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Arvind Kumar Agnihotri
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Sustainable Materials

Proceedings of EGRWSE-23, Volume 2

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Editors
Arvind Kumar Agnihotri
Department of Civil Engineering
Dr. B. R. Ambedkar National Institute of Technology
Jalandhar, Punjab, India

Krishna R. Reddy
Department of Civil, Materials and Environmental Engineering
University of Illinois
Chicago, IL, USA

Ajay Bansal
Department of Chemical Engineering
Dr. B. R. Ambedkar National Institute of Technology
Jalandhar, Punjab, India

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Preface

The relentless growth of the global population has imposed an immense burden on our natural resources. Compounding this issue, the swift pace of industrialization and urbanization has exacerbated the situation, resulting in severe environmental degradation. The toll on the environment has prompted technocrats and researchers to seek sustainable technologies urgently. The surge in domestic and industrial waste, coupled with deteriorating environmental conditions, has spurred regulatory bodies into action, leading to more stringent pollution norms. Time is of the essence as we strive to discover technologies with long-term viability, and recycling waste materials emerges as a crucial aspect of sustainability.

The escalating volume and diversity of waste materials, coupled with a scarcity of landfill space and a depletion of natural earth materials, underscore the pressing need for innovative recycling methods. Recycling and reusing waste materials not only address the immediate waste disposal challenge but also alleviate the demand for natural resources, fostering a more sustainable environment. The construction industry, notorious for its resource consumption and waste production, plays a significant role in environmental damage and resource depletion.

Waste materials, defined as by-products lacking lasting value from human and industrial activities, are steadily increasing with population growth. The common practice of dumping such materials on lands poses environmental and social problems, necessitating effective solutions. Reusing waste materials, such as pond ash, rice husk ash, fly ash, and tire wastes, in construction applications like roads and embankments has gained popularity, offering a sustainable alternative.

For processing and manufacturing industries, the disposal of residual waste products poses a significant challenge, especially when these products are toxic, ignitable, corrosive, or reactive. Addressing this challenge requires effective, economic, and environmentally friendly methods. Constructing roads, highways, and embankments using these waste materials presents a feasible solution, mitigating the pollution caused by industrial waste.

The benefits of recycling waste materials are manifold:

- Environmental protection: Recycling reduces pollution of air, land, water, and soil, preventing the burning or landfilling of recyclable materials.
- Conservation of natural resources: By recycling more waste, the dependence on rapidly depleting raw resources is diminished, contributing to resource conservation.
- Energy efficiency: Recycling saves energy compared to producing items from raw materials, leading to increased energy efficiency and potential cost savings.
- Job creation: The recycling industry generates employment opportunities in collection, sorting, and recycling activities, creating a positive ripple effect in local communities.

This comprehensive book encompasses a variety of multidisciplinary articles, catering to students, working professionals, practitioners, and researchers interested in sustainable practices and waste management.

Jalandhar, India — Arvind Kumar Agnihotri
Chicago, USA — Krishna R. Reddy
Jalandhar, India — Ajay Bansal

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About the Editors

Dr. Arvind Kumar Agnihotri is Professor in the Department of Civil Engineering at NIT Jalandhar. He completed his Ph.D. from IIT Roorkee, M.Tech. from NIT Kurukshetra and B.E. from Panjab University Chandigarh. He possesses a work experience of around 34 years in research, teaching, and academic administration, with several years spent holding key leadership positions. His areas of interest are geotechnical and geoenvironmental engineering, reinforced earth (geosynthetics and geofibers), ground improvement and soil-structure interaction. He has supervised 15 Ph.D. theses and 58 M.Tech. dissertations. He has 85 publications in international refereed journals and 60 publications in various national and international conferences/symposia. He has served Head of the Civil Engineering department, Dean Academics, Dean Planning and Development, and officiated as Campus Director at Dr. B. R. Ambedkar National Institute of Technology, Jalandhar. He has completed several sponsored projects, including World Bank projects. He is Fellow/Member of many professional organizations like ASCE, IGS, ISTE, ISSMGE and IRC. He has organized many national and international events successfully. He has edited 5 books, and he is Reviewer of many international journals.

Dr. Krishna R. Reddy is University Scholar, Distinguished Researcher, and Professor of Civil and Environmental Engineering and Director of both the Sustainable Engineering Research and Geotechnical and Geoenvironmental Engineering laboratories at the University of Illinois Chicago (UIC), USA. He received his Ph.D. in civil engineering from the Illinois Institute of Technology in Chicago. Prior to joining UIC, he worked for three years in consulting as Geotechnical/Geoenvironmental Engineer. His research expertise includes environmental remediation, waste containment, beneficial use of waste and recycled materials and sustainable and resilient engineering. Dr. Reddy has authored four books, 298 journal papers, 30 edited books and conference proceedings, 25 book chapters and 200 conference papers. His h-index is 73 with more than 18,000 citations. Because of his excellent contributions, Dr. Reddy received several awards, such as the Fulbright US Scholar Award, ASCE Wesley W. Horner Award, ASTM Hogentogler Award, UIC Distinguished Researcher Award, University of Illinois Scholar Award and the University of Illinois Award for Excellence in Teaching. He is Fellow of the American Society of Civil Engineers.

Dr. Ajay Bansal is Professor of Chemical Engineering at Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, India. He received his Ph.D. in Chemical Engineering from Panjab University, Chandigarh; M.Tech. from Indian Institute of Technology, New Delhi; and B.E. from Government Engineering College, Raipur (now NIT Raipur). He received the university gold medal for being first in his batch of B.E. at Pt. Ravishankar Shukla University, Raipur. He has served as Head of Chemical Engineering Department for two terms and was Associate Dean for Research and Consultancy at NIT Jalandhar. Dr. Bansal has more than 28 years of teaching, consulting and research experience within the fields of chemical and environmental engineering. His research expertise includes areas, such as nano-photocatalysis, advanced oxidation processes, waste water treatment, solid waste management, multiphase reactors, and rheologically complex fluids. He has supervised 8 Ph.D. dissertations, published 3 books, 3 book chapters, 45 journal papers and 65 conference papers. Dr. Bansal is on the editorial board and is Reviewer of many journals. He has been Active Member of various professional societies and is Fellow of Institution of Engineers (India) and Fellow of Indian Institute of Chemical Engineers (IIChE), Kolkata. Dr. Bansal has served twice as Vice-President of IIChE. He has been Chairman and Honorary Secretary of Doaba Regional Centre of IIChE as well.

Sustainability Enhancement by Adoption of Circular Economy in Construction and Demolition Waste Management—Indian Case Study

Mamta Negi and Vijit Chaturvedi

Abstract This paper aims to find the correlation between the construction and demolition waste (CDW) produced in India and pathways it can be utilized back in the circular economy (CE) in turn promoting sustainability. The construction industry is extremely resource intensive, with high dependency on capital, materials, and manpower. This material can be the existing raw material that exerts pressure on the existing depleting natural resources, so a sustainable way would be the use of CDW in circular economy (CE) as input material. Rapid urbanization also results in huge CDW waste generation. Moreover, CDW is generally sent back to landfill which is an unsustainable way of waste disposal causing land and water pollution. This study will analyze how the use of CE of CDW is promoting sustainability in construction industry. The paper analyzes through secondary sources and a case study approach how CE is adopted in the construction industry and promotes sustainable development.

Keywords Construction industry · Construction demolition waste · Circular economy · Sustainable development goals · India

1 Introduction

Construction plays a significant role in the development of the world at large. It is the backbone of the growth and development of a nation. Real estate and infrastructure account for 13% of the world GDP [14]. There is a positive correlation between nations' development and construction [18]. Country industry accounts for 9% of the country's GDP and 21% of the jobs [11]. The construction in such large also causes huge construction and demolition waste (CDW) which often ends in landfill, taking up valuable space and polluting the soil and groundwater. There is a huge need and demand to take steps so that CDW is utilized back through the implementation

M. Negi (✉) · V. Chaturvedi
Amity Business School, Amity University, Noida, UP, India
e-mail: tewarimamta@gmail.com

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of the circular economy principle. India is the second largest producer of CDW in the world [2]. The construction industry generates a significant amount of waste, including construction and demolition waste (CDW) that poses a severe threat to the environment and society [6]. To address this issue, the circular economy has emerged as a potential solution to reduce waste, promote sustainable consumption, and maximize the value of resources [8]. Despite the existing literature on CDW and its effect on the environment, there is still a significant gap in addressing the potential of CDW as a valuable resource in the circular economy.

The circular economy framework aims to decrease CDW and amplify the value of natural resources by promoting the reuse, recycling, and reduction of waste. The effective use of CDW in a project can contribute to achieving the objectives of the circular economy and Sustainable Development Goals (SDGs). By bridging this literature gap, this paper objects to contribute to a more sustainable construction industry and address the global challenges of resource depletion and environmental degradation. The paper also highlights the implications of the circular economy in achieving a balanced integration of economic performance, social comprehensiveness, and environmental resilience toward sustainable development and SDGs [10]. The Indian government is also pioneering in the launch and implementation of various schemes at the central and state level to promote CE to facilitate sustainability at large.

2 Circular Economy and Construction and Demolition Waste Benefits

The basic nature of traditional construction industry is unidirectional and does not follow the circular economy path of "take-make-dispose". It implies the resources are extracted from natural reserves, converted to new products, and utilized in construction. Subsequently, the materials are disposed of as waste at the end of its functional life [18].

As per [17] discussed that in general, construction and demolition waste (C&DW) is divided into two types: inert materials (i.e., concrete, bricks, and sand) and non-inert materials (i.e., plastic, glass, paper, wood, and other organic materials).

The CDW comprises of soil, sand, gravel, bricks, masonry, concrete, metals, and woods (Figs. 1 and 2).

The main process involved in this is

There are economic, social, and environmental benefits of the implementation of the CE principle in CDW generated. Mixing CDW with municipal solid waste (MSW) otherwise shall result in worsening the MSW, so there are multiple benefits.

1. The cost is saved by reducing waste generated and use of recycled products. The movement of waste from properly designed rules shall result in pay pocket. The unauthorized dumping of CDW shall result in a reduction of lack of materials, lowering the low-cost housing.

Fig. 1 CDW composition. *Source Clarence* [5]

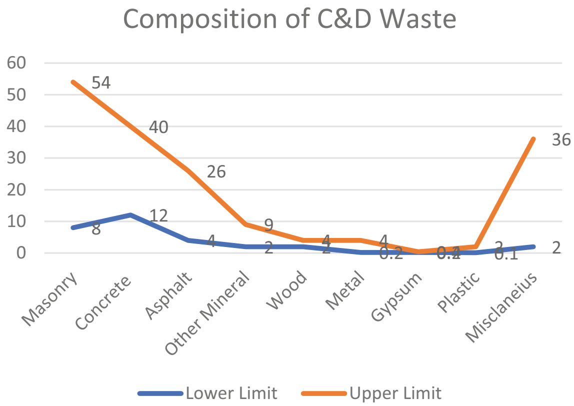
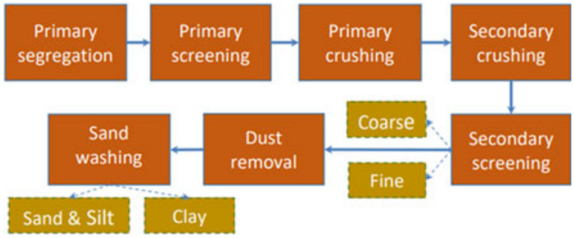


Fig. 2 C&D waste processing steps and outputs. *Source* BMPTC [4]



2. This value addition helps to generate biophilic structures as well as jobs (architects/structural designers), thus strengthening the occupant connectivity to natural environment, through direct and indirect use of nature and space condition.
3. Increased use of local materials shall promote more local jobs and also help company gain tax benefits.
4. CDW management shall boost the higher attainment of green building rating. Unauthorized waste dumping will else result in air pollution, soil pollution by leaching out to soil, and water pollution by disrupting the local hydrology.
5. This supports in low GHG emissions which would be created in production, transportation, and usage of natural materials.
6. The human health is benefitted by reduction of adverse effects of waste generated disposed in the environment.
7. With the superior quality of air, water, and soil, the quality of human life is increased, and civic pride is induced.
8. There is equal distribution of material in the world at large reducing poverty.

Some of the practical implemented schemes by GOI for CDW utilization are

1. The incorporation of CE procedures as modular construction, efficient material management, and circular approach to the urban planning construction sector can optimize the reduction of virgin material ingestion by up to 37% by 2050

[12]. This reduction shall result in less thrust on the already overburdened and depleting natural source in the world.

2. The foundation of "lighthouse projects" under Pradhan Mantri Awas Yojna in 2021 under GHTC (Global Housing Technology Challenge) aims to build houses using alternate construction technologies [16] which shall contribute to the reduction of demolition waste generation. LHPs use alternate technology prone to geographical, climatic, and hazardous condition specific to the area. Out of the 54 locations, 6 chosen along with the technology are

Location	Technology
Chennai, Tamil Nadu	Precast components at site
Rajkot	Monolithic construction
Indore MP	Prefabricated sandwich panel system
Lucknow, UP	PVC stay in place of formwork
Ranchi, Jharkhand	Precast concrete construction system-3D volumetric
Agartala, Tripura	Light gauge and pre-engineered structural steel system

Source MoHUA [1]

This type of construction shall result in less waste generation during the construction phase and demolition stage resulting in environmental and economic benefits.

3. The use of recycled products in the nationwide infrastructure improvement program, AMRUT, paver blocks manufactured from CDW can be used to improve pedestrian facilities in 500 Indian cities [3]. With the increasing growth in the infrastructure sector, this helps in the consumption of finished product of recycled waste generated.
4. NITI Aayog supports nodal Ministries in functionalizing tactic plans for red mud, fly ash, steel slag, and e-waste.
5. The Indian Road Congress indicates the codes of practices for the use of recycled material and products for road works [15].

3 Barriers to the Implementation of Circular Economy for Construction and Demolition Waste Management

The technical aspect of waste utilization and processing is kept with the Swatch Bharat Mission under with Ministry of Urban Development. The facility needs to set up CDW processing plants in cities with more than 10 lakhs population. BMPTC is setting up guidelines for CDW utilization in dwelling units and infra-housing schemes.

As already observed, the benefits of the adoption of CE principles in CDW are multifold.

But despite all the benefits of the CDW management, there are numerous challenges for the implementation of sustainable management practices. All of the steps of the Indian government are in vain. Currently, the existence of laws and regulations, regional and national policies, and governing reuse and recycling principles for C&D waste is negligible in India [9].

There are numerous challenges in the implementation of CDW as

1. Technical challenge. There are linear construction practices currently prevailing in India. There are no quality control mechanisms. There are no pre-defined mechanisms, for the storage and retrieval of building elements. The last estimation of CDW was done in 2013, so it was a decade before which is much irrelevant today. There is a poor economic viability of the present CDW.
2. Economic challenges. The necessary finances are not available with the ULBs for the implementation of SBM schemes. The construction industry is unorganized and dominated by class B, and class C contractors are not equipped with high technology or skills. The existing challenge is that GST is 18% which is not very encouraging for the use of refurbished material.
3. Operational challenges such as lack of infrastructure. Though there are chosen cities still the availability of CDW plants, there is a shortage of land for CDW plants. No formal recycling systems in developing countries except for very few places. There is no big penalty for the non-compliance with the CDW in the CE even where rules exist.
4. Capacity-building challenges like lack of knowledge and awareness among various stakeholders, such as architects, designers, contractors, and statutory agencies. There is a lack of pressure from the client or the governing agencies on the use of CDW. There is less market for the CDW produced in the market. The cost associated with the CDW is not calculated in the overall project cost. As the waste configuration is heterogeneous, after the culmination-of-life each kind of waste ought to be treated in a different manner to accomplish full environmental gains.

4 Sustainability and CE

Application **of circular economy** and lifecycle thinking in the CDW sector can make vivacious influences in achieving **Sustainable Development Goals (SDGs) 9 (Targets 9.1, 9.2, 9.3, and 9.5)** by concentrating on the development of resilient and sustainable infrastructure, employment generation, developing CE-based business models, and enhancing the technical advancement of CE application in the built environment. CDW in cities will also enhance resource efficiency, reduce per capita waste generation, and improve air quality, thereby helping in **achieving SDG 11 (Targets 11.6 and 11.b)** [19].

Furthermore, implementing reduce, reuse, and recycle CDW strategies throughout the building will minimize the adverse effects of the waste generated on human health, fulfilling **SDG 12 (Targets 12.2, 12.4, and 12.5**) [19].

The states that have CDW plants in India are Delhi, Surat, Ahmedabad, Bangalore, Bhopal, Indore, Thane, Pune, Nagpur, Hyderabad, Noida, Prayagraj, Chandigarh, and Chennai which are the 14 cities with existing C&D waste management facilities.

The main blocks of CE are refuse, reduce, rethink, reuse, reduce, repair, refurbish, repurpose, recycle, remanufacture, and recover.

5 Case Study

In June 2006, Supertech was granted more land for working under similar terms following which it chose to change the Structure Plan. By 2012, developer proposed to modify the first construction plan definitely with 15 structures rather than the previous 14 and furthermore expanded the level to 14 stories rather than the endorsed 9. Apart from this, the builder also added two new towers with 40 floors, which was challenged by RWA and became the center point of the legal battle henceforth [7].

On Aug. 28 the honorable Supreme Court of India gave orders of razing the Noida Twin Towers (Apex and Ceyna, sector 98 A) to the ground. Edifice Engineering carried the annihilation, using approximately 3.7 tons of explosives to topple the 100-m buildings. The technique used was implosion. Holes were punctured in specific areas of the building, and explosives were positioned. The organized blast was conducted in ground-up matter, with explosion starting from ground floor.

1. *Demolition Preparation*: The total cost of only the explosives was almost 20 Cr with an insurance policy of Rs. 100 crore to cover damages to neighboring buildings if any. Approximately 7000 holes were drilled, and 20,000 circuits were set in the tower to trigger the demolition. About 500 m of exclusion zone was made for demolition.
2. *Evacuation of Public*: The building was covered with geo-tactile fabric and inhabitants evacuated one day prior to control the damage. About 5000 residents of neighboring areas, 200 domestic animals, and 1000+ automobiles were moved out of the impact radius. The 27-km stint of the Noida-Greater Noida expressway was shut for almost 45 min for public safety. All the electricity and gas lines in the near vicinity were cut off as preventive measures.
3. Noise Pollution: The demolition leads to a peak noise pollution level of 101.2 decibels.
4. *Dust Cloud and Pollution Concerns*: After the demolition was heavy the air pollution, storm, and dust veil arose and visibility was not clear for up to an hour. Anti-smog guns and water sprinklers were used to control the air pollution level. However no high AQI level was reported post the blast [13]. Cloud dust of 3300 tons was dissipated during the annihilation

Construction and demolition waste generated. The demolition was implemented using the “waterfall technique” which left almost 80,000 tons of debris at the site. When the head of CDW plant at Noida was contacted, he was informed that only 30,000 tons of debris has been removed from the site and the rest is still in the basement of the building. The reason underlying this is opposition from the resident due to noise pollution in the crushing of the debris and conflict of interest between the developer authority and the selling agency. This further questions the very step of demolition as a solution. The only bright part that can be seen in the whole process is this cannot be undone so at least the CDW generated during the process should be used back again in the circular economy. As part of the interview, it was confirmed that after proper segregation almost there was a 20% increase in the selling of goods generated at the C&D waste plant.

6 Process in CDW Plant

The main process involved in a CDW plant is collection of waste, segregation by man/material, crushing of material with an impact crusher, separation by vibrator and magnetic separator, and further screening as different aggregate size.

The direct result of CDW is fine aggregate, recycled aggregate, recycled concrete aggregate, and manufactured soil.

Various end products in the process are bricks, tiles, wall tiles, hollow bricks, blocks, kerb stones, planters, drain post, pre-cast boundary panels, etc. (Tables 1 and 2).

The major revenue is from selling steel, which is 3–4% of the total waste produced. The recycled waste produced is used in various heads, as given in Table 1 (Fig. 3).

Table 1 Actual usage of concrete and demolition waste in the Noida plant

Gardening and landscaping	Earthwork	Civil engineering	Structural engineering
Drainage material	Falling of line ditches	Unbounded	As input in concrete
Layer in sports fields	Noise protection dams	Gravel base layer and anti-freeze base layer	Mix in situ concrete
Upgrading of soil characteristics	Anti-freeze sub-layer beneath the building	Combined anti-freeze base layer	Ready mix concrete
Increase of bearing capacity (below garden walls)	Soil exchanges	Upper layer modification of the base layer	Structural elements out of concrete
	Enhancement of bearing capacity of earth/soil	Hydraulically bound base layer	Concrete goods
	Construction of temporary lanes	Concrete base layer	As input in other concrete material as mortar, stone, burned bricks, sand lime bricks, or lightweight concrete

Table 2 Actual from the construction and demolition waste site Noida

S. No.	Type of aggregate	Maximum utilization percentage		
		PCC	RCC	Lean concrete
1	*Coarse aggregate*			
	Recycled concrete aggregate	25	20 only up to M25 grade	
	Recycled aggregate	Nil	Nil	100
2	*Fine aggregate*			
	RCA	25	20 only up to M25 grade	100

Fig. 3 Finished goods of the reprocessed material. *Source* Site

7 Conclusion

Increasing urbanization is imperative with new construction of buildings such as housing for all, education institutions, medical facilities, shopping complexes, infrastructure such as roads, railways, and highways also demolition of old structures, dilapidated buildings, and excavation or reconstruction. Construction is the corner stone of development, and CDW management by CE is necessary for sustainable construction.

Thus, from the paper, we can infer that there is a strong relation between CDW, CE, and sustainable construction contributing to SDGs. There is huge potential, and above-mentioned steps and more need to be taken for CDW management for attainment of SDGs. There is an inbuilt overlap between the three CDW, CE, and sustainable construction, and implementation shall add to sustainable development. There is a definite contribution to sustainability by the application of CE in the industry (Fig. 4).

The case study demonstrates that CDW can increase the CE's financial benefits. For efficient CDW waste management, all the stages of the construction life

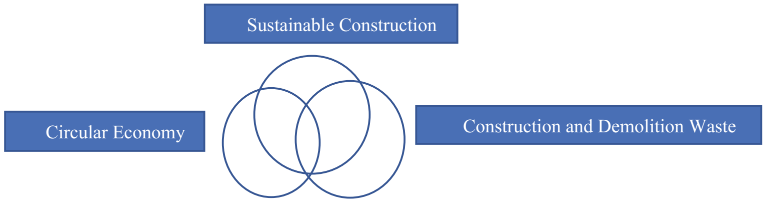


Fig. 4 Interaction between CE, CDW, and sustainable construction

cycle need to incorporate the necessary steps. This will result in the sustainable development of society, enhancing the socio-economic and environmental fabric.

The gap in the current finding is that the relationship establishment and utilization of CDW is a relative novice regarding practitioner, researcher, governance, business, and policymakers. An important aspect in which life cycle assessment, product recovery, and sequential planning of the building still need to be done. One of the limitations is most studies are on material, and still, economic and social factors are neglected. There is less focus on policies and supply chain integration. Also, various stages need a thorough analysis of the CDW implementation technique. Further detailed scope of CE in each stage needs to be studied.

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Delineation of Surface Water Potential Zones and Identification of Sites in Mahanadi River Basin, Odisha, India, Using GIS

Abhijeet Das

Abstract One of the most crucial stages for developing surface water resources for drinking water use is assessing the water quality (WQ). So, agriculture and human health are seriously threatened by the geogenic and anthropogenic variables that affect surface water quality. It is obvious that the current water shortage in the area has necessitated a review of the river's water quality. Water samples from 19 locations were taken in 2018–2023, to test 20 physicochemical parameters in the selected sampling sites in Mahanadi River Basin (MRB), Odisha. This study has spotlighted an evaluation of surface water quality for drinking purposes by integrated use of Stepwise Weight Assessment Ratio Analysis (SWARA/S)-based WQI, with reliability-based multi-criteria decision-making (MCDMs) such as Simple Additive Weighting (SAW) that has been employed. The substantial engineering feature used in the study, which incorporates temporal large and contextual data based on the specific period, leads it distinctiveness. Geographical Information System (GIS) techniques were used to create surface maps of river water attributes, and sampling-broad analysis utilizing GPS was found to be a potentially effective tool. In addition, the geospatial approaches such as Inverted Distance Weighted (IDW) are used to anticipate for an unobserved place utilising nearby known qualities and interpolate the spatial variability of point attributes, and it is represented in the form of maps using ArcGIS 10.5 software. The result obtained from the research portray that the river water is alkaline in nature and the pH value ranges between 7.74 to 7.91, respectively. The spatial distribution results showed that the higher values of coliform, TKN, chloride and sulphate were recorded in the places close to the coastline, indicating the occurrence of sea water intrusion and salinization. Further, the S-WQI revealed that 10.53% (sites MP-8 and MP-19) and 5.26% (site MP-9) of samples belong to poor/very poor water quality while 84.21% of sites come under the zone of excellent water. It revealed that the main cause could be deterioration of domestic water, illegally dumped municipal solid waste and agricultural runoff were the leading sources causing adulteration of the river's water quality. Despite being a crucial component

A. Das (✉)
Research Scholar, Department of Civil Engineering, C.V. Raman Global University (CGU), Bhubaneswar, Odisha 752054, India
e-mail: das.abhijeetlaltu1999@gmail.com; abhijeetlaltu1994@gmail.com; 2101070005@cgu-odisha.ac.in

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for grading overused water stations, WQI involves sensitive issues. As a consequence, MCDM models, such as SAW, were implemented to resolve discrepancies, incorporating WQI index and evaluating the model's performance based on factors such as uncertainty, sensitivity, and reliability. The final ranking was calculated by taking the factor weights and field data into consideration. The proposed approaches depicted by MP-9, was perhaps the most filthy/contaminated, when compared to other places, followed by MP-(8) and MP-(19) respectively. This was apparent from the high S-WQI levels in this vicinity. It also accompanied with high values of TC, TKN, EC, SAR, TDS, TH, Cl^{-}, $SO_4{}^{2-}$ and Fe^{2+}, which were highest among all the areas and also more abundant than their desired concentration. However, it was pertinent that the pollution level at these stations was associated more with increasing and diverse anthropogenic activities like overexploitation of water, fertiliser influences and agricultural return flow and industrial presence within and around the river course. The resultant WQI model significantly contributes to sustainable surface water resource management in the studied areas and generates improved prediction precision with fewer input parameters. Hence, the current work determines that we are unable to use the surface water at MP-(8), (9) and (19), directly without treatment, and for this resource to be used sustainably, strict management procedures must be put in place. So, it is recommended that river water can be utilised for residential purposes and, after disinfection, can be consumed.

Keywords Surface water · Geogenic · Anthropogenic · MRB · SWARA · SAW · Geospatial

1 Introduction

Life on earth relies on the existence of water. So, rivers are a significant source of freshwater for drinking, agriculture and industry [81]. Therefore, it is essential to avoid and manage river water pollution [56]. Further, the public is particularly worried about both organic and inorganic materials contaminating water. In many places of the world today, surface water, an essential naturally occurring resource, is overused to satisfy rising human demand for drinking water, agricultural, urban development and industrial uses [33]. Globally, water resources have decreased as a result of climate change, which is exacerbated by the rise in water demand brought on by urbanisation [26]. However, due to urban sprawl and population growth, which exposed water supplies to a decline in both quantity and quality, the world has recently experienced a freshwater resource shortage [45]. In contrast to groundwater, which fluctuates in temperature, surface water is always clear, colourless and odourless and is therefore purer [63]. Controlling water quality has consequently become one of the top issues in many nations, especially in dry and semi-arid areas. Unfortunately, India's surface water quality is quickly declining because of excessive consumption without a sufficient recharge, unchecked pesticide use and fertiliser leakage into the aquifer system [66]. In addition, home wastewater, municipal solid waste and industrial wastewater all contribute to water pollution [87]. The amount of nitrogen cycling between the living world and the soil, as well as between the water and the atmosphere, has increased significantly as a result of recent human activities [57]. Surface water supplies are particularly vulnerable to microbial contamination due to both natural and human activities, such as the discharge of raw sewage, the leaching of animal manure, leaking septic tanks, wastewater used for irrigation and rainwater runoff [58]. As a result, drinking water quality continually contains fluctuating concentrations of dissolved components brought on by both natural (rainfall, weathering and the breakdown of rock and soil) and human activity (residential and commercial). Unsafe drinking water, poor sanitation and poor hygiene have all been linked to the daily death rate from diarrheal infections, which can be contracted by drinking untreated, contaminated water [59]. Agriculture-related activities, particularly fertilisation, wastewater leaks from landfills and atmospheric nitrogen solubility are the main sources of pollution [42]. This is now a hazard for both human health and the environment. In fact, the abundance of synthetic fertilisers, aquaculture wastes, sewage disposal and animal wastes also contributes to global concern. Insufficient wastewater management leads to contaminated drinking water and endangers the public [60]. As a result, in order to reduce adverse effects on drinking, the quality of agricultural water must be checked [48]. As a result, developing protective risk management also requires the detection of microbial contamination [5]. Water management practises have been established recently, and they mostly rely on surface water and consistent runoff [101]. Not only is resource scarcity a problem for sustainable surface water development, but also quality decline [22]. A hazard to human sustainable development might come from the mismatch between the availability and demand for water resources [28, 30]. Continuous evaluation and management of water quality aids in the ongoing development of the pollution control measures used [86]. Water quality should therefore be regularly assessed, especially in places where there is a greater danger of sewage contamination and where there are less sophisticated or effective water treatment systems [92]. To avoid and manage river water pollution, accurate data on water quality are needed. Continuous water quality assessment based on spatial-scale water quality tests is also necessary to monitor contaminants and water resource management [35]. Several studies have employed categorisation, correlation analysis and time series numerical analysis of collected data as tools for evaluating water quality [90]. These techniques have the benefit of not requiring professional knowledge of the environment or water quality [61]. However, the procedure of arranging the data for time series numerical analysis on long-term measurable data is laborious and time-consuming [15]. The issues of categorising the important parameters used to quantitatively assess the state of water resources are complex, as is the impact of many distinct factors that together define the water quality [83, 84]. The water quality index (WQI) is regarded as a mathematical instrument that greatly simplifies such data sets and offers a single classification value that indicates the level of contamination or water quality condition of water bodies [80]. WQI metrics calculations have been enhanced and developed in a variety of ways to better correctly and effectively depict water quality [54]. To make a thorough assessment of water quality, the WQI converts the quality of the water into a single score, which aids the public and policymakers in understanding water quality [20]. One of the key techniques in determining a set of reasonable weights for the water quality factors is because a slight change in weighting will impact the overall perception of water quality [41]. However, the selection and weighting of criteria depends on the specific end use of the index, which may be for drinking, leisure or irrigation reasons [52]. Entropy-based weights have become a practical method that weights water quality factors using information entropy [25]. The traditional entropy weights, however, also have drawbacks, such as instability traits brought on by changes in sample size and value and failing to take the conflict between the indexes into account [38]. In this work, the Stepwise Weight Assessment Ratio Analysis (SWARA/S) weighing method was taken into account to address the drawbacks of the conventional entropy method [93]. This technique belongs to a class of correlation-based techniques that uses analytical testing of the decision matrix to ascertain the data present in the criteria used to evaluate the weights of the criterion [55]. All the parameters' weights and quality rating scales are combined to provide a cumulatively determined numerical score, which is known as the S-WQI [36]. These are an enhancement over conventional WQIs, which are often focused on the Delphi method, analytical hierarchical process and expert survey method and which otherwise rely on weighting factors based on expert opinion and subjective assessments [31]. However, the study reported that, using this proposed SWARA model, could reduce model uncertainty significantly compared to other WQI models [2]. The study also revealed that these models significantly improved model accuracy in terms of reducing model eclipsing and ambiguity problems [4]. Meanwhile, ambiguity and eclipsing are two major problems of the WQI models that can arise due to various factors, such as the utilization of inappropriate sub-index functions, bias in the model classification scheme, and overestimation or underestimation of aggregation results. The process of uncertainty analysis serves to measure the degree of variability in the output of a given model, whereas sensitivity analysis aims to identify the specific sources of input that may be responsible for this uncertainty [6, 34]. Therefore, the assessment of water quality required to be enhanced using multi-criteria decision-making (MCDM) analysis in order to determine the specific relationships between the quality parameters and measuring locations [51]. Several authors have used the MCDM method in previous decades for a variety of purposes, including managing water resources, evaluating the quality of the water and solving issues that relates to solar panels, health and risk mitigation, technology and data management and the environment [94]. The use of MCDM in the analysis of water quality produced outstanding outcomes. This necessitates the need for the Simple Additive Weighting (SAW) method for not only giving a site's overall score based on both physical and chemical factors while also giving actions made during emergencies priority [37]. This approach suggests the possibility to collaborate and develop an integrated or combined approach that logically obtains favourable feedback while also fitting into the MCDM structure [12]. These types of studies were primarily focused on a single problem-solving strategy in each given region, therefore there was a research gap that needed to be filled. This study demonstrates the value of this innovative integrated method [47]. Geographical Information System (GIS) software is used to create a variety of thematic spatial maps to analyse variance in the surface water quality [49]. Through the use of Inverse Distance Weighted (IDW) interpolation techniques, the spatial variation maps were extracted [8]. It refers to an interpolation technique that predicts the unknown points to produce a continuous surface out of the point data [39]. In this process, based on the neighbouring known points, weight is given to the unknown point [74]. The weight depends on how far a measured location is from a nearby unmeasured point [3]. Furthermore, the GIS has progressively becoming a prevailing tool as it offers powerful concepts for analyzing and presenting spatial data, which can help policy makers in constructing decisions for managing water resources. So, the utilization of SAW in conjunction with GIS technologies displays comprehensive and conclusive results, permitting a more realistic description and valuation of natural factors [89]. However, not much research has been carried out on the hydrochemical and quality assessment of drinking water in Mahanadi River Basin (MRB), Odisha. Keeping this in mind, the goal of this study is to evaluate the spatial and yearly changes of physicochemical parameters affecting the water quality and also identify the drinking water sensitive zones for surface water quality using S-WQI, SAW and GIS. This study was subsequently extended with maps showing the spatial variation of water quality metrics. Finally, the maps were created and compared with one another. In fine, this ground-breaking research offers one of the earliest attempts at an integrated strategy for surface water quality in MRB. This study has the potential to serve as a crucial example in understanding the water quality deterioration at different seasons and ensuring the sustainable use of surface water resources in similar water-stressed regions. Hence, it represents the first attempt to integrate drinking with GIS, as these approaches have not yet been completely considered by the previous studies within the Mahanadi River Basin, Odisha.

2 Study Area

Mahanadi River System (MRS) is the third largest in the Indian Peninsula and has historically irrigated agricultural land in the Indian States of Chhattisgarh and Odisha. It is well recognised as the largest river in the state of Odisha that provides household water to major towns [18]. The basin lies between the geographical coordinates of 80°30′ E to 86°50′ E and 19°20′ N to 23°35′ N. It extends over an area of about 141,600 km^2. The river is 851 km in total, with 357 km in Chhattisgarh and 494 km in Odisha. The Mahanadi's flow from the upper watershed into the river's downstream section is regulated by the Hirakud Dam. It separates into various distributaries and canals downstream of the Naraj Barrage, forming a delta [16, 17]. The basin is characterised by a tropical climate with 1200–1400 mm of rain on average each year [71]. It is in the subtropical zone, and the placement of the catchment in relation to the Bay of Bengal has a major impact on the climate. Also, the patterns of mountains of the Eastern Ghats play a crucial part in the precipitation pattern. This river always has stagnant water in it from January to May each year, which contributes to the build-up of pollution in the area. Finally, during the rainy season, the filthy water is released into the Bay of Bengal. More than 90% of the total precipitation falls during the monsoon season, which starts in June and lasts until October, even if it happens in spells of varying lengths and intensities [23]. The basin's economy is mostly based on agriculture, with a combination of commercial and subsistence farming systems predominating in rice production. As a result, the basin's two primary land uses are agriculture and forest, which are both supported by extensive irrigation infrastructure created by major and medium-sized projects. Additionally, it suggests that the central Odisha districts found inside the basin have smaller-scale rainfed farming systems and more dense forestry. In the basin, rice predominates among the cereal crop types, followed by pulses. The Mahanadi Basin is separated into three sub-basins, including the Upper (21.34%), Middle (37.16%) and Lower Mahanadi (41.5%). Typically, the bottom basin has a surface area of roughly 57,960 km^2. The temperature variation in the basin depends on 24–27 °C. Approximately 66.8 billion cubic metres (BCM) of resource potential is on average, of which 50 BCM is surface water that can be used. The per capita availability of water based on the average annual runoff is 1826 m^3. In the basin, there are roughly 54 medium irrigation projects, 22 big irrigation projects and 5 hydroelectric projects. The basin's projected total live storage capacity is 14.244 BCM, of which 12.799 BCM is operational and 1.465 BCM is under development. This equates to 21.32% annual flow and 28.4% of the reliable usable water that accounts for 75% of the water supply. This river estimates per capita irrigation withdrawal as 686 m^3, and the net area under irrigation as 1.85 million hectares. The intensity of irrigation was found to be 112%, and the projected proportion of groundwater in irrigation is 34%. Cereals are found to consume 76% of the irrigated land, with a rate of irrigation efficiency of 47%. It is noteworthy to point out that the effluents generated from businesses including steel, ferroalloys, charge chrome, textile, polythene, plastic, paper and pharmaceuticals, which mostly contain harmful materials including heavy metals, damage the water in the river's upper basin [29]. Although, such industries usually posses' environmental audits clearance. Because of the pollutants, it is discovered to cause a number of bio-molecular pressures on the local wildlife, including a large variety of fish [5]. The most widely accepted soil types are mixed red, black, red and yellow soils, respectively. Figure 1 displays the location of the research area and its monitoring locations.

3 Sampling and Chemical Analysis

A preparatory investigation has been made in the Mahanadi River Basin (MRB), and 19 stations were preferred for the surface water sampling. Additionally, from 2018 to 2023, more than 25 samples were obtained from the State Pollution Control Board (SPCB), Odisha. Twenty variables were utilised to simplify the model, namely pH, biochemical oxygen demand (BOD), dissolved oxygen (DO), TC (total coliform), total dissolved solids (TDS), total hardness (TH), alkalinity, chloride (Cl^-), sulphate

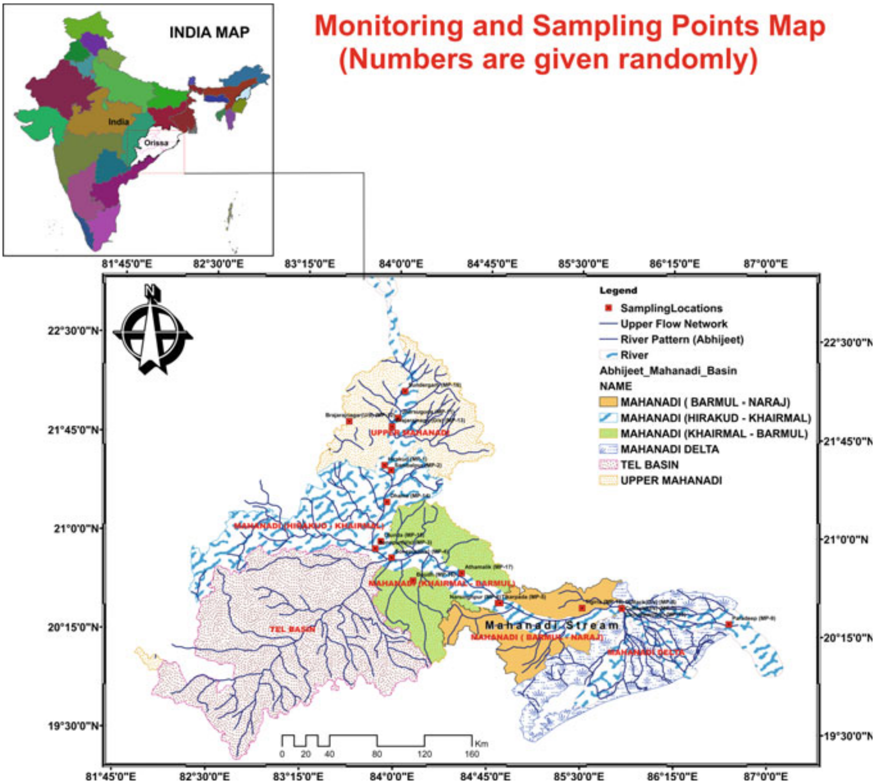

Fig. 1 Detailed map of the study area

(SO_4^{2-}), iron (Fe^{2+}), fluoride (F^-), boron (B^+), total suspended solids (TSS), electrical conductivity (EC), chemical oxygen demand (COD), NH_3-N (ammoniacal nitrogen), free ammonia (Free NH_3), total kjeldahl nitrogen (TKN), sodium adsorption ratio (SAR), and total hardness (TH). The locations of the stations were labelled using a handheld Global Positioning System (GPS). Afterwards, chemical assessment was conducted out using standard analytical procedures [14]. Before taking the samples, the sampling bottles were cleaned and soaked in HCL. After being collected, the bottles were carefully packed and kept at 4 °C in the refrigerator. Total dissolved solids (TDS), dissolved oxygen (DO), electrical conductivity (EC) and pH were measured at in situ by potable multi-metre, while the (Cl^-) chloride, sulphate (SO_4^{2-}), fluoride (F^-) and nitrate (NO_3^-) were measured using spectrophotometric technique. Alkalinity and total hardness (TH) were analysed by titration methods. A total of 2 metals namely iron (Fe^{2+}) and boron (B^+) were analysed by ion chromatograph (IC). The remaining parameter testing was carried out in accordance with the Bureau of Indian standards [21]. In addition, observations that lacked any of the data were deleted. Distilled water (blank samples) was examined in parallel for quality control, and each analysis was conducted twice [8]. Here, standard reference materials (SRM) were tested for quality control and technique correctness. Meanwhile, water quality variables were indeed inspected, using ion balance error (IBE) to evaluate chemical data with accuracy, which is affirmed in milliequivalent per litre (meq/L). The recorded IBE is below the permissible level of plus/minus 5%.

4 Methodology

Reliable evaluation of the dataset with several variables, examined at different sampling sites, was done using water quality index development [67]. Consequently, in order to determine whether there is a similarity in the variation of water performance indicators between the sampling sites, Stepwise Weight Assessment Ratio Analysis (SWARA) weighing method was incorporated in this innovative study. In addition, it is a rating system that shows the combined impact of each of the chosen water quality parameters on the water's overall quality. The main goal of this review was to evaluate this approach, which also involves evaluating the spatiotemporal variability of the water quality of a water source by developing a straightforward WQI calculation process, with less work and better accuracy based on MCDM techniques, for the assessment of the quality of sub-surface water and surface water [43]. Such evaluations are simply accomplished with the use of a single numerical score or index. The computational steps, defining and ranking of the decision criteria, determination of the comparative importance of each criterion, estimation of the coefficient of each criterion, determination of recalculated weight and finally and calculation of the relative weight (W_i) are suggested by Kersuliene et al. [93]. Last, the combination of weights and a quality rating scale (Y_i) result in S-WQI is carried out as follows: S-WQI $= \sum W_i * Y_i$, where Y_i refers to each parameter, which is given as the proportion of the observed value of the ith parameter (I_i) to its standard value (S_i): $Y_i = (I_i/S_i)$ *100. The proposed index's quality grading scale, as recommended by [96] symbolises waters with S-WQI < 50, must be of excellent quality, S-WQI between 50 and 100 as good, S-WQI between 100 and 150 as medium, S-WQI between 150 and 200 as poor and S-WQI > 200 as extremely poor. Although, the technique for establishing WQI for water quality evaluation has both strengths and limitations that can be quickly streamlined by multi-criteria decision-making (MCDM) techniques using Simple Additive Weighting (SAW) to evaluate the parameter's weight separately [37]. The main advantage of this algorithm is that this technique uses the best variables randomly selected from the input variables to build a ranking score. This procedure also reduces the overall error of the model [97]. So, effectiveness of procedures suggested by SAW approach, derived from the basic language, is used to identify and address complex water concerns and the conceptual model of assessment processes [75]. Another advantage is that it avoids model fitting. This algorithm's insensitivity to the data's normality is another important advantage. Additionally, it makes it simple for decision-makers to consider the effects of uncertainty, which frequently characterise difficulties with water management [32]. As a result, rigidity, uncertainty and eclipse issues will always present a