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From Construction to Contamination: Examining Soil Quality Degradation Associated with Construction and Demolition Waste in an Indian Urban Area

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A B S T R A C T

In light of India's accelerated urban expansion, the present research delves into an emergent environmental predicament precipitated by the unregulated disposal of construction and demolition (C&D) waste, with a critical focus on its deleterious effects on urban soil integrity. The rampant urbanization pervasive across India has catalysed an unprecedented surge in C&D waste, much of which finds its way into unauthorized dumpsites, engendering ecological perils. This investigation is centered around a residential locale in Visakhapatnam, Andhra Pradesh, besieged by the uncontrolled proliferation of illicit dumping. Employing a methodical soil quality assessment, the study juxtaposes conditions at two strategically selected sites: S1, in proximity to a C&D dump, and S2, situated 1000 meters distant, devoid of direct waste exposure. The analysis uncovers disturbing trends, including disrupted moisture profiles, a propensity for neutral to alkaline pH spectra, and a spike in electrical conductivity, signaling heightened salinity. The nutrient composition was found lacking requisite standards, coupled with an anomalous spike in organic carbon — a collective aftermath of C&D waste mismanagement. These revelations unearth a spectrum of ecological consequences, manifesting as deteriorated vegetative vitality, infrastructural compromise owing to hastened corrosive processes, potential aquifer contamination, and a decline in urban biological diversity. The research emphatically calls for immediate, multifaceted reforms in waste governance, augmented community consciousness, and decisive policy shifts, all converging towards the ideals of ecological conservation and the sustainable evolution of urban landscapes.

Keywords: Construction & Demolition waste, Environmental Impact, Soil health, Urbanization, Waste Management

Introduction

India, a nation characterized by its vibrant economy and rapid urbanization, is currently undergoing a transformative phase driven by urban expansion. This process, a consequence of rapid economic growth, encapsulates the multifaceted evolution of Indian cities, which have become thriving centres of innovation, technological advancement, and industrial progress. With a population exceeding 1.3 billion, India's urban areas contribute significantly, accounting for nearly two-thirds of the nation's economic output and thus reflecting the concentrated economic activities within these urban spaces [1]. The ongoing wave of urbanization has turned Indian cities into laboratories for shaping the trajectory of the nation's economic growth. Throughout history, these urban areas have played pivotal roles in steering India's economic prowess, with statistics indicating their substantial contribution, making up nearly two-thirds of the national economic output. The allure of improved livelihoods and opportunities spurred by modernization has made these urban hubs attractive magnets for migration. Projections indicate a staggering 50% surge in urban populations within the next two decades, making the urban sprawl an inevitable reality. However, this urban transformation, though indicative of progress, brings along a host of intricate challenges [2]. The influx of this demographic surge places immense strain on urban infrastructure, housing, and essential services, necessitating a comprehensive approach to ensure that the urban residents' quality of life continues to foster progress and well-being [3].

One of the inevitable consequences of the surging urbanization is a corresponding increase in construction activities. As cities expand, old structures yield to new buildings, reshaping skylines and urban fabrics. Yet, this transformation is not without its challenges, particularly in the domain of construction and demolition (C&D) waste management [4]. Amidst the rapid urbanization fuelled by construction, the management of C&D waste, a critical aspect, often goes unnoticed. The remarkable growth in C&D waste generation is emblematic of India's construction-driven urbanization trajectory. While this growth signifies development, it also highlights the complexities surrounding the management of waste resulting from these activities. In various Indian cities, the narrative of C&D waste takes a grim turn. An oversight on waste management has led to unauthorized dumping of debris, frequently occurring in open spaces proximate to residential zones. These practices are not mere eyesores; they pose substantial environmental hazards. The consequences span a range of issues, including soil degradation, groundwater contamination, and the more insidious health risks posed to nearby communities [5].

The unchecked and unsanctioned dumping of debris, often adjacent to residential areas on open lands, has the potential to unleash environmental havoc. This includes soil contamination, pollution of groundwater sources, and adverse health impacts for communities living in close proximity. The composition of C&D waste, a testament to human ingenuity and architectural innovation, holds a paradox within its layers. It embodies not only the foundations of progress but also hazardous constituents with far-reaching implications for the environment and human well-being [6]. The presence of toxic materials such as lead, asbestos, heavy metals, and volatile organic compounds within construction materials and waste creates a dual threat – one to the environment and another to human health. Mismanaged C&D waste can initiate a cascade of environmental vulnerabilities. Hazardous substances embedded within this waste matrix leach into the soil, seep into groundwater reservoirs, and disperse as airborne particles, leading to soil degradation, water pollution, air contamination, and compromised vegetation. These consequences resonate across ecosystems, leading to the loss of biodiversity, disruption of natural processes, and a diminished capacity of natural systems to provide essential services [7].

Despite the urgency and complexity of the issue at hand, comprehensive studies on C&D waste management within the Indian context remain scarce. This paper endeavours to address this crucial gap by delving into the issue of unauthorized C&D waste dumping and its ramifications on soil pollution. Furthermore, it aims to propose potential solutions related to the management of C&D waste. By shedding light on this overlooked aspect of India's urbanization, this study aspires to contribute to a more comprehensive understanding of the challenges posed by construction and demolition waste and pave the way for informed strategies to mitigate its adverse effects. In doing so, it seeks to lay the groundwork for sustainable urban development in the face of accelerating urbanization [8]

2. Study Area

Visakhapatnam district, situated in the northern coastal part of Andhra Pradesh, is a region of significant environmental and economic importance. Nestled between the lush terrains of the Eastern Ghats and the vast expanses of the Bay of Bengal, the district presents a picturesque landscape coupled with a tropical sub-humid climate. The area experiences moderate to intense summers and significant seasonal rainfall. But beyond its natural appeal, Visakhapatnam stands out as a beacon of industrial progress in the state. Known for its port activities, Visakhapatnam is not only a major port city but also a critical financial and industrial hub within Andhra Pradesh [9]. The rapid industrial and urban expansion has brought with it a surge in building and infrastructure activities. Over the past two decades, there has been a marked escalation in these activities, which, while indicative of development, has also led to environmental challenges, especially in the form of construction and demolition (C&D) waste [10]. Recent figures sourced from the Greater Visakhapatnam Municipal Corporation (GVMC) paint a telling picture. According to their data, the town planning department amassed a staggering 90,000 tonnes of construction waste in just a two-year window. This alarming statistic is further compounded by the observation that certain areas within the city have become clandestine dumping grounds for unauthorized C&D waste disposal. Such haphazard dumping, aside from posing aesthetic concerns, has potential ecological and health ramifications. In a candid conversation with the Times of India, S Mahapatra, the assistant city planner who focuses on Construction and Debris Waste Management, offered some insights. Mahapatra noted that from April 2020 to February 2021, the amount collected in spot fines was Rs 2,34,200. However, this figure is seemingly inconsequential compared to the sheer volume of unauthorized debris that finds its way to various corners of the city. The financial dynamics of the C&D waste management process might provide some clues to this problem [11]. An esteemed agency collaborating with GVMC, shared that their official rate for debris collection stands at Rs 360 per tonne. However, there exists a parallel, informal economy where vendors, in a bid to reduce costs, contract third parties for debris collection. These third parties, incentivized by cost-cutting, often resort to dumping waste in the nearest colonies, typically under the cover of night. Such clandestine activities have resulted in unauthorized dumping spots mushrooming across the city [11].

In light of the environmental and urban context of Visakhapatnam, Kailasapuram (study area) emerges as a critical focal point in the discourse on C&D waste management. This locality, uniquely positioned amidst a hill on one side and a residential area on the other, presents both geographical charm and strategic challenges for urban planning. The dichotomy of its location accentuates the environmental impact of waste dumping, given the area's proximity to natural landscapes and urban habitats.

Over the years, Kailasapuram has witnessed a concerning expansion of unauthorized waste dumping (See Fig.1). Particularly alarming is the encroachment on government-owned open land, which has been at the receiving end of such activities since 2005 (See Fig.2). Satellite imagery analysis from Google provides a stark visualization of the issue. In 2005, the C&D waste footprint was a mere 1 acre. However, a disturbing growth pattern emerges when we observe that by 2023, the affected area had ballooned to 4.5 acres. This four-and-a-half-fold increase over approximately two decades highlights not only the escalation of illegal dumping but also the inadequacy of measures in place to curb these practices (See Fig. 3)

This spatial expansion of debris and waste signifies more than just a loss of land. It reflects the negligence of sustainable practices in urban expansion and the consequential strain on the local environment. The close proximity to residential zones amplifies the health risks to local communities, while the adjacency to the hill potentially affects the area's biodiversity and geological stability (See Fig. 4).

This situation necessitates a multi-pronged approach involving stringent monitoring, community engagement, policy reform, and technological intervention for efficient tracking and management of C&D waste. The trajectory that Kailasapuram is on threatens its ecological balance and urban livability, compelling stakeholders to redirect their efforts towards environmental preservation and sustainable urbanization.

Fig. 1: The Study Area exhibits the presence of Construction and Demolition Waste that has been improperly disposed of alongside the road

Fig. 2: The unauthorized disposal of Construction and Demolition Waste on government-owned land within the designated study area

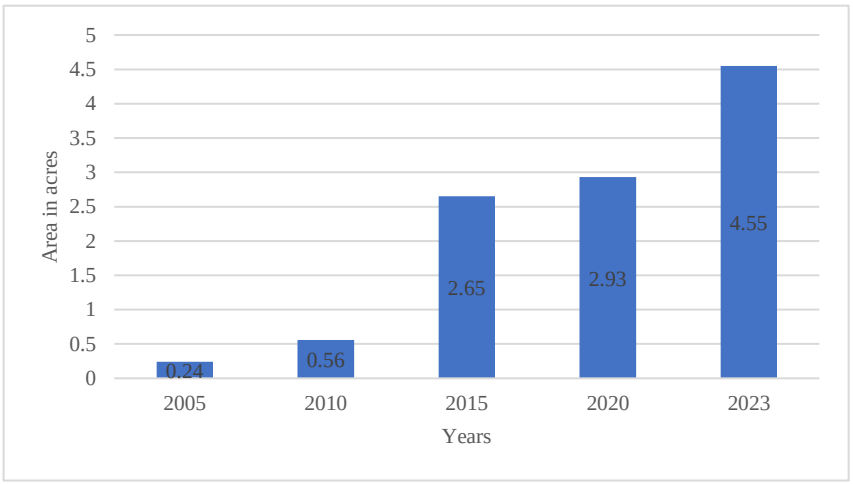

Fig. 3: C&D waste disposal in the study area grows with time.

Fig. 4: Satellite image showing C&D waste scattered over 4.5 acres of open land in the study area.

Fig. 5: The satellite image depicts the specific region within the study area where Sample S1 and Sample S2 were obtained. These samples were acquired from locations that are approximately 1000 meters apart

3. Materials & Methods

This section of the study delineates the methodologies employed to investigate the impact of Construction and Demolition (C&D) waste on the environmental quality and public health in the study area of Visakhapatnam, India. The study has empirical analysis of soil quality surrounding the debris disposal site.

Soil Sample Collection and Analysis

A systematic approach was adopted for the collection and subsequent analysis of soil samples to assess the environmental impact of C&D waste. The site chosen for this study was a known illegal dumping ground in the study area. The soil samples were collected with the following protocol to ensure consistency and reliability of the data:

Sampling Sites: Two distinct locations were identified for soil collection. The first site, labelled as S1, was situated directly at the debris point, considered to be heavily contaminated due to the proximity to waste. The second site, designated as S2, was located approximately 1000 meters away from the C&D dumping ground, serving as a comparative baseline to understand the extent of contamination (See Fig. 5).

Sample Size and Collection: At each designated site, four separate samples of soil were collected, each weighing approximately 1 kilogram. The samples were extracted following standard soil sampling techniques to avoid cross-contamination and to preserve the integrity of the soil composition.

Analytical Procedure: The collected samples were subjected to rigorous testing as per National Accreditation Board for Testing and Calibration Laboratories (NABL) standards in India. The analysis primarily focused on determining the presence and concentrations of contaminants typically associated with C&D waste. The laboratory procedures were conducted in accordance with standardized testing methods to ensure accuracy and repeatability of the results.

Understanding the context of the sample locations provides a more in-depth perspective on the results and their implications. Given that the samples are from urban residential areas with tree vegetation and a dependency on groundwater, the discussion needs to focus on how soil quality affects urban ecosystems and residential health, rather than agricultural productivity.

4. Results

Amidst the burgeoning urban landscapes of India, the inadvertent victim of the construction and demolition (C&D) waste crisis appears to be the very foundation of these sprawling cities: the soil. Our investigation into the soil quality of two residential urban locales, distinguished as sites S1 and S2, uncovered several critical environmental implications, particularly relevant given the absence of agricultural activities and the reliance on groundwater in these areas (See Table 1).

Moisture

The moisture content within the examined soil, below 50% at both sites, is initially a positive indicator, minimizing the risk of excessive leachate production that could contaminate the crucial groundwater reserves urban residents rely upon. However, this lower moisture level also poses a risk of reduced groundwater replenishment, crucial in urban settings for sustaining local tree vegetation and maintaining the soil's structural integrity against the stress of urban construction [12].

pH

Soil pH levels at both sites were within the neutral to slightly alkaline range, vital for urban green spaces as it supports tree vegetation health. This pH range is less conducive to the leaching of toxic metals, thereby indirectly protecting the groundwater quality. However, any shift towards more alkaline conditions could adversely affect the microbial diversity essential for nutrient cycling and organic matter decomposition in the soil, crucial processes for urban tree vegetation [13].

Electrical conductivity

Electrical conductivity readings painted a more concerning picture, with values exceeding standard limits, indicating high salinity. The elevated electrical conductivity in the soil samples is a direct indictment of C&D waste's role in escalating soil salinity. The debris, often laden with soluble salts, releases these ions into the soil upon weathering and water exposure [14].

Vegetation Health: High salinity can impede the absorption of water by plant roots, causing physiological drought conditions and inhibiting the uptake of essential nutrients. For urban residential areas, this effect could lead to the deterioration of local green spaces, parks, and tree-lined streets, which are vital for maintaining air quality, providing shade, and reducing urban heat islands [15].

Infrastructure Integrity: Increased salinity accelerates the corrosion of concrete and metals, a significant concern for underground utilities, home foundations, and structural stability of buildings and public works, potentially leading to increased maintenance costs and structural failures.

Groundwater Quality: There's also a risk of saline water infiltrating local groundwater supplies, particularly concerning for communities reliant on these sources for their daily water needs. This infiltration could make water unsuitable for consumption and domestic use, leading to a host of public health and sanitation issues [16].

Nutrients: While nutrient levels (nitrogen, phosphorus, potassium) were below agricultural standards, their relevance in this urban setting lies in their ability to support the local tree vegetation. The detected levels suggest a potential limitation on the growth of supportive vegetation within these residential areas, possibly leading to urban heat islands and reduced biodiversity [17].

Organic Carbon: The elevated levels of organic carbon, while essential for soil fertility, present concerns when exceeding typical concentrations. High organic carbon levels can indicate an excess of decomposable organic matter, potentially resulting from the accumulation of Construction and demolition waste. This surplus can lead to:

Oxygen Depletion: As microorganisms break down the organic matter, they consume oxygen, potentially leading to hypoxic conditions that can adversely affect root health and soil biodiversity.

Nutrient Imbalance: The decomposition process can also release excessive nutrients into the soil, disrupting the nutrient balance and possibly leading to eutrophication in nearby water bodies if runoff occurs [18].

Greenhouse Gas Emissions: There's an increased risk of methane and carbon dioxide emissions, potent greenhouse gases, during the decomposition of organic matter, contributing to local and global climate change impacts.

Toxic Metals: The proximity of toxic metal concentrations to their threshold levels is perhaps the most immediate public health concern. Metals like arsenic, chromium, and barium are known carcinogens and can have several sub-lethal effects, including organ damage and developmental problems in children [19].

Health Implications: In residential zones, these metals can enter the human body through various pathways: ingestion, inhalation of dust, skin contact, or consumption of contaminated groundwater. Long-term exposure to these elements could lead to chronic health conditions, including kidney damage, bone degradation, and neurological issues.

Ecological Impact: Toxic metals do not degrade over time, accumulating in the soil and potentially entering the food chain through plants and animals, leading to long-term ecological imbalances. Their presence also inhibits the growth of sensitive plant species, reducing local biodiversity [20].

Property Values: Knowledge of soil contamination can lead to reduced property values, reflecting the area's perceived health risks and potential costs associated with remediation efforts.

In light of these findings, urban residential areas are confronted with an intricate web of environmental and health challenges due to improper C&D waste management. The data underscores the urgency for more stringent regulations on waste disposal, improved community awareness and education, and comprehensive urban planning that prioritizes the health of the soil and, consequently, the health of the urban population.

Table 1: Soil quality test reports

S.No	Parameters	Units	Sample		Maximum limits
			S1	S2	
1	Moisture	%	2.83	3.7	<50
2	pH	-----	7.93	7.91	6.5-9.0
3	Electrical Conductivity	dsm-1 at 25oC	1.08	0.84	0.25-0.75
4	Total Nitrogen	Mg/kg	9.50	15.61	2-16
5	Phosphorus	Mg/kg	2.78	4.02	35-70
6	potassium	Mg/kg	10.6	5.6	100-250
7	Organic Carbon	%	1.86	0.38	0.5-0.75
TOXIC METALS					
8	Arsenic	Mg/kg	4.71	2.23	<5
9	Barium	Mg/kg	53.4	19.4	<100
10	Cadmiun	Mg/kg	0.06	Nil	0.01-1

5. Conclusion

In conclusion, it can be inferred that the aforementioned points collectively support the notion that...The study emphasises the urgent environmental problem caused by unauthorised disposal of construction and demolition (C&D) waste. It specifically highlights the negative impacts of this waste on the integrity of urban soil in Visakhapatnam, Andhra Pradesh. The critical analysis of the study uncovers concerning patterns, such as the disturbance of soil moisture, the transition towards pH levels that range from neutral to alkaline, and the rise in soil electrical conductivity. These trends are predominantly linked to the unauthorised disposal of construction and demolition (C&D) waste. The inquiry provides additional insight into the wider ecological and health risks associated with these practises, as construction and demolition (C&D) waste frequently contains dangerous substances such as lead, asbestos, and other volatile compounds. These compounds create substantial risks, leading to contamination of soil and groundwater and posing health hazards to adjacent communities. This study serves as a poignant reminder of the environmental and public health risks that arise from the inadequate handling of construction and demolition (C&D) waste. It underscores the pressing necessity for implementing rigorous waste management regulations and adopting sustainable methods of waste disposal.

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