fouling	0.01–0.1	1–2 weeks	Maintenance cleaning (e.g., chemically enhanced backflush)
Irreversible fouling	0.001–0.01	6–12 months	Chemical cleaning
Permanent, long-term, or irrecoverable fouling	0.0001–0.001	Several years	Cannot be removed
Ref. Gkotsis *et al.*, (2014)			

3. Mechanism of Fouling

The fouling mechanisms observed in MBRs can be categorized into three primary stages.

(1) Pore narrowing/plugging: The decrease in the permeate flow rate is caused by the membrane surface coverage. This leads to slow fouling and pore plugging. Preventing pore clogging is crucial and can be achieved through various pretreatment stages. (2) Pore clogging/blocking: The occurrence of this phenomenon can be attributed to the SMP and the strong adsorption of colloids, biomass particles, and organic matter. (3) Formation of cake layers: This can be due to the accumulation of larger substances that exceed the size of the membrane pores and develop a biofilm. The formation of cake layers is influenced by factors such as MLSS concentration, membrane flux, and air scouring (Liu *et al.*, 2001). Furthermore, the formation of cake layers in the MBR operation is influenced by the production of EPS and SMP through microbial metabolisms in the liquid phase (Le-Clech *et al.*, 2006; Meng *et al.*, 2009).

4. Factors Influencing Membrane Fouling

Membrane fouling factors encompass the material of the membrane module, the pressure difference experienced during filtration, the cross-flow velocity, HRT, and SRT. The presence of these factors, either individually or in combination, creates an environment that promotes membrane fouling. It is crucial to have in-depth knowledge of the impact of different factors to effectively control and predict this phenomenon (Z. Wang *et al.*, 2008). Figure 1 illustrates the various factors that contribute to membrane fouling. Table 2 provides a comprehensive overview of the factors affecting and impacting membrane fouling.

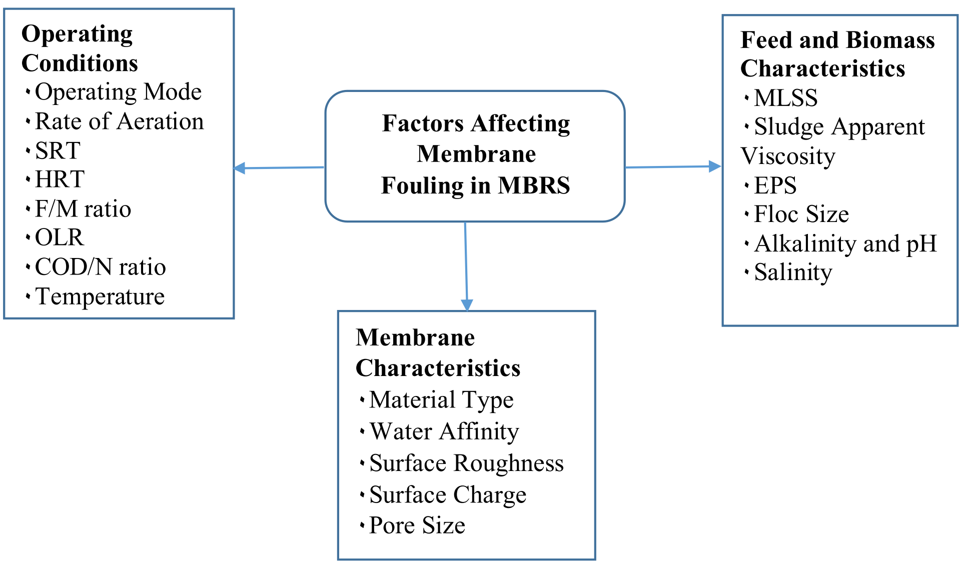

Fig. 1: Factors affecting membrane fouling (Iorhemen *et al.*, 2016).

Table 2: Factors affecting and impacting membrane fouling.

Factor	**Description**	**Impact on Fouling**	**Reference**
Feed water Composition	Includes organic matter, suspended solids, colloids, and inorganic salts.	High levels of organic matter and suspended solids increase organic fouling and particulate fouling, while salts cause scaling.	Drews (2010)
Membrane Material and Surface	The chemical composition, surface roughness, and hydrophilicity/ hydrophobicity of the membrane.	Hydrophobic membranes tend to attract organic and bio-foulants more readily. Surface roughness increases fouling propensity.	Meng *et al.* (2017)
Flux and Operational Conditions	The rate of filtration (flux), transmembrane pressure (TMP), and operational modes (continuous vs. intermittent).	High flux and TMP can lead to accelerated fouling due to higher deposition rates of foulants on the membrane surface.	Drews (2010)
Sludge Characteristics	Includes mixed liquor suspended solids (MLSS), particle size distribution, and extracellular polymeric substances (EPS).	High MLSS and EPS content lead to increased biofouling and organic fouling. Smaller particle size increases the fouling rate.	Lee *et al.* (2003)
Temperature	It affects the viscosity of the mixed liquor and microbial activity in the bioreactor.	Higher temperatures generally increase fouling due to higher microbial activity and faster biofilm formation.	Drews (2010)
pH and Ionic Strength	The pH level and ionic strength of the feed water influence the solubility of inorganic salts and microbial activity.	Extremes in pH can lead to scaling, while higher ionic strength can reduce fouling by compressing the electric double layer.	Meng *et al.*, (2017)
Hydrodynamic Conditions	Shear forces, cross-flow velocity, and turbulence at the membrane surface.	Higher shear forces and turbulence can reduce fouling by deterring foulant deposition and aiding in fouling layer removal.	Drews (2010); Le-Clech *et al.* (2006)
Membrane Cleaning Protocols	Includes the frequency and methods of physical (e.g., backwashing) and chemical cleaning (e.g., acid/base washes).	Effective cleaning reduces fouling, but improper cleaning can lead to membrane damage and irreversible fouling.	Le-Clech *et al.* (2006)

5. Impacts of Fouling

The following are the impacts of membrane fouling:

a) **Reduction in Permeate Flux:** Fouling reduces permeate flux, which is the rate at which clean water can pass through the membrane. This reduction occurs because the fouling layer increases the resistance to water flow (Meng *et al.*, 2017).

b) **Increased Operational Costs:** Fouling increases operational costs because of frequent cleaning, and membrane replacement as well as energy consumption (Le-Clech *et al.*, 2006).

c) **Decreased Membrane Life:** Persistent fouling can cause irreversible damage to the membrane, leading to a shortened lifespan. This results in the need for more frequent replacements, further increasing the overall system costs (Drews, 2010).

d) **Increased Frequency of Cleaning and Maintenance:** Fouling necessitates more frequent cleaning, which can disrupt operations. Frequent chemical cleanings can also contribute to membrane degradation, further shortening its life and increasing maintenance demands (Guo *et al.*, 2012).

e) **Environmental Impacts:** The increased use of chemicals for cleaning and the disposal of used membranes can have negative environmental impacts. Additionally, the energy-intensive nature of managing fouling increases the carbon footprint of MBR systems (Santos *et al.*, 2011).

6. Membrane Fouling Control Techniques

Controlling membrane fouling in MBRs is crucial to optimize performance and extend membrane lifespan. This not only has economic benefits but also ensures smooth long-term operation with minimal operational and maintenance costs. Modifying the operational parameters during the optimal phase and pretreatment of the influent can effectively minimize the risk of membrane fouling. Additionally, the introduction of adsorbents and coagulants, and membrane surface properties alteration have been explored as potential methods (Hamedi *et al.*, 2019). Following are some techniques to prevent membrane fouling:

6.1 Physical Cleaning

The process of physical cleaning is commonly accomplished through two methods: backflushing, where the flow is reversed, or relaxation, where permeation is stopped while the membrane is still cleaned with air bubbles. In light of the growing body of research on physical cleaning, various alternative approaches have been suggested. These include online ultrasonication (Kobayashi *et al.*, 2003), the introduction of suspended particles and carriers (Jiang *et al.*, 2013), and mechanical cleaning (Van den Brink *et al.*, 2013). According to X. Yang *et al.* (2013), vibration has shown great potential as a physical cleaning method.

6.2 Chemical Cleaning

It involves the use of sulphuric, citric, oxalic various chemical reagents, including bases like caustic soda, and oxidants like hypochlorite (Liu *et al.*, 2001). In-situ maintenance cleaning involves two methods: CIP, where the membrane is cleaned in place without draining the membrane tank, and CIA, which involves cleaning the membrane after draining the membrane tank. Furthermore, the combination of chemical agents and other physical methods can be employed to augment their efficacy or minimize the chemical burden.

6.3 Physicochemical Cleaning

This method combines physical cleaning techniques with the use of chemical agents to improve the efficiency of cleaning. A commonly employed technique in MBRs for cleaning is the physico-chemical method known as CEB. This involves introducing a diluted chemical cleaning agent into the backflush water. Periodic CEB is performed when conventional physical cleaning methods, such as backflushing, fail to restore membrane permeability effectively (Buzatu *et al.*, 2012). In general, CEB is commonly known as a form of maintenance cleaning. Additional physico-chemical cleaning methods have been explored, such as the utilization of ultra-sonication to enhance chemical cleaning (Cai *et al.*, 2009).

6.4 Air Scouring

Air scouring, also known as aeration, utilizes large bubbles to eliminate reversible fouling and concentration polarization. These issues arise from the buildup of rejected materials near the membrane. In addition, the presence of aeration is crucial for the maintenance of the suspended sludge flocs in the reactor and for supplying dissolved oxygen to the microorganisms (Braak *et al.*, 2011). In a study conducted by Sun *et al.* (2016), it was found that aeration accounts for approximately 50% of energy consumed in MBRs. The use of intermittent aeration at intervals of 10–30 seconds is more effective compared to continuous aeration at the same rates. Furthermore, the implementation of intermittent aeration has been found to have a substantial impact on nutrient removal in MBRs. However, it has been observed that the introduction of cyclic aeration leads to the deflocculation of sludge, resulting in alterations to the rates of fouling. Therefore, the factors that influence intermittent aeration, like the rates of aeration, and the cycle, need to be considered. Optimizing the intervals of all rights reserved is crucial for effectively controlling fouling, which ultimately leads to improved efficiency in MBR operation (Hamedi *et al.*, 2019).

6.5 Backwashing and Relaxation

It is effective in reducing reversible fouling by eliminating cake layers. The process of backwashing involves reversing the flow of permeate to remove particles that have accumulated on the membrane surface. To alleviate the pressure on the membrane, the filtration process is temporarily halted, allowing for relaxation (Deng, 2015; K. M. Wang et al., 2018).

6.6 Rotating Speed

The membrane filtration efficiency is enhanced with an increase in rotation speed, as it promotes effective fouling control. In a study conducted by Jiang et al. (2013), it was found that rotating flat sheet MBRs have a lower fouling potential compared to conventional MBRs while consuming the same amount of energy. G. Wu *et al*. (2008) proposed a critical speed of 60 rpm. Paul & Jones (2015) found that rotation plays a relatively minor role in reducing fouling, accounting for only 12% of the overall reduction. On the other hand, the impact of air scouring on fouling was found to be more significant.

6.7 Addition of Coagulants and Adsorbents

This technique improves flocculation by neutralizing the negative charges of biomass and adsorbing colloidal and soluble substances (J. Wu *et al*., 2006). X. L. Yang *et al*. (2011) investigated the impact of coagulants, specifically PFS and PFC, on membrane performance. The study revealed that PFS has the potential to effectively reduce membrane fouling by enhancing sludge levels. The content of this article is subject to copyright protection. The floc size is determined by the enhancement of charge neutralization of organic particles, with all rights reserved. Additionally, the application of PFC has been found to enhance phosphorus removal and mitigate membrane fouling. The use of natural zeolites and PAC as adsorbents was investigated. The aim was to reduce the concentration of biopolymers and the specific resistance of the cake layer (Rezaei & Mehrnia, 2014). The reduction in membrane pore blocking is observed as the cake layer becomes more porous and less compact, leading to increased stability (W. Yang *et al*., 2010). According to the report, the PAC-MBR has shown effectiveness in controlling fouling even in challenging conditions such as salt shock.

6.8 Application of Ultrasound

Juang & Lin (2004) demonstrated the effectiveness of ultrasound in improving membrane permeability and reducing membrane fouling in crossflow filtration of macromolecules. The membrane flux enhancement was found to be influenced by factors such as ultrasound intensity, irradiation radiation, and direction. In a study conducted by Sui et al. (2008), the focus was on examining the impact of ultrasound working time on membrane fouling control. The researchers carried out their experiments using an anaerobic MBR and aimed to demonstrate the potential of ultrasound as an effective method for online membrane fouling control. According to M. Xu et al. (2010), online ultrasonic equipment was utilized to manage membrane fouling in a waste-activated sludge digestion MBR. The study revealed that intermittent ultrasonic irradiation proved to be highly effective in managing membrane fouling in the MBR system.

6.9 Membrane Surface Modification

Membrane modification is considered a promising approach to mitigate membrane fouling by altering the surface properties of the membrane, particularly through hydrophilic modification. Various techniques have been employed to improve the hydrophilicity of polymeric membranes, given their inherent weak hydrophilic nature (X. M. Wang *et al*., 2011). The techniques frequently employed for membrane modification encompass blending (Y. Q. Wang *et al*., 2006), grafting (Lu *et al*., 2017), coating (G. R. Xu *et al*., 2013), and nanoparticle incorporation (Mei *et al*., 2014). According to the report, the use of nanoparticles has been found to enhance the hydrophilicity of surfaces and improve their antifouling properties. This technology is characterized by the increased interactions of smaller particles that are well distributed. These interactions allow for more efficient utilization of nanoparticle sites, resulting in enhanced flux and reduced fouling (Kim & Van Der Bruggen, 2010).

Numerous studies have investigated the effects of different types of nanoparticles. The successful integration of Ag nanoparticles into PSF ultrafiltration membranes has been reported by Zodrow *et al*. (2009). One notable limitation observed in the application of Ag nanoparticles in the modified membrane is the gradual reduction of Ag concentration over time. Several studies have been conducted to investigate the application of ZnO nanoparticles in altering membrane surfaces (Tan *et al*., 2015). The results indicate that the addition of ZnO nanoparticles enhances the permeability of the PVDF membrane by approximately five times (Hong & He, 2012) and increases the permeability of the PES membrane by 110–220% (Zhao *et al*., 2015).

The CNT membranes gained significant attention as a valuable method for enhancing the hydrophilicity of membrane surfaces. This is due to the presence of oxygen-containing functional groups in CNTs, which effectively enhance membrane permeability (Zuo *et al*., 2016). Multiple research studies have extensively examined the antifouling properties of CNTs, highlighting their impressive antimicrobial capabilities, hydrophilicity, and ability to prevent biofouling. These studies have also emphasized the significant role of CNTs in enhancing permeability. In addition, it has been found that carbon nanotubes have a longer lifespan compared to conventional nanoparticles, as demonstrated by Sianipar et al. (2016) in their study conducted in 2016.

CONCLUSIONS

Membrane fouling continues to be a pressing issue in the operation of MBRs, with far-reaching consequences for system performance, operational expenses, and long-term viability. This review has elucidated the complex mechanisms behind fouling and highlighted their detrimental impacts on MBR efficiency. Recent advancements in fouling control, particularly through surface modification and the application of ultrasound, offer promising solutions to mitigate these challenges. However, several obstacles, such as the high cost of advanced materials and the need for more robust long-term solutions, still hinder the widespread adoption of these techniques. While numerous fouling control techniques exist, each has its limitations, and the complex nature of fouling mechanisms means that ongoing research is essential to developing more effective and sustainable solutions. Future research should focus on developing more sustainable and economically viable fouling control strategies, leveraging emerging technologies like AI and machine learning for predictive maintenance, and fostering multidisciplinary collaborations to address this multifaceted issue. Overall, while significant progress has been made, the ongoing effort to control membrane fouling is essential for the future of wastewater treatment and the advancement of sustainable water management practices.

Declaration of Competing Interest

No conflict of interest.

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EFFECT OF WILDFIRE ON BELOWGROUND FAUNAL COMMUNITIES IN VARIABLE LANDSCAPES: A COMPREHENSIVE REVIEW

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ABSTRACT

Wildfires are increasingly frequent and severe globally, with profound impacts on ecosystems. While the effects of fire on aboveground communities are well-documented, less is known about the responses of belowground fauna. This comprehensive review synthesizes current knowledge on how wildfires affect soil-dwelling organisms across diverse landscapes. We examine the direct and indirect impacts of fire on various faunal groups, including microarthropods, nematodes, and earthworms, and explore how landscape variability influences these effects. The review highlights the complex interplay between fire intensity, soil properties, and faunal community composition. We discuss the implications of these findings for ecosystem recovery and resilience, and identify critical knowledge gaps to guide future research. Understanding the responses of belowground communities to wildfire is crucial for developing effective post-fire management strategies and predicting long-term ecosystem changes in a warming world.

No. of Pages: 10 **References: 28**

Keywords: Wildfire, soil fauna, ecosystem resilience, landscape ecology, biodiversity.

1. INTRODUCTION

Wildfires are a natural and essential component of many ecosystems worldwide, shaping landscapes and influencing biodiversity patterns (Pausas & Keeley, 2019). However, climate change, land-use alterations, and fire suppression policies have led to an increase in the frequency, intensity, and extent of wildfires in recent decades (Flannigan et al., 2013). These changes have profound implications for ecosystem structure and function, affecting both above- and belowground communities.

While the impacts of fire on aboveground vegetation and fauna have been extensively studied, the effects on belowground communities remain less understood (Certini, 2005). Soil-dwelling organisms play crucial roles in ecosystem processes, including nutrient cycling, organic matter decomposition, and soil structure maintenance (Bardgett & van der Putten, 2014). Understanding how these communities respond to wildfire is essential for predicting ecosystem recovery and resilience in fire-prone landscapes.

This review aims to synthesize current knowledge on the effects of wildfire on belowground faunal communities across variable landscapes. We examine the direct and indirect impacts of fire on different faunal groups, explore how landscape characteristics influence these effects, and discuss the implications for ecosystem functioning and recovery. By identifying key knowledge gaps and research priorities, we seek to guide future investigations in this critical area of fire ecology.

2. Literature Review

Forest fires are dramatic events in the dynamics of natural forest ecosystems. Today, natural disturbances

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are considered to be integral parts of ecosystems and essential factors for their dynamics.

Andrey S. Zaistev, et al., 2016 observed that the reasons why forest fires are often neglected by soil zoologists and ecologists and to identify the major problems which deter soil zoologists from this area of research and from publishing obtained results. Also they show that forest fires are harder to study than many other types of disturbances. Fires are largely unpredictable and are often unique, which makes it difficult to apply statistically robust sampling plans and select proper controls. Spatial heterogeneity of fire intensity and soil fauna distribution complicate the resulting picture. Moreover, high variability of soil biota in time and space, and complicating effects of multiple fires make the results of such studies hard to interpret.

Zaitsev et al., 2014; Malmstrom et al., 2009 stated that Even less information is available about the consequences of soil community shifts for ecosystem functioning. Studies in boreal forests have shown that fire reduced the total abundance of soil meso- and macro-fauna on a short-term basis and also studies of the impact of forest fires on soil organisms remain rather scarce and also focus on soil meso-fauna (0.2-2 mm) and soil macro-fauna (2-20 mm) keeping in mind that these formal categories often overlap within the same taxa. The meso-fauna is normally more abundant than the macro-fauna, up to 10^6 and 10^3 individuals m^{-2}, respectively, whereas the typical biomasses are 0.1-1 and 2-8 gm^2 for meso- and macro-fauna, respectively.

Zaitsev, et al., 2016 analyse the review on soil fauna to to examine and structure the reasons for this, and suggest possible solutions, which would help to improve and develop post-fire soil ecological research. Several questions are important in this respect:

1. Do soil ecologists tend to avoid this field of research, despite its high importance in light of global change and safeguarding ecosystem functioning? And if so, then why?
2. Are there considerable amounts of unpublished data from research on soil animals related to forest fires that cannot be found in the scientific publications?
3. What are the most effective methodological approaches and solutions for studying post-fire succession, biodiversity and functional implications of soil community degradation and recovery after fires, given the low predictability of fires in-situ and associated problems with sufficient replicability of the studies?

Ana Barreiro, et al., 2021reported that, the fire impact on soil microorganisms and the subsequent soil recovery depends on different factors such as the fire severity, the soil resilience, and the environmental conditions. The data interpretation is very complex and involves the comparison of the burnt soil with the unburnt one, which requires the characterization of diverse microbial aspects in relation to its environment, in other words, studies with an ecological perspective. The laboratory experiments simplify data interpretation, but they are not fully comparable with field studies because of the higher complexity of the latter (additional influence of plant and climatic conditions). Studies have been focused on the wildfire impact on soil after the sampling at one fixed time, which makes the data interpretation very difficult. In contrast, a small number of heating laboratory studies and/or experimental fire field investigations under controlled conditions, with more concise conclusions, have been performed.

Daniel G. Neary, et al., 1999 stated that the extensive, long-term, and or conclusive studies documenting fire's effect on below-ground processes that result in sustainability declines (or increases) are scarce. This situation is of great concern to ecologists, land managers and, more recently, many state and federal agencies.

DeBano et al., 1998 stated that Fires typically have five phases: pre-ignition, flaming combustion, smoldering combustion, glowing combustion, and extinction and also stated that, the largest and significant effect of fires in forest, shrub, and grass ecosystems is the transfer of heat from burning biomass to the soil system. And also found that particularly susceptible are those belowground dwelling invertebrates which are not highly mobile and primarily reside in litter or the surface soil horizons as they are most vulnerable to the direct effects of intense surface fires or ground fires.

Edwards and Walton, 1992 observed that, it is difficult to assess the biological diversity of soil organisms. Traditional soil biological diversity surveys that estimated biomass or population size tended to assign soil organisms to general categories such as `bacteria', `fungi', `micro-arthropods', 'macro arthropods', etc. There is a lack of information on the numbers and subsequent identification of soil organisms. For example, it has been estimated that fewer than 1% of all bacteria living in soil or water have been identified, compared to 3% of nematodes and 13% of insects.

The studies by Klopatek et al., 1988, 1990, 1994 concur with Vilarino and Arines (1991), who suggested that high fuel loads in forested ecosystems generate more intense and prolonged burning and incur heavier losses of VAM fungi compared to areas like grasslands with lower fuel loads and less-intense burning conditions.

Campbell and Tanton, 1981reported the effects of fire on invertebrates and subsequent effects on belowground sustainability are difficult to assess and generalize because of fire severity variability, high pre-fire invertebrate species variability, selective modification of the balance of species by fires, and post-fire invertebrate community response to changes in litter and OM changes.

Ream, 1981 stated that the direct effects of fire on most soil vertebrates are minimal as they are mobile enough to escape fires by burrowing deep enough into the soil to escape lethal temperatures or by fleeing on the surface. Indirect effects, such as loss of habitat, exposure of soil burrow openings, and increased predation, are more effective in reducing vertebrate diversity and abundance for several years following fires.

Yamina Pressler, et al 2018 reported that the effect of fire on soil mesofauna (nematodes and arthropods) is weaker than for microorganisms (bacteria, fungi, microbes), but far fewer studies were available for mesofauna than for microorganisms. There are clear differences in the morphologies, physiologies and ecologies between microorganisms and soil mesofauna that could explain these results. Soil mesofauna, particularly arthropods, are larger, possess greater vagility and tend to occupy higher trophic positions than microorganisms. Soil arthropods appear to be either resistant to or highly resilient to fire as their abundance did not significantly increase or decrease with fire. Soil arthropod richness, evenness, and diversity did decrease significantly with fire, but the number of studies available is limited. Also stated that the significant negative effect of fire was consistent across microbial taxa and parameters considered in this meta-analysis suggesting that soil microbial communities are not resistant to fire. All meta-analysis computations were done in R (< www.r-project.org >) using the metafor package (Viechtbauer 2010).

3. Methodology

We conducted a comprehensive literature search using Web of Science, Scopus, and Google Scholar databases. The search terms included combinations of keywords such as "wildfire," "soil fauna," "belowground communities," "landscape variability," and specific faunal group names (e.g., "microarthropods," "nematodes," "earthworms"). We focused on peer-reviewed articles published between 1990 and 2023, with emphasis on more recent studies (last 10 years) to capture the latest findings in the field.

The initial search yielded over 500 articles, which were screened based on their relevance to the review's objectives. After excluding studies that did not directly address wildfire effects on soil fauna or lacked landscape-level considerations, we retained 213 articles for in-depth analysis. These papers were categorized based on the faunal groups studied, ecosystem types, fire characteristics, and methodological approaches.

We synthesized the findings from these studies to identify common patterns, contradictions, and knowledge gaps in our understanding of wildfire effects on belowground communities. Special attention was given to studies that incorporated landscape variability in their analyses, as this aspect is crucial for understanding the context-dependency of fire impacts on soil fauna.

4. Direct Effects of Wildfire on Soil Fauna

4.1 Thermal Impacts

The most immediate effect of wildfire on soil fauna is the direct thermal impact. Soil temperature increases during a fire can be lethal to many organisms, particularly those residing in the upper soil layers (Certini, 2005). The severity of these impacts depends on various factors, including fire intensity, soil moisture content, and the depth at which organisms are located (Neary et al., 1999). Table 1 summarizes the lethal temperature thresholds for various soil faunal groups based on experimental studies.

Table 1: Lethal temperature thresholds for major soil faunal groups.

Faunal Group	Lethal Temperature Range (°C)	Reference
Microarthropods	40-70	Malmström et al., 2009
Nematodes	38-62	Venette & Ferris, 1997
Earthworms	35-45	Curry, 2004
Enchytraeids	32-40	Maraldo et al., 2009
Protozoa	45-60	Bamforth, 2004

The variability in lethal temperature thresholds reflects differences in physiological adaptations and life history strategies among soil faunal groups. Microarthropods, for instance, show a wider range of thermal tolerance compared to soft-bodied organisms like earthworms (Malmström et al., 2009; Curry, 2004).

4.2 Mortality and Population Declines

Numerous studies have reported significant reductions in soil faunal abundance and diversity immediately following wildfire events. For example, Camann et al. (2008) found that microarthropod densities decreased by up to 90% in burned areas compared to unburned controls in a ponderosa pine forest. Similarly, Vázquez et al. (2007) observed a 70-80% reduction in nematode abundance following a severe wildfire in a Mediterranean forest ecosystem.

However, the magnitude of these declines varies considerably depending on fire intensity, soil depth, and pre-fire community composition. Malmström et al. (2009) demonstrated that while surface-dwelling Collembola were severely impacted by fire, deeper-dwelling Oribatid mites showed greater resilience due to their position in the soil profile.

To visualize the general trend of soil faunal abundance following wildfire, we present a conceptual diagram generated using Python (Figure 1).

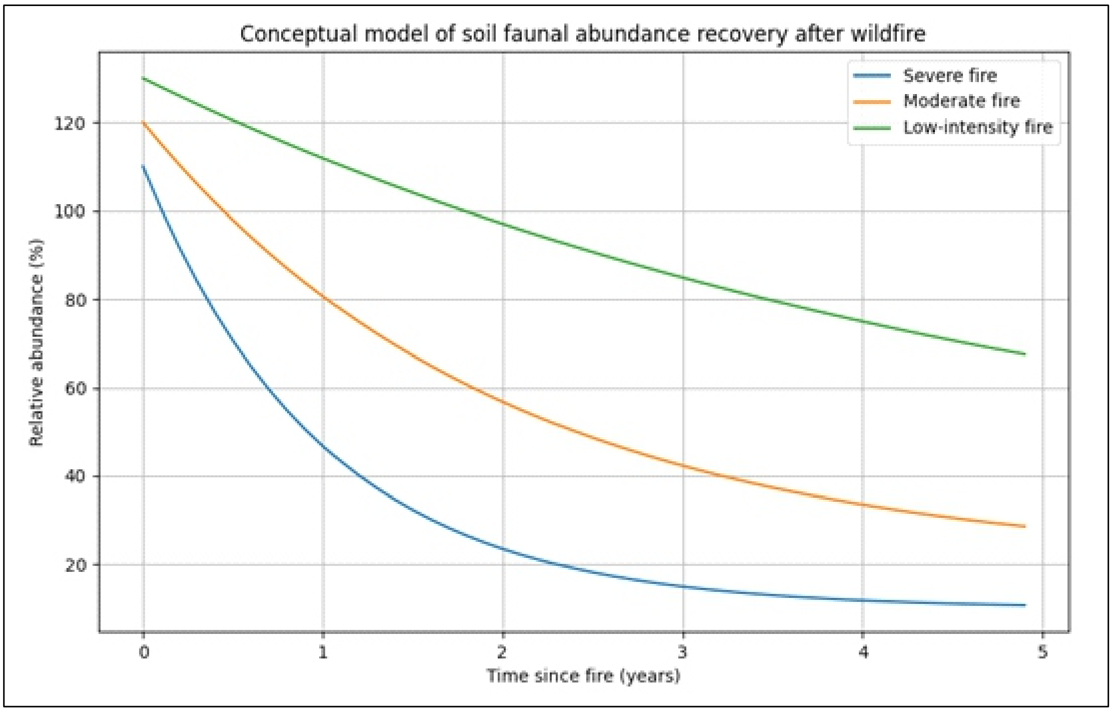

Figure 1: Conceptual model of soil faunal abundance recovery after wildfire of varying intensities.

This conceptual model illustrates the general patterns of soil faunal abundance recovery following wildfires of different intensities. The rate and extent of recovery depend on various factors, including fire severity, ecosystem type, and the specific faunal group in question.

4.3 Changes in Community Composition

Beyond overall abundance declines, wildfires can significantly alter the composition of soil faunal communities. These changes often reflect differences in species' vulnerability to fire and their recolonization abilities. For instance, Kim and Jung (2008) found that while overall microarthropod abundance decreased following fire in a Korean pine forest, the relative abundance of certain Collembola species increased, likely due to their rapid reproduction and dispersal capabilities.

Similarly, Pressler et al. (2019) observed shifts in nematode community composition after wildfire in Australian eucalypt forests, with an increase in the proportion of bacterial-feeding nematodes relative to fungal-feeding species. This shift was attributed to changes in soil microbial communities and resource availability following the fire.

To illustrate these community composition changes, we present a stacked bar plot comparing pre- and post-fire community structures for a hypothetical soil faunal community (Figure 2).

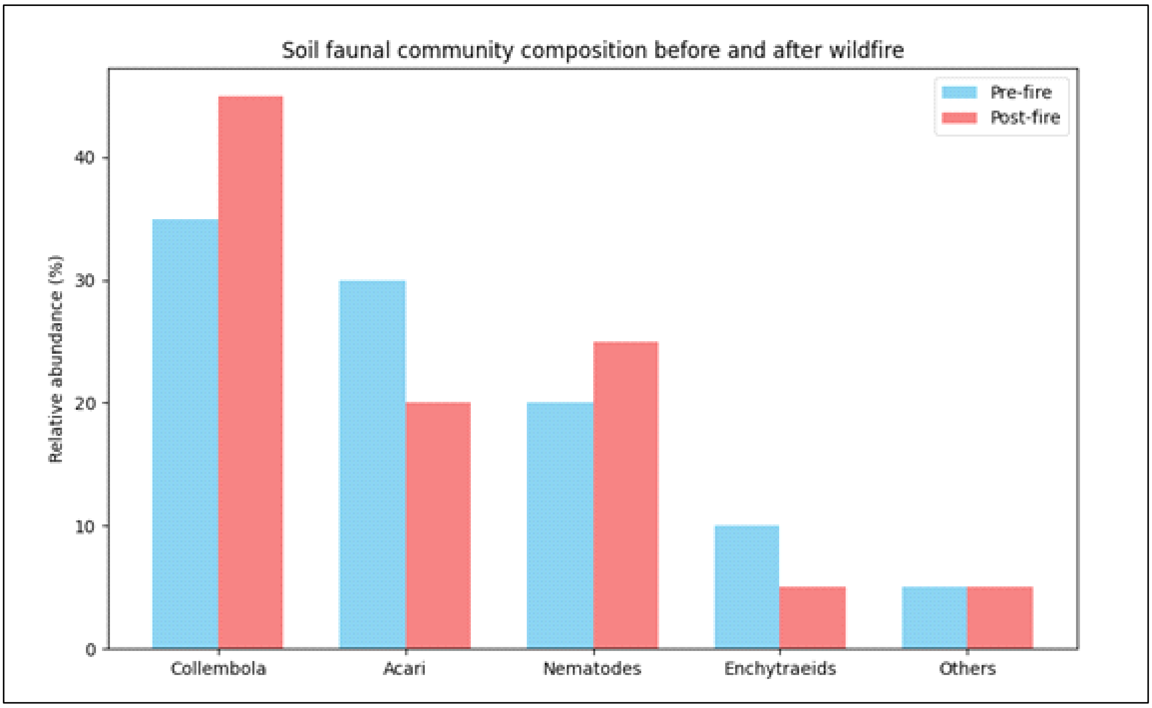

Figure 2: Hypothetical example of soil faunal community composition changes following wildfire.

This figure demonstrates how wildfire can alter the relative abundances of different faunal groups, potentially leading to shifts in ecosystem functioning and recovery trajectories.

5. Indirect Effects of Wildfire on Soil Fauna

5.1 Alterations in Soil Physical and Chemical Properties

Wildfires can significantly modify soil properties, indirectly affecting belowground faunal communities. These changes include alterations in soil structure, pH, organic matter content, and nutrient availability (Certini, 2005). For example, high-intensity fires can lead to soil hydrophobicity, reducing water infiltration and affecting soil moisture regimes critical for many soil organisms (DeBano, 2000).

Úbeda et al. (2009) reported increases in soil pH and available nutrients (particularly phosphorus and potassium) following wildfire in Mediterranean forests. These chemical changes can influence microbial communities and, consequently, the soil fauna that depend on them for food resources.

5.2 Changes in Vegetation and Litter Input

Fire-induced changes in aboveground vegetation have cascading effects on belowground communities. The loss of plant cover and alterations in species composition affect the quantity and quality of litter inputs to the soil system (Hart et al., 2005). This, in turn, influences the resource base for detritivorous soil fauna and can lead to shifts in community structure.

Malmström et al. (2009) observed that changes in litter quality following fire in boreal forests had long-lasting effects on soil microarthropod communities, with implications for decomposition processes and nutrient cycling.

5.3 Microclimate Modifications

Wildfire can significantly alter soil microclimate conditions, affecting temperature and moisture regimes critical for soil fauna. The removal of vegetation cover and changes in soil albedo can lead to increased soil temperatures and reduced moisture retention (Neary et al., 1999). These microclimatic changes can have profound impacts on the survival, reproduction, and activity of soil organisms.

To illustrate the potential changes in soil temperature following wildfire, we present a hypothetical temperature profile comparison (Figure 3).

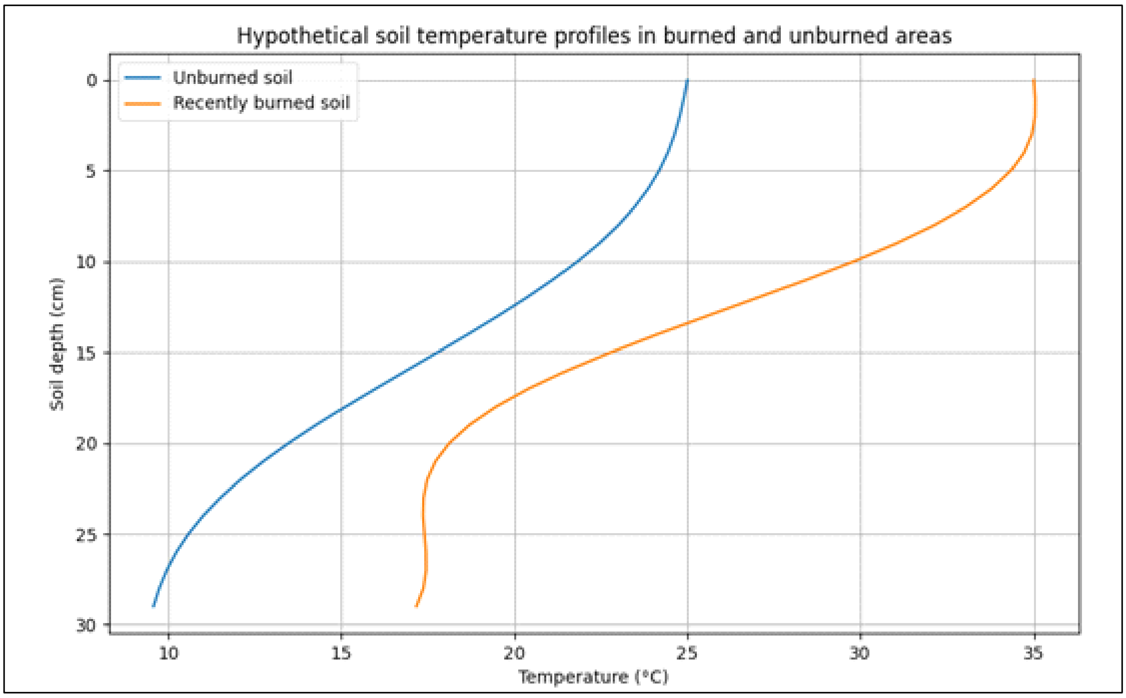

Figure 3: Hypothetical soil temperature profiles in burned and unburned areas.

This figure illustrates how wildfire can alter soil temperature regimes, potentially creating more extreme and variable conditions for soil fauna, especially in upper soil layers.

6. Landscape-Level Factors Influencing Wildfire Effects on Soil Fauna

6.1 Topography and Soil Type

Landscape characteristics play a crucial role in modulating the effects of wildfire on soil fauna. Topography influences fire behavior and severity, which in turn affects the magnitude of impacts on belowground communities. For instance, Alves et al. (2021) found that soil faunal responses to fire in Brazilian savannas varied significantly with slope position, with upslope areas experiencing more severe effects due to higher fire intensities.

Soil type is another critical factor determining the resilience of belowground communities to fire. Sandy soils, for example, tend to experience more rapid and extreme temperature increases during fire compared to clay-rich soils, potentially leading to greater faunal mortality (Neary et al., 1999). Conversely, clay soils may provide better insulation and moisture retention, offering some protection to deeper-dwelling organisms.

6.2 Vegetation Type and Fire Regime
The type of vegetation and associated fire regimes in a landscape significantly influence the responses of soil fauna to wildfire. Ecosystems with frequent, low-intensity fires (e.g., some grasslands and savannas) may harbor soil communities that are more resilient to fire disturbance compared to those in ecosystems with infrequent, high-intensity fires (e.g., some temperate forests) (Pausas & Keeley, 2019).

For example, Coyle et al. (2017) found that soil nematode communities in longleaf pine savannas, which are adapted to frequent fire, showed relatively rapid recovery following prescribed burns. In contrast, Pressler et al. (2019) observed more prolonged impacts on soil fauna in Australian eucalypt forests subjected to infrequent, high-intensity wildfires.

6.3 Landscape Heterogeneity and Refugia
Landscape heterogeneity can create refugia that facilitate the survival and post-fire recolonization of soil fauna. These refugia may include unburned patches, areas with varying fire severities, or microsites that provide protection from extreme temperatures (e.g., large woody debris, rock outcrops) (Pryke & Samways, 2012).

Nugnes et al. (2018) demonstrated the importance of landscape heterogeneity in Mediterranean pine forests, where soil fauna in areas with a mosaic of burn severities showed faster recovery compared to uniformly burned landscapes. The presence of nearby unburned areas served as a source for recolonization, highlighting the importance of landscape-scale processes in post-fire community dynamics.

7. Implications for Ecosystem Functioning and Recovery

7.1 Nutrient Cycling and Decomposition
The effects of wildfire on soil faunal communities have significant implications for ecosystem functioning, particularly nutrient cycling and decomposition processes. Soil fauna play crucial roles in litter fragmentation, microbial grazing, and the distribution of organic matter within the soil profile (Bardgett & van der Putten, 2014).

Fire-induced changes in soil faunal abundance and community composition can alter these processes. For example, Vázquez et al. (2007) found that reductions in nematode populations following wildfire in Mediterranean forests led to decreased nitrogen mineralization rates, potentially affecting plant growth and ecosystem recovery.

7.2 Soil Structure and Water Retention
Many soil faunal groups, particularly earthworms and some microarthropods, contribute to soil structure formation through burrowing activities and the production of fecal pellets (Lavelle et al., 2006). Fire-induced reductions in these organisms can lead to changes in soil porosity, aggregation, and water retention capacity.

Certini (2005) highlighted that the loss of soil fauna following severe wildfires can exacerbate soil erosion and reduce water infiltration, potentially leading to increased runoff and nutrient losses. These changes can have long-lasting effects on ecosystem recovery and resilience to future disturbances.

7.3 Plant-Soil Interactions
Soil fauna mediate many plant-soil interactions, including mycorrhizal associations, seed dispersal, and herbivory (Bardgett & van der Putten, 2014). Alterations in belowground faunal communities following wildfire can thus indirectly affect plant community recovery and succession.

For instance, Rodríguez et al. (2017) found that changes in soil microarthropod communities following fire in Mediterranean shrublands influenced seedling establishment patterns, potentially affecting long-term vegetation dynamics.
To illustrate the complex interactions between wildfire, soil fauna, and ecosystem processes, we present a conceptual diagram (Figure 4).

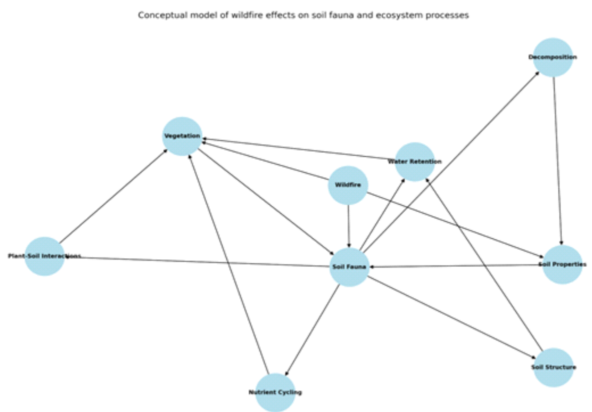

Figure 4: Conceptual model illustrating the complex interactions between wildfire, soil fauna, and ecosystem processes.

This diagram highlights the central role of soil fauna in mediating various ecosystem processes and the potential cascading effects of wildfire-induced changes in belowground communities.

8. Knowledge Gaps and Future Research Directions

Despite the growing body of research on wildfire effects on soil fauna, several knowledge gaps remain. Addressing these gaps is crucial for developing a more comprehensive understanding of fire ecology and improving post-fire management strategies.

8.1 Long-term Studies

Many studies on wildfire impacts on soil fauna focus on short-term responses, typically within the first few years after fire. However, long-term studies are essential for understanding the trajectory of community recovery and potential shifts in ecosystem functioning over time. Future research should prioritize long-term monitoring of soil faunal communities across different ecosystems and fire regimes.

8.2 Functional Diversity and Ecosystem Services

While many studies report changes in taxonomic diversity following fire, less attention has been given to functional diversity and its implications for ecosystem services. Future research should focus on linking changes in soil faunal community composition to specific ecosystem functions and services, such as carbon sequestration, nutrient cycling, and soil formation.

8.3 Interactions with Climate Change and Other Disturbances

As climate change alters fire regimes and creates novel environmental conditions, understanding the interactive effects of fire, climate, and other disturbances (e.g., drought, invasive species) on soil fauna becomes increasingly important. Future studies should adopt multi-factorial approaches to disentangle these complex interactions and their consequences for ecosystem resilience.

8.4 Landscape-scale Processes and Connectivity

More research is needed on how landscape-scale processes, such as dispersal and meta-community dynamics, influence the recovery of soil faunal communities following wildfire. Understanding the role of landscape connectivity and the importance of refugia in facilitating recolonization can inform conservation strategies and land management practices.

8.5 Standardization of Sampling and Analytical Methods

The diversity of sampling and analytical methods used in soil fauna research can make comparisons across studies challenging. Developing standardized protocols for sampling, identifying, and analyzing soil faunal communities in fire-affected ecosystems would facilitate more robust meta-analyses and synthesis of findings across different regions and ecosystem types.

9. CONCLUSION

This comprehensive review has synthesized current knowledge on the effects of wildfire on belowground faunal communities across variable landscapes. We have examined the direct and indirect impacts of fire on different soil faunal groups, explored how landscape characteristics influence these effects, and discussed the implications for ecosystem functioning and recovery.

Key findings include:

1. Wildfires can cause significant reductions in soil faunal abundance and alter community composition, with the magnitude of these effects varying depending on fire intensity, soil depth, and pre-fire community structure.
2. Indirect effects of fire, such as changes in soil properties, vegetation, and microclimate, can have long-lasting impacts on belowground communities and their functional roles in ecosystems.
3. Landscape-level factors, including topography, soil type, vegetation, and spatial heterogeneity, play crucial roles in modulating the responses of soil fauna to wildfire and influencing post-fire recovery dynamics.
4. Changes in soil faunal communities following wildfire can have cascading effects on ecosystem processes, including nutrient cycling, decomposition, soil structure formation, and plant-soil interactions.
5. Several knowledge gaps remain, particularly regarding long-term community dynamics, functional diversity, interactions with climate change, and landscape-scale processes.

Understanding the responses of belowground communities to wildfire is crucial for predicting ecosystem resilience and developing effective post-fire management strategies. As wildfires become more frequent and severe in many parts of the world, integrating soil faunal responses into fire ecology research and ecosystem management practices will be essential for maintaining the health and functioning of fire-prone ecosystems.

Future research addressing the identified knowledge gaps will contribute to a more holistic understanding of fire ecology and improve our ability to manage and conserve ecosystems in the face of changing fire regimes and global environmental conditions.

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The authors declare no conflict of interest.

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GROUNDWATER QUALITY ASSESSMENT FOR DRINKING PURPOSE IN LADWA BLOCK OF KURUSHETRA DISTRICT, HARYANA

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ABSTRACT

Water is used for drinking, irrigation and industrial purposes. In the present context of developmental activities requirement of water has increased many folds which resulted in declining of per capita water availability. Further in agriculture dominant areas groundwater is excessively used for irrigation which also resulted in declining of water table and quality deterioration. The study area Ladwa block is located in Kurukshetra district of Haryana between the geo-coordinates latitudes 29.95^{0}N to 30.07^{0}N and longitudes 76.97^{0}E to 77.12^{0}E and covers an area of 130.56 sq. km. Geologically alluvium and geomorphologically alluvial plain is present. The main objective was to study groundwater quality for drinking purpose in the study area. In the study area nine groundwater samples were collected in 250 ml double capped plastic bottles. Geo-coordinates of sample locations were noted with the help of mobile GPS. Chemical analysis of nine groundwater samples were done using Tamilnadu Water Supply and Drainage (TWAD) Board, Chennai prepared Field Water Testing kit for twelve chemical parameters viz. pH, alkalinity, hardness, chloride, total dissolved solids, fluoride, iron, nitrite, nitrate, ammonia, phosphate and residual chlorine. Results of groundwater samples analysis were compared with BIS (IS 10500:2012) drinking water standards to know the suitability of groundwater for drinking purpose. The study shows that in the study area pH ranges 6.5 to 8, alkalinity 220 mg/l to 380 mg/l, hardness 50 mg/l to 360 mg/l, chloride 30 mg/l to 300 mg/l, total dissolved solids 600 mg/l to 960 mg/l, fluoride nil to 2 mg/l, iron nil to 0.3 mg/l, ammonia nil to 1 mg/l, nitrite 0.2 mg/l to 0.5 mg/l, nitrate 45 mg/l to 100 mg/l, phosphate nil in all the nine groundwater samples and residual chlorine nil to 0.2 mg/l. The study is highly useful for planning and monitoring of groundwater quality for drinking purpose in the study area.

No. of Pages: 6 **References: 10**

Keywords: Groundwater, quality, drinking, Ladwa, Kurukshetra, Haryana.

INTRODUCTION

Water is important for survival of living beings. Increasing demand of water for drinking, irrigation and industrial has put pressure on surface water and groundwater. Good quality water is necessary to avoid health problems. Many workers have done good work on groundwater quality assessment for drinking purpose (Suresh and Kottureshwara (2009), Ackah et al.(2011), Mohapatra et al. (2011), Rahman et al. (2012), Sujatha et al. (2012), Singh et al. (2015), Bodrud-Doza et al. (2016), Sarfraz et al. (2016), Shinde et al. (2016), Sridhar et al. (2017)).

STUDY AREA

Ladwa block is located in Kurukshetra district, Haryana (Fig.1). The geo-coordinates of the study area are latitudes 29.950 N to 30.070 N and longitudes 76.970E to 77.120 E and covers an area of 130.56 sq. km. Geologically alluvium and geomorphologically alluvial plain is present.

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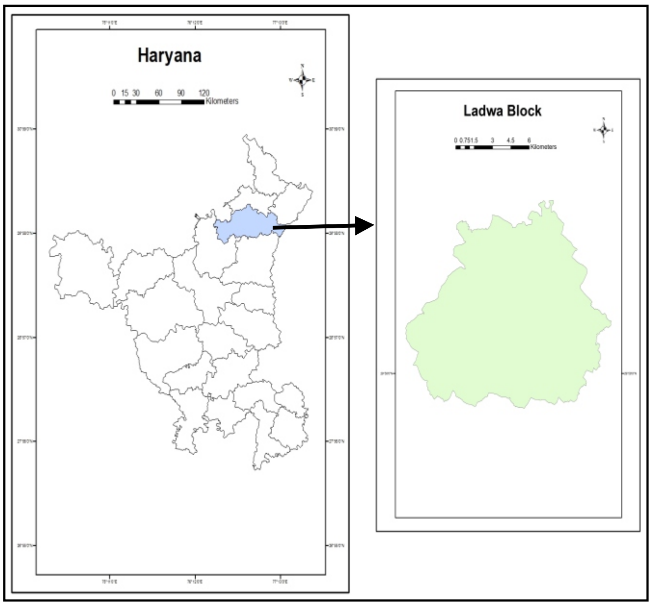

Fig. 1: Location map of the study area.

OBJECTIVE

The main objective of the study was to assess groundwater quality for drinking purpose in the study area.

MATERIALS AND METHODOLOGY

In the study area nine groundwater samples were collected in 250 ml double capped plastic bottles from tube wells (TW). Geo-coordinates of sample locations were noted with the help of mobile GPS. Chemical analysis of nine groundwater samples were done using Tamilnadu Water Supply and Drainage (TWAD) Board, Chennai prepared Field Water Testing kit for twelve chemical parameters viz. pH, alkalinity, hardness, chloride, total dissolved solids (TDS), fluoride, iron, nitrite, nitrate, ammonia, phosphate and residual chlorine. Result of chemical analysis of groundwater samples were entered in excel software and prepared bar graph for each chemical parameter. Result of groundwater samples analyses were compared with BIS (IS 10500:2012) drinking water standards (Table 2) to know the suitability of groundwater for drinking purpose.

Table 1: Result of chemical analysis of groundwater samples.

S. No.	Sample Location	Latitude	Longitude	Source	pH (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Chloride (mg/l)	TDS (mg/l)	Fluoride (mg/l)	Iron (mg/l)	Ammonia (mg/l)	Nitrite (mg/l)	Nitrate (mg/l)	Phosphate Chlorine	Residual (mg/l)
1	Salimpur	29.96	76.99	TW	7	220	200	80	600	0	0	0	0.5	75	0	0
2	Barondi	29.96	77.04	TW	7.5	380	360	60	960	1.5	0	1	0.5	100	0	0
3	Bapda	29.97	77.05	TW	7.5	350	350	60	912	2	0.3	1	0.5	100	0	0
4	Budha	29.98	77.07	TW	7.5	300	260	30	708	1.5	0	0.5	0.5	100	0	0
5	Ladwa	29.99	77.06	TW	8	290	220	50	672	1	0	0	0.5	100	0	0
6	Sambalkha	30.01	77.07	TW	7.5	290	240	50	696	1.5	0	0.5	0.5	75	0	0
7	Kharkali	30.04	77.09	TW	7.5	250	220	300	924	0	0	0.5	0.2	75	0	0
8	Dugari	30.06	77.06	TW	7	350	320	50	864	0.5	0	0.5	0.5	45	0	0.2
9	Lohara	30.02	76.99	TW	6.5	280	50	300	876	1	0	1	0.2	75	0	0

Table 2: BIS drinking water standards (IS: 10500:2012).

S. No.	Parameters	Potable		Non-Potable
		Desirable	Permissible	
1.	pH	6.5 - 8.5	-	<6.5 and >8.5
2.	Alkalinity (mg/l)	<200	200-600	>600
3.	Hardness (mg/l)	<200	200-600	>600
4.	Chloride (mg/l)	<250	250-1000	>1000
5.	Total Dissolved Solids (mg/l)	<500	500-2000	>2000
6.	Fluoride (mg/l)	<1.0	1.0-1.5	>1.5
7.	Iron (mg/l)	<0.3	-	>0.3
8.	Ammonia (mg/l)	<0.5	-	>0.5
9.	Nitrite (mg/l)	<1.0	-	>1.0
10.	Nitrate (mg/l)	<45	-	>45
11.	Phosphate (mg/l)	<1.0	-	>1.0
12	Residual Chlorine (mg/l)	<0.2	0.2-1.0	>1.0

RESULTS AND DISCUSSION

i. pH

In the study area pH ranges 6.5 to 8 (Table 1, Fig.2). As per BIS (IS 10500: 2012) drinking water standards pH is desirable between 6.5 to 8.5 and non-potable if less than 6.5 and more than 8.5 (Table 2). pH is desirable in all the nine groundwater samples (Salimpur, Barondli, Bapda, Budha, Ladwa, Sambalkha, Kharkali, Dugari, Lohara).

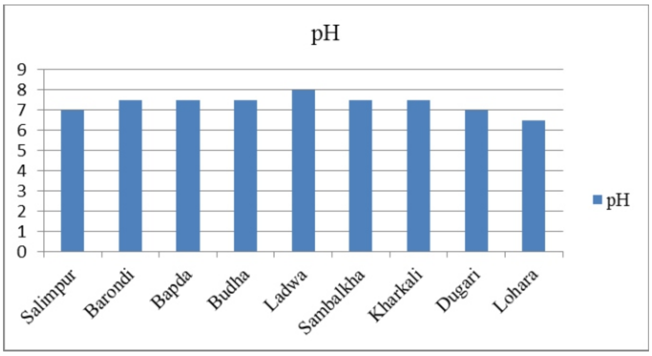

Fig.2: pH in groundwater samples.

ii. Alkalinity

In Ladwa block alkalinity ranges 220 mg/l to 380 mg/l (Table 1, Fig.3). As per BIS (IS 10500: 2012) drinking water standards alkalinity is desirable if less than 200 mg/l, permissible between 200 mg/l- 600 mg/l and non-potable if more than 600 mg/l (Table 2). Alkalinity is permissible in all the nine groundwater samples (Salimpur, Barondli, Bapda, Budha, Ladwa, Sambalkha, Kharkali, Dugari, Lohara).

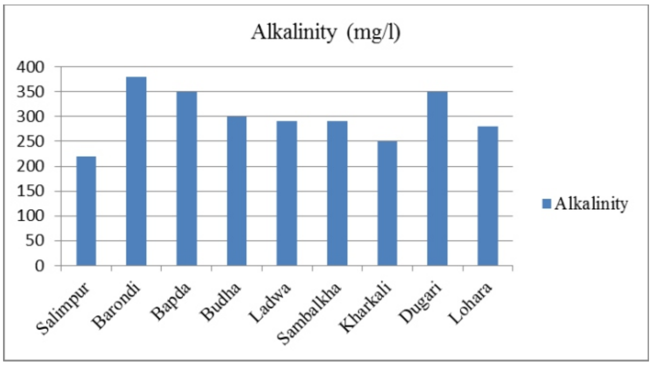

Fig. 3: Alkalinity in groundwater samples.

iii. Hardness

Hardness ranges 50 mg/l to 360 mg/l in the study area (Table 1, Fig.4). As per BIS (IS 10500: 2012) drinking water standards hardness is desirable if less than 200 mg/l, permissible between 200 mg/l - 600 mg/l and non-potable if more than 600 mg/l (Table 2). Hardness is desirable in two groundwater samples (Salimpur, Lohara) and permissible in seven groundwater samples (Barondi, Bapda, Budha, Ladwa, Sambalkha, Kharkali, Dugari).

iv. Chloride

Chloride ranges 30 mg/l to 300 mg/l in the study area (Table 1, Fig.5). As per BIS (IS 10500: 2012) drinking water standards chloride is desirable if less than 250 mg/l, permissible between 250 mg/l - 1000 mg/l and non-potable if more than 1000 mg/l (Table 2). Chloride is desirable in seven groundwater samples (Salimpur, Barondi, Bapda, Budha, Ladwa, Sambalkha, Dugari) and permissible in two groundwater samples (Kharkali, Lohara).

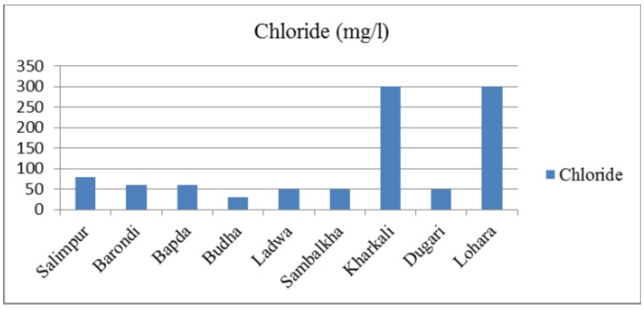

Fig.5: Chloride in groundwater samples .

v. Total Dissolved Solids

Total dissolved solids (TDS) range 600 mg/l to 960 mg/l in the study area (Table 1, Fig.6). As per BIS (IS 10500: 2012) drinking water standards TDS is desirable if less than 500 mg/l, permissible between 500 mg/l-2000 mg/l and non-potable if more than 2000 mg/l (Table 2). TDS is permissible in all the nine groundwater samples (Salimpur, Barondli, Bapda, Budha, Ladwa, Sambalkha, Kharkali, Dugari, Lohara).

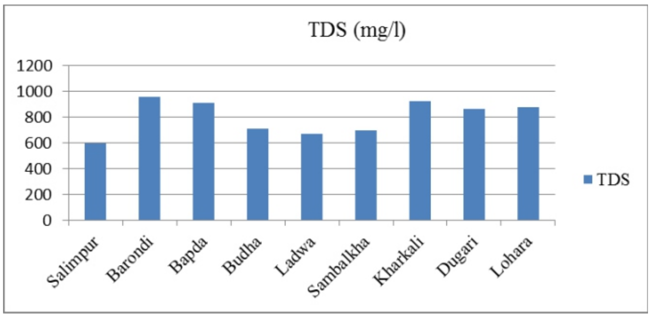

Fig. 6: TDS in groundwater samples.

vi. Fluoride

Fluoride ranges nil to 2 mg/l in the study area (Table 1, Fig.7). As per BIS (IS 10500: 2012) drinking water standards fluoride is desirable if less than 1.0 mg/l, permissible between 1.0 mg/l -1.5 mg/l and non-potable if more than 1.5 mg/l (Table 2). Fluoride is desirable in three groundwater samples (Salimpur, Kharkali, Dugari) and permissible in five groundwater samples (Barondki, Budha, Ladwa, Sambalkha, Lohara) and non-potable in one groundwater sample (Bapda (2 mg/l)).

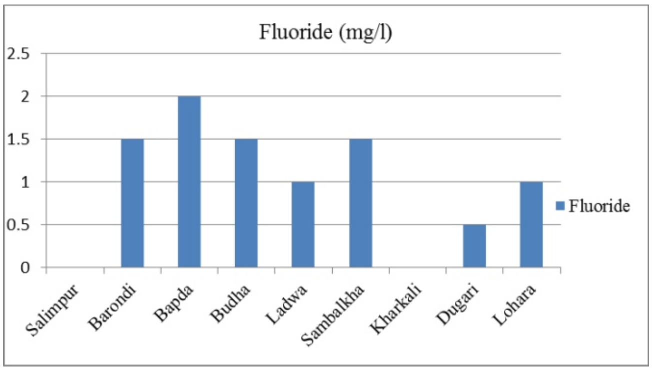

Fig. 7: Fluoride in groundwater samples.

vii. Iron

In the study area iron ranges nil to 0.3 mg/l (Table 1, Fig.8). As per BIS (IS 10500: 2012) drinking water standards iron is desirable if less than 0.3mg/l and non-potable if more than 0.3 mg/l (Table 2). Iron is desirable in all the nine groundwater samples (Salimpur, Barondli, Bapda, Budha, Ladwa, Sambalkha, Kharkali, Dugari, Lohara).

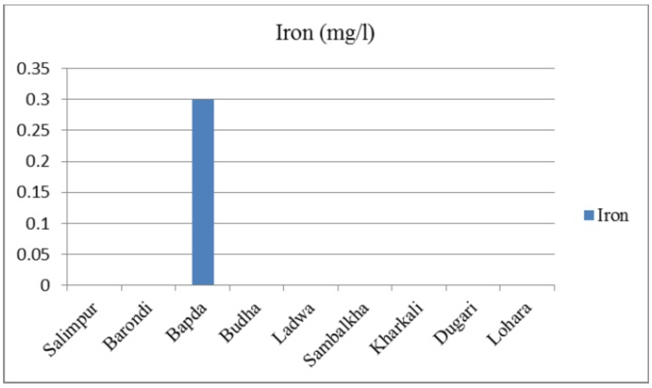

Fig. 8: Iron in groundwater samples.

viii. Ammonia

Ammonia ranges 0 mg/l to 1 mg/l in the study area (Table 1, Fig.9). As per BIS (IS 10500: 2012) drinking water standards ammonia is desirable if less than 0.5 mg/l and non-potable if more than 0.5 mg/l (Table 2). Ammonia is desirable in six groundwater samples (Salimpur, Budha, Ladwa, Sambalkha, Kharkali, Dugari) and non-potable in three groundwater samples (Barondi (1 mg/l), Bapda (1 mg/l), Lohara (1 mg/l)).

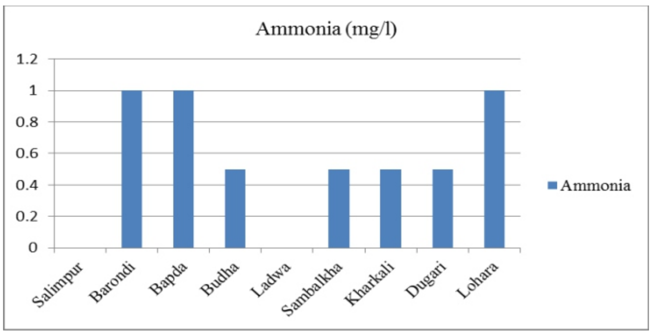

Fig. 9: Ammonia in groundwater samples.

ix. Nitrite

In the study area nitrite ranges 0.2 mg/l to 0.5 mg/l (Table 1, Fig.10). As per BIS (IS 10500: 2012) drinking water standards nitrite is desirable if less than 1.0 mg/l and non-potable if more than 1.0 mg/l (Table 2). Nitrite is desirable in all the nine groundwater samples (Salimpur, Barondli, Bapda, Budha, Ladwa, Sambalkha, Kharkali, Dugari, Lohara).

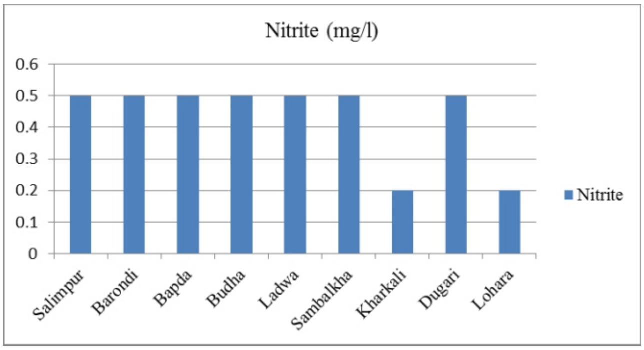

Fig.10: Nitrite in groundwater samples.

x. Nitrate

Nitrate ranges 45mg/l to 100 mg/l in the study area (Table 1, Fig.11). As per BIS (IS 10500: 2012) drinking water standards nitrate is desirable if less than 45 mg/l and non-potable if more than 45mg/l (Table 2). Nitrate is desirable in one groundwater sample (Dugari) and non-potable in eight groundwater samples (Salimpur (75 mg/l), Barondi (100 mg/l), Bapda (100 mg/l), Budha (100 mg/l), Ladwa (100 mg/l), Sambalkha (75 mg/l), Kharkali (75 mg/l), Lohara (75 mg/l)).

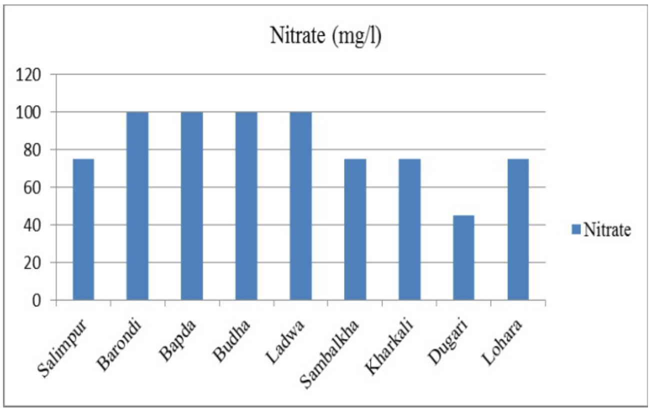

Fig.11: Nitrate in groundwater samples .

xi. Phosphate

In the study area phosphate is nil in all the nine groundwater samples (Table 1, Fig.12). As per BIS (IS 10500: 2012) drinking standards Phosphate is desirable if less than 1.0 mg/l and non-potable if more than 1.0 mg/l (Table 2). Phosphate is desirable in all the nine groundwater samples (Salimpur, Barondli, Bapda, Budha, Ladwa, Sambalkha, Kharkali, Dugari, Lohara).

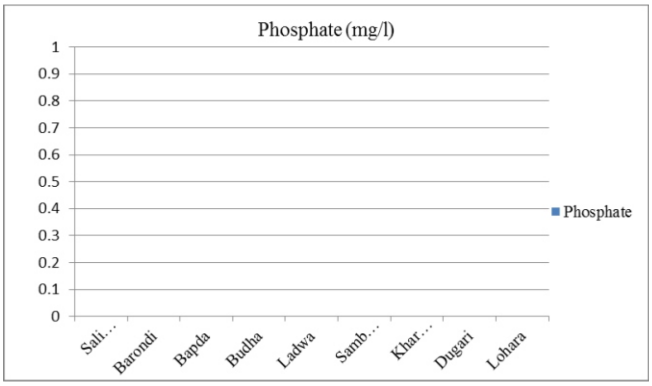

Fig.12: Phosphate in groundwater samples.

xii. Residual Chlorine

Residual Chlorine ranges nil to 0.2 mg/l in the study area (Table 1, Fig.13). As per BIS (IS 10500: 2012) drinking water standards residual chlorine is desirable if less than 0.2 mg/l, permissible between 0.2 mg/l-1 mg/l and non-potable if more than 1.0 mg/l (Table 2). Residual chlorine is desirable in eight groundwater samples (Salimpur, Barondli, Bapda, Budha, Ladwa, Sambalkha, Kharkali, Lohara) and permissible in one groundwater sample (Dugari).

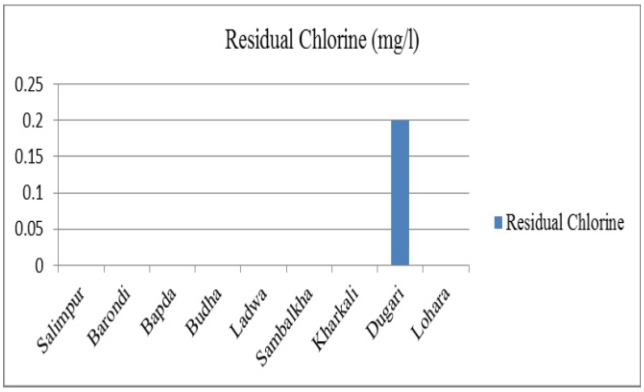

Fig.13: Residual Chlorine in groundwater samples.

CONCLUSIONS

In the study area pH, nitrite, phosphate are desirable in all the nine groundwater samples. Alkalinity is permissible in all the nine groundwater samples. Hardness is desirable in two groundwater samples and permissible in seven groundwater samples. Chloride is desirable in seven groundwater samples and permissible in two groundwater samples. Total dissolved solids (TDS) is permissible in all the nine groundwater samples. Fluoride is desirable in three groundwater samples and permissible in five groundwater samples and non-potable in one groundwater sample. Iron is desirable in all the nine groundwater samples. Ammonia is desirable in six groundwater samples and non-potable in three groundwater samples. Nitrate is desirable in one groundwater sample and non-potable in eight groundwater samples. Residual Chlorine is desirable in eight and permissible in one groundwater samples. The study is highly useful for planning and monitoring of groundwater quality for drinking purpose in the study area.

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ASSESSMENT OF GLOBAL ENVIRONMENTAL HEALTH THROUGH THE LENS OF CLIMATE CHANGE

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ABSTRACT

Climate Change refers to long-term alterations in temperature, precipitation, wind patterns, and other aspects of the Earth's climate system. These changes are driven largely by human activities, particularly the burning of fossil fuels, deforestation, and certain industrial processes, which release greenhouse gases. Climate Change brings impacts such as rising sea levels, more intense and frequent extreme weather events, shifting ecosystems, and threats to biodiversity. Climate Adaptation, Mitigation, and Resilience are critical strategies to address and manage the impacts of climate change and discussed in this paper with different examples. Climate Mitigation involves efforts to reduce or prevent the emission of greenhouse gases to limit the extent of climate change. Mitigation aims to slow down global warming and minimize future impacts on natural and human systems. Climate Adaptation is the process of adjusting systems, practices, and policies to withstand the current and anticipated impacts of climate change. It involves modifying infrastructure, improving water management, adopting climate-resilient agricultural methods, and planning for climate-resilient cities. Climate Resilience refers to the ability of systems—such as communities, economies, and ecosystems—to recover from and adapt to climate-related shocks and stresses. Building resilience involves strengthening institutions, improving risk assessments, implementing early warning systems, and fostering adaptive capacity. It encompasses both adaptation and mitigation efforts to create societies that can sustain themselves despite the challenges posed by climate change. This article attempts to understand how mitigation addresses the causes of Climate Change, adaptation tackles the impacts, and resilience builds the capacity to endure and recover from climate-related disruptions.

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Keywords: Climate Change, geopolitics, mitigation, adaptation, resilience, economics.

INTRODUCTION

Climate change refers to long-term shifts and alterations in temperature and weather patterns, primarily caused by human activities (McNutt, 2013). These activities include the burning of fossil fuels, deforestation, and industrial processes, which release large amounts of greenhouse gases like carbon dioxide and methane into the atmosphere (McNutt, 2013; Oberthür, 2016). These gases trap heat, leading to a warming effect known as the greenhouse effect. The consequences of climate change include more frequent and severe weather events, rising sea levels,

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and disruptions to ecosystems and biodiversity Climate change has a significant global impact for several reasons (Oberthür, 2016). Global temperatures are increasing, leading to more frequent and severe heat waves, which can cause health problems and reduce agricultural productivity. Melting glaciers and polar ice caps contribute to rising sea levels, which can lead to coastal flooding and erosion, threatening coastal communities and ecosystems. Climate change increases the frequency and intensity of extreme weather events such as hurricanes, floods, droughts, and wildfires, causing widespread damage and displacement (Bošnjaković, 2012; McNutt, 2013).

Changes in temperature and precipitation patterns can disrupt ecosystems, leading to loss of biodiversity and altering the distribution of species, which can impact food security and livelihoods. Increased CO^2 levels are causing oceans to become more acidic, affecting marine life, particularly organisms with calcium carbonate shells or skeletons, such as corals and shellfish (McNutt, 2013). Changes in climate can alter growing seasons, reduce crop yields, and increase the prevalence of pests and diseases, threatening food security. Climate change can exacerbate health issues by increasing the spread of diseases, causing heat-related illnesses, and impacting mental health due to stress from extreme weather events and displacement (Hitz and Smith, 2004). The economic impact of climate change includes damage to infrastructure, increased insurance costs, and loss of productivity, all of which can strain economies, especially in vulnerable regions. Resource scarcity, displacement, and competition for resources can lead to social and political tensions, potentially exacerbating conflicts and leading to migration (Bošnjaković, 2012). The interconnected nature of these impacts means that climate change is a global issue that requires coordinated international efforts to mitigate and adapt to its effects.

Geopolitics of Climate Change

The geopolitics of climate change refers to how global political and economic relations are influenced by the impacts of climate change and the efforts to mitigate and adapt to it. Climate change can alter the availability and distribution of natural resources like water, arable land, and fossil fuels, leading to potential conflicts or cooperation over these resources (Bošnjaković, 2012). Countries vary in their contributions to and impacts from climate change. This can affect international relations, trade policies, and economic stability, with vulnerable countries often seeking reparations or assistance from more developed nations. Climate change can cause displacement due to extreme weather events, sea-level rise, and resource scarcity, leading to migration that can strain political and social systems in receiving areas, potentially causing conflicts (Hitz and Smith, 2004). Climate change requires coordinated global action, leading to international agreements like the Paris Agreement. These agreements can shift geopolitical alliances and power dynamics as countries negotiate their responsibilities and contributions (WHO, 2014). The move towards renewable energy and the reduction of carbon emissions can shift geopolitical power from fossil fuel-rich nations to those leading in green technologies, impacting global energy markets and political alliances. Many nations view climate change as a threat to national security, influencing defence strategies and international military cooperation. Understanding these dynamics is crucial for developing effective policies and strategies to address the multifaceted challenges posed by climate change on a global scale.

Policies associated with Climate Change at global, regional and local levels

Policies addressing climate change span global, regional, and local levels, with each level focusing on specific aspects of mitigation and adaptation strategies (Hitz and Smith, 2004; Barnett, 2007; Majra and Gur, 2009; Dalby, 2010; Bošnjaković, 2012; Hommel and Murphy, 2013; McNutt, 2013; Streck and Terhalle, 2013; Dalby, 2013, 2015; Oberthür, 2016)

Here's an overview of key policies at each level:

Global Level

Paris Agreement (2015): An international treaty under the United Nations Framework Convention on Climate Change (UNFCCC), aiming to limit global warming to well below 2°C, preferably to 1.5°C, compared to pre-industrial levels.

Kyoto Protocol (1997): A previous international treaty that committed its parties to reduce greenhouse gas emissions, based on the premise that global warming exists and human-made CO_2 emissions have caused it.

UN Sustainable Development Goals (SDGs): Goal 13 focuses specifically on taking urgent action to combat climate change and its impacts.

Regional Level

European Green Deal (EU): A set of policy initiatives by the European Commission with the overarching aim of making Europe climate-neutral by 2050.

North American Climate, Clean Energy, and Environment Partnership (USA, Canada, Mexico): A collaboration to reduce greenhouse gas emissions, promote clean energy, and enhance environmental cooperation.

African Union Agenda 2063: Includes initiatives to address climate change and promote sustainable development in African countries.

Local Level

Climate Action Plans (CAPs): Many cities and municipalities develop CAPs to reduce local greenhouse gas emissions and adapt to climate change impacts. For example, New York City's Climate Mobilization Act.

Renewable Energy Mandates: Local governments may set requirements for renewable energy use in new buildings, such as California's Solar Mandate.

Urban Green Spaces Initiatives: Local policies promoting the creation and maintenance of green spaces to enhance resilience to climate change, like London's Green Infrastructure Plan.

Key Policy Instruments

These three policies are part of a multi-tiered approach necessary to address the complex and global nature of climate change effectively (Barnett, 2007; Dalby, 2013, 2015).

Carbon Pricing: Includes carbon taxes and cap-and-trade systems to incentivize emission reductions.

Renewable Energy Standards: Mandates or incentives for renewable energy generation.

Energy Efficiency Standards: Regulations for buildings, appliances, and industrial processes to improve energy efficiency.

Climate Resilience Planning: Strategies to enhance the resilience of infrastructure and communities to climate impacts.

Current scenario of global climate change looks and it's future directions

The current scenario of global climate change presents several concerning trends and impacts.

Global temperatures have been steadily increasing, leading to heat waves, altered weather patterns, and melting polar ice caps (McNutt, 2013). There's an increase in frequency and intensity of extreme weather events such as hurricanes, floods, and droughts. Melting glaciers and thermal expansion of seawater are causing sea levels to rise, threatening coastal communities (Dalby, 2015). Habitats are changing faster than many species can adapt, leading to biodiversity loss and ecosystem disruptions. Climate change exacerbates social and economic inequalities, affecting vulnerable populations disproportionately. Future directions depend heavily on global efforts to mitigate and adapt to climate change (Majra and Gur, 2009). Reduction of greenhouse gas emissions through international agreements, technological innovations, and shifts towards renewable energy sources are urgently needed. According to Dalby (2014) developing resilience in infrastructure, agriculture, and communities to cope with the impacts that are already inevitable; hence strengthening policies and regulations at local, national, and global levels to address climate change comprehensively should be prioritized. The future will be shaped by how effectively nations collaborate and implement solutions to mitigate climate change while adapting to its unavoidable consequences (Hommel and Murphy, 2013).

Serious Lack of Political Will

The issue of Climate Change often intersects with political will, where decisions made by governments and policymakers can significantly impact efforts to mitigate its effects. Factors such as economic interests, short-term political gains, and differing priorities among nations can all influence the level of commitment towards addressing climate change on a global scale. Efforts like international agreements (e.g., the Paris Agreement) aim to foster cooperation, but challenges remain in aligning diverse political agendas with long-term environmental goals (Streck and Terhalle, 2013; Dalby, 2010). The lack of strong political will behind global climate mitigation efforts can be attributed to several factors. Addressing these challenges requires sustained public advocacy, international cooperation, technological advancements, and policy innovations to overcome inertia and prioritize effective climate action (Dalby 2013, 2015).

1. **Short-term vs. Long-term Priorities:** Politicians often prioritize issues that yield immediate benefits or are more visible to voters over long-term and often less tangible environmental concerns.
2. **Economic Considerations:** Mitigating climate change requires significant investments in renewable energy, technology upgrades, and

infrastructure changes, which can be perceived as costly and may impact short-term economic growth.

3. **Political Interests and Pressure:** Industries that contribute to greenhouse gas emissions often have significant political influence, lobbying against regulations that could affect their profitability or competitiveness.
4. **Global Coordination Challenges:** Climate change is a global issue that requires cooperation among nations, but achieving consensus on targets and actions can be challenging due to differing economic priorities, development stages, and historical responsibilities.
5. **Public Opinion and Awareness:** While awareness of climate change has grown, it may not always translate into consistent voter pressure on politicians to prioritize climate policies over other issues.
6. **Policy Uncertainty:** Changing political landscapes and short-term policy cycles can lead to uncertainty in long-term climate policy frameworks, making it harder to implement and sustain effective mitigation measures.

COP initiative and Climate Change

The COP (Conference of the Parties) initiative is the main decision-making body of the United Nations Framework Convention on Climate Change (UNFCCC). It involves annual meetings where countries come together to negotiate and assess progress in addressing climate change (Painter, 2018; De-Lara et al., 2022). These conferences aim to review the implementation of the UNFCCC, the Kyoto Protocol, and the Paris Agreement, and to promote strategies for reducing greenhouse gas emissions and adapting to climate impacts. COP meetings are crucial for setting international climate policies and targets (De-Lara et al., 2022).

Major successes and failures of COP with respect to Climate Change

The Conference of the Parties (COP) under the United Nations Framework Convention on Climate Change (UNFCCC) has had numerous successes and failures over the years (Hjerpe and B.-O. 2010). Here are some key points:

Major Successes:

Paris Agreement (COP21, 2015): A landmark agreement where 196 parties committed to limit global warming to well below 2°C, with efforts to limit it to 1.5°C. Countries agreed to submit nationally determined contributions (NDCs) and update them every five years (Mace, 2005).

Kyoto Protocol (COP3, 1997): Established legally binding emission reduction targets for developed countries. Created mechanisms like carbon trading, clean development mechanism (CDM), and joint implementation (JI) (Christoff, 2008). Financial Commitments: Green Climate Fund (GCF) was established to support developing countries in adaptation and mitigation practices (COP16, 2010). Pledge to mobilize $100 billion per year by 2020 for climate action in developing countries (COP15, 2009).

Technological and Capacity Building Support: Establishment of the Technology Mechanism to enhance the development and transfer of climate technologies (COP16, 2010).

Major Failures:

Implementation Gaps: Many countries have struggled to meet their emission reduction targets, and the overall global emissions have continued to rise (Parker et al., 2012).

Lack of Ambition: Some NDCs are not ambitious enough to meet the 1.5°C or 2°C targets, leading to criticism that the Paris Agreement alone is insufficient (Ivanova, 2016).

Withdrawal and Non-Participation: The U.S. withdrawal from the Paris Agreement under the Trump administration (later rejoined under Biden) highlighted the vulnerability of international agreements to domestic politics (De-Lara et al., 2020). Insufficient Financial Contributions: The $100 billion annual climate finance target has not been fully met, and there are concerns about the transparency and effectiveness of the funds allocated (Mace, 2005).

Adaptation and Loss and Damage: Slow progress on addressing loss and damage and providing adequate support for adaptation in vulnerable countries. Despite these challenges, the COP process has been crucial in maintaining global attention on climate change and fostering international cooperation. The ongoing negotiations and commitments continue to play a vital role in addressing the climate crisis (Ivanova, 2016; De-Lara et al., 2020).

Climate Change Mitigation

Climate Change mitigation refers to efforts to reduce or prevent the emission of greenhouse gases into the atmosphere. The goal is to limit the magnitude and rate of long-term climate change (Anita et al., 2010). Mitigation strategies can be of multidimensional nature and dynamics. One the important step is reducing greenhouse gas emissions. This involves cutting down emissions from various sources like burning fossil fuels for energy, industrial processes, and deforestation (Bahadur et al., 2013; Demski et al., 2017). Secondly, enhancing the carbon sinks by increasing the capacity of forests, oceans, and soil to absorb CO from the atmosphere.

Switching to renewable energy sources (such as wind, solar, and hydroelectric power instead of fossil fuels); and improving energy efficiency by enhancing the efficiency of buildings, transportation, and industries to use less energy for the same output (McEvoy et al., 2013). By adapting to practices that can successfully reduce emissions from agriculture and forestry and increase carbon sequestration in trees and soil, it is possible to prevent Climate Change. These actions are essential to slow down global warming, reduce its impacts, and ensure a sustainable environment for future generations (Demski et al., 2017).

Climate Change Mitigation through Sustainable Approaches

Mitigating climate change involves a combination of strategies that reduce greenhouse gas emissions and enhance carbon sinks. Combining these strategies can significantly mitigate the impacts of climate change and contribute to a sustainable future (Anita et al., 2010; Bahadur et al., 2010, 2013; Gifford, 2011; McEvoy et al., 2013; Chen et al., 2017; Demski et al., 2017; Tang, 2019).

Some key strategic approaches are mentioned below:

Renewable Energy: Transitioning from fossil fuels to renewable energy sources like solar, wind, hydro, and geothermal power.

Energy Efficiency: Improving energy efficiency in buildings, transportation, and industries to reduce overall energy consumption.

Reforestation and Afforestation: Planting trees and restoring forests to absorb CO2 from the atmosphere.

Sustainable Agriculture: Implementing practices that reduce emissions from agriculture, such as improved crop rotation, reduced tillage, and better manure management.

Carbon Capture and Storage (CCS): Developing technologies to capture CO2 emissions from industrial sources and store them underground.

Transportation: Promoting electric vehicles, public transportation, cycling, and walking to reduce emissions from the transportation sector.

Policy and Regulation: Implementing policies and regulations that limit emissions, such as carbon pricing, emissions trading systems, and stricter emission standards.

Reducing Waste: Minimizing waste through recycling, composting, and reducing single-use plastics to lower methane emissions from landfills.

Behavioural Changes: Encouraging changes in individual behaviour, such as reducing meat consumption, conserving energy, and supporting sustainable products.

Research and Innovation: Investing in research and development of new technologies and methods for reducing emissions and adapting to climate impacts.

Challenges for Successful Climate Change Mitigation

Mitigating climate change involves a complex array of serious challenges that act as a wall against successful ground level implementation of Climate Change mitigation strategies (McEvoy et al., 2013). Transitioning to renewable energy and green technologies requires significant investment. Developing countries, in particular, may struggle with these costs (Bahadur et al., 2013). Achieving international consensus and cooperation is difficult. Different countries have varying interests, priorities, and levels of commitment to climate action. While renewable technologies are advancing, there are still technological hurdles to overcome, such as energy storage and grid integration for renewable resources (Demski et al., 2017). Existing infrastructure is largely built around fossil fuels. Shifting to renewable energy requires substantial changes to this infrastructure. Effective climate action often requires significant changes in consumer behaviour and lifestyle, which can be challenging to implement and sustain (Bahadur et al, 2010).

Enacting and enforcing policies that reduce greenhouse gas emissions can be politically and administratively challenging. Climate Change disproportionately affects vulnerable populations; hence, ensuring that mitigation efforts are fair and adds complexity to the issue (Duarte et al., 2013). Scientific and technical uncertainties like predicting the precise impacts of climate change and the effectiveness of various mitigation strategies involves uncertainties. Industrial Resistance: Industries reliant on fossil fuels often resist change due to potential economic losses. Gaining widespread public support and understanding of climate change and necessary actions is a continuous challenge (Anita et al., 2010).

Net Zero

"Net Zero" refers to achieving a balance between the amount of greenhouse gases produced and the amount removed from the atmosphere (Davis et al., 2018). Specifically, it means reducing greenhouse gas emissions to as close to zero as possible and balancing any remaining emissions by offsetting them with an equivalent amount of carbon removal or offsetting measures, such as reforestation or carbon capture technologies (Rogelj et al., 2021).

Net Zero is important in the context of addressing climate change because greenhouse gases like carbon dioxide (CO2) contribute to global warming and climate disruption (Deutch, 2020). By aiming for Net Zero emissions, countries, businesses, and organizations commit to mitigating their environmental impact and transitioning towards more sustainable practices (Bataill, 2020). Many governments and businesses have set Net Zero targets to combat climate change and limit global temperature rise to less than 2 degrees Celsius above pre-industrial levels, as outlined in international agreements like the Paris Agreement (Fankhauser et al., 2022).

Net Zero: Opportunities and Limitations

Net zero refers to achieving a balance between the amount of greenhouse gases produced and removed from the atmosphere, typically through reductions in emissions and the offsetting of remaining emissions by activities like carbon capture and storage (Voss and Musall, 2012; Davis et al., 2018; Deutch, 2020; Bataill, 2020; Rogelj et al., 2021; Fankhauser et al., 2022). Here are some opportunities and limitations associated with net zero:

Opportunities:

Climate Mitigation: Net zero aims to mitigate climate change by significantly reducing greenhouse gas emissions, thereby slowing down global warming.

Technological Innovation: It drives innovation in clean energy technologies, such as renewable energy sources, energy-efficient technologies, and carbon capture and storage.

Economic Benefits: Transitioning to net zero can create new jobs and economic opportunities in renewable energy sectors and sustainable practices.

Health Benefits: Reductions in air pollution associated with fossil fuel combustion can lead to improved public health outcomes.

Global Cooperation: Promotes international cooperation and agreements to tackle climate change collectively.

Limitations:

Technological Readiness: Some technologies required for achieving net zero, like large-scale carbon capture and storage, are not yet commercially viable or widespread.

Cost: Transitioning to net zero can be costly, especially for industries heavily reliant on fossil fuels. The financial burden may disproportionately affect certain sectors or regions.

Social Equity: The costs and benefits of transitioning to net zero may not be equally distributed across society, potentially exacerbating inequalities.

Behavioural Change: Achieving net zero requires significant changes in consumption patterns and behaviours, which can be challenging to implement on a global scale.

Natural Carbon Sinks: Relying on natural carbon sinks (such as forests and oceans) to offset emissions raises concerns about their capacity and long-term viability.

Overall, while net zero offers a pathway towards addressing climate change, it involves overcoming technological, economic, and social challenges to achieve widespread success (Voss and Musall, 2012).

Can Net Zero be achieved realistically?

Achieving Net Zero is certainly challenging but not impossible. It requires significant changes across industries, technology advancements, policy frameworks, and global cooperation (Rogelj et al., 2021). Many experts believe it's realistically achievable with concerted efforts and innovation, although the exact timeline and feasibility vary depending on the strategies and commitments of different countries and sectors (Deutch, 2020).

The concept of achieving net zero emissions is crucial in the fight against climate change. While it's challenging and requires significant effort globally, it's not inherently a failed objective (Bataill, 2020). Many countries and organizations are actively working towards this goal, setting targets to reduce emissions and offset remaining emissions through various means like reforestation and carbon capture technologies. Success will depend on global cooperation, technological advancements, and policy frameworks that support sustainable practices (Fankhauser et al. 2022).

Green Infrastructure

Green infrastructure refers to natural or nature-based systems designed to provide multiple environmental, social, and economic benefits (Lennon, 2015). It involves integrating natural features and processes into urban planning and development to manage storm water, reduce heat islands, improve air quality, enhance biodiversity, and provide recreational spaces. Examples include green roofs, rain gardens, urban forests, and permeable pavements. Green infrastructure refers to the strategically planned and managed networks of natural lands, green spaces, and other green features designed to provide ecosystem services and support healthy urban environments (Mell, 2008, 2015).

Green infrastructure helps improve air and water quality, reduces urban heat island effects, and supports biodiversity conservation. Access to green spaces promotes physical activity, reduces stress, and enhances mental health among urban residents. It can increase property values, reduce energy costs (e.g., through shading and cooling effects), and lower infrastructure maintenance costs (e.g., by managing storm water naturally). Green spaces serve as gathering places, fostering community interaction and social cohesion (Kambites and Owen, 2006).

Establishing and maintaining green infrastructure can be expensive, especially in densely built urban areas where land is at a premium. Competing land use priorities may hinder the allocation of space for green infrastructure, especially in rapidly growing cities. Green infrastructure requires ongoing care and management to ensure its effectiveness, which can strain municipal budgets and resources. Ensuring the longevity and resilience of green infrastructure in the face of climate change and urban development pressures requires careful planning and adaptation. Addressing these challenges requires integrated planning, stakeholder collaboration, and innovative financing mechanisms to fully realize the benefits of green infrastructure in urban environments (Lennon, 2015).

Can green infrastructure be successfully implemented in poorer countries?

Green infrastructure can be successfully implemented in poorer countries. While it may present challenges such as funding constraints and varying levels of technical expertise, there are several reasons why it can work. Green infrastructure often offers long-term cost savings through reduced energy consumption, improved public health outcomes, and lower maintenance costs compared to traditional infrastructure. Many green technologies can be adapted to local conditions and needs, making them suitable for diverse geographical and economic contexts. There are international initiatives and funding mechanisms aimed at supporting green infrastructure projects in developing countries, enhancing their feasibility (Kambites and Owen, 2006).

Green infrastructure can provide direct benefits to communities, such as cleaner air and water, improved sanitation, and job creation through local implementation and maintenance. It can also contribute to climate resilience by mitigating the impact of extreme weather events and reducing greenhouse gas emissions (Mell, 2008, 2015).. Successful implementation often involves a combination of policy support, capacity building, and collaboration between governments, communities, and international organizations.

Green infrastructure refers to systems and practices that mimic natural processes to manage various environmental issues sustainably. One notable global success in green infrastructure is the city of Copenhagen, Denmark (Mell, 2008, 2015). It has implemented extensive green roofs, rain gardens, and permeable pavements to manage storm water effectively. This approach not only reduces flooding risks but also improves air quality and enhances urban biodiversity. Copenhagen's efforts are a significant example of how integrating green infrastructure into urban planning can create more sustainable and resilient cities (Sinnett et al., 2015).

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Major green infrastructure achievements achieved in third world countries

Third-world countries have made significant strides in green infrastructure despite facing numerous challenges (Sinnett et al., 2015). Many countries have invested in solar, wind, and hydroelectric power to diversify their energy mix and reduce reliance on fossil fuels. Initiatives to plant trees and restore degraded lands have been undertaken to combat deforestation and enhance biodiversity (Lennon, 2015). Implementing sustainable water management practices such as rainwater harvesting, water recycling, and efficient irrigation systems to conserve water resources (Monteiro et al., 2020).

Construction of eco-friendly buildings that utilize energy-efficient designs, materials, and technologies to reduce carbon foot print; along with the improvement in waste management systems through recycling, composting, and waste-to-energy projects to minimize environmental impact can help (Mell, 2008, 2015). Promotion of public transportation, cycling infrastructure, and electric vehicles to reduce air pollution and greenhouse gas emissions are urgent needs (Sinnett et al., 2015). . The development and implementation of policies, regulations and incentives to support green infrastructure investments and sustainable development goals are important points to be considered. These achievements highlight the proactive efforts of third-world countries to address environmental challenges and promote sustainable development despite facing economic constraints (Mell, 2008, 2015).

Mitigating Climate Change

Green infrastructure plays a crucial role in mitigating climate change for several reasons. Plants absorb carbon dioxide (CO_2) during photosynthesis, reducing the concentration of greenhouse gases in the atmosphere (Lennon, 2015). Green infrastructure, such as parks and green roofs, can help lower local temperatures in urban areas by providing shade and evaporative cooling, thus reducing energy consumption for cooling buildings. Vegetation and permeable surfaces can absorb rainwater, reducing runoff and alleviating pressure on drainage systems during heavy rainfall events, which are becoming more frequent due to climate change (Van Oijstaeijen et al., 2020).

Green spaces support diverse ecosystems, preserving habitats for plants and animals that are increasingly threatened by climate change (Lennon, 2015). Trees and plants can filter pollutants from the air, improving overall air quality in urban environments. Overall, integrating green infrastructure into urban planning and landscapes not only helps mitigate climate change by reducing greenhouse gas emissions and energy use but also enhances resilience to its impacts (Wilker et al., 2016).

Climate Change Resilience

Climate resilience refers to the ability of systems, communities, and societies to anticipate, prepare for, respond to, and recover from the impacts of climate change (Thompson et al., 2009). It encompasses a wide range of measures and strategies aimed at reducing vulnerability to climate impacts and enhancing adaptive capacity. Climate resilience is crucial because it helps societies withstand and bounce back from climate-related shocks and stresses, such as extreme weather events, sea-level rise, droughts, and disruptions to ecosystems and economies (Côté and Darling, 2010. By building resilience, communities can better protect lives and livelihoods, ensure food and water security, preserve infrastructure, and maintain economic stability in the face of a changing climate (Cannon and Müller-Mahn, 2010).

Opportunities and limitations of Climate Change resilience

Climate change resilience presents several opportunities and some limitations (Nyong et al., 2007; Davoudi et al., 2009; Laukkonen et al., 2009; Anita et al., 2010; Gifford, 2011; Chen et al., 2017; Tang, 2019).

Opportunities:

Enhanced Adaptation: Resilience efforts encourage adaptive strategies that can help communities cope with and recover from climate impacts more effectively.

Innovation and Technology: Resilience initiatives drive innovation in technologies, infrastructure, and practices that can mitigate climate risks and improve response capabilities.

Economic Benefits: Investing in resilience can lead to cost savings over time by reducing damage from climate disasters and lowering insurance premiums.

Community Empowerment: Building resilience often involves community engagement and empowerment, fostering social cohesion and capacity building.

Long-Term Sustainability: Resilience measures promote sustainable development practices that benefit both current and future generations.

Limitations:

Resource Constraints: Implementing comprehensive resilience strategies requires substantial financial resources, which may be limited in some regions or communities.

Complexity and Interdependencies: Climate resilience involves interconnected systems, making it challenging to predict and manage all potential impacts and interactions.

Equity Concerns: Vulnerable populations, including low-income communities and marginalized groups, may have limited access to resources and face greater challenges in building resilience.

Political and Institutional Barriers: Lack of political will, institutional capacity, and coordination can hinder effective implementation of resilience measures.

Uncertainty and Changing Conditions: Climate change projections and impacts are subject to uncertainties, making it difficult to accurately assess future risks and plan accordingly.

Overall, while climate resilience offers significant benefits in terms of adaptation and sustainability, addressing its limitations requires concerted efforts at multiple levels, from policy-making to community engagement and international cooperation.

Climate Change Economics

Climate change economics refers to the study of the economic impacts of climate change and the economic aspects of policies and measures to mitigate or adapt to it (Berrang-Ford et al., 2011). It involves understanding how climate change affects economic systems, sectors, and resources, as well as assessing the costs and benefits of various actions to address climate change (Kerr, 2007). This field examines issues such as carbon pricing, investments in renewable energy, adaptation strategies for vulnerable communities and industries, and the economic consequences of climate-related events like extreme weather and sea-level rise (Dinar, 1998; Nordhaus and Boyer, 2003).

Importance of Climate Change Economics

Climate change economics is crucial for several reasons. It helps in efficiently allocating resources to mitigate and adapt to climate change impact (Patz and Olson, 2006). This includes investments in renewable energy, infrastructure resilience, and sustainable practices. Economic analysis informs policymakers on the costs and benefits of different climate policies (Aggarwal, 2003). This includes carbon pricing mechanisms, subsidies for green technologies, and regulations on emissions (Byjesh et al., 2010). It assesses the economic risks associated with climate change, such as damage to infrastructure, agriculture, and health, helping businesses and governments prepare and manage these risks (Soora et al., 2013).

Economic incentives drive innovation in clean technologies and practices, accelerating the transition to a low-carbon economy (Byjesh et al., 2010). Understanding the economic impacts of climate change fosters international cooperation in tackling global issues like reducing greenhouse gas emissions and supporting vulnerable populations (Srivastava et al., 2010). It supports long-term planning by businesses and governments, ensuring sustainable development pathways that account for climate risks and opportunities (Aggarwal, 2003). Overall, integrating economics into climate change action is essential for achieving environmental sustainability while promoting economic growth and societal well-being (Ravindranath et al., 2006).

Limitations of Climate Change economics and its drawbacks

Climate change economics faces several limitations and drawbacks. Climate change is a highly complex and uncertain phenomenon, making economic modelling challenging. Uncertainties in future emissions, technological advancements, and climate impacts complicate cost-benefit analysis. Effective climate action requires global cooperation, yet international agreements like the Paris Agreement face challenges in enforcement and commitment (Ravindranath et al., 2006). Economic models often discount future costs and benefits, potentially undervaluing long-term impacts of climate change mitigation and adaptation (Schelling, 1992). Climate policies can have uneven distributional impacts across different regions, industries, and socio-economic groups, leading to concerns about fairness and social equity (Srinivasan, 2012). Economic models may not adequately account for human behaviour, political dynamics, and institutional barriers that influence policy adoption and effectiveness (Kumar and Parikh, 2001).

Traditional economic approaches assume perfect markets, but climate change involves significant market failures like externalities (e.g., carbon emissions) that are not adequately priced. Transitioning to a low-carbon economy requires substantial technological innovation and infrastructure investment, which may not be fully captured in economic models. (Guiteras, R. 2009). Economic analyses often overlook the full value of ecosystem services threatened by climate change, such as biodiversity and natural resources. Addressing these limitations requires interdisciplinary approaches, improved modelling techniques, and policies that integrate social, environmental, and economic objectives effectively Dinar, 1998; Nordhaus and Boyer, 2003).

Food for Thought

The future of climate change is concerning and depends heavily on global action, as well as local and individual efforts. Here's an overview of the major trends and projections if we continue on our current path:

1. Rising Temperatures
Average global temperatures are projected to rise by 1.5°C to 4°C above pre-industrial levels by the end of the century, depending on emission scenarios.

The 1.5°C threshold is critical. Exceeding it may trigger feedback loops (such as melting permafrost releasing methane) that accelerate warming even further.

2. Extreme Weather Events
More intense and frequent weather events, like hurricanes, droughts, floods, and heatwaves, are expected as the climate continues to warm.

Regions that already experience high temperatures could see more heatwaves, and rainfall patterns are likely to shift, causing some areas to become wetter and others drier.

3. Rising Sea Levels
Sea levels are expected to rise due to both melting polar ice and the thermal expansion of oceans as they warm.

By 2100, sea levels could rise between 0.6 and 1.1 meters (2-3 feet) under high-emission scenarios, significantly impacting coastal communities and small island nations.

4. Impact on Ecosystems and Biodiversity
Many species face a high risk of extinction as they struggle to adapt to rapidly changing temperatures and shifting habitats.

Coral reefs, crucial for marine biodiversity, are especially vulnerable, with nearly all reefs projected to experience annual bleaching by the end of the century if emissions aren't curbed.

5. Food and Water Security Challenges
Climate change is expected to disrupt agricultural productivity due to heat stress, changing precipitation patterns, and extreme weather.

Water scarcity will likely worsen in certain regions, particularly areas dependent on glaciers for freshwater or prone to drought.

6. Health Risks
Heat-related illnesses, respiratory issues from air pollution, and the spread of infectious diseases are anticipated to increase.

Vulnerable populations, especially those in low-income areas, will face disproportionate impacts on health.

7. Economic Implications
The economic impacts of climate change are profound, potentially costing the global economy trillions of dollars due to damages from extreme weather, loss of biodiversity, health expenses, and productivity declines.

Potentially Positive Future Scenarios:
If countries adhere to significant emission reduction commitments, such as achieving net-zero carbon emissions by mid-century, warming could be limited to around 1.5°C to 2°C.

Green technologies and renewable energy sources are advancing rapidly, making it increasingly feasible to transition away from fossil fuels.

Adaptation strategies, like building resilient infrastructure and sustainable agriculture, can help mitigate some impacts.

The outcome largely depends on immediate global action to reduce emissions and increase sustainable practices.

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STUDY OF GROUNDWATER QUALITY FOR DRINKING PURPOSE IN KHARKHODA BLOCK OF SONIPAT DISTRICT, HARYANA

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ABSTRACT

Groundwater is important because of its drinking, agriculture and industrial uses. Present developmental activities have put pressure on this precious natural resource. In urban areas its quality is deteriorated due to anthropogic pollution like sewerage and industrial waste water mixing with groundwater. The present study area Kharkhoda block is located in Sonipat district, Haryana. The geo-coordinates of the study area are latitudes 28.79^0 N to 29.01^0 N and longitudes 76.77^0E to 77.02^0E and covers an area of 302.03 sq. km. The main objective was to assess groundwater quality for drinking purpose in the study area. Geologically alluvium and geomorphologically alluvial plain are present in the area. In the study area fourteen groundwater samples were collected in 250 ml double capped plastic bottles. Geo-coordinates of sample locations were noted with the help of mobile GPS. Chemical analysis of fourteen groundwater samples were done using Tamilnadu Water Supply and Drainage (TWAD) Board, Chennai prepared Field Water Testing kit for twelve chemical parameters viz. pH, alkalinity, hardness, chloride, total dissolved solids (TDS), fluoride, iron, nitrite, nitrate, ammonia, phosphate and residual chlorine. Chemical analysis results were entered in excel software and preaped bar graphs for each chemical parameter for all the fourteen sample locations. Results of groundwater samples analysis were compared with BIS (IS 10500:2012) drinking water standards to know groundwater quality for drinking purpose. In the study area pH ranges 6.5 to 8, alkalinity ranges 180 mg/l to 830 mg/l, hardness ranges 50 mg/l to 1400 mg/l, chloride ranges 20 mg/l to 2800 mg/l, TDS ranges 588 mg/l to 4752 mg/l, fluoride ranges 1 mg/l to 5 mg/l, iron ranges nil to 10 mg/l, ammonia ranges 0.5 mg/l to 1 mg/l, nitrite ranges 0.5 mg/l to 2 mg/l, nitrate ranges 45 mg/l to 100 mg/l, phosphate ranges nil to 1 mg/l, residual chlorine ranges nil to 3 mg/l.This study is highly useful for planning and monitoring of groundwater for drinking purpose in the study area.

No. of Pages: 6 **References: 10**

Keywords: Groundwater, quality, drinking, assessment, Kharkhoda, Sonipat, Haryana.

INTRODUCTION

Water is important for survival of living beings and many non-living processes on the planet Earth. Water is required for drinking, irrigation and industrial purposes. Good quality water is essential for drinking to avoid many health problems. Role of groundwater is more than surface water because of its easily availability and approach upto a single human. But the availability and quality of groundwater is decreasing day by day due to increasing population, excessive use in irrigation and industries. Rajankar et al. (2009), Sarala and Ravi Babu (2012), Shekhar and Sarkar (2013),Annapoorna and Janardhana (2015), Kumar et al. (2015), Punia et al. (2015), Zayed and Elhdad (2015), Zidi et al.(2017), Bunkar and Kumar (2019), Sharmila et al.(2020) had done work on groundwater quality for uses in drinking, agriculture and industrial purposes.

STUDY AREA

Kharkhoda block is located in Sonipat district, Haryana (Fig.1). The geo-coordinates of the study area

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are latitudes 28.79^0 N to 29.01^{0}N and longitudes 76.77^0 E to 77.02^0 E and covers an area of 302.03 sq. km. Geologically alluvium and geomorphologically alluvial plain are present in the study area.

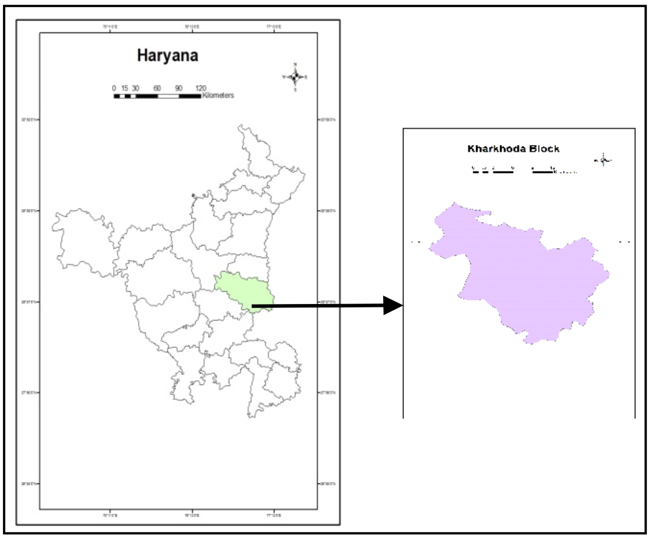

Fig.1: Location map of the study area.

OBJECTIVE

The main objective of the study was to assess groundwater quality for drinking purpose in the study area.

MATERIALS AND METHODOLOGY

In the study area fourteen groundwater samples were collected in 250 ml double capped plastic bottles. Geo-coordinates of sample locations were noted with the help of mobile GPS. Chemical analysis of fourteen groundwater samples were done using Tamilnadu Water Supply and Drainage (TWAD) Board, Chennai prepared Field Water Testing kit for twelve chemical parameters viz. pH, alkalinity, hardness, chloride, total dissolved solids (TDS), fluoride, iron, nitrite, nitrate, ammonia, phosphate and residual chlorine (Table 1). Chemical analysis results were enetere in excel software and prepared bar graph for each chemical parameter. Results of groundwater samples analysis were compared with BIS (IS 10500:2012) drinking water standards (Table 2) to know groundwater quality for drinking purpose.

Table 1: Result of groundwater samples analysis.

S.	Sample No.	Latitude Location	Longitude	pH	Alkalinity (mg/l)	Hardness (mg/l)	Chloride (mg/l)	TDS (mg/l)	Fluoride (mg/l)	Iron (mg/l)	Ammonia (mg/l)	Nitrite (mg/l)	Nitrate (mg/l)	Phosphate (mg/l)	Residual Chlorine (mg/l)
1	Salimpur	29.96	76.99	TW	7	220	200	80	600	0	0	0	0.5	75	00
1	Kanwali	28.92	76.97	7.5	830	750	510	2508	1.5	0	0.5	0.5	100	0	0
2	Kharkhoda	28.88	76.91	7	500	1400	900	3360	5	0	1	1	100	0	0
3	Sheri-1	28.94	76.88	8	620	210	250	1296	5	0	0.5	1	75	0	0
4	Sheri-2	28.94	76.88	7.5	550	330	2460	4008	1.5	0	0.5	0.5	45	0	0
5	Khanda-1	28.93	76.88	7.5	510	650	2800	4752	2	10	1	2	45	1	0.5
6	Rohna	28.86	76.89	7.5	300	370	20	828	3	0	0.5	1	45	0	0
7	Turkpur	28.89	76.98	7	200	250	40	588	2	0	0.5	0.5	100	0	0
8	Khanda-2	28.92	76.89	7	640	700	1000	2808	3	0	1	1	45	0.5	0.2
9	Thana Khurd	28.89	76.96	6.5	400	380	230	1212	5	0	0.5	0.5	45	0.5	0.2
10	Thana Kalan	28.88	76.95	7.5	180	450	1200	2169	1.5	0.3	0.5	0.5	100	0.5	0.2
11	Jharauti-1	28.91	76.94	7	500	130	20	780	1	0	0.5	0.5	45	0	0
12	Jharauti-2	28.92	76.94	7	450	50	20	624	1	2	0.5	0.5	45	0	0.5
13	Nirthana	28.96	76.89	8	200	190	610	1200	5	2	1	1	45	0	0.2
14	Barona	28.85	76.90	7.5	300	230	30	996	3	0	0.5	1	45	0	3

Table 2: Drinking water standards (BIS: 10500:2012).

S. No.	Parameters	Potable		Non-Potable
		Desirable	Permissible	
1.	pH	6.5 to 8.5	-	<6.5 and >8.5
2.	Alkalinity (mg/l)	<200	200-600	>600
3.	Total Hardness (mg/l)	<200	200-600	>600
4.	Chloride (mg/l)	<250	250-1000	>1000
5.	Total Dissolved Solids (TDS) (mg/l)	<500	500-2000	>2000
6.	Fluoride (mg/l)	<1.0	1.0-1.5	>1.5
7.	Iron (mg/l)	<0.3	-	>0.3
8.	Ammonia (mg/l)	<0.5	-	>0.5
9.	Nitrite (mg/l)	<1.0	-	>1.0
10.	Nitrate (mg/l)	<45	-	>45
11.	Phosphate (mg/l)	<1.0	-	>1.0
12.	Residual Chlorine (mg/l)	<0.2	0.2-1.0	>1.0

RESULTS AND DISCUSSION

i. pH

In the study area pH ranges 6.5 to 8 (Table 1, Fig.2). As per BIS (IS 10500:2012) drinking water standards pH is desirable from 6.5 to 8.5 and non-potable if than 6.5 and more than 8.5 (Table 2). pH is desirable in all the fourteen goundwater samples (Kanwali, Kharkhoda, Sheri-1, Sheri-2, Khanda, Rohna,Turkpur, Khanda-2, Thana Khurd, Thana Kalan, Jharauti-1, Jharauti-2, Nirthana and Barona) in the study area.

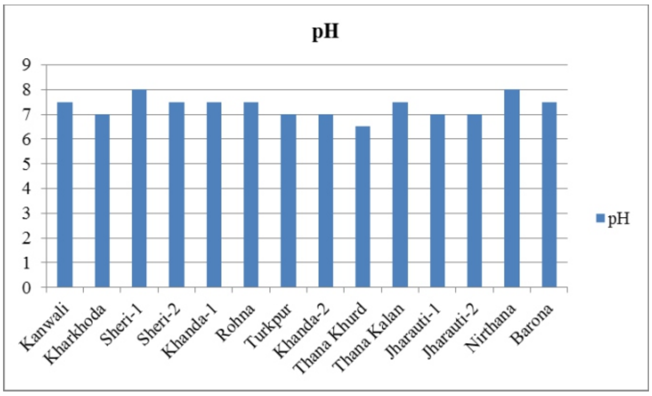

Fig. 2: pH in groundwater samples.

ii. Alkalinity

In the study area alkalinity ranges 180 mg/l to 830 mg/l (Table 1,Fig.3). As per BIS (IS 10500:2012) drinking water standards alkalinity is desirable if less than 200 mg/l, permissible between 200 mg/l-600 mg/l and non-potable if more than 600 mg/l (Table 2). Alkalinity is desirable in one groundwater sample (Thana Kalan), permissible in ten groundwater samples (Kharkhoda, Sheri-2, Khanda-1, Rohna, Turkpur, Thana Khurd, Jharauti-1, Jharauti-2, Nirthan, Barona) and non-potable in three groundwater samples (Kanwali, Sheri-1, Khanda-2).

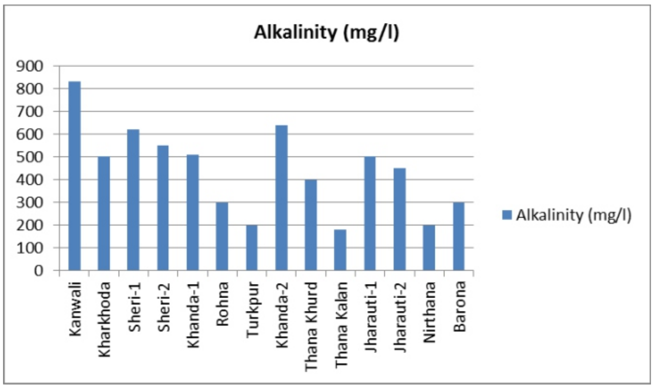

Fig. 3: Alkalinity in groundwater samples.

iii. Hardness

In the study area hardness ranges 50 mg/l to 1400 mg/l (Table 1,Fig.4). As per BIS (IS 10500:2012) drinking water standards hardness is desirable if less than 200 mg/l, permissible between 200 mg/l - 600 mg/l and non-potable if more than 600 mg/l (Table 2). Hardness is desirable in three groundwater samples (Jharauti-1, Jharauti-2, Nirthan), permissible in seven groundwater samples (Sheri-1, Sheri-2, Rohna, Turkpur, Thana Khurd, Thana Kalan, Barona) and non-potable in four groundwater samples (Kanwali, Kharkhoda, Khanda-1, Khanda-2).

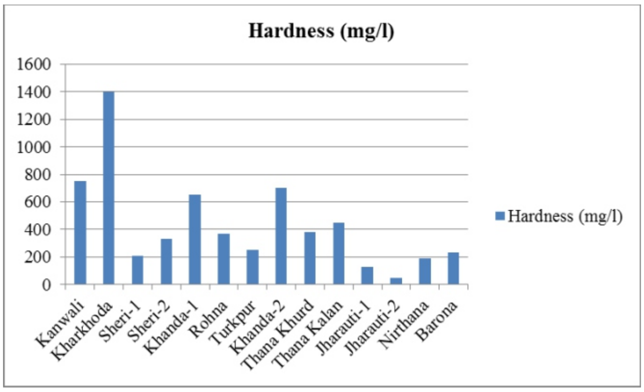

Fig. 4: Hardness in groundwater samples.

iv. Chloride

In the study area chloride ranges 20 mg/l to 2800 mg/l (Table 1,Fig.5). As per BIS (IS 10500:2012) drinking water standards chloride is desirable if less than 250 mg/l, permissible between 250 mg/l - 1000 mg/l and non-potable if more than 1000 mg/l (Table 2). Chloride is desirable in six groundwater samples (Rohna, Turkpur, Thana Khurd, Jharauti-1, Jharauti-2, Barona), permissible in five groundwater samples (Kanwali, Kharkhoda, Sheri-1, Khanda-2, Nirthan) and non-potable in three groundwater samples (Sheri-2, Khanda-1, Thana Kalan).

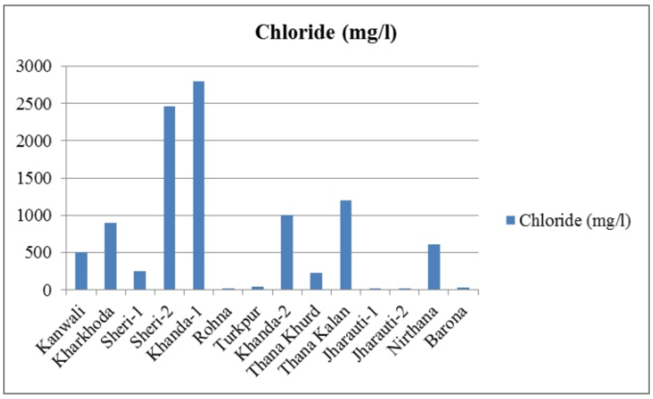

Fig. 5: Chloride in groundwater samples.

v. Total Dissolved Solids (TDS)

In the study area TDS ranges 588 mg/l to 4752 mg/l (Table 1,Fig.6). As per BIS (IS 10500:2012) drinking water standards TDS is desirable if less than 500 mg/l, permissible between 500 mg/l -2000 mg/l and non-potable if more than 2000 mg/l (Table 2). TDS is permissbile in eight groundwater samples (Sheri-1, Rohna, Turkpur, Thana Khurd, Jharauti-1, Jharauti-2, Nirthan, Barona) and non-potable in six groundwater samples (Kanwali, Kharkhoda, Sheri-2, Khanda-1, Khanda-2, Thana Kalan).

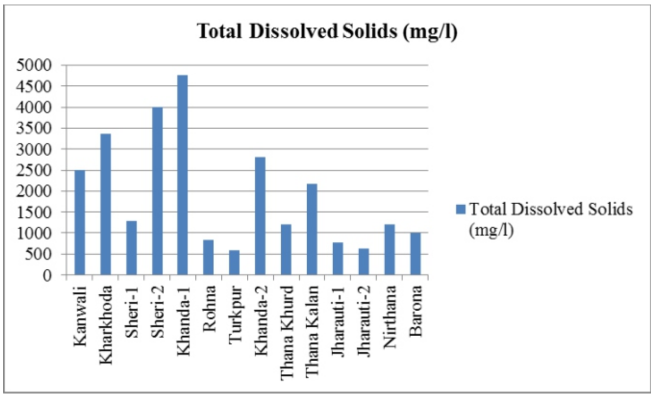

Fig. 6: TDS in groundwater samples.

vi. Fluoride

In the study area fluoride ranges 1 mg/l to 5 mg/l (Table 1, Fig.7). As per BIS (IS 10500:2012) drinking water standards fluoride is desirable if less than 1.0 mg/l, permissible between 1.0 mg/l-1.5 mg/l and non-potable if more than 1.5 mg/l (Table 2). Fluoride is permissible in five groundwater samples (Kanwali, Sheri-2, Thana Kalan, Jharauti-1, Jharauti-2) and non-potable in nine groundwater samples (Kharkhoda, Sheri-1, Khanda-1, Rohna, Turkpur, Khanda-2, Thana Khurd, Nirthan, Barona).

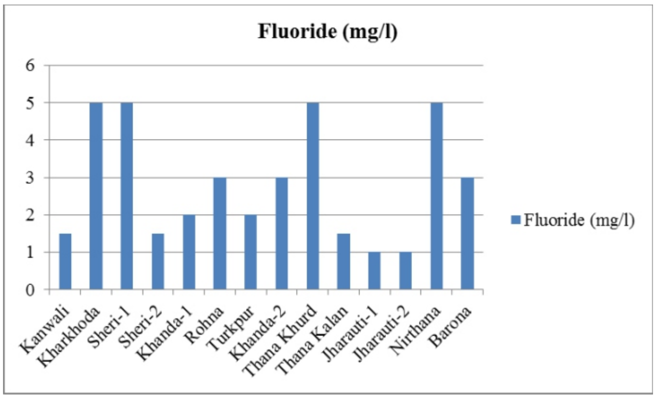

Fig. 7: Fluoride in groundwater samples.

vii. Iron

In the study area iron ranges nil to 10 mg/l (Table 1,Fig.8). As per BIS (IS 10500:2012) drinking water standards iron is desirable if less than 0.3mg/l and non-potable if more than 0.3 mg/l (Table 2). Iron is desirable in ten groundwater samples (Kanwali, Kharkhoda, Sheri-1, Sheri-2, Rohna, Turkpur, Khanda-2, Thana Khurd, Jharauti-1, Barona) and non-potable in four groundwater samples (Khanda-1, Thana Kalan, Jharauti-2, Nirthan).

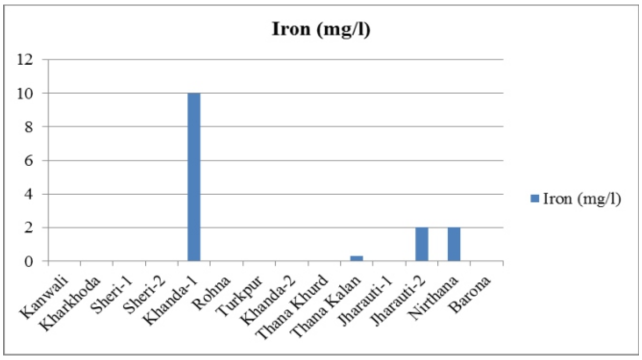

Fig. 8: Iron in groundwater samples .

viii. Ammonia

In the study area ammonia ranges 0.5 mg/l to 1 mg/l (Table 1,Fig.9). As per BIS (IS 10500:2012) drinking water standards ammonia is desirable if less than 0.5 mg/l and non-potable if more than 0.5 mg/l (Table 2). Ammonia is desirable in ten groundwater samples (Kanwali, Sheri-1, Sheri-2, Rohna, Turkpur, Thana Khurd, Thana Kalan, Jharauti-1, Jharauti-2, Barona) and non-potable in four groundwater samples (Kharkhoda, Khanda-1, Khanda-2, Nirthan).

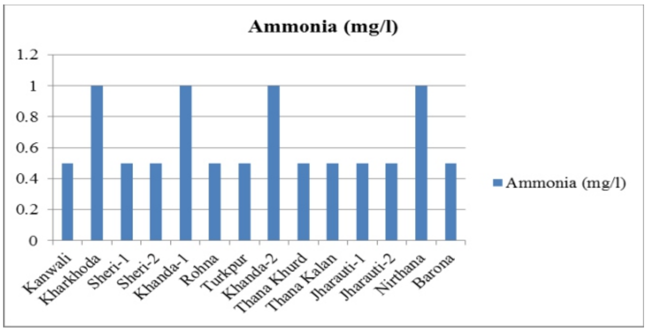

Fig. 9: Ammonia in groundwater samples.

ix. Nitrite

In the study area nitrite ranges 0.5 mg/l to 2 mg/l (Table 1, Fig.10). As per BIS (IS 10500:2012) drinking water standards nitrite is desirable if less than 1.0 mg/l and non-potable if more than 1.0 mg/l (Table 2). Nitrite is desirable in thirteen groundwater samples (Kanwali, Kharkhoda, Sheri-1, Sheri-2, Rohna, Turkpur, Khanda-2, Thana Khurd, Thana Kalan, Jharauti-1, Jharauti-2, Nirthan, Barona) and non-potable in one groundwater sample (Khanda-1).

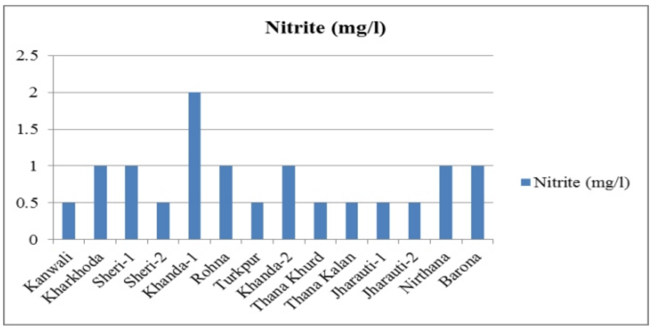

Fig. 10: Nitrite in groundwater samples.

x. Nitrate

In the study area nitrate ranges 45 mg/l to 100 mg/l (Table 1,Fig.11). As per BIS (IS 10500:2012) drinking water standards nitrate is desirable **if less than** 45 mg/l and non-potable if more than 45mg/l (Table 2). Nitrate is desirable in nine groundwater samples (Sheri-2, Khanda-1, Rohna, Khanda-2, Thana Khurd, Jharauti-1, Jharauti-2, Nirthan, Barona) and non-potable in five groundwater samples (Kanwali, Kharkhoda, Sheri-1, Turkpur, Thana Kalan).

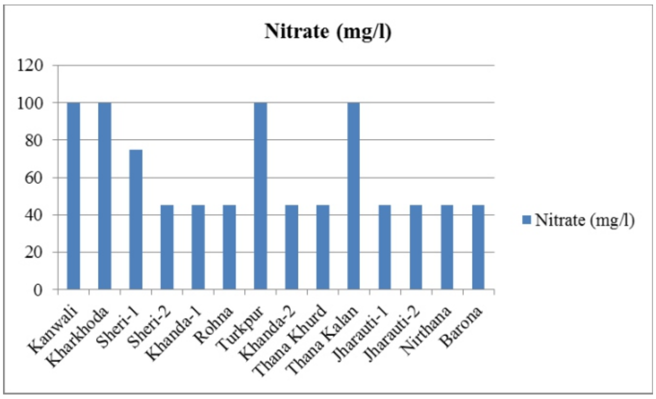

Fig. 11: Nitrate in groundwater samples.

xi. Phosphate

In the study area phosphate ranges nil to 1 mg/l(Table 1,Fig.12). As per BIS (IS 10500:2012) drinking standards phosphate is desirable if less than 1.0 mg/l and non-potable if more than 1.0 mg/l (Table 2). Phosphate is desirable in all the fourteen groundwater samples (Kanwali, Kharkhoda, Sheri-1, Sheri-2, Khanda-1, Rohna, Turkpur, Khanda-2, Thana Khurd, Thana Kalan, Jharauti-1, Jharauti-2, Nirthan, Barona).

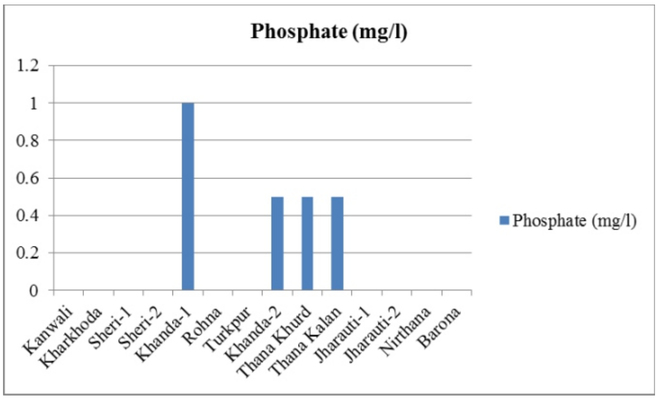

Fig.12: Phosphate in groundwater samples

xii. Residual Chlorine

In the study area residual chlorine ranges nil to 3 mg/l (Table 1,Fig.13). As per BIS (IS 10500:2012) drinking water standards residual chlorine is desirable if less than 0.2 mg/l, permissible between 0.2 mg/l-1 mg/l and non-potable if more than 1.0 mg/l (Table 2). Residual Chlorine is desirable in seven groundwater samples (Kanwali, Kharkhoda, Sheri-1, Sheri-2, Rohna, Turkpur, Jharauti-1), permissible in six groundwater samples (Khanda-1, Khanda-2, Thana Khurd, Thana Kalan, Jharauti-2, Nirthan) and non-potable in one groundwater sample (Barona).

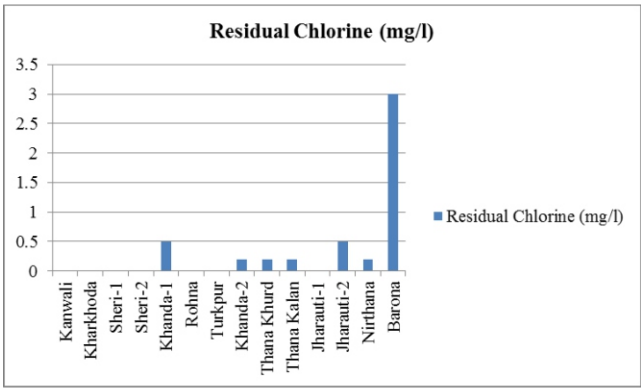

Fig.13: Residual Chlorine in groundwater samples.

CONCLUSIONS

In the study area pH, phosphate is desirable in all the fourteen goundwater samples. Alkalinity is desirable in one groundwater sample, permissible in ten groundwater samples and non-potable in three groundwater samples. Hardness is desirable in three groundwater samples, permissible in seven groundwater samples and non-potable in four groundwater samples. Chloride is desirable in six groundwater samples, permissible in five groundwater samples and non-potable in three groundwater samples. TDS is permissbile in eight groundwater samples and non-potable in six groundwater samples. Fluoride is permissible in five groundwater samples and non-potable in nine groundwater samples. Iron is desirable in ten groundwater samples and non-potable in four groundwater samples. Ammonia is desirable

in ten groundwater samples and non-potable in four groundwater samples. Nitrite is desirable in thirteen groundwater samples and non-potable in one groundwater sample.Nitrate is desirable in nine groundwater samples and non-potable in five groundwater samples. Residual Chlorine is desirable in seven groundwater samples, permissible in six groundwater samples and non-potable in one groundwater sample. The study is highly useful for planning and monitoring of groundwater for drinking purpose in the study area.

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PERFORMANCE ASSESSMENT OF A UASB REACTOR COUPLED WITH POLYMERIC FILTER MEDIA FOR NUTRIENT REMOVAL

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ABSTRACT

This study investigates the performance of an Up-flow Anaerobic Sludge Blanket (UASB) reactor for the treatment of low-strength domestic wastewater. The polymeric filter medium (PFM) improved the effectiveness of post-treatment. At steady-state, the average COD removal efficiency of UASB reactor achieved by 85.54 ± 6.53%. However, the effluent remains contained in residual nutrients, like total phosphorus (TP) and total Kjeldahl nitrogen (TKN), imposing further treatment. To address this, a polymeric filter medium made of chitosan-agarose cryogels was used, considerably reducing nutrient contents. The optimised experiments revealed that a 20 cm bed height and a flow rate of 100 mL/h bring about the optimum removal performance. The combined UASB-PFM system promotes wastewater treatment by reducing both organic and nutrient loading, providing an attractive option for improving the quality of wastewater prior to release.

No. of Pages: 7 **References: 15**

Keywords: Total Phosphorus; Up-flow Anaerobic Sludge Blanket; Polymeric Filter Media; Total Kjeldahl Nitrogen; Chemical Oxygen Demand; Hydraulic Retention Time.

INTRODUCTION

The upflow anaerobic sludge blanket (UASB) reactor has developed as a reliable and cost-effective wastewater treatment method, especially in low and middle-income countries. The UASB system is an appealing alternative to typical aerobic treatment methods since it consumes less energy, generates less sludge, and recovers biogas [Haandal and Lettinga, 1994; Chamhum et al., 2023]. UASB reactors have been widely used for municipal industrial wastewater treatment in countries such as India, Brazil, and Colombia for decades, displaying excellent efficiency in chemical oxygen demand (COD) removal and organic matter degradation [Chernicharo et al., 2006; Aslam and Sekerdag, 2008]. Despite its efficacy in organic matter dissolution, UASB reactor effluents contain significant levels of nutrients such as TP and TKN, which must be treated before discharge into the environment. Usually, oxidation and maturation ponds have been used as post-treatment therapies; however, these methods need large amounts of land, making them impracticable in urban environments [Aiyuk et al., 2006; Foresti, 2002; Hasan et al., 2021]. To overcome these limitations, researchers have focused on developing alternative post-treatment methods, such as polymeric filter media (PFM) constructed from chitosan-agarose cryogels.

Chitosan, a biopolymer derived from chitin, is widespread due to its biocompatibility, biodegradability, and high nutrient adsorption capabilities. The use of chitosan-based cryogels as a

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PFM for treatment of wastewater has been studied as a promising technique for enhancing phosphorus and nitrogen removal efficiency from UASB [Foresti et al., 2006; Khalidi et al, (2023)]. The inter-connected porous structure of cryogels allows for a wide surface area and quick mass transfer, making them ideal for nutrient trapping and removal efficiency. Moreover, the mechanical strength of these cryogels renders them appropriate for continuous treatment operations with minimum deterioration [Tandukar et al., 2002; Shamshad et al., 2025]

The current study explored the efficacy of UASB reactors combined with a polymeric filter medium for the treatment of domestic wastewater. The study aimed to optimize reactor conditions, evaluate nutrient removal performance, and determine the feasibility of replacing standard post-treatment techniques with PFM technology. Fixed-bed column tests were carried out with varying bed heights and flow rates to determine the adsorption capacity of chitosan-agarose cryogels for nitrogen and phosphorus removal [Bhatt et al. 2007; Berillo et al., 2024].

According to the above findings, the present research contributed to a more efficient and space-saving post-treatment system for UASB reactor effluents, providing a long-term solution for wastewater management. Combining UASB technology with unique PFM post-treatment overcomes limitations in typical wastewater treatment technologies, particularly nitrogen and phosphorous removal in metropolitan areas with limited space.

1. Methodology

2.1 UASB Reactor Setup and Operation

A laboratory scale The Up-flow Anaerobic Sludge Blanket (UASB) reactor was designed and used to treat synthetic wastewater over 758 days. The reactor was built with a borosilicate glass cylindrical column that has an internal diameter of 70 mm, a functional height of 850 mm, and an operational volume of 3.269 L. It had six sampling ports at various heights, allowing for thorough monitoring of process parameters.

Startup and Hydraulic Conditions

The reactor was turned on at a low flow rate of 50 mL/h to allow for microbial acclimation and sludge granulation. To attain steady-state conditions, the flow volume was gradually increased over a 100-day period to 500 mL/h. At this flow rate, the time of hydraulic retention was 6.53 hours, and the up-flow velocity was 0.13 m/h.

The study maintained the influent COD concentration at 200 ± 25 mg/L, ensuring a consistent organic loading rate (OLR) suitable for anaerobic digestion.

Characteristics of Influent and Effluent

In order to encourage microbial growth, the synthetic wastewater employed in this study contained a variety of essential nutrients and minerals. The composition of synthetic wastewater included $NaHCO_3$, $CaCl_2$, KH_2PO_4, K_2HPO_4, NH_4Cl, $FeCl_3$, ZnCl2, $CoCl_2$, $MgCl_2$, and sucrose in specified concentrations. The characteristics of wastewater were as, Total COD (mg/L) 200.64 ± 25.59, Alkalinity (mg/L as $CaCO_3$) 500.5 ± 40.8, pH 7.15 ± 0.39,

The effluent quality parameters, including COD removal efficiency, alkalinity, volatile fatty acids (VFA), and pH, were continuously monitored to assess the reactor's performance. The pH of the reactor was maintained at 7.4 ± 0.03 during the steady-state condition.

Sludge Granulation and Biogas Recovery

The formation of granular sludge was observed, enhancing substrate utilization and biomass retention. Gas bubbles generated in the system facilitated internal mixing within the sludge bed, improving treatment efficiency. The biogas production was monitored using a liquid displacement method, with an average methane production of 400 ± 150 mL/d in the steady-state period.

Experimental Setup Schematic

Figure 1 illustrates the schematic diagram of the UASB reactor utilized in the experimental setup design. The diagram provides a detailed illustration of the reactor's structural components and operational parameters, serving as a reference for its configuration and functionality in the study.

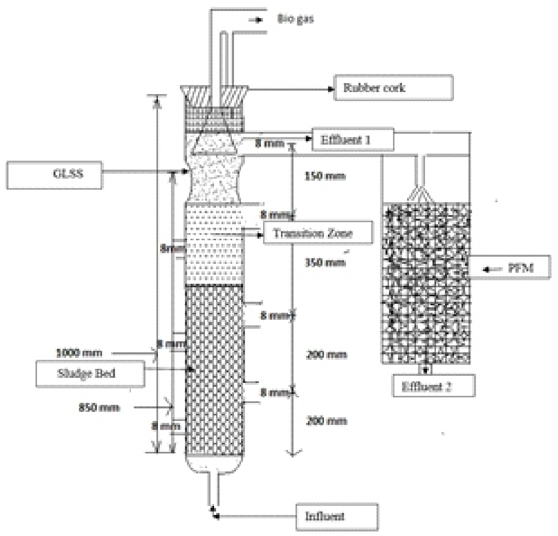

Fig. 1: Lab-scale UASB reactor designed for experimental studies.

2.1 Polymeric Filter Media Treatment

The post-treatment used Chitosan-Agarose Cryogels (CA Cryogels) as polymeric filter media. The column heights (10 cm, 15 cm, and 20 cm) with a 2 cm diameter were evaluated at flow rates of 100-500 mL/h to determine optimal nutrient removal conditions.

2.2 Analytical Techniques

The levels of COD, TP, and TKN were analyzed following the APHA Standard Procedures (2005) [APHA, 2005]. COD was examined by the Closed Reflux Titration Process, where wastewater samples were digested with dichromate reagent at 150°C for 2 hours and titrated using Ferrous Ammonium Sulphate (FAS) with Ferroin indicator to quantify oxidation levels. The Stannous Chloride Method was used to quantify TP. In acidic conditions, phosphate reacts with ammonium molybdate reagent to form molybdophosphoric acid, which then gets reduced to molybdenum blue and measured at 690 nm using a UV-Vis Spectrophotometer. The Kjeldahl Procedure was used to estimate TKN, which consisted of acid digestion, NaOH neutralization, and ammonia distillation, subsequently performing sulfuric acid titration to determine nitrogen content. The content of biogas was determined using gas chromatography (GC) and a thermal conductivity detector. This method allowed for the precise identification and characterization of gas components such as methane and CO2.

The GC-TCD system produced precise and reliable results, allowing for a detailed assessment of biogas composition for experimental purposes. The biogas was injected into a Shimadzu GC-2014 with a Porapak Q column at a flow rate of 30 mL/min, using high-purity nitrogen as the carrier gas. The methane and carbon dioxide peaks were discovered using retention times and calibration standards.

Table 1: Different parameters and methods used for the analysis.

Parameter	Method	Instrumentation
COD	Closed Reflux, Titration	Spectrophotometer
TP	Stannous Chloride	UV-Vis Spectrophotometer
TKN	Kjeldahl	Titration
Biogas	Gas Chomatography	GC with TCD Detector

1. RESULTS AND DISCUSSION

3.1 UASB Reactor Performance

To reduce sludge washout, the reactor may not be started at the initial flow rate (500 mL/h). Therefore, the reactor was started at 50 mL/h of flow rate and increased step by step to achieve the target flow rate as shown in time series plot, Fig.2. Subsequently the Organic Loading Rate (OLR) also increased in accordance with flow rate. The reactor achieved a steady-state condition in 100 days. During steady state conditions the reactor was operated at a constant flow rate of 500 mL/h which resulted in a time of hydraulic retention of 6.53 hs. Under steady-state conditions, the influent COD concentration was 200±25 mg/L, with an organic loading rate (OLR) of 0.731±0.163 kg COD/m^3/day.

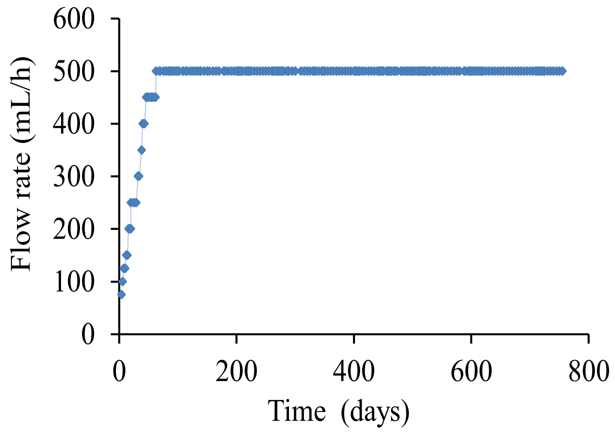

Fig. 2 Variation of flow rate from starting to targeted flow rate condition.

Efficiency of COD Removal

The efficiency of COD removal increased to about 60% in 50 days and continued to improve till the achieving steady state condition. The time series of COD removal is represented in Fig.3. The total COD removal efficiency was 70.65±9.5, 80.56±6.52 and 85.54±6.53 % at HTs of 10.89, 8.17 and 6.5 h, respectively. The COD removal efficiency stabilized between 90 and 100 days of reactor operation. Under steady-state conditions, a total COD (TCOD) removal efficiency of 85.54±6.53% was achieved at a hydraulic retention time (HT) of 6.5 hours.

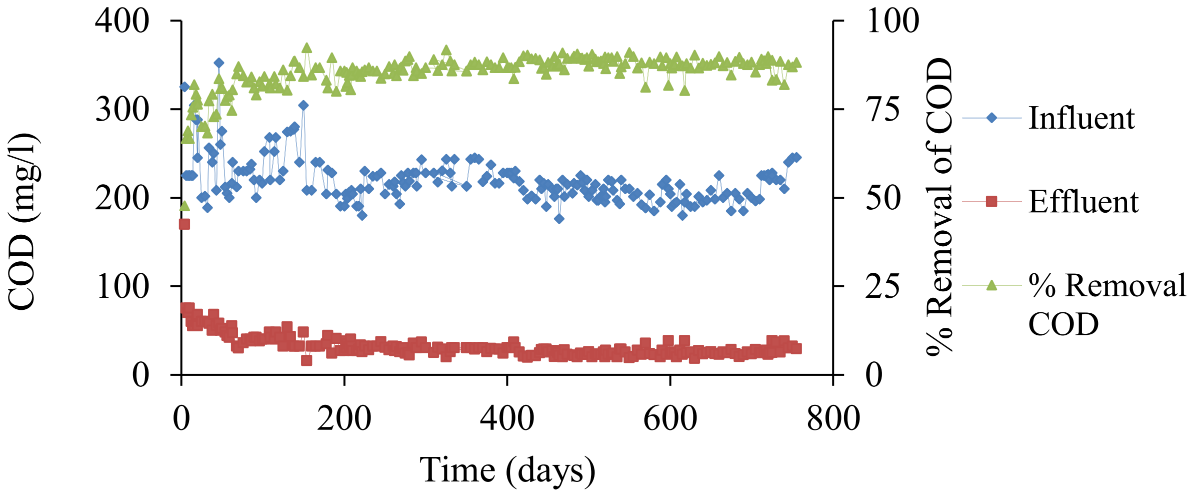

Fig. 3: Percentage variation of COD Removal Efficiency, Influent COD, and Effluent COD.

pH Stability

During the operational condition of the UASB reactor, pH at the steady state condition was 7.4±0.03 as shown in Fig.4. The range of influent pH was of 7.15±0.398. The pH of effluent of the UASB reactor varied between 7.0±0.50 which is the typical range for anaerobic processes.

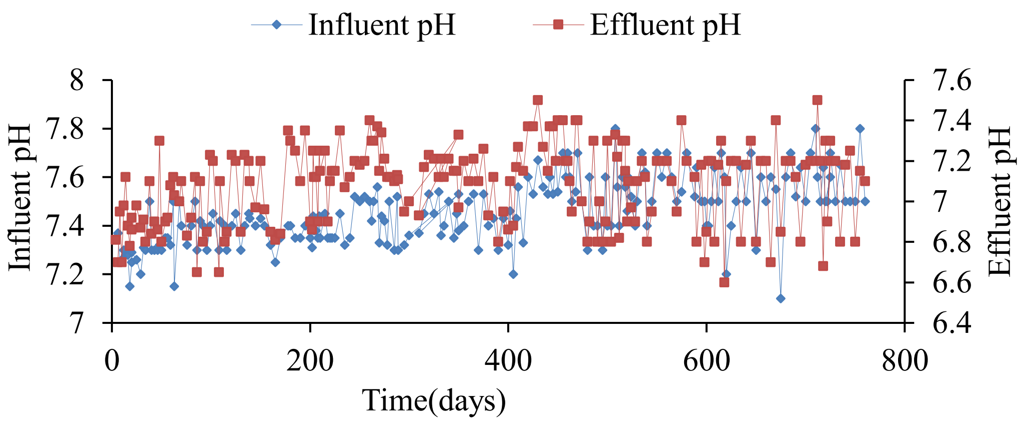

Fig. 4: Time series of pH of influent and effluent in the reactor.

Biogas Production

The biogas (CH_4 & CO_2) was collected and measured though liquid displacement method. At the initial stage of 15 days after the beginning of reactor, the formation of gas was recorded as negligible, however, after 15 days the gas production reached to measurable amount. Fig.5 shows the biogas production during the whole studies. From the figure, gas production gradually increased during the start-up period and remained stable during the steady-state phase. In the steady state period, the average production of methane gas was 400±150 mL/d and total biogas production was 650.60±80.5 mL/d.

The formation of methane varies from 200-280 mL of CH_4/g of COD removal. There are mainly two factors, (OLR & HRT) that are responsible for the formation of biogas and removal of COD. The formation of methane gas was 75.5±10.25% and carbon dioxide gas was 25±10.5 at the optimum temperature (30±5^{o}C) and HRT of 6.5h which is reflected in Fig.6.

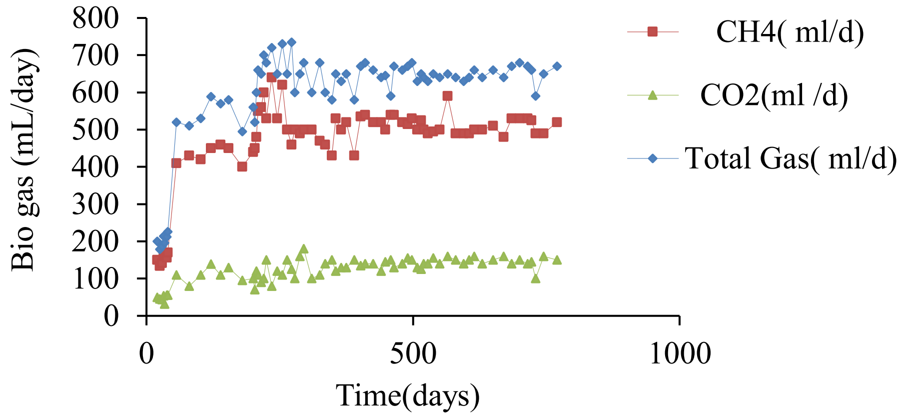

Fig. 5: Production of Methane, Carbon dioxide and Total biogas during the entire Study.

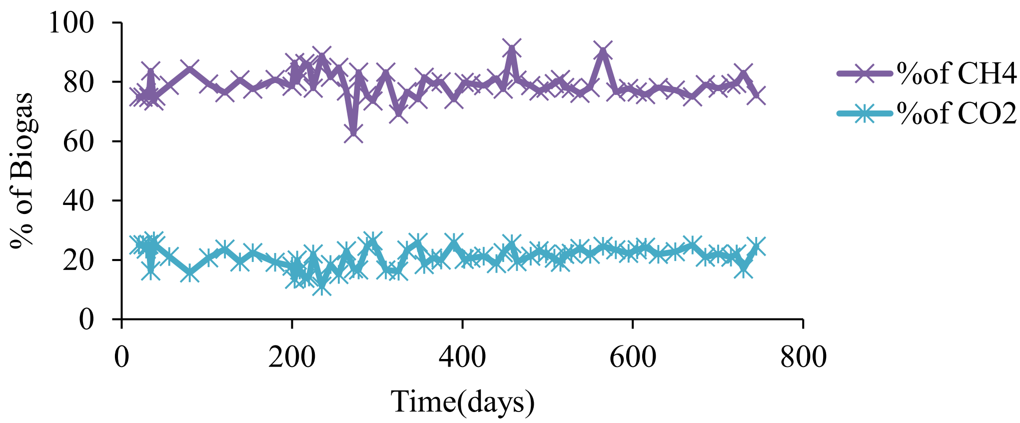

Fig. 5: Production of Methane, Carbon dioxide and Total biogas during the entire Study.

3.1 Post-Treatment Performance

Total Phosphorus (TP) Removal

The optimum adsorption capacity (q) was enhanced with a higher volumetric flow but decreased as bed height increased. The high regression coefficient values suggest that the kinetic data aligned well with the Thomas Model. The Thomas Model provided a strong fit for the experimental data across all examined flow rates, with a correlation coefficient exceeding 0.80, indicating that both the external and internal dispersion were not the limiting factors [Aksu and Gonen, 2004]. Additionally, the rate constant (K_{th}) increased with rising flow rates, suggesting a reduction in mass transport residence time. The initial TP concentration of 16±0.6 mg/L was reduced significantly using CA Cryogels. The highest removal efficiency was achieved with a 20 cm bed height at 100 mL/h.

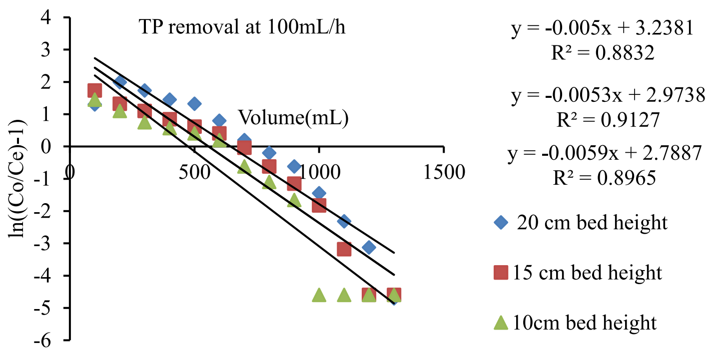

Fig. 7: Thomas kinetic plot for the removal of TP at different bed heights.

Total Kjeldahl Nitrogen (TKN) Removal

The influent TKN concentration of 27±0.5 mg/L decreased effectively, confirming the efficiency of CA Cryogels as a post-treatment.

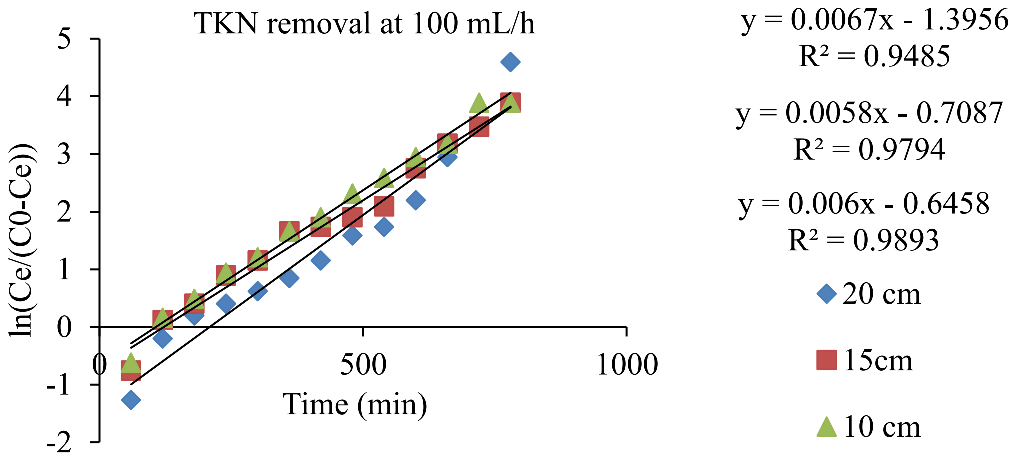

Fig. 8: Thomas kinetic plot for the removal of TKN at different bed heights.

3.1 Impact of Hydraulic Retention Time

The time of hydraulic retention played a critical role in reactor performance. An increase in HRT from 5 to 10 hours led to a 10% improvement in COD removal. However, further increases beyond 12 hours did not yield significant additional benefits.

3.2 Performance Comparison with Conventional Methods

A comparative analysis of the UASB-PFM system with conventional wastewater treatment methods like activated sludge process (ASP) and oxidation ponds highlighted the advantages of polymeric filter media in reducing land footprint, operational costs, and energy consumption. The anaerobic process combined with polymeric adsorption provided superior nutrient removal compared to conventional aerobic systems.

3.3 Granulation and Sludge Bed Stability

The sludge bed stability played a crucial role in reactor performance. A well-developed granular sludge bed was formed, with an average particle size of 1.5 mm. The granulation process was enhanced through the addition of bio-stimulants, reducing the start-up period from the usual 90 days to approximately 60 days.

3.4 Biogas Composition

The methane content of biogas increased steadily, reaching a peak of 80% after 150 days of operation. The CO2 content was maintained at an average of 15%, indicating efficient microbial activity.

4. Conclusion

The column study was done in thee-bed height (20,15,10cm) and five flow rates (100-500 mL/h) to test the efficiency of removal of TP, TKN, and TCOD by using CA cryogels at different time intervals. Out of different combinations of bed heights and flow rates, the best result was obtained at 20 cm bed height and 100 mL/h flow rate.

At 20 cm of bed height, 2cm diameter of CA cryogel &100 mL/h flow rate of Effluent I (Effluent of UASBR), The TP, TKN and TCOD removal efficiency was found initially (first hour) 87±5.5, 75±3.5% and 91.5±1.5 respectively but decreases with time of operation and at the end of the 13h of experiments the efficiency falls to 5±3.8, 4.5±2.5 and 89±3.4 respectively.

Nomenclature

COD – Chemical Oxygen Demand
TCOD – Total Chemical Oxygen Demand
TP – Total Phosphorus
TKN – Total Kjeldahl Nitrogen
OLR – Organic Loading Rate
HT – Hydraulic Retention Time
UASB – Up-flow Anaerobic Sludge Blanket
K_{th} – Thomas Model Rate Constant

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ASSESSMENT OF GLOBAL ENVIRONMENTAL HEALTH THROUGH THE LENS OF CLIMATE CHANGE

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ABSTRACT

Climate Change refers to long-term alterations in temperature, precipitation, wind patterns, and other aspects of the Earth's climate system. These changes are driven largely by human activities, particularly the burning of fossil fuels, deforestation, and certain industrial processes, which release greenhouse gases. Climate Change brings impacts such as rising sea levels, more intense and frequent extreme weather events, shifting ecosystems, and threats to biodiversity. Climate Adaptation, Mitigation, and Resilience are critical strategies to address and manage the impacts of climate change and discussed in this paper with different examples. Climate Mitigation involves efforts to reduce or prevent the emission of greenhouse gases to limit the extent of climate change. Mitigation aims to slow down global warming and minimize future impacts on natural and human systems. Climate Adaptation is the process of adjusting systems, practices, and policies to withstand the current and anticipated impacts of climate change. It involves modifying infrastructure, improving water management, adopting climate-resilient agricultural methods, and planning for climate-resilient cities. Climate Resilience refers to the ability of systems—such as communities, economies, and ecosystems—to recover from and adapt to climate-related shocks and stresses. Building resilience involves strengthening institutions, improving risk assessments, implementing early warning systems, and fostering adaptive capacity. It encompasses both adaptation and mitigation efforts to create societies that can sustain themselves despite the challenges posed by climate change. This article attempts to understand how mitigation addresses the causes of Climate Change, adaptation tackles the impacts, and resilience builds the capacity to endure and recover from climate-related disruptions.

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INTRODUCTION

Climate change refers to long-term shifts and alterations in temperature and weather patterns, primarily caused by human activities (McNutt, 2013). These activities include the burning of fossil fuels, deforestation, and industrial processes, which release large amounts of greenhouse gases like carbon dioxide and methane into the atmosphere (McNutt, 2013; Oberthür, 2016). These gases trap heat, leading to a warming effect known as the greenhouse effect. The consequences of climate change include more frequent and severe weather events, rising sea levels, and disruptions to ecosystems and biodiversity Climate change has a significant global impact for

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several reasons (Oberthür, 2016). Global temperatures are increasing, leading to more frequent and severe heat waves, which can cause health problems and reduce agricultural productivity. Melting glaciers and polar ice caps contribute to rising sea levels, which can lead to coastal flooding and erosion, threatening coastal communities and ecosystems. Climate change increases the frequency and intensity of extreme weather events such as hurricanes, floods, droughts, and wildfires, causing widespread damage and displacement (Bošnjaković, 2012; McNutt, 2013).

Changes in temperature and precipitation patterns can disrupt ecosystems, leading to loss of biodiversity and altering the distribution of species, which can impact food security and livelihoods. Increased CO^2 levels are causing oceans to become more acidic, affecting marine life, particularly organisms with calcium carbonate shells or skeletons, such as corals and shellfish (McNutt, 2013). Changes in climate can alter growing seasons, reduce crop yields, and increase the prevalence of pests and diseases, threatening food security. Climate change can exacerbate health issues by increasing the spread of diseases, causing heat-related illnesses, and impacting mental health due to stress from extreme weather events and displacement (Hitz and Smith, 2004). The economic impact of climate change includes damage to infrastructure, increased insurance costs, and loss of productivity, all of which can strain economies, especially in vulnerable regions. Resource scarcity, displacement, and competition for resources can lead to social and political tensions, potentially exacerbating conflicts and leading to migration (Bošnjaković, 2012). The interconnected nature of these impacts means that climate change is a global issue that requires coordinated international efforts to mitigate and adapt to its effects.

Geopolitics of Climate Change

The geopolitics of climate change refers to how global political and economic relations are influenced by the impacts of climate change and the efforts to mitigate and adapt to it. Climate change can alter the availability and distribution of natural resources like water, arable land, and fossil fuels, leading to potential conflicts or cooperation over these resources (Bošnjaković, 2012). Countries vary in their contributions to and impacts from climate change. This can affect international relations, trade policies, and economic stability, with vulnerable countries often seeking reparations or assistance from more developed nations. Climate change can cause displacement due to extreme weather events, sea-level rise, and resource scarcity, leading to migration that can strain political and social systems in receiving areas, potentially causing conflicts (Hitz and Smith, 2004). Climate change requires coordinated global action, leading to international agreements like the Paris Agreement. These agreements can shift geopolitical alliances and power dynamics as countries negotiate their responsibilities and contributions (WHO, 2014). The move towards renewable energy and the reduction of carbon emissions can shift geopolitical power from fossil fuel-rich nations to those leading in green technologies, impacting global energy markets and political alliances. Many nations view climate change as a threat to national security, influencing defence strategies and international military cooperation. Understanding these dynamics is crucial for developing effective policies and strategies to address the multifaceted challenges posed by climate change on a global scale.

Policies associated with Climate Change at global, regional and local levels

Policies addressing climate change span global, regional, and local levels, with each level focusing on specific aspects of mitigation and adaptation strategies (Hitz and Smith, 2004; Barnett, 2007; Majra and Gur, 2009; Dalby, 2010; Bošnjaković, 2012; Hommel and Murphy, 2013; McNutt, 2013; Streck and Terhalle, 2013; Dalby, 2013, 2015; Oberthür, 2016)

Here's an overview of key policies at each level:

Global Level

Paris Agreement (2015): An international treaty under the United Nations Framework Convention on Climate Change (UNFCCC), aiming to limit global warming to well below 2°C, preferably to 1.5°C, compared to pre-industrial levels.

Kyoto Protocol (1997): A previous international treaty that committed its parties to reduce greenhouse gas emissions, based on the premise that global warming exists and human-made CO2 emissions have caused it.

UN Sustainable Development Goals (SDGs): Goal 13 focuses specifically on taking urgent action to combat climate change and its impacts.

Regional Level

European Green Deal (EU): A set of policy initiatives by the European Commission with the overarching aim of making Europe climate-neutral by 2050.

North American Climate, Clean Energy, and Environment Partnership (USA, Canada, Mexico): A collaboration to reduce greenhouse gas emissions, promote clean energy, and enhance environmental cooperation.

African Union Agenda 2063: Includes initiatives to address climate change and promote sustainable development in African countries.

Local Level

Climate Action Plans (CAPs): Many cities and municipalities develop CAPs to reduce local greenhouse gas emissions and adapt to climate change impacts. For example, New York City's Climate Mobilization Act.

Renewable Energy Mandates: Local governments may set requirements for renewable energy use in new buildings, such as California's Solar Mandate.

Urban Green Spaces Initiatives: Local policies promoting the creation and maintenance of green spaces to enhance resilience to climate change, like London's Green Infrastructure Plan.

Key Policy Instruments

These three policies are part of a multi-tiered approach necessary to address the complex and global nature of climate change effectively (Barnett, 2007; Dalby, 2013, 2015).

Carbon Pricing: Includes carbon taxes and cap-and-trade systems to incentivize emission reductions.

Renewable Energy Standards: Mandates or incentives for renewable energy generation.

Energy Efficiency Standards: Regulations for buildings, appliances, and industrial processes to improve energy efficiency.

Climate Resilience Planning: Strategies to enhance the resilience of infrastructure and communities to climate impacts.

Current scenario of global climate change looks and it's future directions

The current scenario of global climate change presents several concerning trends and impacts

Global temperatures have been steadily increasing, leading to heat waves, altered weather patterns, and melting polar ice caps (McNutt, 2013). There's an increase in frequency and intensity of extreme weather events such as hurricanes, floods, and droughts. Melting glaciers and thermal expansion of seawater are causing sea levels to rise, threatening coastal communities (Dalby, 2015). Habitats are changing faster than many species can adapt, leading to biodiversity loss and ecosystem disruptions. Climate change exacerbates social and economic inequalities, affecting vulnerable populations disproportionately. Future directions depend heavily on global efforts to mitigate and adapt to climate change (Majra and Gur, 2009). Reduction of greenhouse gas emissions through international agreements, technological innovations, and shifts towards renewable energy sources are urgently needed. According to Dalby (2014) developing resilience in infrastructure, agriculture, and communities to cope with the impacts that are already inevitable; hence strengthening policies and regulations at local, national, and global levels to address climate change comprehensively should be prioritized. The future will be shaped by how effectively nations collaborate and implement solutions to mitigate climate change while adapting to its unavoidable consequences (Hommel and Murphy, 2013).

Serious Lack of Political Will

The issue of Climate Change often intersects with political will, where decisions made by governments and policymakers can significantly impact efforts to mitigate its effects. Factors such as economic interests, short-term political gains, and differing priorities among nations can all influence the level of commitment towards addressing climate change on a global scale. Efforts like international agreements (e.g., the Paris Agreement) aim to foster cooperation, but challenges remain in aligning diverse political agendas with long-term environmental goals (Streck and Terhalle, 2013; Dalby, 2010). The lack of strong political will behind global climate mitigation efforts can be attributed to several factors. Addressing these challenges requires sustained public advocacy, international cooperation, technological advancements, and policy innovations to overcome inertia and prioritize effective climate action (Dalby 2013, 2015).

1. **Short-term vs. Long-term Priorities:** Politicians often prioritize issues that yield immediate benefits or are more visible to voters over long-term and often less tangible environmental concerns.
2. **Economic Considerations:** Mitigating climate change requires significant investments in

renewable energy, technology upgrades, and infrastructure changes, which can be perceived as costly and may impact short-term economic growth.

3. **Political Interests and Pressure:** Industries that contribute to greenhouse gas emissions often have significant political influence, lobbying against regulations that could affect their profitability or competitiveness.
4. **Global Coordination Challenges:** Climate change is a global issue that requires cooperation among nations, but achieving consensus on targets and actions can be challenging due to differing economic priorities, development stages, and historical responsibilities.
5. **Public Opinion and Awareness:** While awareness of climate change has grown, it may not always translate into consistent voter pressure on politicians to prioritize climate policies over other issues.
6. **Policy Uncertainty:** Changing political landscapes and short-term policy cycles can lead to uncertainty in long-term climate policy frameworks, making it harder to implement and sustain effective mitigation measures.

COP initiative and Climate Change

The COP (Conference of the Parties) initiative is the main decision-making body of the United Nations Framework Convention on Climate Change (UNFCCC). It involves annual meetings where countries come together to negotiate and assess progress in addressing climate change (Painter, 2018; De-Lara et al., 2022). These conferences aim to review the implementation of the UNFCCC, the Kyoto Protocol, and the Paris Agreement, and to promote strategies for reducing greenhouse gas emissions and adapting to climate impacts. COP meetings are crucial for setting international climate policies and targets (De-Lara et al., 2022).

Major successes and failures of COP with respect to Climate Change

The Conference of the Parties (COP) under the United Nations Framework Convention on Climate Change (UNFCCC) has had numerous successes and failures over the years (Hjerpe and B.-O. 2010). Here are some key points:

Major Successes:

Paris Agreement (COP21, 2015): A landmark agreement where 196 parties committed to limit global warming to well below 2°C, with efforts to limit it to 1.5°C. Countries agreed to submit nationally determined contributions (NDCs) and update them every five years (Mace, 2005).

Kyoto Protocol (COP3, 1997): Established legally binding emission reduction targets for developed countries. Created mechanisms like carbon trading, clean development mechanism (CDM), and joint implementation (JI) (Christoff, 2008). Financial Commitments: Green Climate Fund (GCF) was established to support developing countries in adaptation and mitigation practices (COP16, 2010). Pledge to mobilize $100 billion per year by 2020 for climate action in developing countries (COP15, 2009).

Technological and Capacity Building Support: Establishment of the Technology Mechanism to enhance the development and transfer of climate technologies (COP16, 2010).

Major Failures:

Implementation Gaps: Many countries have struggled to meet their emission reduction targets, and the overall global emissions have continued to rise (Parker et al., 2012).

Lack of Ambition: Some NDCs are not ambitious enough to meet the 1.5°C or 2°C targets, leading to criticism that the Paris Agreement alone is insufficient (Ivanova, 2016).

Withdrawal and Non-Participation: The U.S. withdrawal from the Paris Agreement under the Trump administration (later rejoined under Biden) highlighted the vulnerability of international agreements to domestic politics (De-Lara et al., 2020). Insufficient Financial Contributions: The $100 billion annual climate finance target has not been fully met, and there are concerns about the transparency and effectiveness of the funds allocated (Mace, 2005).

Adaptation and Loss and Damage: Slow progress on addressing loss and damage and providing adequate support for adaptation in vulnerable countries. Despite these challenges, the COP process has been crucial in maintaining global attention on climate change and fostering international cooperation. The ongoing negotiations and commitments continue to play a vital role in addressing the climate crisis (Ivanova, 2016; De-Lara et al., 2020).

Climate Change Mitigation

Climate Change mitigation refers to efforts to reduce or prevent the emission of greenhouse gases into the atmosphere. The goal is to limit the magnitude and rate of long-term climate change (Anita et al., 2010). Mitigation strategies can be of multidimensional nature and dynamics. One the important step is reducing greenhouse gas emissions. This involves cutting down emissions from various sources like burning fossil fuels for energy, industrial processes, and deforestation (Bahadur et al., 2013; Demski et al., 2017). Secondly, enhancing the carbon sinks by increasing the capacity of forests, oceans, and soil to absorb CO from the atmosphere.

Switching to renewable energy sources (such as wind, solar, and hydroelectric power instead of fossil fuels); and improving energy efficiency by enhancing the efficiency of buildings, transportation, and industries to use less energy for the same output (McEvoy et al., 2013). By adapting to practices that can successfully reduce emissions from agriculture and forestry and increase carbon sequestration in trees and soil, it is possible to prevent Climate Change. These actions are essential to slow down global warming, reduce its impacts, and ensure a sustainable environment for future generations (Demski et al., 2017).

Climate Change Mitigation through Sustainable Approaches

Mitigating climate change involves a combination of strategies that reduce greenhouse gas emissions and enhance carbon sinks. Combining these strategies can significantly mitigate the impacts of climate change and contribute to a sustainable future (Anita et al., 2010; Bahadur et al., 2010, 2013; Gifford, 2011; McEvoy et al., 2013; Chen et al., 2017; Demski et al., 2017; Tang, 2019).

Some key strategic approaches are mentioned below:

Renewable Energy: Transitioning from fossil fuels to renewable energy sources like solar, wind, hydro, and geothermal power.

Energy Efficiency: Improving energy efficiency in buildings, transportation, and industries to reduce overall energy consumption.

Reforestation and Afforestation: Planting trees and restoring forests to absorb CO2 from the atmosphere.

Sustainable Agriculture: Implementing practices that reduce emissions from agriculture, such as improved crop rotation, reduced tillage, and better manure management.

Carbon Capture and Storage (CCS): Developing technologies to capture CO2 emissions from industrial sources and store them underground.

Transportation: Promoting electric vehicles, public transportation, cycling, and walking to reduce emissions from the transportation sector.

Policy and Regulation: Implementing policies and regulations that limit emissions, such as carbon pricing, emissions trading systems, and stricter emission standards.

Reducing Waste: Minimizing waste through recycling, composting, and reducing single-use plastics to lower methane emissions from landfills.

Behavioural Changes: Encouraging changes in individual behaviour, such as reducing meat consumption, conserving energy, and supporting sustainable products.

Research and Innovation: Investing in research and development of new technologies and methods for reducing emissions and adapting to climate impacts.

Challenges for Successful Climate Change Mitigation

Mitigating climate change involves a complex array of serious challenges that act as a wall against successful ground level implementation of Climate Change mitigation strategies (McEvoy et al., 2013). Transitioning to renewable energy and green technologies requires significant investment. Developing countries, in particular, may struggle with these costs (Bahadur et al., 2013). Achieving international consensus and cooperation is difficult. Different countries have varying interests, priorities, and levels of commitment to climate action. While renewable technologies are advancing, there are still technological hurdles to overcome, such as energy storage and grid integration for renewable resources (Demski et al., 2017). Existing infrastructure is largely built around fossil fuels. Shifting to renewable energy requires substantial changes to this infrastructure. Effective climate action often requires significant changes in consumer behaviour and lifestyle, which can be challenging to implement and sustain (Bahadur et al, 2010).

Enacting and enforcing policies that reduce greenhouse gas emissions can be politically and administratively challenging. Climate Change disproportionately affects vulnerable populations; hence, ensuring that mitigation efforts are fair and adds complexity to the issue (Duarte et al., 2013). Scientific and technical uncertainties like predicting the precise impacts of climate change and the effectiveness of various mitigation strategies involves uncertainties. Industrial Resistance: Industries reliant on fossil fuels often resist change due to potential economic losses. Gaining widespread public support and understanding of climate change and necessary actions is a continuous challenge (Anita et al., 2010).

Net Zero

"Net Zero" refers to achieving a balance between the amount of greenhouse gases produced and the amount removed from the atmosphere (Davis et al., 2018). Specifically, it means reducing greenhouse gas emissions to as close to zero as possible and balancing any remaining emissions by offsetting them with an equivalent amount of carbon removal or offsetting measures, such as reforestation or carbon capture technologies (Rogelj et al., 2021).

Net Zero is important in the context of addressing climate change because greenhouse gases like carbon dioxide (CO2) contribute to global warming and climate disruption (Deutch, 2020). By aiming for Net Zero emissions, countries, businesses, and organizations commit to mitigating their environmental impact and transitioning towards more sustainable practices (Bataill, 2020). Many governments and businesses have set Net Zero targets to combat climate change and limit global temperature rise to less than 2 degrees Celsius above pre-industrial levels, as outlined in international agreements like the Paris Agreement (Fankhauser et al., 2022).

Net Zero: Opportunities and Limitations

Net zero refers to achieving a balance between the amount of greenhouse gases produced and removed from the atmosphere, typically through reductions in emissions and the offsetting of remaining emissions by activities like carbon capture and storage (Voss and Musall, 2012; Davis et al., 2018; Deutch, 2020; Bataill, 2020; Rogelj et al., 2021; Fankhauser et al., 2022). Here are some opportunities and limitations associated with net zero:

Opportunities:

Climate Mitigation: Net zero aims to mitigate climate change by significantly reducing greenhouse gas emissions, thereby slowing down global warming.

Technological Innovation: It drives innovation in clean energy technologies, such as renewable energy sources, energy-efficient technologies, and carbon capture and storage.

Economic Benefits: Transitioning to net zero can create new jobs and economic opportunities in renewable energy sectors and sustainable practices.

Health Benefits: Reductions in air pollution associated with fossil fuel combustion can lead to improved public health outcomes.

Global Cooperation: Promotes international cooperation and agreements to tackle climate change collectively.

Limitations:

Technological Readiness: Some technologies required for achieving net zero, like large-scale carbon capture and storage, are not yet commercially viable or widespread.

Cost: Transitioning to net zero can be costly, especially for industries heavily reliant on fossil fuels. The financial burden may disproportionately affect certain sectors or regions.

Social Equity: The costs and benefits of transitioning to net zero may not be equally distributed across society, potentially exacerbating inequalities.

Behavioural Change: Achieving net zero requires significant changes in consumption patterns and behaviours, which can be challenging to implement on a global scale.

Natural Carbon Sinks: Relying on natural carbon sinks (such as forests and oceans) to offset emissions raises concerns about their capacity and long-term viability.

Overall, while net zero offers a pathway towards addressing climate change, it involves overcoming technological, economic, and social challenges to achieve widespread success (Voss and Musall, 2012).

Can Net Zero be achieved realistically?

Achieving Net Zero is certainly challenging but not impossible. It requires significant changes across industries, technology advancements, policy frameworks, and global cooperation (Rogelj et al., 2021). Many experts believe it's realistically achievable with concerted efforts and innovation, although the exact timeline and feasibility vary depending on the strategies and commitments of different countries and sectors (Deutch, 2020).

The concept of achieving net zero emissions is crucial in the fight against climate change. While it's challenging and requires significant effort globally, it's not inherently a failed objective (Bataill, 2020). Many countries and organizations are actively working towards this goal, setting targets to reduce emissions and offset remaining emissions through various means like reforestation and carbon capture technologies. Success will depend on global cooperation, technological advancements, and policy frameworks that support sustainable practices (Fankhauser et al. 2022).

Green Infrastructure

Green infrastructure refers to natural or nature-based systems designed to provide multiple environmental, social, and economic benefits (Lennon, 2015). It involves integrating natural features and processes into urban planning and development to manage storm water, reduce heat islands, improve air quality, enhance biodiversity, and provide recreational spaces. Examples include green roofs, rain gardens, urban forests, and permeable pavements. Green infrastructure refers to the strategically planned and managed networks of natural lands, green spaces, and other green features designed to provide ecosystem services and support healthy urban environments (Mell, 2008, 2015).

Green infrastructure helps improve air and water quality, reduces urban heat island effects, and supports biodiversity conservation. Access to green spaces promotes physical activity, reduces stress, and enhances mental health among urban residents. It can increase property values, reduce energy costs (e.g., through shading and cooling effects), and lower infrastructure maintenance costs (e.g., by managing storm water naturally). Green spaces serve as gathering places, fostering community interaction and social cohesion (Kambites and Owen, 2006).

Establishing and maintaining green infrastructure can be expensive, especially in densely built urban areas where land is at a premium. Competing land use priorities may hinder the allocation of space for green infrastructure, especially in rapidly growing cities. Green infrastructure requires ongoing care and management to ensure its effectiveness, which can strain municipal budgets and resources. Ensuring the longevity and resilience of green infrastructure in the face of climate change and urban development pressures requires careful planning and adaptation. Addressing these challenges requires integrated planning, stakeholder collaboration, and innovative financing mechanisms to fully realize the benefits of green infrastructure in urban environments (Lennon, 2015).

Can green infrastructure be successfully implemented in poorer countries?

Green infrastructure can be successfully implemented in poorer countries. While it may present challenges such as funding constraints and varying levels of technical expertise, there are several reasons why it can work. Green infrastructure often offers long-term cost savings through reduced energy consumption, improved public health outcomes, and lower maintenance costs compared to traditional infrastructure. Many green technologies can be adapted to local conditions and needs, making them suitable for diverse geographical and economic contexts. There are international initiatives and funding mechanisms aimed at supporting green infrastructure projects in developing countries, enhancing their feasibility (Kambites and Owen, 2006).

Green infrastructure can provide direct benefits to communities, such as cleaner air and water, improved sanitation, and job creation through local implementation and maintenance. It can also contribute to climate resilience by mitigating the impact of extreme weather events and reducing greenhouse gas emissions (Mell, 2008, 2015).. Successful implementation often involves a combination of policy support, capacity building, and collaboration between governments, communities, and international organizations.

Green infrastructure refers to systems and practices that mimic natural processes to manage various environmental issues sustainably. One notable global success in green infrastructure is the city of Copenhagen, Denmark (Mell, 2008, 2015). It has implemented extensive green roofs, rain gardens, and permeable pavements to manage storm water effectively. This approach not only reduces flooding risks but also improves air quality and enhances urban biodiversity. Copenhagen's efforts are a significant example of how integrating green infrastructure into urban planning can create more sustainable and resilient cities (Sinnett et al., 2015).

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Major green infrastructure achievements achieved in third world countries

Third-world countries have made significant strides in green infrastructure despite facing numerous challenges (Sinnett et al., 2015). Many countries have invested in solar, wind, and hydroelectric power to diversify their energy mix and reduce reliance on fossil fuels. Initiatives to plant trees and restore degraded lands have been undertaken to combat deforestation and enhance biodiversity (Lennon, 2015). Implementing sustainable water management practices such as rainwater harvesting, water recycling, and efficient irrigation systems to conserve water resources (Monteiro et al., 2020).

Construction of eco-friendly buildings that utilize energy-efficient designs, materials, and technologies to reduce carbon foot print; along with the improvement in waste management systems through recycling, composting, and waste-to-energy projects to minimize environmental impact can help (Mell, 2008, 2015). Promotion of public transportation, cycling infrastructure, and electric vehicles to reduce air pollution and greenhouse gas emissions are urgent needs (Sinnett et al., 2015). . The development and implementation of policies, regulations and incentives to support green infrastructure investments and sustainable development goals are important points to be considered. These achievements highlight the proactive efforts of third-world countries to address environmental challenges and promote sustainable development despite facing economic constraints (Mell, 2008, 2015).

Mitigating Climate Change

Green infrastructure plays a crucial role in mitigating climate change for several reasons. Plants absorb carbon dioxide (CO_2) during photosynthesis, reducing the concentration of greenhouse gases in the atmosphere (Lennon, 2015). Green infrastructure, such as parks and green roofs, can help lower local temperatures in urban areas by providing shade and evaporative cooling, thus reducing energy consumption for cooling buildings. Vegetation and permeable surfaces can absorb rainwater, reducing runoff and alleviating pressure on drainage systems during heavy rainfall events, which are becoming more frequent due to climate change (Van Oijstaeijen et al., 2020).

Green spaces support diverse ecosystems, preserving habitats for plants and animals that are increasingly threatened by climate change (Lennon, 2015). Trees and plants can filter pollutants from the air, improving overall air quality in urban environments. Overall, integrating green infrastructure into urban planning and landscapes not only helps mitigate climate change by reducing greenhouse gas emissions and energy use but also enhances resilience to its impacts (Wilker et al., 2016).

Climate Change Resilience

Climate resilience refers to the ability of systems, communities, and societies to anticipate, prepare for, respond to, and recover from the impacts of climate change (Thompson et al., 2009). It encompasses a wide range of measures and strategies aimed at reducing vulnerability to climate impacts and enhancing adaptive capacity. Climate resilience is crucial because it helps societies withstand and bounce back from climate-related shocks and stresses, such as extreme weather events, sea-level rise, droughts, and disruptions to ecosystems and economies (Côté and Darling, 2010. By building resilience, communities can better protect lives and livelihoods, ensure food and water security, preserve infrastructure, and maintain economic stability in the face of a changing climate (Cannon and Müller-Mahn, 2010).

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Opportunities and limitations of Climate Change resilience

Climate change resilience presents several opportunities and some limitations (Nyong et al., 2007; Davoudi et al., 2009; Laukkonen et al., 2009; Anita et al., 2010; Gifford, 2011; Chen et al., 2017; Tang, 2019).

Opportunities:

Enhanced Adaptation: Resilience efforts encourage adaptive strategies that can help communities cope with and recover from climate impacts more effectively.

Innovation and Technology: Resilience initiatives drive innovation in technologies, infrastructure, and practices that can mitigate climate risks and improve response capabilities.

Economic Benefits: Investing in resilience can lead to cost savings over time by reducing damage from climate disasters and lowering insurance premiums.

Community Empowerment: Building resilience often involves community engagement and empowerment, fostering social cohesion and capacity building.

Long-Term Sustainability: Resilience measures promote sustainable development practices that benefit both current and future generations.

Limitations:

Resource Constraints: Implementing comprehensive resilience strategies requires substantial financial resources, which may be limited in some regions or communities.

Complexity and Interdependencies: Climate resilience involves interconnected systems, making it challenging to predict and manage all potential impacts and interactions.

Equity Concerns: Vulnerable populations, including low-income communities and marginalized groups, may have limited access to resources and face greater challenges in building resilience.

Political and Institutional Barriers: Lack of political will, institutional capacity, and coordination can hinder effective implementation of resilience measures.

Uncertainty and Changing Conditions: Climate change projections and impacts are subject to uncertainties, making it difficult to accurately assess future risks and plan accordingly.

Overall, while climate resilience offers significant benefits in terms of adaptation and sustainability, addressing its limitations requires concerted efforts at multiple levels, from policy-making to community engagement and international cooperation.

Climate Change Economics

Climate change economics refers to the study of the economic impacts of climate change and the economic aspects of policies and measures to mitigate or adapt to it (Berrang-Ford et al., 2011). It involves understanding how climate change affects economic systems, sectors, and resources, as well as assessing the costs and benefits of various actions to address climate change (Kerr, 2007). This field examines issues such as carbon pricing, investments in renewable energy, adaptation strategies for vulnerable communities and industries, and the economic consequences of climate-related events like extreme weather and sea-level rise (Dinar, 1998; Nordhaus and Boyer, 2003).

Importance of Climate Change Economics

Climate change economics is crucial for several reasons. It helps in efficiently allocating resources to mitigate and adapt to climate change impact (Patz and Olson, 2006). This includes investments in renewable energy, infrastructure resilience, and sustainable practices. Economic analysis informs policymakers on the costs and benefits of different climate policies (Aggarwal, 2003). This includes carbon pricing mechanisms, subsidies for green technologies, and regulations on emissions (Byjesh et al., 2010). It assesses the economic risks associated with climate change, such as damage to infrastructure, agriculture, and health, helping businesses and governments prepare and manage these risks (Soora et al., 2013). Economic incentives drive innovation in clean technologies and practices, accelerating the transition to a low-carbon economy (Byjesh et al., 2010). Understanding the economic impacts of climate change fosters international cooperation in tackling global issues like reducing greenhouse gas emissions and supporting vulnerable populations (Srivastava et al., 2010). It supports long-term planning by businesses and governments, ensuring sustainable development pathways that account for climate risks and opportunities (Aggarwal, 2003). Overall, integrating economics into climate change action is essential for achieving environmental sustainability while promoting economic growth and societal well-being (Ravindranath et al., 2006).

Limitations of Climate Change economics and its drawbacks

Climate change economics faces several limitations and drawbacks. Climate change is a highly complex and uncertain phenomenon, making economic modelling challenging. Uncertainties in future emissions, technological advancements, and climate impacts complicate cost-benefit analysis. Effective climate action requires global cooperation, yet international agreements like the Paris Agreement face challenges in enforcement and commitment (Ravindranath et al., 2006). Economic models often discount future costs and benefits, potentially undervaluing long-term impacts of climate change mitigation and adaptation (Schelling, 1992). Climate policies can have uneven distributional impacts across different regions, industries, and socio-economic groups, leading to concerns about fairness and social equity (Srinivasan, 2012). Economic models may not adequately account for human behaviour, political dynamics, and institutional barriers that influence policy adoption and effectiveness (Kumar and Parikh, 2001).

Traditional economic approaches assume perfect markets, but climate change involves significant market failures like externalities (e.g., carbon emissions) that are not adequately priced. Transitioning to a low-carbon economy requires substantial technological innovation and infrastructure investment, which may not be fully captured in economic models. (Guiteras, R. 2009). Economic analyses often overlook the full value of ecosystem services threatened by climate change, such as biodiversity and natural resources. Addressing these limitations requires interdisciplinary approaches, improved modelling techniques, and policies that integrate social, environmental, and economic objectives effectively Dinar, 1998; Nordhaus and Boyer, 2003).

Food for Thought

The future of climate change is concerning and depends heavily on global action, as well as local and individual efforts. Here's an overview of the major trends and projections if we continue on our current path:

1. Rising Temperatures

Average global temperatures are projected to rise by 1.5°C to 4°C above pre-industrial levels by the end of the century, depending on emission scenarios.

The 1.5°C threshold is critical. Exceeding it may trigger feedback loops (such as melting permafrost releasing methane) that accelerate warming even further.

2. Extreme Weather Events

More intense and frequent weather events, like hurricanes, droughts, floods, and heatwaves, are expected as the climate continues to warm.

Regions that already experience high temperatures could see more heatwaves, and rainfall patterns are likely to shift, causing some areas to become wetter and others drier.

3. Rising Sea Levels

Sea levels are expected to rise due to both melting polar ice and the thermal expansion of oceans as they warm.

By 2100, sea levels could rise between 0.6 and 1.1 meters (2-3 feet) under high-emission scenarios, significantly impacting coastal communities and small island nations.

4. Impact on Ecosystems and Biodiversity

Many species face a high risk of extinction as they struggle to adapt to rapidly changing temperatures and shifting habitats.

Coral reefs, crucial for marine biodiversity, are especially vulnerable, with nearly all reefs projected to experience annual bleaching by the end of the century if emissions aren't curbed.

5. Food and Water Security Challenges

Climate change is expected to disrupt agricultural productivity due to heat stress, changing precipitation patterns, and extreme weather.

Water scarcity will likely worsen in certain regions, particularly areas dependent on glaciers for freshwater or prone to drought.

6. Health Risks

Heat-related illnesses, respiratory issues from air pollution, and the spread of infectious diseases are anticipated to increase.

Vulnerable populations, especially those in low-income areas, will face disproportionate impacts on health.

7. Economic Implications

The economic impacts of climate change are profound, potentially costing the global economy trillions of dollars due to damages from extreme weather, loss of biodiversity, health expenses, and productivity declines.

Potentially Positive Future Scenarios:

If countries adhere to significant emission reduction commitments, such as achieving net-zero carbon emissions by mid-century, warming could be limited to around 1.5°C to 2°C.

Green technologies and renewable energy sources are advancing rapidly, making it increasingly feasible to transition away from fossil fuels.

Adaptation strategies, like building resilient infrastructure and sustainable agriculture, can help mitigate some impacts.

The outcome largely depends on immediate global action to reduce emissions and increase sustainable practices.

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DETERMINATION OF LEAF DUST ACCUMULATION AND ITS EFFECT ON PLANT SPECIES GROWN ALONG NH-30 FROM REWA (M.P.) TO PRAYAGRAJ (U.P.), INDIA.

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ABSTRACT

The present investigation was undertaken to study the dust interception efficiency of the plant species growing along National Highway- 30 from Rewa (M.P.) to Prayagraj (U.P.) India and also in A.P.S. University Rewa campus (as control site).Particulate matter can cause serious health hazard owing to their ability to remain suspended for long period of time and travelling long distances in the atmosphere. Roadside trees can play a significant role in capturing these air suspended pollutants, absorb noise and serve as acoustic screens on busy highways. Result indicated that the dust accumulation pattern in various species was in the order *Calotropis procera* > *Butea monosperma* > *Neolamarkia cadamba* > *Tectona grandis* > *Mangifera indica* > *Azadirachta inica* > *Dalbergia sisso* > *Acacia nilotica* > *Saraca asoca* > *Ficus religiosa*. The highest amount of leaf dust 1.624 mg/cm^2 was recorded in *Calotropis procera* whereas, the lowest dust deposition 0.210 mg/cm^2 was recorded in *Ficus religiosa* at polluted sites. The foliar dust accumulation of selected plants varied due to surface, structure, size, orientation and phyllotaxy of leaves. Higher dust holding capacity was observed for leaves with larger size, wax coated, rough surface and folded margins. Contrarily, leaves with smooth and flat surface, and vertically directed with folded margins accumulated lower dust.

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Keywords: Air Pollution, Dust Deposition, Plants, Micro morphological traits, Rewa.

INTRODUCTION

Outdoor air pollution is a major global public health issue, leading to 6.67 million death world wide and 1.67 million deaths in India annually (Health effects Institute, 2020). Dust is an important abiotic factor and has a key influence on the various plant species. The severe pressure of dust may be responsible for the morphological and biochemical changes in the plant species which further initiated adaptive evolution to merge with the changing environment. Vehicles are the prime source of dust generation for roadside plants. Vehicular exhaust adds up huge amounts of soot particles, smoke poisonous gases (SO_2, NO_2, CO_2, VOCs etc.), Heavy metals and organic molecules on the roads all over the world. All these air pollutants are known to produce adverse effects on the health of plants, animals and humans (Kulshreshtha *et al.*, 2009; Rezaei *et al.*, 2010; Atkinson *et al.* 2012; Singh et al., 2023). In the arid ecosystem due to dryness of soil, the windblown dust is common feature and plays a great role in increasing dust pollution in the environment (Younis *et al.* 2013). Similarly, high-speed vehicles and agricultural as well as other anthropogenic activities also generate too much high dust pollution in the air (Manins *et al.*, 2001; Van Jaarsveld, 2008; Balwan and Saba, 2021; Prakash and

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Verma, 2022). Poor road infrastructure, the frequency of running vehicles in terms wheel determine the rate of dust generation. Pesticides in general also influence the plants and animals in various ways (Prakash and Verma, 2020; Chaudhary et al., 2021). Trees are biomonitors and sinks for air pollutants but better sinking ability comes from trees with high tolerance for air pollution (Yuniati *et al.*, 2024; Mandal *et al.*, 2023; Chowdhury *et al.*, 2022), and dense vegetation could effectively block the penetration of road particulate matter (Zheng *et al.*, 2021; Lukowskie *et al.*, 2020; Roy *et al.*, 2020). Among the evergreen, coniferous plants are an excellent choice for air purification due to the abundant wax layer on the needles, smaller leaves, and more complex shoot structures (Freer-Smith *et al.*, 2005). The ability of leaves to act as dust receptors depends upon their surface geometry, orientation, phyllotaxy, epidermal and cuticle features, leaf pubescence, leaf and branch density, leaf micro morphology (roughness, trichomes and wax), canopy type and plant height (Sgrigna *et al.*, 2015, Burkardt *et al.*, 2010, Rasanen *et al.*, 2013). Smaller plants with short petioles and rough surface accumulate more dust than larger plants with long petioles and smoother leaf surface (Thakar and Mishra, 2010).

MATERIALS AND METHODS

Study Area

The entire study area extended from National Highway -30 from Rewa (M.P.) to Prayagraj (U.P.), geographically Rewa lies between 24°18' and 25°12' north lattitute and 81°2' and 62°18' east longitudes while Prayagraj lies between latitude 24°47' north and 25° north and longitudes 81°19' East and 82°21' east. The total distance of NH-30 between Rewa to Prayagraj is 125 km. both Rewa and Prayagraj have humid subtropical climate, with cold, misty winter a hot summer and a humid monsoon season. The annual mean temperatue of Prayagraj is 26.1°c (79.0°F), monthly mean temperature are 18-29°c (64-84°F) and annual rainfall is 1027mm (40 in) while annual mean temperature of Rewa are 25.1°c (77.1°F) and rainfall here is around 1020 mm/40.2 inch per year. National highway-30 is 5th longest highway of India that stretches for almost 1984.3km and passes through six states, including Uttarakhand, UP, MP, Chhatisgarh, Telangana, Andhra Pradesh, that start from Sitargang in Uttarakhand and ends at Ibrahimpatnam, Vijaywada (Andhra Pradesh). The National Highway-30 is one of busiest route and connecting major tourist places and the district being an education hub and gateway to agriculture to produce is subjected to continuous heavy traffic loads.

Sampling Sites

For conducting studies the whole area was divided into 7 sampling site in which one as control site. (1) S1- Rewa city Bypass (M.P), (2) S2- Mangawa (M.P.), (3) S3- Sohagi (M.P), (4) S4- Chakghat (M.P), (5.) S5-Ghoorpur (U.P), (6) S6- Naini (U.P) and (7) S7- A.P.S University Rewa (MP) (as control site).

Sampling and Analysis of Leaf Dust Deposition

Nearly equal size of 10 leaves from selected tree species growing along different roadsides of the highway, collected from a height of approximately 2 meter (ambient height) within one day to minimize temporal changes as well as in A.P.S. University Campus (as control site) in the month of December 2024. The leaf samples collected in the zip lock plastic bags with lesser wind speed. During collection, samples immediately closed and labeled in preweighted plastic bags to avoid contamination and transported into the laboratory. The dust adhering on the dorsal and ventral surface of leaves was carefully cleaned with the help of fine brush in the same polythene. Again the weight of polythene was taken with the help of electronic balance in order to determine the amount of dust present on the leaf surface.

After cleaning, the leaf area was calculated with the help of graph paper. Each leaf sample out line was drawn on a graph paper and then the number of square was counted in cm^2 to obtain the leaf area. The amount of dust deposited on leaf surface in mg/cm2 was calculated by the following formula (Prajapati and Tripathi, 2008).

$$W = (W_2 - W_1)/a$$

Where W is dust content (mg/cm2), W_1 is initial weight of polythene, W_2 is final weight of Polythene with dust and “a” is total area of leaf (cm^2).

Table 1: Morphological characteristics of selected plants growing along National Highway-30.

S.No	Plant Species	Common Name	Habit	Family Shape	Leaf texture	Leaf	Orientation
1.	*Acacia nilotica*	Babool	Tree	Fabaceae	Elliptical/ Oblong	Smooth & Waxy	Alternate
2.	*Azadirachta inica*	Neem	Tree	Meliaceae	Lanceolate	Medium	Opposite
3.	*Butea monosperma*	Palas	Shrub / Small Tree	Fabaceae	Ovate/ Elliptical	Leathery & Coriaceous	Alternate
4.	*Calotropis procera*	Madar	Shrub/ Small tree	Apocynaceae	Ovate/ Elliptical	Glabrous	Opposite
5.	*Dalbergia sisso*	Sheesham	Tree	Fabaceae	Ovate/ Elliptical	Leathery	Alternate
6.	*Ficus religiosa*	Peepal	Tree	Moraceae	Small elliptic	Glossy & coriaceous	Alternate
7.	*Mangifera indica*	Aam	Tree	Anacardiaceae	Lanceolate	Leathery	Alternate
8.	*Neolamarkia cadamba*	Kadam	Tree	Rubiaceae	Ovate/ Lanceolate	Leathery	Opposite
9.	*Saraca asoca*	Ashoka	Tree	Fabaceae	Oblong/ Elliptic	Glossy	Alternate
10.	*Tectona grandis*	Sagon	Tree	Lamiaceae	Broadly elliptical	Rough & Hairy	Opposite

Table 2: Dust load (mg/cm2) on level of 10 tree species growing along different sites of National Highway-30 Rewa (MP) to Prayagraj (UP) and Control Site.

S. No.	Plant species	S1	S2	S3	S4	S5	S6	S7
1.	*Acacia nilotica*	0.510	0.515	0.520	0.481	0.382	0.401	0.024
2.	*Azadirachta inica*	0.821	0.830	0.854	0.810	0.781	0.801	0.033
3.	*Butea monosperma*	1.483	1.501	1.530	1.432	1.391	1.404	0.048
4.	*Calotropis procera*	1.591	1.602	1.625	1.563	1.501	1.541	0.050
5.	*Dalbergia sisso*	0.642	0.659	0.687	0.638	0.610	0.622	0.029
6.	*Ficus religiosa*	0.305	0.320	0.335	0.291	0.210	0.225	0.020
7.	*Mangifera indica*	0.823	0.935	0.949	0.817	0.801	0.811	0.038
8.	*Neolamarkia cadamba*	1.391	1.402	1.432	1.351	1.291	1.313	0.045
9.	*Saraca asoca*	0.391	0.402	0.421	0.323	0.292	0.301	0.021
10.	*Tectona grandis*	1.301	1.312	1.321	1.283	1.231	1.252	0.040
	Average	0.926	0.948	0.967	0.899	0.849	0.867	0.035

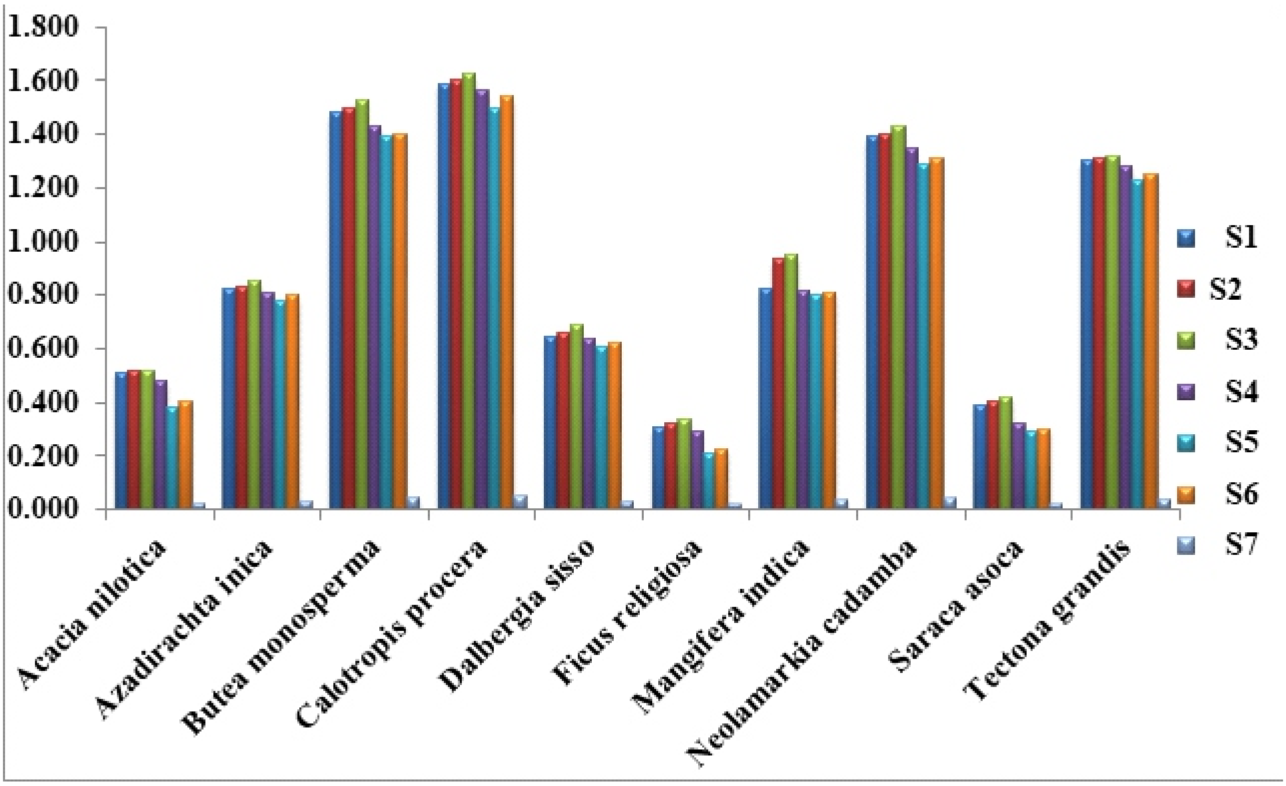

Figure 2: Dust deposition on leaves of selected plant species of sampling sites.

RESULT AND DISCUSSION

Dust deposition on leaves of selected 10 plant species growing along National highway-30 as well as control site are given in Table1. The average maximum dust deposition was observed on the leaf of *Calotropis procera* (1.571 mg/cm^2) growing at polluted sites followed by *Butea monosperma* (1.457mg/cm^2), *Neolamarkia cadamba* (1.363 mg/cm^2), *Tectona grandis* (1.283 mg/cm^2), *Mangifera indica* (0.856 mg/cm^2), *Azadirachta inica* (0.816 mg/cm^2), *Dalbergia sisso* (0.643 mg/cm^2), *Acacia nilotica* (0.468 mg/cm^2), *Saraca asoca* (0.355 mg/cm^2). *Ficus religiosa* (0.281 mg/cm^2) showed lowest average dust deposition on leaves. Result revealed that greater accumulation of dust on leaf of plant species growing along NH-30 of sampling sites maximum at Sohagi (S3)> Mangawan (S2) > Rewa Bypass (S1) > Chakghat (S4) > Naini (S6) > Ghoorpur (S5) as compared to their respective plant of control site (APSU campus). The average dust load was found at S1 (0.926 mg/cm^2), S2 (0.048 mg/cm^2), S3 (0.967 mg/cm^2), S4 (0.899 mg/cm^2), S5 (0.849 mg/cm^2), S6 (0.867 mg/cm^2) and S7 (0.035 mg/cm^2) – control site respectively (Table2). The observed deposition on the plant leaves has provided the information of particulate ambient air pollution in the sampled sites as compared to control site of APSU campus (Figure 2).

Plants growing along National Highway-30 are consistently exposed to dust emitted from various sources. Although dust particles settled everyday on the leaf surface but there is no uniform deposition in all the species. Surface geometry, epidermal and cuticular features of leaves, and height and canopy of the tree influence the capacity of leaves as dust receptors and the phyllotaxy leaf orientation and sessile or semi-sessile nature of leaves in a horizontal direction. Simple leaves are considered to be better dust collectors than the trees having compound leaves (Sett, 2017). Weather condition, direction and speed of wind and exposure time also influence interception capacity of holding plants. These factors may be responsible for variation in dust deposition on the leaves of plant species under present investigation.

The maximum dust holding capacity has been observed for the leaves of *Calotropis procera*, *Butea monosperma*, *Neolamarkia cadamba*, *Tectona grandis*, *Mangifera indica*, *Azadirachta inica*, *Dalbergia sisso*, *Acacia nilotica*, *Saraca asoca* and *Ficus religiosa* at polluted sites. Large surface area and texture of leaf surface of these species may be attributed for holding the maximum dust particles. Higher dust accumulation in *Calotropis procer, Butea monosperma*, *Neolamarkia cadamba* may be due to rough and leathery leaf surface and short petiole, while in *Tectona grandis* may be due to large and rough leaf surface. In case of *Mangifera indica*, *Azadirachta inica*, it may be due to their waxy coating on leaves with slightly folded margin. In *Dalbergia sisso*, *Acacia nilotica* less dust deposition occurs may be due to small leaf surface and in *Saraca asoca* due to smooth leaf surface, vertical orientation & long petiole less dust deposition occurs. The lowest dust deposition in *Ficus religiosa* could be attributed to its smooth leaves with flat leaf surface and more flattering of leaves with wind movement due to long petiole. Although the observation on seasonal variation in foliar dust accumulation have not been a part of this study but the seasonal influence on dust deposition in plant leaf has been a subject of various recent studies (Bhaskar and Mehta, 2010, Guttikunda and Jawahar, 2011, Malandrino, *et al*., 2013, Nair *et al*., 2014, Salvador *et al*., 2012, Xu *et al.,* 2018). Singh *et al.* (2023) Singh and Tiwari (2025) have observed the Higher concentration of particulate matter accumulation was noticed during winter season (due to low temperature, wet surface of leaves that help in particulate matter capturing) followed by summer (due to high temperature and strong wind speed) and lowest in rainy season (due to washing leaves).

CONCLUSIONS:

This study concludes that accumulation of dust on the leaf of plant species indicates the presence of considerable amount of dust in the amount of ambient air near National Highway. It is further conclude that dust accumulation varies with structure, phyllotaxy, size of particle, presence/absence of hairs, and wax on leaf surface of selected plants. Plants leave with wax coating and rough surface with folded margins accumulate more dust than leaves with vertically oriented, smooth, flat surface without folded margins. Thus plants can serve as an indicator of dust pollution and the plants can be used in the abatement of dust pollution by acting as natural filters.

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A REVIEW STUDY ON BIODIVERSITY OF EASTERN HIMALAYA AND ITS CONSERVATION STRATEGIES

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ABSTRACT

The Eastern Himalaya is one of the most ecologically diverse regions on Earth, serving as a critical biodiversity hotspot with high levels of endemism. Spanning northeastern India, Bhutan, south eastern Tibet, and northern Myanmar, this region harbors thousands of plant and animal species, many of which are endangered. However, rapid environmental changes, deforestation, habitat fragmentation, climate change, and anthropogenic pressures threaten its biodiversity. This review synthesizes existing literature on the biodiversity of the Eastern Himalaya and examines conservation strategies, including protected areas, community-based initiatives, and trans boundary co-operation. Strengthening these strategies through policy implementation, local engagement, and scientific research is essential for safeguarding the region's rich ecological heritage.

No. of Pages: 3 **References: 22**

Keywords: Biodiversity, Conservation, Flora and Fauna.

INTRODUCTION

The Eastern Himalaya is part of the broader Indo-Burma and Himalayan biodiversity hotspots (Mittermeier et al., 2011). It encompasses northeastern India (Arunachal Pradesh, Sikkim, Assam, West Bengal), Bhutan, northern Myanmar, and southeastern Tibet, covering diverse ecosystems ranging from tropical forests to alpine meadows (CEPF, 2017). This region supports over 10,000 plant species, 300 mammal species, 1,000 bird species, and numerous amphibians, reptiles, and invertebrates (WWF, 2022). However, biodiversity loss due to habitat destruction, climate change, and illegal activities necessitates urgent conservation measures (Myers et al., 2000).

2. Biodiversity of the Eastern Himalaya

2.1 Flora

The Eastern Himalaya hosts approximately 10,000 species of vascular plants, with 30–40% endemism (Singh & Singh, 2021). Notable plant families include Orchidaceae, Rhododendronaceae, and Lauraceae (Rao, 2020). The forest types include:

- **Tropical and Subtropical Forests**: Dominated by Dipterocarps, bamboos, and epiphytic orchids (Bhagwat et al., 2017).
- **Temperate Forests**: Composed of oaks (*Quercus* spp.), rhododendrons, and maples (*Acer* spp.).
- **Alpine Meadows**: Home to medicinal plants like *Aconitum*, *Saussurea*, and *Rheum* spp. (Kala, 2019).

2.2 Fauna

The Eastern Himalaya harbors numerous flagship and lesser-known species:

- **Mammals**: Snow leopard (*Panthera uncia*),

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red panda (*Ailurus fulgens*), clouded leopard (*Neofelis nebulosa*), and Himalayan black bear (*Ursus thibetanus*) (Acharya et al., 2021).

- **Birds**: Over 1,000 bird species, including the Himalayan monal (*Lophophorus impejanus*), Blyth's tragopan (*Tragopan blythii*), and the endangered black-necked crane (*Grus nigricollis*) (Inskipp et al., 2016).
- **Amphibians and Reptiles**: Unique species such as the Himalayan salamander (*Tylototriton verrucosus*) and king cobra (*Ophiophagus hannah*) (Borthakur et al., 2022).
- **Invertebrates**: High diversity of butterflies, such as Bhutan glory (*Bhutanitis lidderdalii*), and endemic insects crucial for pollination.(Yonzon, P. 2005)

3. Threats to Biodiversity

3.1 Habitat Loss and Deforestation

Deforestation due to agriculture, logging, and infrastructure development has led to severe habitat fragmentation (WWF, 2022). Between 2000 and 2020, forest cover declined by approximately 10% in some areas (Reddy et al., 2021).

3.2 Climate Change

Rising temperatures, glacial retreat, and shifting monsoon patterns affect species distributions (Thakur et al., 2020). Alpine species are particularly vulnerable due to limited migration options (Sharma et al., 2019).

3.3 Illegal Wildlife Trade and Poaching

Targeted species include pangolins (*Manis spp.*), red pandas, and rare orchids (Nijman, 2020). Poaching networks exploit weak law enforcement and porous international borders (TRAFFIC, 2022).

3.4 Human-Wildlife Conflict

Increasing encounters with elephants, leopards, and bears have led to retaliatory killings and habitat degradation (Choudhury, 2021).

3.5 Infrastructure Development

Hydropower projects, road construction, and urbanization disrupt migration corridors and fragment ecosystems (Chettri et al., 2019).

4. Conservation Strategies

4.1 Protected Areas and Biosphere Reserves

Several national parks and reserves have been established:

- **Namdapha National Park (India)**: A biodiversity hotspot with multiple habitat types .
- **Jigme Dorji National Park (Bhutan)**: Protects alpine, temperate, and subtropical ecosystems (WWF Bhutan, 2021).
- **Makalu Barun National Park (Nepal)**: Home to snow leopards and red pandas (Acharya et al., 2021).

4.2 Community-Based Conservation

- **Eco-tourism**: Programs in Sikkim and Bhutan generate revenue while promoting conservation (Chettri et al., 2020).
- **Traditional Knowledge Integration**: Indigenous communities contribute to sustainable forest management (Rai & Sundriyal, 2019).

4.3 Trans boundary Conservation Initiatives

- **Kanchenjunga Landscape Initiative (India, Nepal, Bhutan)**: Focuses on ecological connectivity (CEPF, 2017). (Allen et al., 2020)
- **Himalayan Conservation Program (WWF)**: Supports habitat restoration across national borders (WWF, 2022).

4.4 Climate Change Adaptation

- **Afforestation and reforestation programs**: Mitigating carbon emissions (Thakur et al., 2020).
- **Wildlife corridors**: Facilitating species movement (Choudhury, 2021).

4.5 Policy Strengthening and Law Enforcement

- **Stricter anti-poaching measures** (TRAFFIC, 2022).
- **Integration of biodiversity conservation into national policies** (Singh & Singh, 2021).

CONCLUSION

The Eastern Himalaya remains a crucial biodiversity hotspot with immense ecological significance. However, deforestation, climate change, poaching, and human-wildlife conflict pose significant threats. Conservation strategies—including protected areas, community participation, transboundary cooperation, and climate resilience initiatives—are vital for sustaining biodiversity. Strengthening policy frameworks, promoting indigenous conservation practices, and improving enforcement mechanisms will be key to ensuring the long-term ecological health of the region.

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EFFECT OF ATLAS CYCLES INDUSTRY EFFLUENT ON PHYTO-CHEMICAL CONSTITUENTS OF *ACHYRANTHES ASPERA* LINN

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ABSTRACT

Impact of industrial pollution on plants and human health is well known. Heavy metals and other pollutants contained in the industrial effluents and agricultural wastes enter into aquatic plants and roots of the other plants, growing in their contacts, causing serious threats to them, because they do not degrade easily unlike other organic pollutants. In the vicinity of industries, often many medicinally important plants are found growing. These industrial effluents are not only changing morphological and anatomical characters of these plants but also affecting their chemical constituents. Hence, an attempt has been made for a comparative Phyto-chemical study of *Achyranthes aspera* Linn. growing in a highly polluted (Atlas Cycles Industry area of Ghaziabad(U.P),India) and at a non-polluted areas (ALTT Centre, Ghaziabad). The plant *Achyranthes aspera* contains various alkaloids. The plant contains -amyrin, flavanoid, glucosides, hentriacontane, saponin, achyranthine (betaine), ecdysterone and amino acids. Seeds mainly contain saponin a and b, hentriacontane, alkaloid, oleanolic acid, saponin and achyranthine. Atlas Cycle Industry (ACI) is a cycle manufacturing unit, which is discharging approximately 400-kiloliter effluent per day. The analysis contains data regarding Colour, Odour, BOD, COD, DO, pH, Temperature, Total Solids (TS), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Oil and Grease, Heavy metals etc. After analysis of effluent it was observed that ACI effluent possess highest amount of heavy metals.

In this study various chemical tests were carried out with the plant powder to find out the impact of selected industry effluent on *A. aspera*. The result shows variation in the quantity of alkaloids, lignin, tannins, carbohydrates, proteins, sugar, suberin, glucosides, saponin, flavinoids, steroids and oils in both the cases *i.e.* polluted & control. Degree of change in colour reaction tests were also observed in industrial and controlled areas. Thin Layer Chromatography (TLC) observations indicate that the number of spots were 2 in polluted and 4-8 in non-polluted samples. The spots were higher in non-polluted samples.

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Keywords: Phyto-chemical, *Achyranthes aspera*, Effluent pollution.

INTRODUCTION

Achyranthes aspera Linn. (Latjira) belongs to family Amaranthaceae, is a 1-3 m high, stiff, erect herb, commonly found as a weed throughout India upto 3000 ft. It is much valued in indigenous medicine. The plant ash is rich in potash and it is suggested that the plant might be of value as a cheap green manure (Anonymous, 1950). The plant is used as one of the ingredient in the "Siddha" preparation of "Naaga Parpam" and "Naaga Chendooram". Fruit contain a large percentage of alkaline ash with potash. Plant grows in drier situations but does not tolerate water

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logging. It can be propagated by seeds. The plant contains -amyrin, campesterol, --sitosterol, palmatate acid, chrysin, flavanoid, glucosides, hentriacontane, saponin, oleanolic acid, achyranthine (betaine), ecdysterone, ecdtstone, inokosterone and amino acids. Seeds contain mainly saponin a and b, hentriacontane, alkaloid, oleanolic acid, saponin and achyranthine (Joshi, 2000). It is a pungent and laxative and used in piles, boils eruptions of the skin etc. The seeds are useful in piles and leprosy. The pharmaceutical industries are facing a problem for the shortage of good raw material. It is essential to ascertain the quality of a plant material before it is employed for the preparation of drugs. Because of the importance of this plant in ISM System it is required to ascertain the genuineness of plant species before preparation of medicines. So an attempt has been made here for detailed phytochemical studies of the whole plant of *Achyranthes aspe*ra Linn. viz. phytochemical analysis, TLC and chlorophyll content were carried out. These numerical data can be considered as a diagnostic constant in identification and authentication of raw drug. Atlas Cycle Industry was selected for the study of *Achyranthes aspera* growing near the vicinity of their effluent. In this study various chemical tests were carried out with plant powder to find out the impact of Atlas Cycle Industry effluent on the selected plant species.

Atlas Cycle Industry (ACI) is a cycle manufacturing unit, which is discharging approximately 400-kiloliter effluent per day. The analysis contains data regarding Colour, Odour, BOD, COD, DO, pH, Temperature, Total Solids (TS), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Oil and Grease, Heavy metals etc. After analysis of effluent it was observed that ACI effluent possess highest amount of heavy metals.

In this study various chemical tests were carried out with the plant powder to find out the impact of selected industry effluent on *A. aspera*. The result shows variation in the quantity of alkaloids, lignin, carbohydrates, protein, suberin, glucoside, saponin, flavoanoid, steroid, oils (traces). Tannin and sugars are absent in both the cases *i.e.* polluted & control. Degree of change in colour reaction tests were also observed in industrial and controlled areas. Thin Layer Chromatography (TLC) observations indicate that the number of spots were 3-4 in polluted and 3-5 in non-polluted samples. The spots were higher in non-polluted samples.

MATERIALS AND METHODS

The effluent was analyzed by APHA (1981) and Trivedi & Goel (1986).The fresh material of *Achyranthes aspera* was collected from both sites non-polluted (ALTT Centre) and polluted (Atlas Atlas Cycle Industry) areas of Ghaziabad, UP India (Plate 1). For colour reaction test I.P. (1966) was consulted. The extraction of plant powder is carried out with ethyl alcohol using a rapid extraction method (Quality control methods for medicinal plant materials: WHO, Geneva, 1998). The Rf values were calculated by given formula.

$$\mathrm{Rf} = \frac{\text{Distnace travelled by the spot from the point of applicatio n}}{\text{Distance between the point of applicatio n and solvent front}}$$

For estimation of chlorophyll, fourth and fifth leaf pairs from apex of the same age group plants were selected. Chlorophyll a, b and total chlorophyll (a + b) were determined according to method given by Arnon, 1949. The amount of chlorophyll a and chlorophyll b were calculated according to the following formula of Arnon (1949).

$$\text{Chl. a (mg/L)} = 12.72\ A_{663} - 2.58\ A_{645}$$
$$\text{Chl. b (mg/L)} = 22.87\ A_{645} - 4.67\ A_{663}$$

$$R.Co. = \frac{ControlValue - TreatedValue}{ControlValue}$$

RESULTS

Effluent Analysis: The effluent was analyzed and the results are given below.

Table 1: Physico-chemical Characteristics of industrial effluent of ACI.

S.No.	Parameters	Characteristic of Effluents	Maximum Recommended Concentration	Authority/ Reference
1.	Colour	Yellowish	Should be absent	I.S.I. : 2490
2.	Odour	--	Odourless	I.S.I. : 2490
3.	pH	4-6	5.5-9.0	I.S.I. : 2296
4.	Suspended Solids	200 mg/l	-----	-----
5.	Total Dissolved Solids (mg/l)	810 mg/l	2100.0	I.S.I. : 3307
6.	Total Suspended Solids (mg/l)	1010 mg/l	600.0	I.S.I. : 3306
7.	Dissolved Solids	720 mg/l	-------	-----------
8.	Total Solids (mg/l	840 mg/l	2700.0	----------
9.	BOD (mg/l)	16.0 mg/l	30.0	I.S.I. : 2490
10.	COD (mg/l)	200 mg/l	250.0	I.S.I. 2490,1982
14	Chromium (Cr)	5 mg/l	-------	----------
15.	Nickel (Ni)	12 mg/l	-------	----------
16.	Zinc (Zn)	15 mg/l	-------	----------
17.	Cadmium (Cd)	4 mg/l	-------	----------
18.	Copper (Cu)	4 mg/l	-------	----------
19.	Temperature	500C	-------	----------

Phyto -Chemical Analysis

Preliminary Colour Reaction Tests: Various tests were carried out with plant powder to study the effect of industrial effluent on selected plant. The result shows the presence of alkaloids, lignin, carbohydrates, protein, suberin, glucoside, saponin, flavoanoid, steroid, oils (traces). Tannin and sugars are absent in both the cases. Degree of change in colour reaction tests are tabulated in table – 2

Table 1: Physico-chemical Characteristics of industrial effluent of ACI.

S. No.	Reagents	Test For	Nature of Colour	Degree of Changes	
				Non-polluted	Polluted
1.	Dragenorff's Reagent {Cromwell (1955)}	Alkaloid	Orange ppt	++++	++
2.	Mayer's Reagent	Alkaloid	Brown	++	+
3.	Wagner's Reagent (Trease & Evans (1983)	Alkaloid	Brown	+++	++
4.	Tannic Acid	Alkaloid	Turbidity	++	+
5.	Hager's Reagent	Alkaloid	Yellow	++	+
6.	Phloroglucinol + Hcl	Lignin	Dark Red	+++	++
7.	$Fecl_3$	Tannin	Negative	-	-
8.	Molisch Test After Hydrolysis	Glucoside	Yellow	+++	++
9.	Millon's Reagent	Protein	Red Ppt	+++	+
10.	Xanthoproteic Test	Protein	Yellow	++++	+++
11.	Bendict's Reagent After Heating	Sugars	Negative	-	-

13.	Molisch Test	Carbohydrates	Red	+++	++
14.	Plant Powder + H_2O + Shake	Saponin	Froth (W)	+++	++
15.	Mg Powder + Conc. HCL	Flavin	Green Black	+++	+++
16.	Libermann's Buchard Reagent	Steroids	Violet	+++	++
17.	Sudan IV	Oils	Red	++	+

TLC: From the observation of TLC, it is found that the number of spots were higher in non-polluted plants than the polluted plants. It may be due to the more number of chemical compounds in plants those thriving in non-polluted sites (Plate 2). The spots are 3-5 in non-polluted and 3-4 in polluted plants. The RF values are tabulated in table – 3

Table 3: The Rf values of *Achyranthes aspera* Linn. growing in non-polluted and polluted areas.

S. No.	Wavelengths	Non – Polluted	Polluted
		Rf values	Rf values
1.	Sunlight	0.24, 0.29, 0.37, 0.90	0.24, 0.29, 0.37, 0.90
2.	UV Light (254 nm)	0.20, 0.24. 0.29, 0.37, 0.90,	0.20, 0.24, 0.37, 0.90,
3.	UV Light (365nm)	0.24, 0.37, 0.90	0.24, 0.37, 0.90

Chlorophyll Estimation: For the estimation of Chlorophyll the fourth and fifth leaf pair from the apex of same age group of plants were selected. Chlorophyll contents a, b and total chlorophyll of both the plants were determined Chlorophyll a, chlorophyll b and total chlorophyll are 81.30% 23.43% and 36.38% of control (Plate 3). The results are tabulated in table–4

Table 4: Effect of Magnum Paper Mill Industry effluent on chlorophyll content of *Achyranthes aspera* Linn.

S. No.	Parameters	Non Polluted	Polluted
1.	Chl a (mg/ g)	30.380 + 0.270	24.700 + 0.146*
		CV = 0.880	CV = 0.590
2.	Chl b (mg/ g)	27.910 + 1.680	16.540 + 0.200**
		CV = 6.020	CV = 1.209
3.	Total Chl (a + b) (mg/ g)	58.270 + 1.800	41.200 + 0.200**
		CV = 3.090	CV =0.485

Significant at 0.1% --* 1.0% – **

DISCUSSION

The effluent samples collected from the industry selected for this study was analysed for different physico-chemical parameters which showed higher values as compared to the standard values recommended by the Indian Standard Institute (I.S.I.;1974, 1974 and 1977). Similar results were also obtained by Kumar, *et al.* (1988) and Vijayavathi *et al.* (2008). A critical observation on the data studied clearly indicate that plants growing at polluted sites were badly affected and there were a significant reduction in number of parameters studied as compared to the plants growing at the control sites.

Major qualitative changes, noticed under the impact of industrial effluent, are reduction in chlorophyll level, photosynthesis rate, accumulation of heavy metals, alternation in pH, BOD, COD, Colour, Temp, Odour, TS, TDS. Heavy metals resulted into reduced growth and yield in comparison to plant species growing at non polluted sites. The impact of industrial effluent on the qualitative and quantitative values of medicinal plants does not appear to have been undertaken much till now.

Colour reaction tests showed the degree of changes in plants of polluted sites. From the observations some alteration in the bio-chemical parameters were also recorded in plants growing near the industrial effluent. The amount of chemical constituents found to have decreased in those plants which were growing in polluted areas. From the observations of TLC, it was seen that the number of spots were decreased in the plant samples of polluted sites. From the findings of this investigation it may be ascertained that there had been qualitative and quantitative alternations in the chemical constituents in the plants growing in industrial areas (polluted). It can also be stated that industrial pollution may also have lowered the drug potency of the plants growing in the vicinity of industries. Similar observations were recorded by Dhar *et al.* (2003) and Ghouse *et al* (1985).

Chl a,b and total chlorophyll were studied in plants collected from polluted as well as non-polluted area. On the other hand chlorophyll content decreased in all the plants collected from polluted sites. Reduction of chlorophyll contents may be due to the accumulation of metals ions in the leaf tissues. Pahlsson (1989) reported the reduction of the chlorophyll contents in vascular plants with Cu and Cd treatments. The decrease in chlorophyll content may also be due to inhibition of cytochrome oxidase, which regulate chlorophyll synthesis (Agrawala and Kumar, 1962). The reduction in chlorophyll content of leaf has also been reported earlier by Rao and Leblanc, (1966), Chang (1975), Balashouri and Prameela Devi (1994). Iqbal and Mehta (1998) who had studied the total chlorophyll contents and dry matter production in different plants irrigated with industrial effluent.

Uptake of heavy metals increased in effluent treated plants, as observed in the present findings, can be compared with the results of Gontarz and Dimowski (2000). They found that the uptake was highest for Cu (Parsley roots and red beets), Cd (carrot, red beet and celery roots), Zn (red beet), Pb (Parsley and celery roots), Ni (parsley roots and red beet), Cr (celery and parsley roots). The results were also similar to Trivedi *et al.* (1983); Pandey and Simba (1989); Sharma and Naik (1991); Pandey *et al.* (1992); Goswami and Naik (1992); Tripathi and Tripathi (1999); Satyakala and Jamil (1997); Dutta and Boissya (1999); Lal *et al.* (1999); Muthusamy and Jayabalan (2001).

CONCLUSION

Various chemical tests were carried out with plant powder to study the effect of industrial pollution on the selected plant. The result showed degree of changes in colour reaction tests. The percentage of extractive values was lower and ash values were higher in polluted plants. From the observations some alteration in the bio-chemical parameters was also recorded in the plants collected from industrial effluent. The preliminary tests, such as colour reaction, fluorescence tests and various phyto-chemical test for alkaloids, lignin, carbohydrates, protein, suberin, glucoside, saponin, flavoanoid, steroid, oils (traces) indicated that the amount of chemical constituents decreased in those plants which were growing in polluted areas. From the observation of TLC, it was seen that the number of spots were decreased in the samples of plant collected from the polluted areas. From the findings of this investigation it may be safely asserted that there had been a qualitative and quantitative alternations in the chemical constituents of plants growing in industrial areas (polluted) of Ghaziabad and it would not be unwise to state that industrial pollution may also affect the drug quality.

We are accordingly inclined to conclude that the plants growing at non polluted areas are more suitable to be considered for bulk and quality production, since all the parameters those studied reflect a declining values in plants collected from polluted area.

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