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SUSTAINABLE

CIVIL INFRASTRUCTURE DEVELOPMENT-

CASE STUDIES

Four Dimensions Publishing Group INC.

EDITED BY
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FIRST EDITION

SUSTAINABLE CIVIL INFRASTRUCTURE DEVELOPMENT: CASE STUDIES

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DEDICATION

This book is dedicated to billions of people who got affected by the outbreak of Covid-19 pandemic worldwide since last few years, initiating loss of lives and livelihoods.

Sustainability is crucial for survival and growth of human civilization.

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PREFACE

Civil engineering is an age-old professional engineering discipline, considered as the "*Mother of Engineering*". The field is quite vast, dealing with the major areas including structural, geotechnical, environmental, water resources, transportation, construction management techniques, etc. The civil engineers are largely involved in design, construction and maintenance of structures like high-rise buildings, transport infrastructure, hydraulic structures, and community public health, among others. In a nutshell, the profession of civil engineering includes application of specific scientific theories on solving technical problems in society and community of the human civilization.

Sustainability of civil infrastructure from the viewpoint of long-term service requirement has been observed to be of immense importance. Major infrastructure developed towards the public utility requirements to the minor infrastructure including residential and commercial buildings, private roadways, factories and industrial structures, local water and environmental projects, etc., should be designed and constructed to meet the enduring requirement against the environment and possible disaster. With the advances of construction industry in the last few decades, adequate analysis and quantification of sustainability and resilience have been the integrated parts of civil infrastructure development. Such approach necessitates optimization of structural and foundation design, material specification, maintenance and management policies, together with socio-impact scrutiny. This edited book consists of fifteen chapters to cover the wide spectrum of sustainable civil infrastructure development with emphasis on real case studies in major to minor projects.

The first chapter presented a real time case study on rehabilitation of a large and old residential building situated in a densely populated urban area. Commencing from the brief description on the scientific details of the repair works conducted stage-wise, critical analysis and interpretations on the improvement in structural stability have been presented as well. The novelty and limitations of the restoration activities undertaken have also been discussed by the author. The chapter is quite useful for the practicing engineers, consulting companies working in the areas of maintaining and restoring of the old building and structures.

The second chapter portrayed a typical case study on the usages of building ruins for community-based post-earthquake re-construction of houses. The study area chosen by the author was a typical locality of Indonesia. The construction work undertaken by the earthquake affected residents comprised of several levels of competency including attention, mimicking, adding and creativity, by utilizing the earthquake left-out wastes of building materials. The chapter described an excellent example of community-based but independent redevelopment of houses by earthquake victims using their own designs and practices.

The third chapter described the earthquake phenomena including geological aspects, seismography, influence of earthquake on civil infrastructures, safeguarding procedures for buildings in affected areas, and the necessities of enforcing appropriate laws and legislative provisions for public interests. The chapter focused on Indian conditions with special emphasis on the north-eastern areas, which is a severe earthquake prone zone. Being brief and informative, the chapter is useful to practicing engineers working in earthquake affected regions.

Foundations of structures transmit the loads into the subsoil beneath. The fourth chapter presented a numerical study on the performance of piled raft foundation embedded in layered soil subjected to vertical loading. Through finite element modeling by $PLAXIS^{3D}$ software, the performance analysis of the piled raft foundation in layered subsoil comprising of clay on top, then silty sand, underlain by dense sand was carried out for vertical loads. From appropriate analysis and interpretations of the numerical results, important conclusions were drawn.

Liquefaction of soil is a major problem against the performance of foundations in earthquake prone zones. The pushover analysis of pile embedded in liquefiable and non-liquefiable soil by finite element modeling has been studied in the chapter five. The numerical computations were performed via a graphical interface finite element program for non-linear static and dynamic structural modeling called OpenSees PL. The in-depth analysis and interpretations yielded important conclusions utilizable by researchers and practicing engineers working in the fields of foundation design in earthquake-prone areas.

Geoenvironmental study on the influence of domestic wastewater on soil characteristics is important to investigate the suitability of the wastewater to be used in irrigation. This important study was presented in chapter six. Through laboratory experimentations, specific engineering properties of the soil collected from a specific locality before and after exposure to wastewater had been studied. When treated with domestic wastewater, significant improvement in soil characteristics was observed which might be advantageous for the agricultural products.

The chapter seven portrayed the eco-planning for clusters of the textile manufacturing industries for sustainable development by means of a typical case study in a selected locality in West Bengal, India. Although textile manufacturing was identified as the second largest revenue and employment generating industry in India, numerous small to medium unplanned textile manufacturing hubs were found in the country. Unsystematic disposal of waste effluents in the surrounding localities adversely affected the environment and general public health severely. Hence, an eco-planning concept which comprised of textile park with adequate water supply and waste disposal technologies, internal roadways for pedestrian and vehicular movements, common commercial and IT centres, etc., was proposed in the study area.

The chapter eight presented a hydrological and environmental study of surface water characteristics in a selected location in north-eastern part of India. Both the pre and post-monsoon water characteristics in terms of pH, temperature, dissolved oxygen, turbidity, total dissolved solids, nitrate, and phosphate, among other physical and chemical water parameters, were tested and the water quality index was computed. Accordingly, the water samples were graded from excellent to unfit for domestic usages.

Saline water intrusion and submarine groundwater discharge are the two most common hydrological phenomena in coastal zones due to density stratified flow. Coastal groundwater management techniques from the viewpoint of saltwater intrusion were discussed in chapter nine. Covering the theoretical and experimental past investigations and the various techniques to control the intrusion in coastal groundwater, the chapter provided a series of important observations and appropriate conclusions therefrom.

Significant areas in north-eastern zones in India are flooded in monsoon periods. The different causes for occurrence of flooding in Assam, India and the efficacy of embankment as a viable flood control structure therein was studied in chapter ten. The rivers Brahmaputra and Barak are major contributories for monsoon floods in majority portions in Assam, India. As analyzed, embankment construction can partially control the enormous flooding in the areas concerned, mainly due to scouring and erosion of river banks and associated geotechnical instabilities, apart from poor maintenance.

The chapter eleven presented a brief review on the sustainable water resource development in Indian scenario. An ever-increasing demand for water supply under the rising social, economic, and environmental requirement against the appropriate risk analysis for water contamination and environmental deterioration, is the fundamental challenge faced by India in recent decades. Effective irrigation techniques using modern tools, encouraging soil conservation and groundwater recharge, prevention of scouring and siltation, development of wetlands and imparting proper education to the citizens aiming towards efficient water usages, were identified as the key factors for sustainable water resource development in India.

A smart city is a modernized urban area that technologically utilizes various electronic methods and sensors to collect specific data, so as to manage assets, resources and services efficiently, with the objective to improve operations across the city by the information so collected. A case study to advance Bengaluru in India as a smart city was presented in chapter twelve. While both the international and national models were separately considered, the guidelines and features for a smart city was discussed, together with appropriate analysis for spatial growth and land usages were studied. The indicators and benchmarks including transportation, water supply, waste management and electricity and the strategies to be undertaken were analyzed. The limitations and challenges against the proposed strategies were highlighted as well.

Chapter thirteen portrayed the use the nanotechnology by developing the anti-fungal and anti- bacterial non-structural building materials. Houses in humid regions are susceptible to bacterial and fungal growths initiating moderate to severe health hazards to the residents. While the remedial measures to eradicate such problem have been expensive and cumbersome, nanotechnology appeared to be an effective technique against such acute scenarios. Extensive laboratory investigations with zinc oxide nano-rods on bacterial or fungal affected samples of building materials using hydrothermal technique were conducted. It was observed that there was a general tendency of significant reduction in the rate of sporulation near the sample area treated by using nano-rods.

The chapter fourteen described the role of robotics and automation in the construction sector. Recent development in the application of autonomous machine and self-driving equipment in construction sector for carrying materials across the work-site and to transport heavy objects was portrayed. The use of artificial intelligent together with robotics is a modern technique in the major to medium construction sites. While the major advantages of using robotics in construction sectors including reduced time and cost, enhanced connectivity and convergence, environmental friendliness, etc., were discussed, the limitations and disadvantages were highlighted as well.

Condensation detection in an enclosed space whereby optimizing building constructions using numerical analysis has been included in the chapter fifteen. The numerical modeling comprised of thermodynamic evolution of moist air in a 2D square room enclosure using COMSOL multi-physics software. The primary objective was detecting occurrence of saturation due to alteration in external environmental characteristics. Comparative studies were carried out on the contour plots of isotherm, relative humidity, velocity along with important indicators of ambient relative humidity, temperature, maximum relative humidity versus saturation indicator plots at the selected study areas and relevant conclusions were drawn therefrom.

To cover the above diversified study areas, academicians from Institutions and Universities, scientists from research organizations, and professional engineers contributed the individual book chapters. It is expected that this edited book shall be enormously beneficial to the academic world as well as to the practicing field-based engineers and technologists.

SUDIP BASACK
February 2023 GHRITARTHA GOSWAMI
JOYDEEP DUTTA

Disclaimer: The contents and views expressed in the individual chapters included herein are written by the author/s concerned and neither the editors nor the publisher do hold any responsibility for the same.

FOREWORD

Sustainable civil infrastructure development is a national priority to most countries in the world, more specifically a developing country like India. The term 'civil infrastructure' include a wide spectrum of engineering such as high-rise buildings, transport infrastructure, hydraulic structures, and community public health and other emerging technologies. It is imperative that the civil infrastructures that are built today should be utilized to shape tomorrow. This essentially necessitates appropriate knowledge and skills right from the planning stage, implementation and long-term maintenance and sustainability for all such civil infrastructure development. The term 'sustainability' refers to long-term viability aiming towards optimum utilization of existing resources interwoven with socio-economic and environmental requirements at present and future. Thus, in recent times, the primary focus should be to build-up resilient, durable and disaster-resistant civil infrastructure for national development.

The current book titled as "*Sustainable Civil Infrastructure Development: Case Studies*" edited by Sudip Basack, Ghritartha Goswami and Joydeep Dutta offer a significant number of real-life case studies on civil infrastructure development. This concerted effort is to be commended for an exceptionally beneficial contribution to civil engineering. The contents are based on detailed knowledge acquired through many years of painstaking field observations and research studies by many reputed academics and practitioners. The balance of theory and practice as well as the depth of the subject matter of the fifteen chapters is remarkable.

Numerous advances covering a wide range of topics in provided methodical compilation of the case histories in several real infrastructure projects are available in the edited book. Commencing from the study-fields in structural, geotechnical, environmental and water resource development, the book covers several emerging areas of rapidly developing multi-disciplinary fields including application of nanotechnology, robotics, automation and artificial intelligence, smart city development, etc.

The current standalone book compilation offer an outstanding package for practitioners, researchers, academics and students, culminating in the understanding of concepts and the delivery of competitive ground breaking solutions in almost every facet of sustainable civil infrastructure development. Undoubtedly, it is indeed one of the remarkable comprehensive compilations of Sustainable Civil Infrastructure Development available today and should be on the shelf of every civil engineer.

February 2023

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CHAPTER ONE

REHABILITATION OF LARGE, OLD RESIDENTIAL BUILDING IN DENSELY POPULATED URBAN AREA: A CASE STUDY

SUDIP BASACK[1]

Abstract

Densely populated urban residential regions are often characterized by irregular planning of buildings and structures, which can result in close spacing, inadequate environmental friendliness, and insufficient public utility services. Such adverse situations are prevalent in several old cities in India, leading to reduced lifespan of numerous residential buildings. Repair and rehabilitation of such structures can be a challenging task for professional engineers, who must ensure the safety and serviceability of adjacent buildings. This paper presents a brief description of the rehabilitation work carried out on an existing old residential building in the city of Kolkata, India. The paper also includes critical analyses of individual activities with scientific interpretations, which may be beneficial for practicing engineers.

Key Words

Dismantling; Old building; Painting; Plastering; Rehabilitation; Roof treatment

Introduction

Urbanization is an integral part of population increase, as humans settle in cities for livelihood, resulting in the establishment of numerous cities around the world. Despite scientific and technological advancements in recent decades, several old cities suffer from improper planning and limited public utility services. The scarcity of land, in the face of steeply increasing population growth, is a major factor that can adversely affect the quality of residential buildings in terms of safety, serviceability, and public health requirements (Dwidayati and Samyahardja 2019). About 3% of the global land area has been occupied by existing cities, which house nearly 50% of the world's population, utilizing about 75% of resources, including all energy consumption and greenhouse gas emissions (Vasilyev *et al.,* 2020).

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Scientific analysis suggests that the global urban population is expected to comprise 70% of the world's overall population by the year 2050. This trend is particularly alarming for megacities (Lele 2017; Langdon 2017).

India has exhibited a heavy urbanization pattern, with about 70% of its population concentrated in towns and cities, although the quality and quantity of necessary infrastructure is significantly below average (Tripathi 2017). The growth and sustainability of urban population depends on several public utility services, including water supply and sewerage, solid waste management, transport infrastructure, health, and environmental safety, among others (Government of India 2011). The Indian urbanization pattern is depicted graphically in Figure 1.

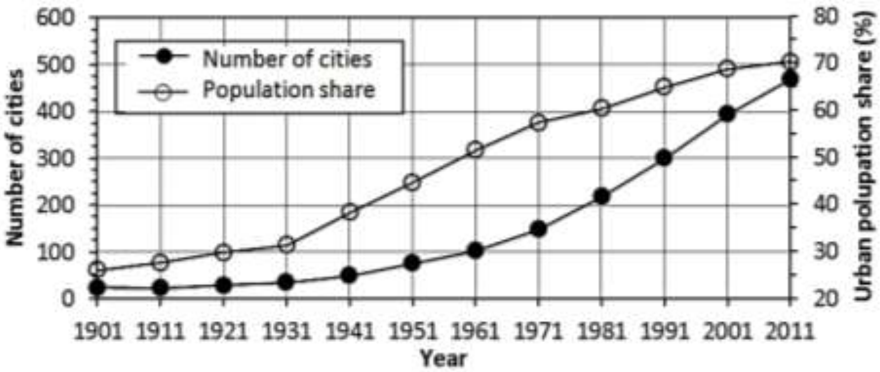


Figure 1. Urbanization in India (Data curated from Census 2011)

As observed, the number of cities during the period 1901 to 2011 has increased following a parabolic pattern with an ascending slope. The number of cities has increased from 24 in the year 1901 to 468 in 2011, with an 18500% increment. The urban population share with respect to the total population increased non-linearly with time. During 1901-1931, the pattern was linear, whereas, in the post-1931 period, the curve took a descending slope with a stabilizing trend. The value increased from 26% in 1901 to 70.24% in 2011, with about 170% increment.

The term ‘megacity’ is defined as a metropolitan area where the total number of inhabitants exceeds 10 million (United Nations 2018). The total number of megacities around the world varies from 33-37, as obtained from different sources, with about 50% in China and India (Demographia 2020; City Population 2022). On this basis, there are five megacities in India, namely Delhi, Mumbai, Kolkata, Chennai, and Bengaluru (Census 2021).

The megacity Kolkata is the 7th most populated city in the world and 3rd largest metropolitan area in India. It is the capital of the state of West Bengal, situating in the eastern part of India at coordinates of 22.57° N and 88.36° E. The megacity is located on the eastern bank of the river Hooghly and about 80 km away from the international border between India and Bangladesh, having an average altitude of 6.4 m above the mean sea level (KMC). More than 15 million residents, with a population density of 24.76 / km^2, lives in the city, as per the recent census report (Census 2021). Being the major business, commercial and financial hub in eastern India, the city is considered as the cultural capital of India, with highest number of noble laureates.

The city of Kolkata was established by British trader Job Charnock in the year 1690, combining the three villages namely, Sutaniti, Gobindapur, and Kolkata. Initially, the area was limited from Chitpur at the north to Bhawanipur at the south. Later on, the city has been extended towards Salt Lake and Rajarhat in the west, Baranagar towards the north to Tollygunge at the south, having a total area of 1480 km^2. In the last few decades, the city has been further extended as ‘Greater Kolkata’ covering various suburban localities (KMC).

Study Area and Location

The rehabilitation work was carried out for a specific large residential building named 'Basack Mansion' situated in north-central Kolkata, specifically near the crossing of Vivekananda Road and Bidhan Sarani, with global coordinates of 22.585°N and 88.368°E. The residential property is in close proximity to the famous residences of Swami Vivekananda, religious reformer Raja Rammohan Roy, and scientist Sir Jagadish Chandra Bose. The area is currently characterized by significantly populated, closely spaced old buildings, mostly residential and commercial. The location of the study area is portrayed in Figure 2.

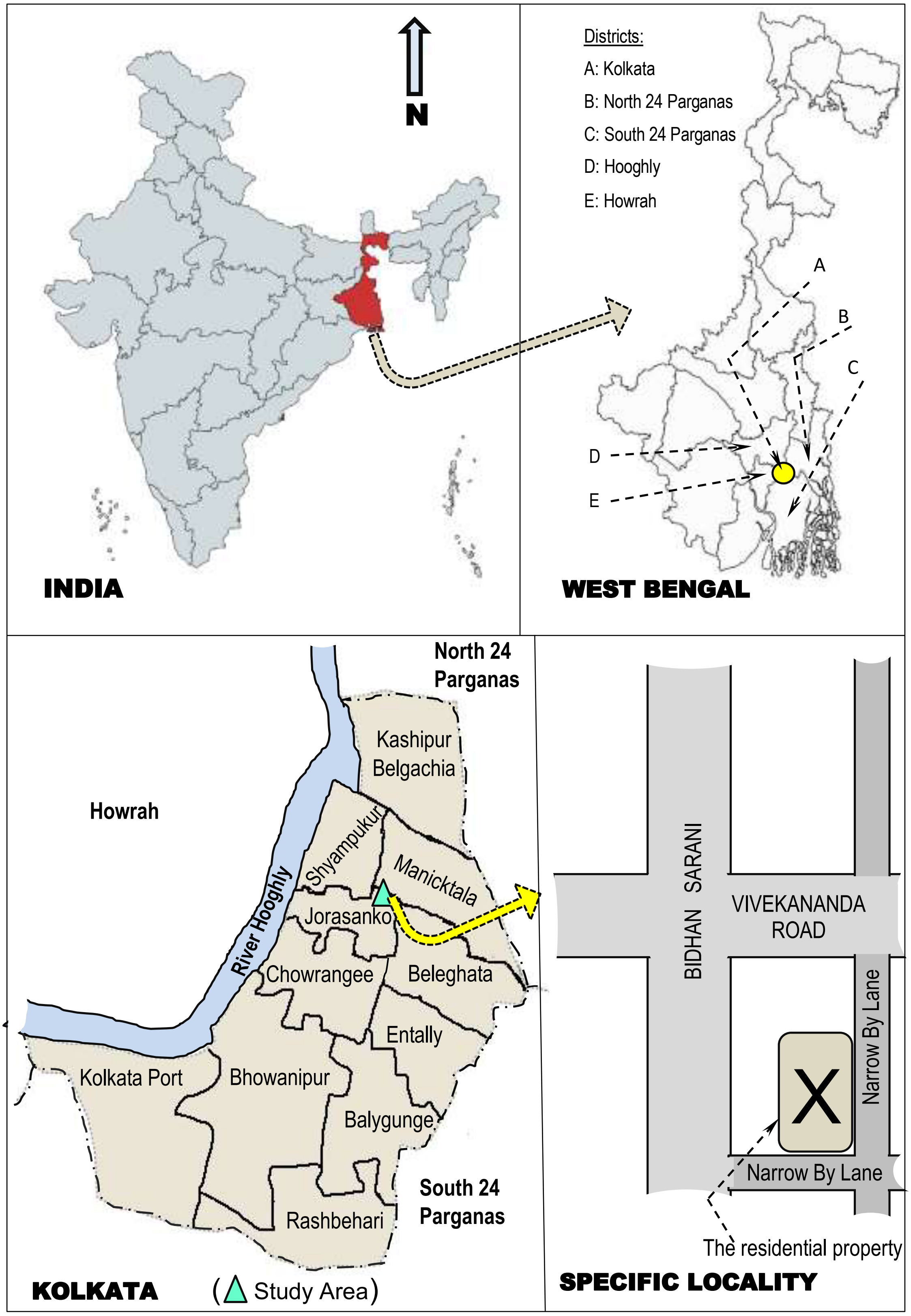


Figure 2. Location of the study area

Architectural Aspects

The residential building under the current study is 3 stories tall, with a total plot area of about 150 m^2 and a covered area of 458 m^2. The property was constructed between 1891-1895 during the British rule in India and was handed over to the ancestors of the current residents in the year 1933. The building is characterized by a courtyard type structure, with an open-to-sky central courtyard surrounded by rooms (Macintosh 1973; Deb 1990). A typical sketch showing such a building is given in Figure 3. Although space-consuming and susceptible to storms and precipitation during monsoons, there are numerous advantages of courtyard type residential buildings, including psycho-social, economic, circulation, and ventilation benefits, ease of internal accessibility, among others (Das 2001).

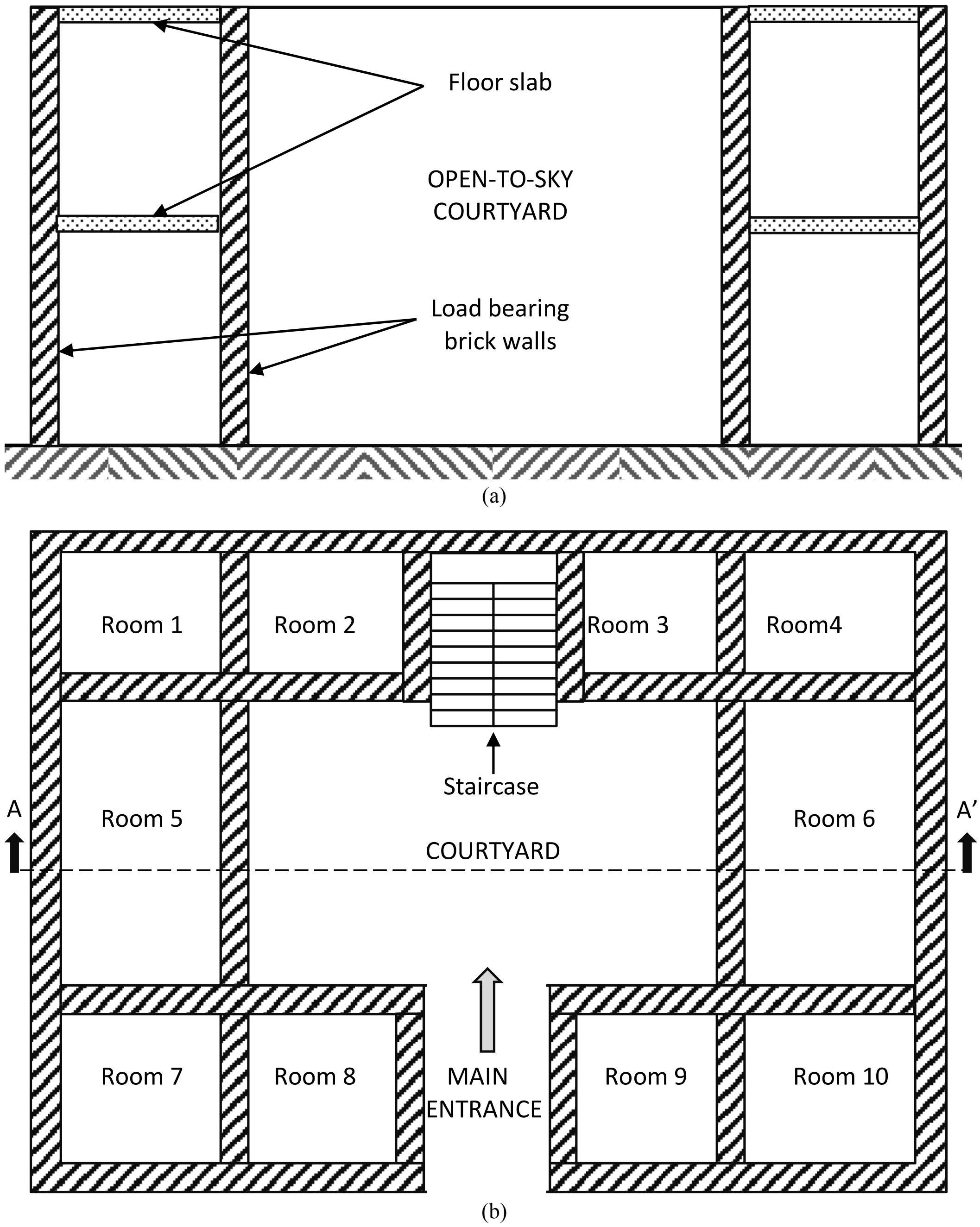
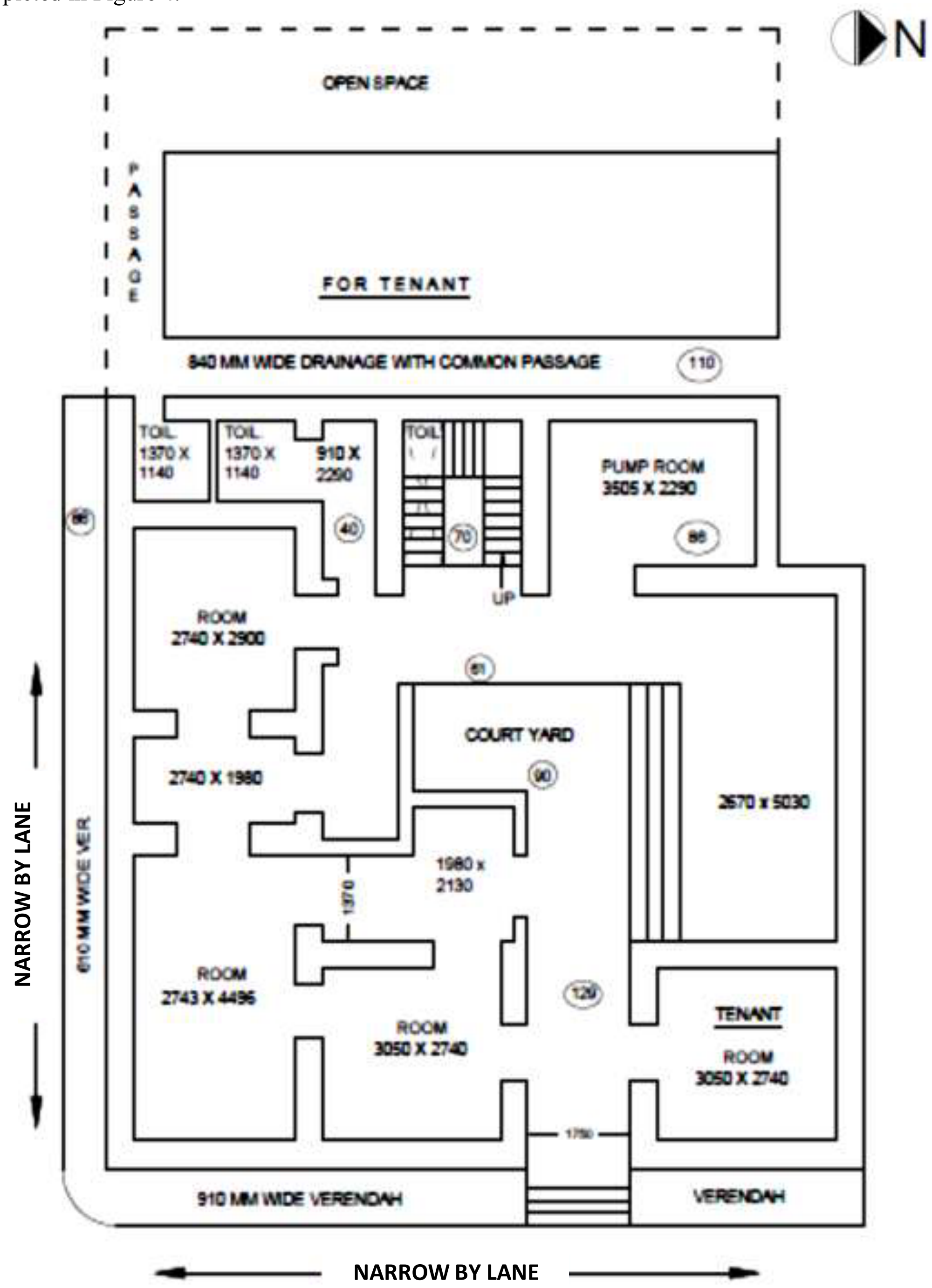


Figure 3. Sketch showing courtyard type residential building: (a) Sectional elevation on AA', and (b) Plan

The building, in particular, is characterized by all-round load-bearing walls of 375 mm thick brick walls with lime mortar binder. The building is supported by strip footings to support the entire structure on normal Kolkata soft soil (Reddy *et al.,* 2014). The plan of the specific building is depicted in Figure 4.



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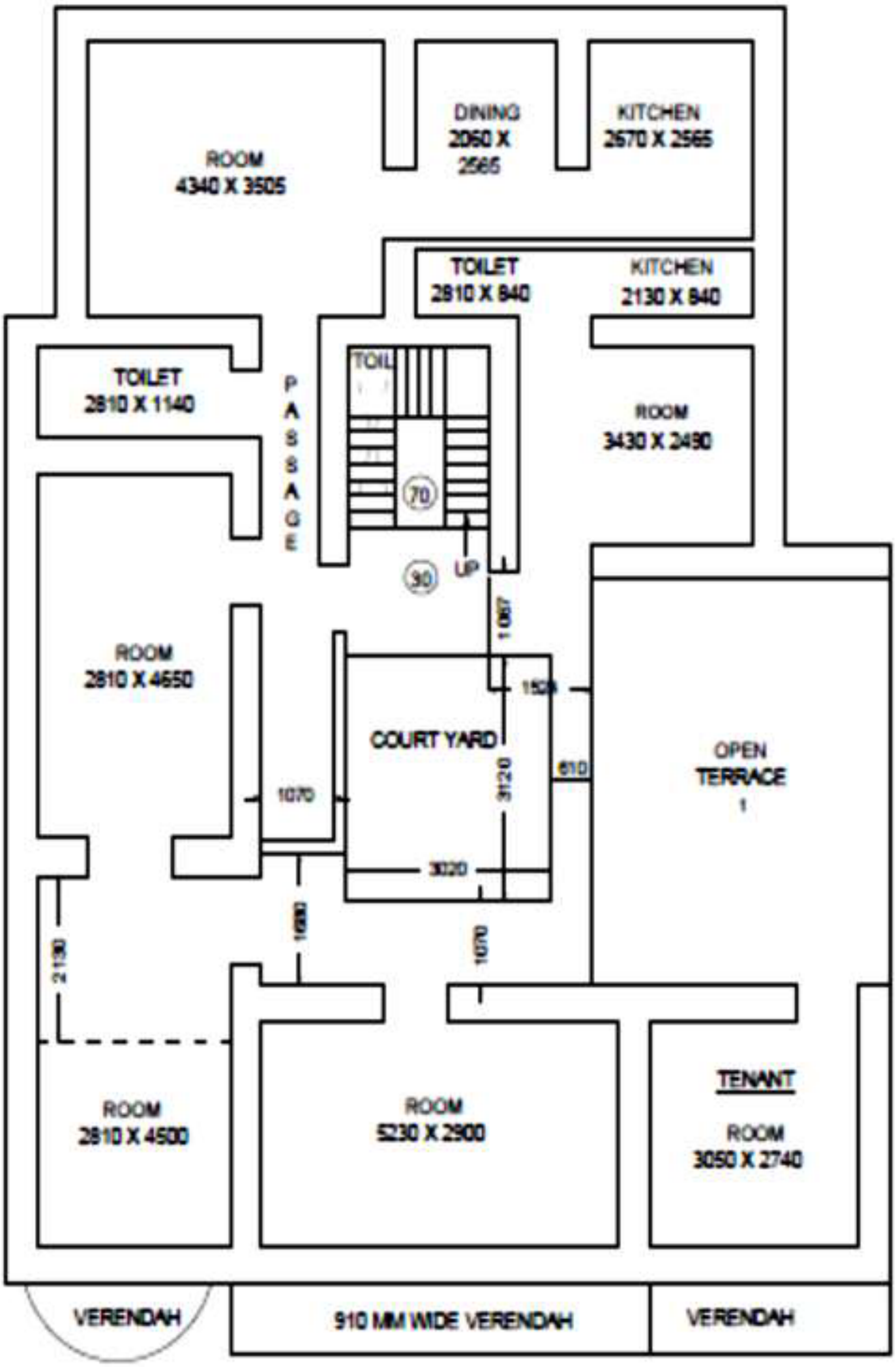
(a)



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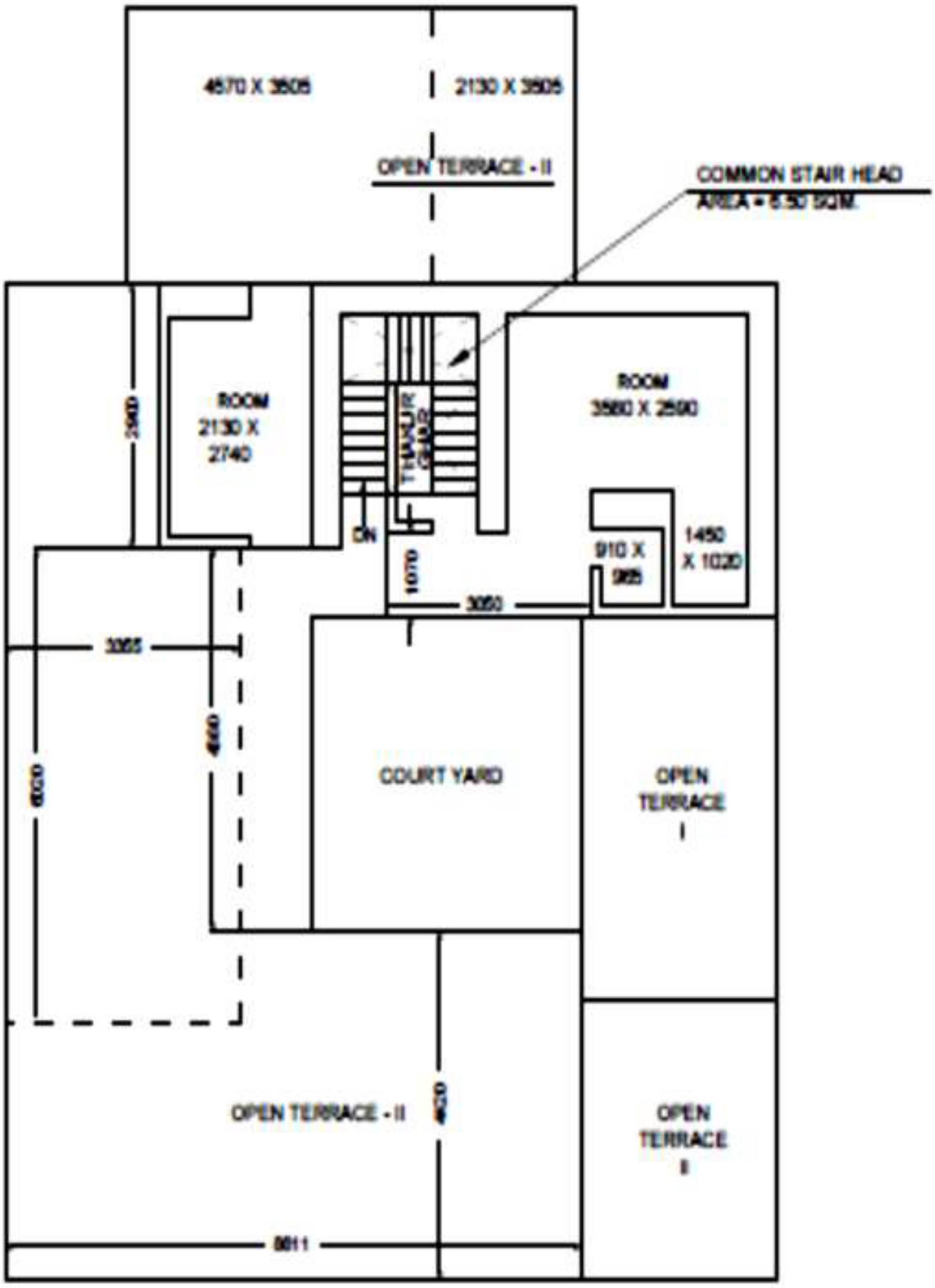

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(c)

Figure 4. Plan of the building: (a) Ground floor, (b) First floor, and (c) Second floor

Pre-rehabilitation Conditions

Being more than 125 years old and without any noteworthy rehabilitation work, the building had remarkably deteriorated day by day both externally and internally. The primary factors contributing to such degradation may be listed as daily and seasonal temperature variations, storms and floods, solar radiation, soil and groundwater corrosive effects, air pollution, biodegradation, etc. (CPWD 2013). The pre-repair condition of the building under consideration was characterized by several cracks in walls and floors, damaged plasters and mortars, settlement of some cantilever balconies, porous roofs initiating water percolation, water leakage in water-supply and sewage pipelines in bathrooms, toilets, and kitchens, among others. However, from a structural viewpoint, the building still survived, possibly owing to high safety factors and the superior quality of materials in the early nineties. A few photographic views portraying the pre-rehabilitated conditions of the building are shown in Figure 5.

Legends: 1. Main entrance; 2. Damaged plasters and mortars; 3. Damaged balcony cornice; 4. Damaged round balcony slab; 5. Damaged parapet wall; 6. Secondary entrance; 7. Rock; 8. Broken cornice; 9. Vegetative growth; 10. Damaged wooden window; 11. Inner balcony over courtyard; 12. Damaged joists; 13. Cracks on staircase; 14. Damaged staircase ceilings; 15. Holes and cracks on roof.

Figure 5. Pre-rehabilitation building condition: (a) Front view, (b) Details of front edge, (c) Side view – ground floor, (d) Side view – upper floors, (e) Southeast corner, (f) Inner balconies, (g & h) Staircase, and (i) Roof

Repair, Rehabilitation and Retrofitting

The long-term and progressive deterioration of the building necessitated substantial repair and rehabilitation to preserve the structure. The rehabilitation work should be broadly classified as structural conservation, chemical preservation, and retrofitting of building elements (CPWD 2013). The stepwise works commencing from planning to execution are sequentially described below.

Planning

The entire rehabilitation work consists of step-by-step planning to execute individual activities including the removal of old plasters, repair of damaged portions, laying new plasters, retrofitting of damaged structural components, roof treatment, renovation of problematic toilets and bathrooms, painting, etc. Prior to the commencement of any activity, the local municipality was approached to obtain the necessary permission against the payment of prescribed fees, as per the statutory provision (KMC 2021). The total estimated external area to be repaired was 25 m in length and 10 m in height. The planning depicting the entire rehabilitation work is shown in Figure 6.

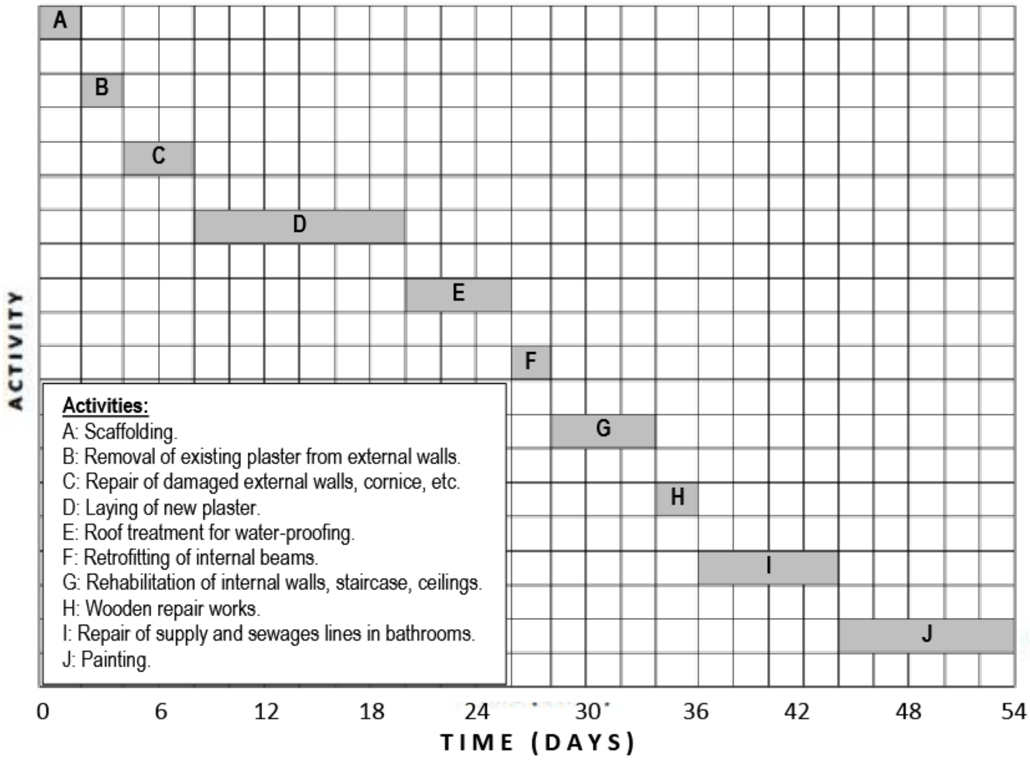


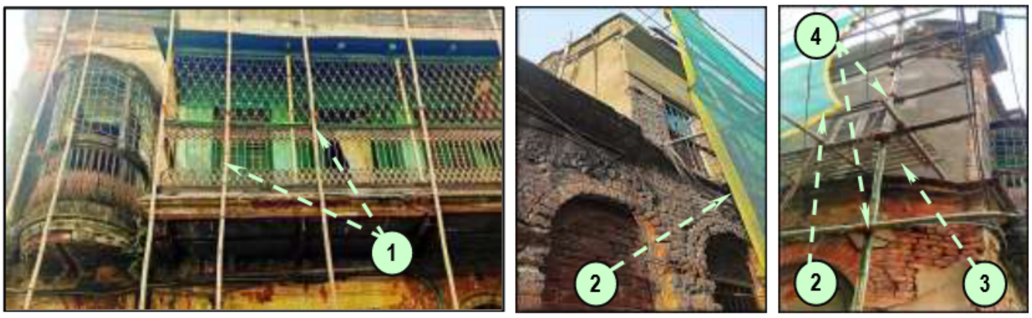
Figure 6. Bar chart of execution of the entire rehabilitation work

As observed from the bar chart above, the entire work was scheduled for 54 days. However, due to adverse atmospheric conditions including high summer temperature and sudden rainfall, minor delay took place, although the entire rehabilitation was completed within 60 days, which was in agreement with the given approval by the local municipality.

Implementation

The work at the site commenced with scaffolding using fresh bamboo trunks procured from the local market, each of which was about 7.5-8m long and 75-90mm in diameter on average. Scaffolding was done on the external walls in the shape of a rectangular frame from the outer road surface to the top of the parapet wall. The entire length of bamboo trunks was used for the main vertical and horizontal members, while intermediate members were cut to the desired length. Adjacent members were rigidly tied up with thick ropes, and movable working platforms were created at selected locations. Such scaffolding is economic and convenient without compromising on stability, compared to metal scaffolding (So 2002; Bambhava *et al.,* 2013). A photographic view of the bamboo scaffolding is shown in Figure 7.

The scaffolding work was followed by the removal of existing plasters, which were more than 125 years old and significantly deteriorated due to weathering and man-made activities. Prior to commencing the work, the entire scaffolding was covered with transparent cloths to prevent the spread of dust and minimize public discomfort.



(a) (b) (c)

Legends: 1. Bamboo members; 2. Transparent cloth cover; 3. Working platform; 4. Rope fastening.

Figure 7. External scaffolding: (a) Front view, (b) Side view, and (c) Corner

Completion of the plaster-dismantling work was followed by identification of local damages including development of cracks, displaced bricks, damaged cornices, etc. These localized damages have been repaired initially, prior to commencement of laying new plasters. The plastering was commenced from the parapet wall and gradually progressed downwards towards the ground floor, so as to ensure convenient workability. Locally available branded cement and yellow sand, mixed at a volumetric ratio of 1:6, was used as mortar. For water-proofing, SikaLatex^{R} Power, a water-based emulsion of styrene-butadiene rubber, was used as an admixture to the cement mortar at a volumetric ratio of 1:4:8 (admixture : water : cement). Apart from water-proofing, the admixture also acts as a bonding-agent and crack filling (Sisanth *et al.,* 2017). Photographic views of newly plastered walls are shown in Figure 8.

(a) (c)

Legends: 1. Plastered wall; 2. Architectural texture; 3. Repaired cornices; 4. Plastered parapet wall.

Figure 8. Plastered exterior walls: (a) Front view, (b) Side view, and (c) Front parapet wall

The plastering of the external walls was followed by roof treatment because frequent rainfall of high intensity in the summer of Kolkata could initiate percolation and dripping of water into the buildings from the damaged roof, obstructing the interior repair works. The total area of the treated roof was about 75 m², while the damaged parapet walls were 24 m in total length and 2 m in height. First, the top 50 mm of the damaged roof surface and the base area of the parapet walls were removed. A wire mesh of 3 mm thick steel wires with a hexagonal pattern was laid on the dismantled roof surface. Thereafter, a plain cement concrete mixture at 1:3:6 volumetric ratio with the SikaLatexR Power admixture was laid on the wire mesh. The repaired surface was adequately compacted manually with a rammer and leveled to the desired slopes to ensure rainwater drainage. Appropriate clearance was kept for the two rainwater outlets situated near the center of the roof. Figure 9 depicts the sketch of the roof treatment work undertaken, while Figure 10 portrays the roof treatment work.

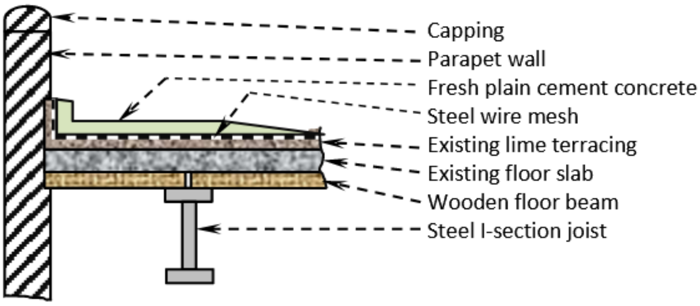


Figure 9. Schematic diagram showing basic principle of roof treatment undertaken

Legends: 1. Rainwater outlet; 2. Steel wire grid; 3. Temporary dead weight; 4. Treated roof; 5. Leveling work in progress; 6. Concrete laying in progress; 7. Parapet wall.

Figure 10. Roof treatment work

Once the waterproofing of the roof was properly completed, the internal rehabilitation work was carried out. As mentioned earlier, the building was primarily a load-bearing walled structure with floor slabs supported by rectangular wooden beams, which were in turn supported on I-section steel joists. The wooden beams were placed at 300 mm c/c spacing, while the joists were fixed at a spacing of 900 mm c/c. Each of the joists had a depth of 100 mm, a flange width of 50 mm, and a thickness of 3 mm. These joists were quite long, spanning over the entire widths of the rooms and also projected out of the load-bearing walls to support the cantilever balconies, exterior or interior. In the vicinity of the joist-wall junction points, the steel was found to be deteriorated, possibly because of long-term exposure to adverse atmospheric conditions, damping in the walls, corrosion, etc. In extreme situations, such deterioration may lead to disastrous consequences, including the collapse of the floor slabs in extreme conditions.

The cantilever ends of the joists were observed to be more deteriorated than the interior ends; hence, the former end was repaired. The rehabilitation of the joists was done in two phases. Firstly, brick wall portions adjacent to the joists were dismantled up to 200 mm, and painted steel channels ISMC 75 x 40 were inserted below the joists. Each ISMC was inserted 200 mm within the walls while the projected length out of the walls was 150 mm. In the second phase, the joists were retrofitted by providing a vertical prop at their ends by painted steel tubular columns of 50 mm external diameter and 3 mm wall thickness. The prop-joist connection was kept flexible via bent steel plates bolted to the tube. The rear end of the tube was fitted to a square steel plate of size 300 mm, which was grouted with the ground floor at a depth of 200 mm. The joist rehabilitation and retrofitting has been depicted by a sketch in Figure 11, while photographic views are shown in Figure 12.

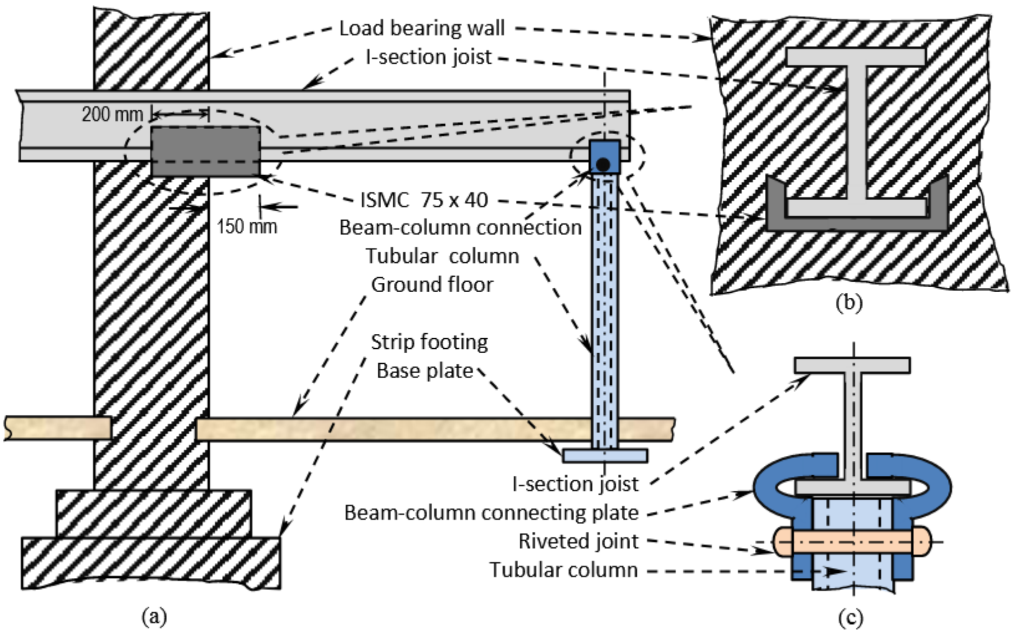


Figure 11. Rehabilitation and retrofitting of I-joist: (a) Basic principle, (b) Repair at joist-wall connection, and (c) Beam-column connection

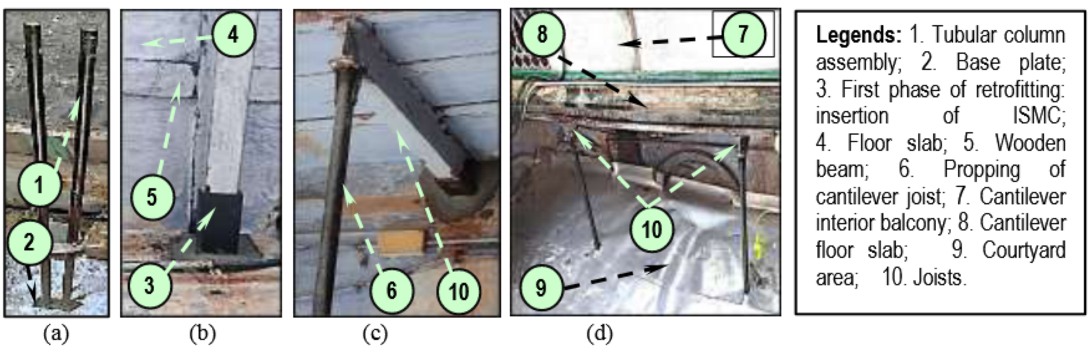


Figure 12. Photographic views of: (a) Tubular column assembly, (b) Retrofitting first phase, (c) Joist propping, and (d) retrofitted joists

The tubular column at best be treated as a long column with the top end hinged and bottom end fixed. The ultimate load (P_u) may be evaluated from Euler's formula, as given by (Timoshenko and Gere 1961):

$$P_u = Min\left\{\frac{\pi}{4}\left({d_0}^2 - {d_i}^2\right)\sigma_u \,,\ \frac{\pi^2 E \frac{\pi}{64}\left({d_0}^4 - {d_i}^4\right)}{{L_{eff}}^2}\right\} \quad (1)$$

Where, d_0 and d_i are the external and internal diameters, σ_u is the ultimate compressive stress of the column material, E is the Young's modulus of the column material and L_{eff} is the effective length of the column.

Assuming E to be 201 GPa and σ_u as 250 MPa for mild steel, the ultimate load has been estimated as given below in Table 1. The computed ultimate load and factor of safety has been shown in the bar chart in Figure 13.

Table 1: Ultimate load and factor safety of tubular column

Geometry			Material		Crushing load, $\frac{\pi}{4}({d_0}^2 - {d_i}^2)\sigma_u$		Buckling load, $\frac{\pi^2 E \frac{\pi}{64}({d_0}^4 - {d_i}^4)}{{L_{eff}}^2}$			
							Top end hinged, bottom end fixed		Both ends hinged	
Diameters (m)		L * (m)	E (GPa)	σ_u (MPa)	Load (kN)	Factor of safety **	Load (kN)	Factor of safety **	Load (kN)	Factor of safety **
d_o	d_i									
0.05	0.044	4.1	201	250	111	15.9	30	4.3	58	8.3

Notes: * Actual column length from tip to the ground floor level was measured as 4.1 m;
** Assuming a live load of 1 kN/m[2] and c/c distance between the joists as 3 m, the total estimated load imposed on each column considering self-weights of 100 mm thick floor slab and joist was 7 kN.

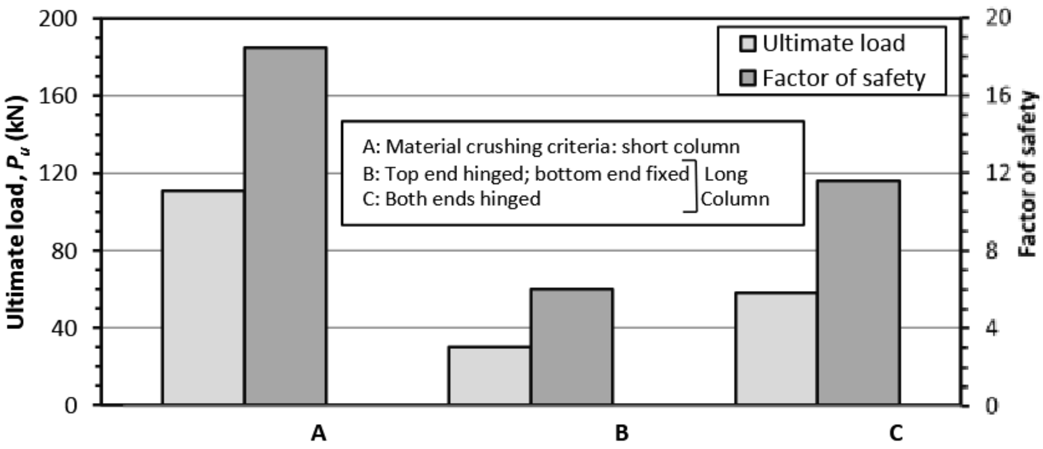
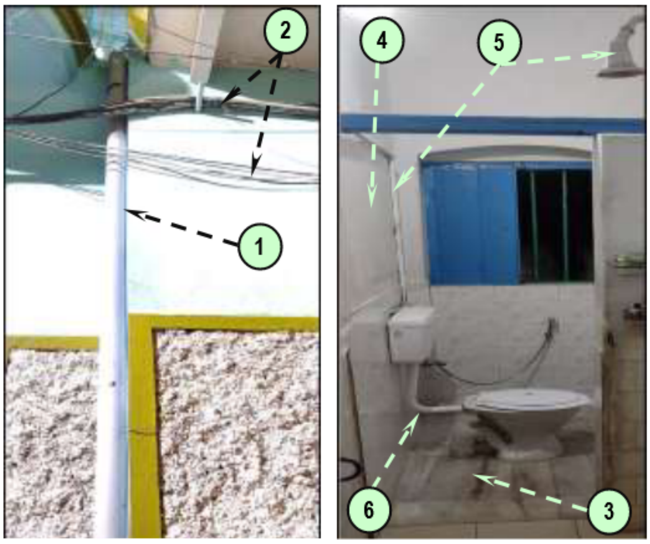


Figure 13. Bar chart showing column loads

The rehabilitation and retrofitting of the joists were followed by the repair of damaged internal walls and staircases. This was done following the same procedure adopted for the external wall repair. Several doors and windows were found to be severely damaged by adverse atmospheric actions and termites. The damaged wooden doors and windows were mostly repaired with freshly procured wooden members. The toilets and bathrooms were repaired thereafter. The existing water supply and sewage lines were metallic and heavily corroded, causing significant leakages and creating public nuisance. The floors and walls were also largely damaged, leading to the percolation of waste waters. Firstly, the existing pipelines were replaced by PVC pipes of the same diameters. The walls were thereafter plastered, and the floors were renovated with marble tiles (see Figure 14).

Finally, the newly plastered walls and renovated doors and windows were painted. The benefits of painting are numerous, including increased durability of the building as a whole, protection from adverse weather, apart from visual enhancement (Fantuccia and Serra 2017). The sequential procedure followed was as follows: (i) The walls were smoothed with sandpaper, (ii) Plaster of Paris was laid on the uneven wall surface, (iii) Primer was applied to the treated wall surface, and (iv) Plastic paints were applied in double coating on the primer layers. Thereafter, the doors, windows, and metal grills were also painted following a similar procedure. The photographic views of the completed building are shown in Figure 15.

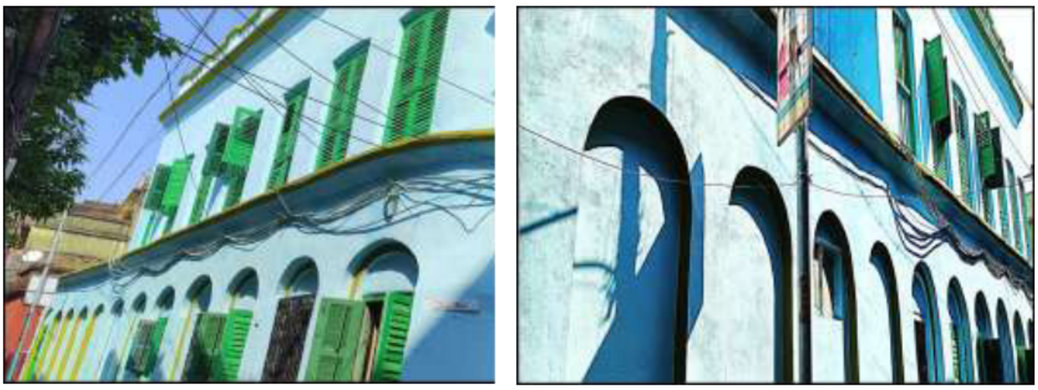


Legends: 1. New PVC sewage line; 2. Local network and electricity lines; 3. Marble floors; 4. Renovated walls; 5. New PVC water-supply lines; 6. New outlet pipes.

(a) (b)

Figure 14. (a) Replacement of sewage pipes, and (b) Renovation of bathrooms and toilets

(a)



(b)

Figure 15. Rehabilitated building: (a) Front view, and (b) Side views

Critical Analysis and Interpretations

It is true that all civil infrastructures essentially require adequate maintenance at regular intervals, without which their proper functioning and durability are adversely affected (Loganathan and Gandhi 2016). Maintenance of historic and heritage structures including old and large residential building like that covered in the current study requires specialized knowledge, skills and workmanships to enhance their longevities (Tucker 2008; Lateef 2009; Forster and Kayan 2009). Appropriate risk assessment and reliability analysis of such rehabilitation works prior to their commencement are crucial (Loganathan *et al.,* 2018a; 2018b).

The 125 years old residential building is primarily based on load-bearing walls from structural view-point, with i-section joists and wooden beams to supports the floor slabs and roof. The walls are thick enough (375 mm thickness) to withstand the loads, including dead load, live load as well as loads against accidental storms and earthquakes. While storm and cyclone occur quite frequently in the city of Kolkata throughout the year under changed weather condition in recent times, earthquake takes place rarely (Pal *et al.,* 2022). Although the building was significantly deteriorated, no significant structural damage was observed even after a century. This implies excellent workmanship of masons in the British era in India to survive a large building for significantly long time without modern reinforced cement concrete framed structure.

The normal Kolkata soil consists of very soft silty clay at the top, followed by stiff clay layers, overlying fine sand (GOWB). A typical representation of subsoil layers is depicted in Figure 16. The top 2 m consists of desiccated soil, made up of vegetative growth, waste materials, brick bats, etc. The average groundwater table was situated at about 1 m below the ground surface.

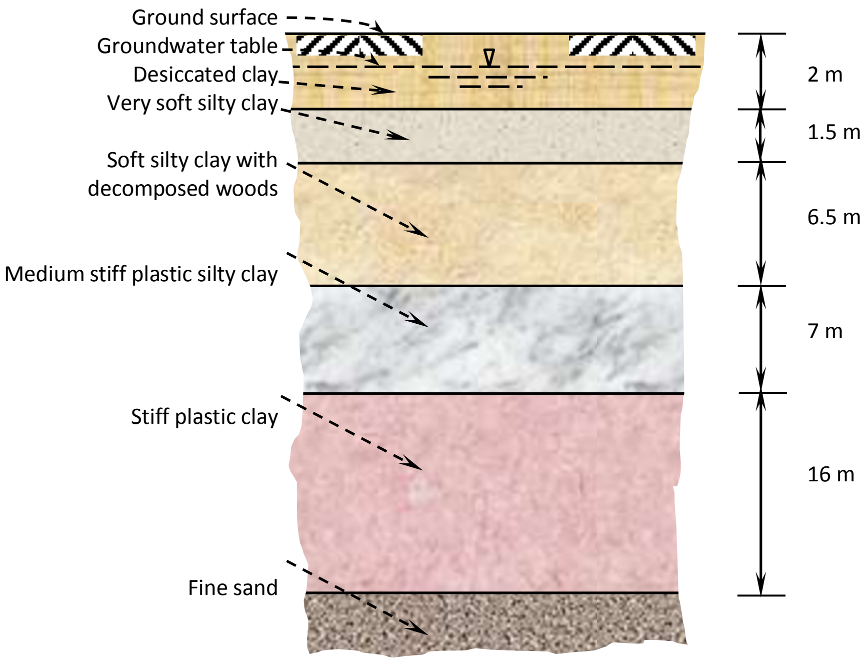


Figure 16. Normal Kolkata soil

Due to rapid dismantling and new construction around Kolkata, including in the locality concerned, subsoil stress release is likely to occur, which could adversely affect the foundation stability of existing nearby buildings (Chatterjee and Majumdar 2022). Such a situation would initiate undesirable differential settlement of foundations, producing tilting of buildings, structural cracks in load-bearing walls, damage to floors, etc., which may lead to partial or complete collapse. Although the current rehabilitation work is expected to enhance the overall stability and durability of the building to some extent, a thorough engineering analysis and judgment would be essential to estimate the lifespan of the renovated structure as well as deciding the next course of action to improve the structural and foundation stability. The application of available modern software would be beneficial to serve the purpose (PLAXIS, STAAD).

Summary and Conclusion

The work presented a detailed description of a large and old residential building situated in north-central Kolkata, India. Initially, the building was significantly damaged. The entire building was rehabilitated following sequential steps of execution. This included plastering, roof treatment, retrofitting of beams, renovation of toilets and bathrooms and finally painting. It is expected that the life of the building will be increased to some extent after the entire rehabilitation work, a thorough and detailed structural and foundation analysis and adopting rigorous rehabilitation work thereafter would be more beneficial.

Acknowledgement

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Conflict of Interest Statement

The author declares that there is no conflict of interest.

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CHAPTER TWO

COMMUNITY-BASED POST-EARTHQUAKE HOUSING RE-CONSTRUCTION USING BUILDING RUINS: A CASE STUDY OF BANTUL, INDONESIA

PEERZADI ARZEENA IMTIYAZ[1]

Abstract

A 6.3 magnitude earthquake struck Bantul, Indonesia on May 26, 2006, causing immense loss of life and property. Approximately 37,927 people were seriously injured, 5,716 human lives were lost, around 156,664 houses were destroyed, and 202,032 were damaged. The total estimated loss during the Bantul earthquake was around IDR 29 trillion (US$ 3 billion). Non-engineered private buildings and houses were mostly damaged during the earthquake due to their high vulnerability to failure. This chapter focuses on the community-based post-earthquake housing reconstruction process in Bantul, using building ruins. The locals displayed a sense of solidarity, collectiveness, and tolerance during the disaster recovery process, which was recognized as a value adopted from their strong local culture. The chapter suggests the use of local practices. The Bantul community exhibited a great level of acceptance and comfort towards their new self-constructed homes using building ruins. Four levels of capabilities, namely attention (niteni), mimicking (niroake), adding (nambahake), and creativity (dan nemoake), have been explained to understand their independent construction using building ruins. The new buildings constructed after the earthquake presented an example of easy procurement of construction materials, self and simple construction, and a strong motivation to understand the sustainability of potential building material ruins. These are the actual requirements in any community for sustainable post-disaster construction.

Key Words

Ruins; Post-earthquake housing construction; Community participation

Introduction

Earthquakes are one of the deadliest natural hazards witnessed on Earth in recent years, posing a serious threat to millions of people around the world. The world's eight to ten most populous cities are located around earthquake fault zones. Currently, the National Earthquake Information Center monitors 20,000 earthquakes a year, or roughly 55 per day, around the globe. One well-known active tectonic region is Indonesia, which is made up of three important active tectonic plates: the Eurasian plate in the north, the Pacific plate in the east, and the Indian Ocean-Australian plate in the south. Indonesia is particularly vulnerable to earthquake disasters due to its crucial placement at the intersection of three tectonic plates. In close proximity to the "Pacific Ring of Fire," Indonesia's 18,000 islands contain active volcanoes and tectonic faults on the islands of Sumatra, Java, Nusa Tenggara, and Sulawesi. There are more than 500 young volcanoes, 128 of which are active and makeup 15% of all active volcanoes in the world (National Development Planning Agency, 2006a).

On May 27, 2006, at 05:54 am local time, an earthquake of 6.3 magnitudes on the Richter scale hit the island of Java, Indonesia, about 20 km from Yogyakarta. It lasted for 52 seconds and caused

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ground shaking reaching a scale of VIII MMI (Modified Mercalli Intensity). Figure 2.1 shows the general map of Indonesia and the epicenter location of the earthquake. This earthquake is popularly known as the “Bantul Earthquake” owing to the serious damages caused in the Bantul Regency, Special Region of Yogyakarta, which is listed as one of the most earthquake-prone cities in Indonesia.

Geologically, Yogyakarta is located around the subduction zone between the Indo-Australian plate and the Eurasian plate. The epicenter of the Bantul earthquake was relatively shallow (33km underground), which resulted in more intense surface shaking than other deeper earthquakes of the same magnitude. The Yogyakarta and Central Java earthquakes affected roughly 1 million people, according to the International Recovery Platform (IRP), 2009, and BAPPENAS, 2006. Approximately 37,927 people were seriously injured, 5,716 human lives were lost, approximately 156,664 houses were destroyed, and 202,032 were damaged (Table 2.1).

Figure 2.1. General map of Indonesia and epicenter of the 27 May 2006 earthquake
(Map prepared using Google Earth)

Table 2.1. Distribution of casualties and housing damage by districts (BAPPENAS,2006)

Province and District	Casualties		Housing Damage		
	Death Toll	Number Injured	Totally destroyed	Damaged	Total
Yogyakarta Province	4,659	19,401	88,249	98,343	186,592
Bantul	4,121	12,026	46,753	33,137	79,890
Sleman	240	3,792	14,801	34,231	49,032
Yogyakarta City	195	318	4,831	3,591	8,422
Kulonprogo	22	2,179	6,793	9,417	16,210
Gugung Kidul	81	1,086	17,967	17,967	33,038
Central Java	1,057	18,526	68,415	103,689	172,104
Klaten	1,041	18,127	65,849	100,817	166,666
Magelang	10	24	499	729	1,228
Boyolali	4	300	715	825	1,540
Sukoharjo	1	67	1,185	488	1,673
Wonogiri	-	4	23	70	93
Purworejo	1	4	144	760	904
Total	5,716	37,927	156,664	202,032	358,696

The fact that Mt. Merapi's volcanic activity was intensifying concurrently with the earthquake made matters worse. Tens of thousands of people were evacuated as a result of the noxious fumes, ash clouds, and lava flows that were produced due to the volcanic activity. The Bantul Earthquake was Indonesia's third significant disaster in the previous 18 months. A major earthquake of magnitude 9.1 on the Richter scale and tsunami had already caused tremendous devastation in Aceh and Nias islands on 26 December 2004, followed by another earthquake on 28 March 2005, of magnitude 8.6 on the Richter scale that hit the island of Nias again.

Literature Review

The world has witnessed huge destruction in terms of lives and property caused due to the increasing frequency of natural disasters (Shaw, 2006). The disasters have had more impact on developing countries than developed ones (Ofori, 2002; Guha & Sapir, 2004; Ponnusamy, 2010), both in terms of immediate effects after the disaster, and through extended suffering during reconstruction and rehabilitation (Lloyd & Jones, 2006). Notably, there is an increasing threat of the frequency and intensity of natural disasters due to the alarming climatic changes that the world is facing (Helmer & Hihorst, 2006; Barnett, 2007; Salehyan, 2008). Earthquakes, however, are not directly related to climatic changes, but the risk of ever-increasing earthquakes can be mainly attributed to the increase in population, urbanization, and unregulated construction. Every disaster is associated with the generation of tremendous amounts of waste due to deaths and injuries, property damage and collapse, and crop destruction (Lindell & Prater, 2003; Shaw, 2006). Therefore, a considerable amount of the total cost of disaster management is spent on recovery, reconstruction, and rehabilitation, including debris management (Pike, 2007).

The Federal Emergency Management Agency (FEMA) defines disaster debris as: “Any material, including trees, branches, personal property, and building materials on public or private property that is directly deposited by a disaster.”

According to the literature, there are some instances where the amount of debris produced in a single incident is five to fifteen times larger than the average amount of waste annually produced by the disaster-affected area (Reinhart & McCreanor, 1999; Brown, Charlotte, Mark & Erica, 2011). Ervianto (2012) suggests that building blocks produce various building materials like wood, concrete, bricks, metals, etc. that account for 75% of total waste. These wastes can be effectively used in the construction process. Among the various types of debris generated during an earthquake, the wide availability of building ruins is suggested by literature (Setyonugroho, 2013; Adriani, 2013). Westover (2009) states that the rubble piled around the buildings after an earthquake is the main sight post-disaster. The characteristics of the debris – type and position, are understood by the description of the ruins. Based on these characteristics, the utilization of demolition material in post-earthquake construction has been suggested (Lizarallde, 2006). When seen in a post-earthquake setting, building materials are unquestionably available in various dimensions and types than under normal circumstances. According to Syukur (2008), the typology of building material ruins is based on form components and functional components in the situation of damaged building materials that were acquired after an earthquake. In certain earthquake-hit communities, people tend to collect, select, and reuse the building material debris based on its condition and specific use (Marcella, 2011). Setyonugroho (2013) explains that post-earthquake construction starts with the cleaning of debris, sorting it, and finally shifting the useful building materials that can still be used in construction. The use of building debris is associated with limited natural resources availability and thereby it is imperative to take advantage of the used building materials that are feasible, without compromising the structural integrity of the building.

In Bantul, Indonesia, after the 2006 earthquake, the practice of reusing building material from the ruins for post-earthquake housing construction was observed to be effective and beneficial. The victims who were severely affected by the disaster provided valuable insight into the practice of reusing material ruins while constructing their own homes (Sunoko, 2008). The concept of using building ruins in self-construction activities during post-earthquake housing construction has been studied in Bantul, and the practice was termed "architecture without architects." Although many researchers have discussed the post-earthquake scenario in Bantul, a comprehensive study involving all aspects of reconstruction has not been presented together.

This chapter aims to highlight the community-based post-earthquake housing reconstruction method in Bantul, Indonesia, by understanding the necessities, approaches, techniques, methods, and outcomes of this practice. The main purpose is to present a comprehensive idea of what the local community can do to ensure a sustainable reconstruction process. It tries to emphasize the necessity for immediate rehabilitation after any disaster and how the local community can provide manpower and local techniques to save time incurred in rehabilitating a large population after an earthquake. This practice can aid the rehabilitation and reconstruction programs of the government in terms of time, manpower, and cost incurred in the process.

Furthermore, the level of acceptance demonstrated by the locals of Bantul towards living a simple life is noteworthy. It is the most important takeaway for any disaster-hit community to overcome its sufferings and productively contribute to sustainable construction and rehabilitation after any disaster.

Economic Loss

A disaster is an event that can be natural or manmade, or progressive suddenly, which causes a profound impact such that people affected or unaffected need to respond with exceptional measures (Fiedrich & Burghardt, 2017). Disasters are frequently dismissed as part of trivial discussions before they happen. It sometimes causes casualties and property losses beyond one's analytical capabilities. During earthquakes, it's most often the buildings that cause most of the destruction especially if they are impoverished and in abundance across a densely populated place like Bantul, Indonesia. In a place like Bantul, the paradigm "Earthquake does not kill people, but buildings do" goes well with its disastrous situation.

Bantul, which occupies 506.85 km^2 (15% of the province's total size), is situated in the southernmost region of Yogyakarta. Bantul Regency had 820,541 inhabitants in 2004 and a population density of 1,611 people per square kilometer (Statistics Centre Bureau, 2008). The Bantul earthquake, in 2006 occurred due to intense pressure between Indo-Australian and Eurasian plates and was one of the most destructive earthquakes that the people of Indonesia had ever experienced. The maximum population in Bantul is involved in small-medium enterprises (SMEs). Being one of the developing country, Indonesia already faces various urban issues like population growth, urban sprawl, a weaker economy, and dense construction while it is facing serious threats of earthquake disasters. According to National Development Planning Agency's 2006b report, the earthquake caused 246% total damage and losses by value when compared to Bantul's gross domestic product. A comprehensive study by the Indonesian government and international experts has estimated a total loss of around IDR 29 trillion (US$ 3 billion) during the Bantul earthquake (National Development Planning Agency, 2006Yogyakarta, and Central Java's building characteristics have been divided into two categories: engineered and non-engineered buildings (Boen, 2006). Since non-engineered private buildings and homes are more prone to collapse because of improper building code implementation in developing nations, these structures sustained the majority of the earthquake's damage. Literature suggests that more than half of the total damage cost and losses were accounted for private homes. Around 157,000 houses were destroyed completely and 203,000 suffered serious damage making them inhabitable. The anticipated losses in public and private infrastructure were estimated at Rp 397 billion and Rp 153.8 billion, respectively (National Development Planning Agency, 2006b). The economic breakup can be understood by the graph presented in Figure 2.2. The earthquake left over 5,800 people dead, 38,000 injured and even more people homeless. This necessitated the need for immediate steps to be taken for the rehabilitation and reconstruction process. Thousands of damaged houses were to be rehabilitated and reconstructed. This large-scale housing reconstruction effort is identified as the most challenging and problematic activity during the recovery phase. It is considered the most crucial factor for restoring normalcy in any community after a disaster (Peacock *et al.,* 2007). Any delay can hamper other recovery effects such as social, economic, and psychological effects (Barakar, 2003; Lindell & Prater, 2003). The relevant bar chart is shown in Figure 2.2.

Issues in Post-earthquake Housing Construction

Effective post-earthquake management is crucial and directly correlated to the overall success of the recovery process in a disaster-hit area. The identification of dwellings that are still structurally sound and maneuvering to assuage the need for temporary housing are quite important. Petterson (1999) suggests that local design details become an important parameter for post-earthquake recovery. Additionally, it has been highlighted by Ranganath (2000) that people do not always favor the engagement of experts from unaffected areas in the development of strategies for impacted communities. This is a result of the perception that the value of the neighborhood working together to solve its problems through collaboration and understanding to meet the needs

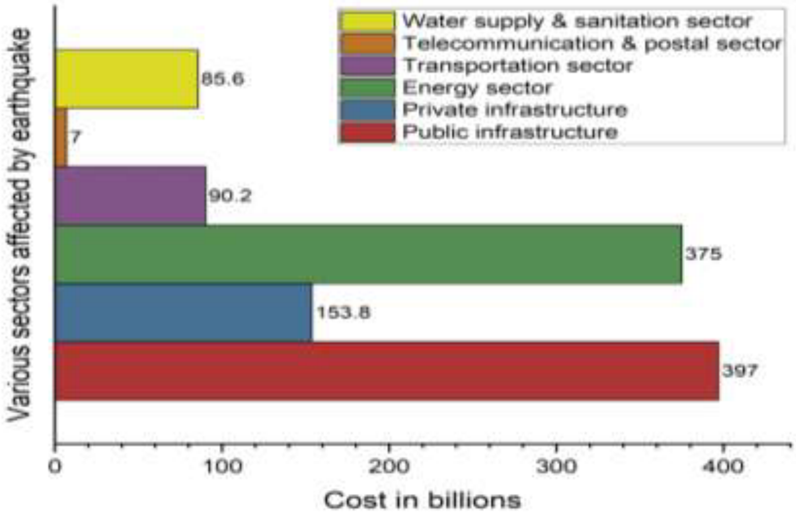


Figure 2.2. Damage and losses to various sectors after the Bantul earthquake (National Development Planning agency, 2006b)

of the neighborhood's residents is being undervalued. The post-earthquake housing construction process in itself is a task, and many issues are associated with it. A brief idea of such issues is presented here to better implement housing construction ideas in practice for areas like Bantul, which are prone to earthquakes now and then. The various issues associated with post-earthquake housing construction include:

(i) Long-drawn rebuilding procedures: Rebuilding a damaged property requires vast financial aid, technical expertise, time, and emotional support in comparison to constructing new buildings.

(ii) Failures during resettlement: The choice of land for resettlement after an earthquake is very crucial. Generally, easily acquired government land is used for a purpose that may not be a good habitable site. Also, the reconstructed projects in many cases fail due to a lack of consultation with the occupants of the houses as a result of the communication gap between the planners and the locals.

(iii) Holistic planning: The participation of people is crucial for post-earthquake housing construction. The planning should encourage cooperation between the locals and the environment. Sustainable development, which includes minimizing environmental harm and the use of non-renewable resources, is the goal of holistic planning.

(iv) Sustainability: Construction practices should focus on reduced energy flow, waste generation, and material use. Buildings should preferably be made using any possible recyclable material while maintaining the durability of the structure. Also, the use of local skilled labor is a good practice to follow.

Community Participation

The term community has been explored by Lee and Newby (1983), Willmott (1986), and Crow and Allen (1995) in three different ways as cited by Smith (2001). They include:

(i) Place: Place community or 'locality' is where people have something in common which can be understood geographically.

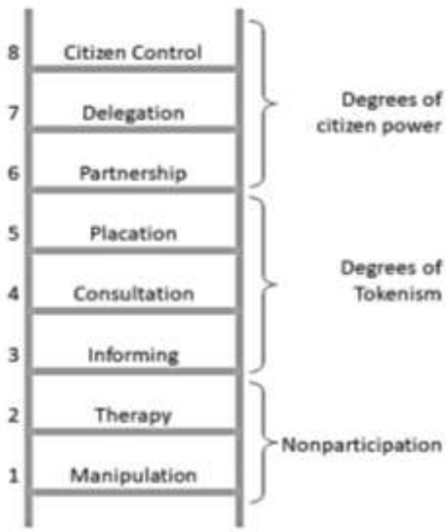
(ii) Interest: An interest community or 'elective' community is where people are linked by factors like religion, occupation, ethnic origin, or sexual orientation.

(iii) Communion: It explains the 'spirit of community' where people have a sense of attachment to a place, group, or idea.

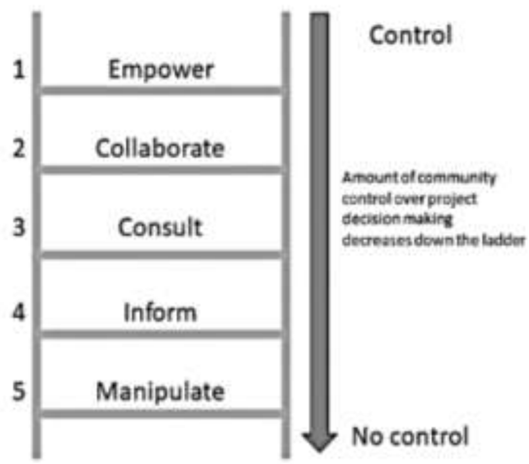
The word ‘community” has been defined in a number of ways, and Hillery (1955) cited that Kumar (2005) states 94 varied definitions exist in scientific literature, among which McMillan & Chavis’ definition is the most widely accepted one. They consist of the four components of a sense of community, i.e., membership, influence, integration, fulfillment of needs, and shared emotional ties. According to McMillan & Chavis (1986), “Community is a feeling that members have of belonging, a feeling that members matter to one another and to the group, and a shared faith that members’ needs will be met through their commitment to being together.”

According to Chambers (1983) in Kumar (2005), the emphasis on "community engagement" began to gain relevance in the 1980s with the advent of "participatory" approaches. However, Kumar (2005) cited Midgley *et al.,* (1986) as saying that although the term "community" was crucial to the problems with participatory development, it was poorly defined. According to Kumar (2005), it is unclear in "community" involvement programs if "community" is intended to be a means or an end to the developmental program.

In order to understand the level of participation in a community, Arnstein (1969) developed ‘A Ladder of Citizen Participation’ with eight levels of citizen participation [Figure 2.3 (a)]. Choguill (1996) later refined this model to better serve the needs of developing nations by categorizing the steps in community participation as neglect, rejection, manipulation, and support. Davidson *et al.,* (2007) merged the two theories to make these classifications appropriate for community involvement in housing reconstruction projects. According to Davidson [Figure 2.3 (b)], the degree of community input into project decision-making decreases as we move down the ladder. Any housing rebuilding initiative should at least reach the basic levels of empowerment and participation to qualify as "Community-Based" or "Community-Driven." This highlights the fact that beneficiaries can serve as managers or even contractors of their housing reconstruction project, in addition to being the owners of the same. This will allow them to construct their homes according to their needs.



(a)



(b)

Figure 2.3. Ladder of community participation (a) Arnstein’s model (b) Davidson’s model

The idea of community involvement entails the public's readiness to contribute worthwhile suggestions in order to improve the caliber of public services to meet the needs of the area's residents. The idea of community involvement is nothing new for the local government of Bantul. Since 2000, it has made tremendous efforts to practice the involvement of the community in the development of Bantul. However, this concept flourished in 2006 post the Bantul earthquake, after which the locals who were unaffected or slightly affected took to their own feet and hands and planned to participate in the rescue, rehabilitation, and reconstruction process. The recovery programs in Bantul had a great deal of success because of the community's cooperation and high level of engagement. The confidence of government agencies to rely on the local public was due to the good social capital, *gotong royong*, which means cooperating among and between the social circles. Since the local community best knows their society and the development patterns of their specific areas, the community preferred to construct their own homes using their designs and preferred materials, which included earthquake debris. This was in accordance with Leuken suggests the process of creating any residential space should involve the user as they best know what suits their needs. The locals collected, selected, and used the earthquake ruins in their construction. The huge public participation and public insight minimized the potential conflict in Bantul and aided its recovery. Literature suggests that communities with firm working relationships better overcome emergencies during any disaster because of mutual trust and understanding (Kapucu, 2006) which is surely true for Bantul. They set up a Self-Reliant Housing Community Group wherein they planned, decided, and executed the rebuilding procedure using their resources, in addition to the Rp 15 million funds from the government. The government's fund was enough to build foundations, the framework of the superstructure, and roofing, while the components such as windows and doors were to be provided by the locals. Also, the requirement of labor was sufficed by the locals themselves. They promoted the idea of *Bagidil* instead of *Bagital*. While *Bagita* is the process of distributing funds equally among the recipients; *Bagidil* aimed at fairly distributing the government's funds based on the priority of eligible recipients. This was quite supportive of the people who were least affected by the earthquake to help the ones who had suffered enormous losses. This social capital in Bantul is an intangible resource that a community can have due to networking and trust among themselves (Field, 2008). Bolino *et al.,* (2002), Lin (2001), Nahapiet and Ghosal (1998) define social capital as: "Social Capital is the resource that is derived from the relationships between individuals, organizations, and communities, embedded in a social structure, mobilized in purposive actions and derived from the network of relationships possessed by an individual or social unit."

The shift of paradigm in Indonesia with respect to disaster management from its response to the recovery phase wasn't as easy as it seems. Prior to the 2006 earthquake, there was no strategic plan in place for effective coordination, disaster preparedness, mitigating the inadequate infrastructure, and information dissemination. Most victims affected by the earthquake were living in very low-quality houses, making them vulnerable to risks, however, they limited access to insurance (Samal *et al.,* 2005). No doubt, the Bantul government had framed certain disaster mitigation policies, but various studies suggest that the local community is more influential in developing such policies and their participation and ownership are much more valuable (Godschalk *et al.,* 1998; Okazaki and Shaw, 2003), hence the government involved the insights of the local community in policy-making after the Bantul earthquake. Community involvement was seen at the district, sub-district, and village levels while they were given a chance to decide on the rehabilitation type that would match their local needs. Due to the enhanced coordination and capacity building among the local community along with a better understanding of the recovery and rehabilitation problems, people in Bantul have potentially improved their post-disaster mitigation responses. This empowerment of the locals towards natural disasters is suggested to be a critical factor in the successful mitigation of disasters (Sharma *et al.,* 2003).

The people of Bantul stood as a strong and hardworking community to achieve their goals after the 2006 earthquake. They started their housing recovery program, and according to the Department of Public Works, they were successful in constructing new homes worth about Rp 35 million. The accomplishment of this rehabilitation program was made possible by the government's financial support of Rp 15 million and the substantial social capital of the Bantul community. Also, the aesthetic appearance of the houses was better than before, in addition to them being earthquake-resistant. The Bantul earthquake can be thereby called a "blessing in disguise" for the people of Bantul in particular and Indonesia in general.

The practice of Architecture without Architects

The recovery phase after any disaster is the most crucial. In Bantul, after the 2006 earthquake, a new dimension to the recovery and rehabilitation phase was witnessed by the world, where the local community aided the process of recovery using their local culture and wisdom. Some of the severely affected victims started the housing reconstruction process on their own, even before the financial assistance and involvement of the government, while they were assisted by other locals. A sense of solidarity, collectiveness, and tolerance was portrayed by the locals during the disaster recovery, which was recognized as a value they adopted from their strong local culture. The usage of material debris and the opinions of residents in the reconstruction process following the earthquake suggest the practice of "architecture without architects," with reference to Mentayani

(2012) and the Empress (2013). They constructed shelters by reusing the ruins of buildings, which, in the long run, turned out to be quite suitable for their dwelling. It was, however, important to understand the relationship between the building material ruins to be used in reconstruction, the shape or form of the materials used, construction practices, and local wisdom. Sunoko *et al.,* (2018) suggest finding a method that was used by the locals during the construction and developing a more comprehensive understanding of the same so that it can lead to the development of more generic methods that can be used in post-earthquake architecture in the future. This type of construction is quite interesting and can be a suitable model to understand sustainable building construction. The peculiarity of such self-reconstructed structures is based on factors like the material used, construction skills, and the availability of funds. The role of rubble in meeting the requirements of post-earthquake housing construction is very dominant in Bantul. Table 2.2 suggests that an average of 86.47 percent of ruined building material was re-used by the people of Bantul. Even certain victims show an optimal tendency to re-use 100 percent of the ruins. Such high percentages speak to the coherent link between the processes of inventorying debris and its reuse. The intact ruins play the dominant role in deciding the plan area of the building during post-earthquake construction.

Figure 2.4 can provide a better understanding of the number of debris reused in post-earthquake housing construction. Brick building materials have a high tendency to be damaged and, therefore, cannot be used in construction. Similarly, bamboo is also unsuitable due to its aging. Most of the building ruins are dominated by wood. The locals prioritize using wood based on its availability, ease of construction, and practicality. Wood can be easily reused with no additional materials required, except for nails that can be obtained from remnants that have been trimmed. The cutting, if required, is mainly done using saws or machetes, and sickles are used in case there aren't enough saws. The process of cutting, splicing, and connecting refers to the habitual work of connecting wood by the local artisans.

The shortcomings of the main building materials obtained from ruins are compensated for by using local trees such as jackfruit, coconut, and melinjo trees by logging, sawing, and cleavage processes to obtain desired bars or boards from them.

Table 2.2. Use of building material ruins and new building materials (Surveys & Measurements, 2013 & 2015)

No.	Wall		Roof	Building Material Ruins (m^2)	New building materials (m^2)	Percentage of Building Material Ruins (%)
	Outside (m^2)	Inside (m^2)	(m^2)			
1	72.50	35.00	57.75	162.25	35.00	78.82
2	95.00	25.00	56.50	176.50	-	100
3	80.00	15.00	32.50	130.50	32.00	75.48
4	96.00	45.00	69.50	210.50	74.75	64.49
5	87.50	46.25	72.50	206.23	35.00	83.03
6	157.50	32.50	126.50	316.50	65.00	79.46
7	42.00	18.00	29.50	89.50	-	100
8	72.00	16.00	35.50	123.50	-	100
9	108.0	45.00	80.00	233.00	36.00	84.55
10	56.00	12.00	34.00	102.00	-	100
11	108.0	-	89.50	197.50	85	56.96
12	60.00	17.50	38.50	116.00	-	100
13	67.50	11.25	44.50	123.25	-	100

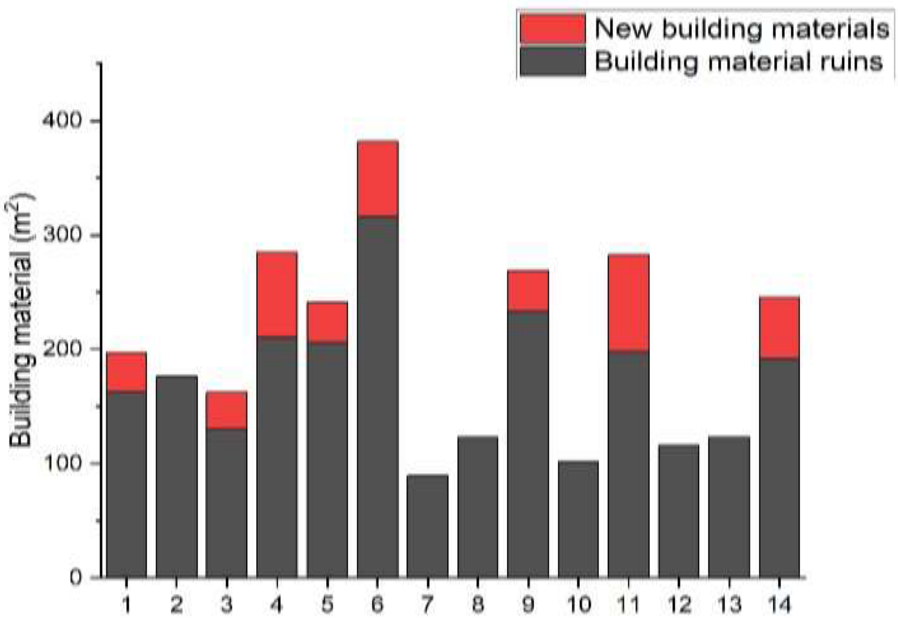


Figure 2.4. Comparison between the use of new building materials against building materials ruins in Bantul reconstruction (Surveys & Measurements, 2013 & 2015)

The victims of the disaster-hit Bantul collectively started the process of restoration by cleaning the site and conducting an inventory of the material debris, followed by construction. The manifestation of material state, form, and size is explained by Sunoko *et al.,* (2016) in terms of the local terminology used by the people of Bantul. "Wutuh-remuk" specifies whether the material is in a single piece or has been damaged, thereby describing the state of the material. A clear pairing between "wutuh" and "remuk" was observed in the study. A condition called "Kandhang" describes the erection of a building made from concrete columns that form a frame structure without using wall charger components and the construction of a wooden roof truss. The form material is explained by the state "dawa-cendhak" (long-short) which explains whether the material is available in its original length or has shortened due to any fractures. Based on this, the use of various elements can be suggested. Due to the failure of the building, the state of the material with respect to its shape is altered. While some still fit in their original shape, the majority suffer distortion in shape. "Kukuh-gapuk" is used to explain this state of the material. In addition to this, reforming the material aesthetics and collecting back the furniture and other household goods to be used as filler buildings were also included. There was a certain sense of typology with respect to reusing building ruins in post-earthquake housing construction. Sunoko *et al.,* (2018) explain these typologies:

(i) Use of materials from different types of buildings but used in the same function (typology type A).
(ii) Use of materials from similar types of buildings but with different functions (typology type B).
(iii) Use of materials from similar types of buildings and with the same function (typology type C).

Wutuh-Remuk: Method to Apprehend Post-Earthquake Artifact Ruins

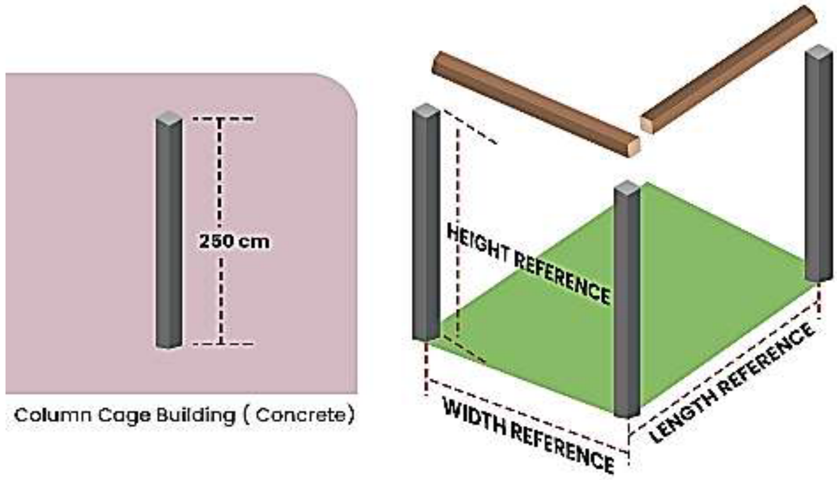
During the initial stages of the recovery phase, the ability of the victim to map the potential artifact ruins is a crucial step toward re-utilizing the ruins. Victims describe the ruins as *donya* (wealth) even if it is not in a proper tangible shape to be used for building construction and believed it would provide *ajine* (value) to the post-earthquake housing construction. *Wutuh-remuk* described the state of shape and size of the material. *Wutuh* was used to describe the shape of material that was still in conformity with the original shape while *remuk* described the state of change in shape. The *wutuh-remuk* method enabled the locals to produce materials that were ready to use for construction. It provided a separation process for categorizing materials as functional, structural, and architectural materials. The materials responsible for providing structural strength were called structural materials. The ones responsible for the appearance were the architectural materials. Functional materials included the equipment and furniture for re-use as filler in the homes.

Wutuh-Remuk, Dawa-Cendhak, and Kukuh-Gapuk:Methods of Reusing Building Materials

The victims of the Bantul earthquake perceived the building ruins as locally available materials that were produced due to a natural disaster. Therefore, they needed to develop methods for characterizing the ruins with respect to their form, size, and functionality. The locals preferred to use their own knowledge and terminology to understand and convey their understanding to others. The wutuh-remuk method was used to describe the shape and size of the ruin with respect to its original form, while the dawa-cendhak method described the state of the material based on its length. The locals used these methods to produce materials for construction, including functional, structural, and architectural materials.

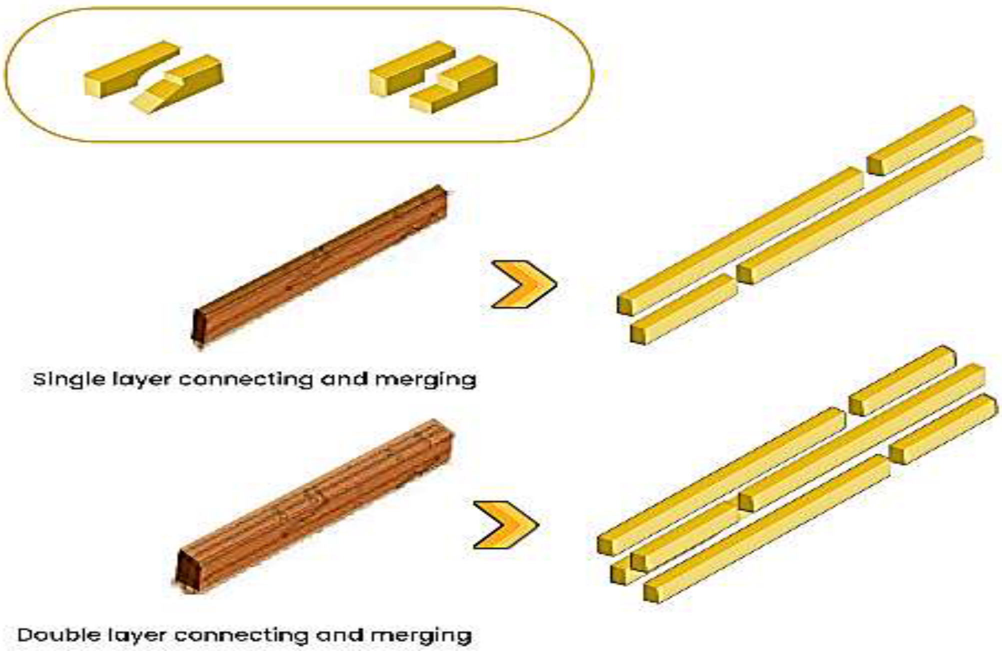
"Wutuh-remuk" is used to describe the shape and size of the ruins in relation to their original form. This method produces materials with the same dimensions as the original, without any processing techniques. The material is reused by directly installing it at the desired location. "Dawa-cendhak" describes the state of the material based on its length. If the length is the same or nearly the same as the original length, it is called "dawa." If there is any change in length, it can be described using "cendhak," specifically if the length is less than half the original length. "Dawa-cendhak" methods produce materials different from their original form by deploying material processing techniques like cutting, splicing, and merging to produce larger and longer materials ("gedhe-dawane"). After knowing the shape and size of the material, it is important to understand its strength. As the material is from a building ruin, it will have reduced strength compared to its original strength. Therefore, it is important to understand the use of such materials in providing structural support to new homes being constructed using the ruins. The rafter ("usuk") is one of the building materials that plays a strong role in not only the formation and size of the new larger bars but also in the formation of additional roofing ("empyak"). The "usuk" determines the width of the additional roofing as an extension of the main roof. This highlights the locals' understanding of the importance of connections in the construction process. "Kukuh-gapuk" produces materials as the main structural components through material processing by either eliminating or reducing the "gapuk" portion to produce "cendhek-dhuwure" (high-low strength materials). "Kukuh" describes the state of the material that has a strength nearly the same as its original strength, while "gapuk" describes the state wherein material strength has considerably reduced from its original strength. All these rules aided the locals in obtaining construction-ready materials after certain or no modifications based on the state of the materials used. A summary of these methods is presented in Figure 2.5 and Table 2.3.

Post-earthquake construction was preferably done on the old building site to have a clear idea of the ratio of new and old building areas. A variety of building shapes in terms of shape, height, and extent were produced by considering the type of building materials, their functions, and the building types. The simple or "straightforward" floor plan and construction using post-earthquake construction materials reflect the architectural work of locals in creating earthquake-resistant building structures. The column height of 2.00-2.25m reduces the shaking level of the building. In addition, the wooden bars along the width and length of the building are arranged using minimal connections, reducing the susceptibility of the buildings to shearing during earthquakes. The new buildings in Bantul were quite different and smaller than the pre-earthquake buildings due to the structural components, namely saka (column), blandar (latai beam), and pengeret (transverse beam), as well as the reduction in the building site area. This reduction was due to the fact that the rubble was not used in the post-earthquake construction.



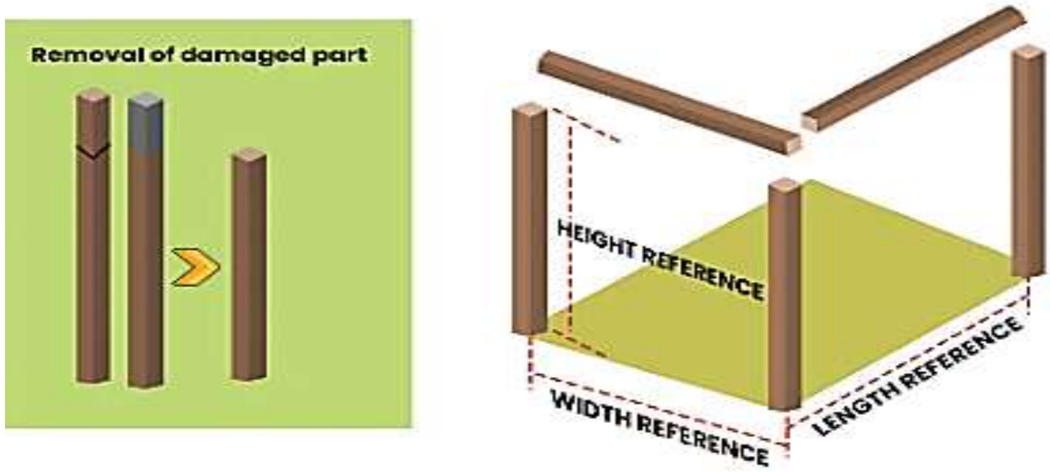
Construction formed from whole material from a cage building

(a)



Construction is formed by means of joining and merging wooden blocks

(b)



Construction formed from building material ruins using a length-reduction process

(c)

Figure 2.5. Construction practices: (a) wutuh-remuk (b) dawa-cendhak (c) kukuh-gapuk

Table 2.3. Methods of reusing the building materials for construction

Method	Material	Use	Processing	Practicality
Wutuh-remuk	Concrete column cages (*kendhang*)	Produces material as a main structural component, as a reference for the height of the building	Installed in the desired position without processing	Concrete columns in cow pen buildings were used to replace wooden residential buildings
	Wooden plank walls (Gebyok)	Produces supporting components to produce the flexible structure	Installed in the desired position without processing	Used along with concrete columns to provide width reference for walls
Dawa-cendhak	Bars rafter (*usuk*)	Produces material larger and longer (*gedhe-dawane*)	Cutting, splicing, and merging according to desired dimensions of length	Construction is done in one- or two layers using bolts and is easier as highly skilled labor is not required
Kukuh-gapuk	Wooden columns	Produces material as the main component for reference of high-low (*cendhek-dhuwure*) of the building	Cutting of obsolete parts and installation as per the desired position	Reusing wood for columns but with shorter lengths, thereby new buildings had a column height of 2.5 m against 3-4 m

Niteni, Niroake, Nambahake, and Nemoake: Methods for Independent Reconstruction

The post-earthquake construction was not specifically guided by the ideas of builders, but rather by the specific materials available for construction. The form and availability of building ruins used in construction dictated the form of the new buildings. In Bantul, while people decided to use post-earthquake rubble as their construction material, specific skills were needed to incorporate its use effectively. Rakhman (2012) suggests that a community's ability to address such circumstances lies with niteni (attention), niroake (mimic), and nambahake (add). Niteni is the outward manifestation of the capacity to pay attention and acquire an understanding of a phenomenon in order to map the potential of a material for reuse in construction based on one's knowledge. On the other hand, niroake and nambahake have more advanced reuse capabilities as they allow for the adaptation and reapplication of previous information to make changes that fit new situations. This practice in Bantul describes the locals' understanding of the material ruins and their reuse. Their knowledge was not limited to understanding the material or mimicking its behavior; they also had the idea of building creative works (nemoake) using the knowledge gained during post-earthquake housing construction.

Urip Sakmadya and Nrimaing Pandum: Construction Models for Sustainable Lifestyle

These practices imply the evolving techniques of the earthquake-affected locals in Bantul, which should serve as an inspiration for the role of assistance any community can provide in mitigating the suffering after a disaster.

It is imperative to understand the principles of "simple living" and "accepting reality" so that one can feel content with post-earthquake dwelling places. The people of Bantul constructed their homes using the post-earthquake ruins, which resulted in a lower ratio of new building areas compared to the old ones. However, they managed and accepted this construction wholeheartedly, which made the practice of "architecture without architects" a great success in itself. The term urip sakmadya is used to describe the unpretentious life. This construction model is based on the principle of using simple patterns along with connected and combined techniques. The concept of accepting facts has been called nirmaing pandum, which uses the concept of makeshift materials. Both of these methods are based on the adjustment of the ruined building materials to be used in the construction of building fields.

The comparison between the site area and the building area post-earthquake is shown in Figure 2.6. The figure suggests that the new buildings constructed using building ruins can cover 30-50 percent of the original plan area of the buildings. The occupancy of the new houses is only one-third of their pre-earthquake houses. This scenario highlights the level of acceptability needed in the community for such construction after an earthquake. The Bantul community not only self-constructed their homes using building ruins but also displayed a great level of acceptance and comfort towards their new dwelling places because they had experienced the situation of being homeless after the earthquake. The new buildings constructed after the earthquake provide an example of easy procurement of construction materials, simple construction, and strong motivation to understand the sustainability of potential building materials. This is what is required in any community to facilitate sustainable construction after any disaster.

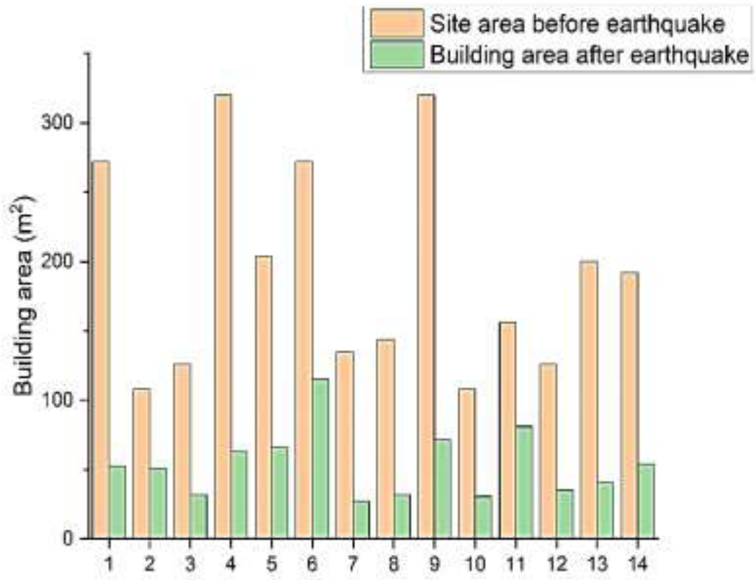


Figure 2.6. Comparison of site area with building area after the earthquake (Surveys & Measurements, 2013 & 2015)

Conclusion

Bantul, a small district in the Yogyakarta province of Indonesia, is known to be the most disaster-prone and poverty-stricken area with limited capability to manage a disaster. The victims of the 2006 earthquake in Bantul were left homeless but not hopeless after the earthquake. They realized, and most importantly accepted, the fact that their homes were destroyed but were grateful for the availability of building waste after the earthquake. This chapter presents an informative case study on Bantul, Indonesia, highlighting the uses of construction waste (earthquake ruins) and potential building materials in post-earthquake housing reconstruction. The victims portray a good example of "Community-Based" post-earthquake housing reconstruction, in which they independently performed the residential redevelopment after the earthquake using their designs and practices while incorporating the use of earthquake debris to its full potential. The dominance of wood-based construction in Bantul provided adequate resilience and flexibility to the structure, while its collapse still gave an opportunity for its reuse in post-earthquake housing construction. The people of Bantul advantageously used this fact to build their homes after the earthquake even before the involvement of the local government. After the recovery, Bantul was reimagined as a well-planned area with a targeted development strategy. The Bantul community not only self-constructed their homes using building ruins but also displayed a great level of acceptance and comfort towards their new dwelling places, even though the building area was reduced by 50-70% with respect to the earlier plan area. This depicts the acceptance of principles like "simple living" and "accepting the reality". The new structures built following the earthquake serve as an example of straightforward material procurement, straightforward construction, and a strong drive to comprehend the sustainability of possible building material ruins. This is necessary for every community to permit disaster-recovery construction.

Conflict of Interest Statement

The author declares that there is no conflict of interest.

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Author Biography

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CHAPTER THREE

LIVING WITH EARTHQUAKES

J N KHATANIAR[1]

Abstract

An earthquake can initiate severe damage to the civil infrastructure and bring disaster to public lives. This chapter describes a brief illustration of the causes and history of major earthquakes, the seismic conditions in India with emphasis on the northeast region, the disastrous effects, and the mitigation techniques to safeguard the civil infrastructures against such calamity.

Key Words

Buildings; Liquefaction; Seismic waves; Seismograph; Tectonic plates

Introduction

An earthquake is caused by the sudden release of potential energy in the Earth's lithosphere, producing seismic waves of various magnitudes of amplitude and frequency (Ohnaka 2013). The underground point of energy release is termed the 'epicenter,' and the seismic waves propagate toward the ground surface (Vassiliou and Hiroo 1982). Earthquakes can induce rapid vibration in the subsoil with high intensity, resulting in excess pore water pressure and decreased effective stress in the soil particles, leading to soil liquefaction that may adversely affect the stability of the underground foundation. In extreme circumstances, this may result in partial or complete collapse of the foundation and supporting structures (Bardet 2003; Dashti 2015). This chapter focuses on safeguarding civil infrastructure against possible seismic damage, with special reference to the earthquake-prone northeastern region of India.

Geological Aspects

The earth's interior consists of fragmented rock plates, called tectonic plates, which can move relative to each other due to the less viscous layer on which they sit. The movement of the plates causes stress to build up along their boundaries, known as faults, resulting in stored strain energy. When the stresses exceed the forces holding the plates in place, they slip along the fault, releasing an enormous amount of stored energy in a very short time. This energy travels through the earth's crust in the form of waves, causing the ground to shake during an earthquake. The sudden release of a large amount of energy can cause devastating destruction without warning.

About 225 million years ago, the earth's surface consisted of a single massive continent known as Pangaea. Over time, Pangaea began to break apart into two major continents, one of which was Gondwana-land that included Africa, South America, India, and Australia. Gondwanaland continued to split into smaller land masses, including the Indian plate, which drifted at a rate of 9 centimeters per year towards the Eurasian plate. The collision of these giant plates under enormous pressure led to the formation of the Himalayas (Rogers and Santosh 2003).

The earthquakes in India are due to the movement of the Indian plate. Currently, the Indian plate is drifting northeastward at a rate of 0.05 m/year, while the Eurasian plate is moving northward at only 0.02 m/year, as illustrated in Figure 3.1 (Prasath *et al.,* 2022). This differential motion causes the Eurasian plate to deform and the Indian plate to experience compression at a rate of 0.004 mm/year.

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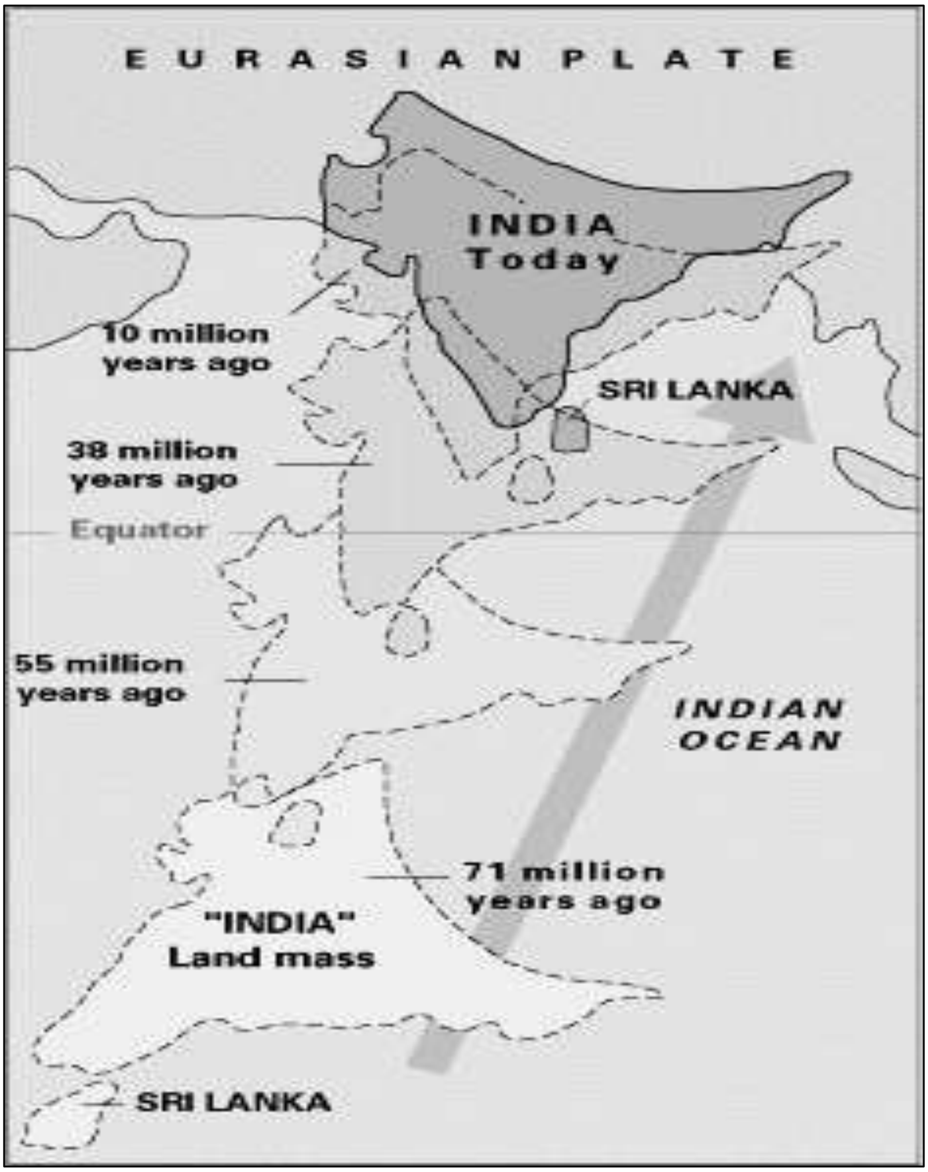

Figure 3.1. Sketch illustrating deformation of Indian plate over Eurasian plate.

According to the world seismic map, six countries, namely Mexico, Japan, California in the USA, Taiwan, Turkey, and India, are most vulnerable to earthquakes. Based on the varying geology and history of earthquakes, India is subdivided into four seismic zones: Zone II, III, IV, and V, as shown in Figure 3.2. Additionally, for urban planning and development, the metropolitan areas are micro-zoned based on local geology, soil profile, etc. (Walling and Mohanty 2009).

Seismography in North-Eastern India

As per the seismic zoning map of India, all seven states of the northeastern part of India, namely, Assam, Arunachal Pradesh, Sikkim, Meghalaya, Manipur, Mizoram, and Tripura, lie in a very high seismic-prone zone, i.e., zone V (Ghione *et al.,* 2021). The premier city of the northeast, Guwahati, was micro-zoned in the year 2008 by the Seismology Division, Department of Earth Sciences, Government of India. Seismic micro-zonation is a scientific approach to evaluating the seismic sensitivity and ground response to the seismicity of a particular area under rapid urbanization that is prone to severe earthquakes (Bansal and Verma 2013).

The majority of casualties and property damage resulting from earthquakes are caused by the collapse of man-made structures rather than the earthquake itself. Earthquakes do not directly cause deaths or property damage, but rather it is the failure of buildings and infrastructure due to poor planning, inadequate design, substandard material quality, or poor workmanship that leads to the loss of life and property. The only way to reduce the risk of these losses is to promote awareness and preparedness, and to approach living with earthquakes in a scientific and systematic manner.

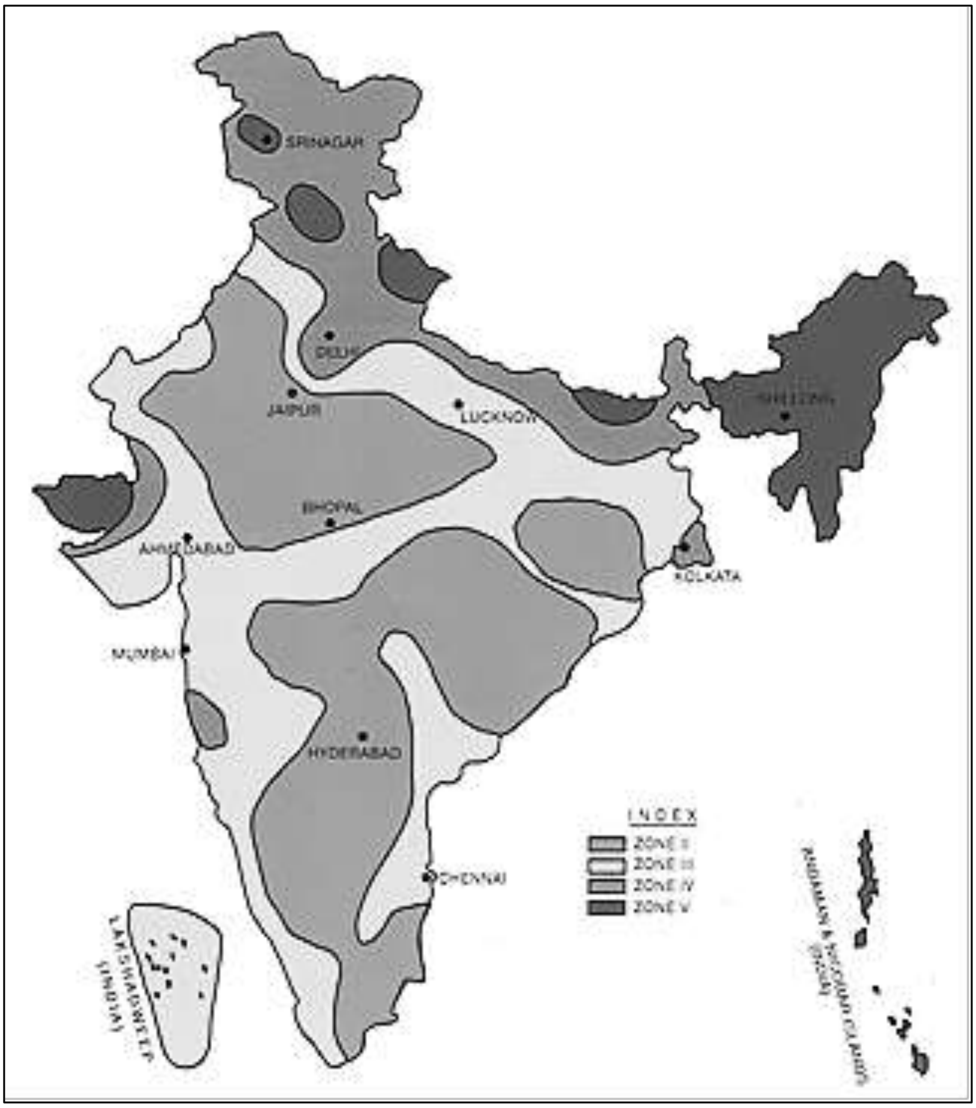

Figure 3.2. Seismic zoning map of India

Influence of Earthquakes on Civil Infrastructures

Earthquakes cause shaking of the ground in all directions. In addition to the normally designed loads, it is necessary to ensure the adequacy of the structure against sudden earthquake forces. Earthquakes cause sudden deflections to the entire building frame. The structural members, which consist of an RCC foundation with columns, tie beams, plinth beams, and floor beams with slabs, need to be properly designed to transfer the entire inertia forces, along with other combinations of loads, safely to the ground. Accuracy in soil investigation to evaluate the soil properties below the structures is therefore essential to ascertain the safe bearing capacity of the ground on which the building foundations are planned to rest, with dead loads, live loads, and sudden earthquake loads all in combination.

The idea behind 'Earthquake Resistant Structures' is that the structures should be engineered and built in such a way that they can withstand the strong shaking of ground with repairable damages but without collapse, so that everything within the building structure is safe.

Safeguarding the Buildings

Proper soil investigation, careful planning, accurate structural design by competent professionals, selection of the right quality and quantity of building materials, and finally, proper workmanship in execution, under strict supervision and adaptation of all guidelines of BIS codes and the latest National Building Code (NBC), are the key factors for attaining a safe and sturdy structure.

Liquefaction of soil caused by an earthquake is another major factor that needs careful consideration for the safety and stability of structures in high-risk earthquake-prone zones. Due to liquefaction, the soil below the structures may lose its normal load-bearing characteristic, which can cause widespread destruction to manmade structures.

The structural response of a building frame during an earthquake depends critically on its overall shape, size, and geometry. Unfavorable architectural features that are detrimental to the earthquake response of the building should be avoided. Structural safety aspects of the buildings should get higher priority than their aesthetic appearance, particularly in the areas that fall under severe earthquake-sensitive zones.

Reinforced Cement Concrete (RCC) is a combination of sand, cement, and stone aggregates in specific grading and proportion called concrete along with the right qualities and right quantities of steel reinforcements. Like a healthy human body, a combination of muscles act as concrete and skeleton act as steel frame which gives strength to stand and move on the Earth.

Plain cement concrete is much stronger under heavy compressive loads, but its behavior under tension is poor. Steel bars respond very well under tensile loads due to their good ductile property. During an earthquake, tremendous multi-directional forces are applied suddenly on the building frame, causing deflection from its normal vertical position on the ground surface like an inverted pendulum. As a result, additional compressive and tensile forces are generated on the frame structure. The right sizes of the concrete members with the right quantity of steel reinforcements are to be determined during structural analysis by a competent Structural Engineer to make the building resistant to earthquake loads. Proper execution of the construction work at the site is also key to an earthquake-resistant building.

Legislation and Law Enforcement

The National Building Codes of India 2016 (NBC) and the Bureau of Indian Standards (BIS) Codes have recently been revised, taking into consideration all safety aspects, including the latest technological advancements in the construction industry, the development of techno-legal and techno-financial regimes, and the experience gained in dealing with natural calamities such as super cyclones and earthquakes suffered by the country (NBC 2016).

The "Construction Bye-laws" of all highly seismic-sensitive states in the northeast need to be reviewed and revised carefully, following the guidelines of NBC (2016) and the recommendations of the National Disaster Management Authority, Ministry of Home Affairs, Government of India. The process of registration of engineers and architects as consultants on record, including Structural Engineers on Record (SER) and Construction Engineers on Record (CER), and the submission of Structural Design Basic Reports (SDBP) as recommended by the National Disaster Management Committee under the Ministry of Home Affairs, should be made mandatory in all the states of the northeast under very high seismic zone (i.e., zone V) for all important and/or major construction projects.

Mishandling of the construction processes of all important structures by unqualified persons should be prevented as a part of pre-disaster management to minimize and control post-disaster management aspects by the authorities under strict rules and regulations.

An earthquake is a natural calamity that cannot be predicted, prevented, or diverted. The technical ability and dedication of the technical consultants, the honest attitudes and approaches of the owners, builders, contractors, and the public in general, as well as the alertness and proper initiatives of the concerned authorities and action plans for generating awareness and preparedness, are all prime factors in making our shelters safe and healthy for us to enjoy life on this beautiful, clean, and green earth.

Everyone's collective efforts can reduce the risk of loss of life and property during the sudden violent earthquake. Proper learning and preparedness to live with the sudden shaking of the earth is the only solution for minimizing damage and enjoying life without fear.

Conclusions

Earthquake is a major disaster to human civilization, causing severe damage to civil infrastructure under extreme circumstances. The specific influence of earthquakes on buildings and other infrastructures, prevention, and remedial measures to be undertaken, together with law enforcement, with particular reference to India, have been discussed in this chapter.

Conflict of Interest Statement

The author declares that there is no conflict of interest.

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CHAPTER FOUR

STUDY OF PILED RAFT FOUNDATION ON LAYERED SOIL SUBJECTED TO VERTICAL LOADING

BHASKARENDRA NATH PATOWARY[1]
UTPAL KUMAR NATH[2,*]

Abstract

Piled-raft foundations are a combination of a shallow foundation (raft) and a deep foundation (pile group). The role of the raft is to provide the required bearing capacity, and the piles are used mainly as settlement reducers, but they can also contribute to the bearing capacity. In this paper, a numerical model was developed using PLAXIS 3D software to analyze piled-raft foundations in layered soil, having a clay layer underlain by silty sand and then dense sand at the lower layer with a water table at a constant depth. A drained condition was assumed, and total vertical displacement was calculated using plastic deformation. The piles and raft were modeled using plate elements. A non-uniform vertical loading in the form of concentrated column loads was imposed on the piled raft. Firstly, models without piles have been taken into account. Then, four numbers of piles were introduced at half of the bay between the column positions. Another model with nine numbers of piles placed directly below the column positions was generated. Models with 16 piles placed at one-third of the bay and 24 piles placed at the column centerline in addition to one-third of the bay were prepared. In all the above models, the pile diameter, embedded length, and raft thickness were varied in the ranges of 300-500 mm, 10-18 m, and 300-400 mm, respectively, have been studied. As observed, the internal friction angle of soil played an important role in the settlement of piled raft foundation. As the pile length increases, the settlement decreases. The introduction of nine piles reduced the total settlement up to 43.39%, while for 16 and 24 piles, the reduction was up to 57.55% and 60.82%, respectively. However, a further increase in the number of piles does not contribute much to the further reduction of settlement of piled raft foundations. The raft thickness had a nominal effect on the settlement. Regarding the position of piles, the inclusion of piles below the column at a considerable distance from the column centerline exhibited good results than piles positioned just below the column.

Key Words

Finite element; Layered soil; Piled-raft; Settlement

Introduction

In the past few decades, there has been increasing recognition that the use of pile groups in conjunction with the raft can lead to considerable economy without compromising the safety and performance of the foundation (Poulos 2001). Such a foundation makes use of both the raft and the piles and is referred to as a pile-enhanced raft or a piled raft (Poulos and Davis 1980). This is fundamentally different from foundation applications where the piles or shafts are placed beneath

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the entire foundation and are assumed to carry all loads. A piled raft is a foundation consisting of three load-bearing elements: piles, raft, and subsoil, acting as a composite construction.

The usage of piles along with the raft foundation reduces settlement (Burland 1995). According to its stiffness, the raft distributes the total load of the structures as contact pressure and over the piles in the ground (Ta and Small 1996; Reul 2004). In piled-raft foundations, the raft provides the required bearing capacity, and the piles are used mainly as settlement reducers but can also contribute to the bearing capacity (Randolph and Wroth 1979).

Parametric Study

A plane strain finite element model was used to analyze the piled raft foundation. In this study, a 16 m x 16 m raft with massive circular piles of varied diameters was analyzed using a finite element software package for soil and foundation. The piles and raft were assumed to be linearly elastic. The Mohr-Coulomb yield criterion was used to represent the soil type as an elastic-perfectly plastic material. Layered soil with a water table at a depth of 4m from ground level was assumed for the study. A drained condition was assumed, and total vertical displacement was calculated using plastic deformation. The layered soil segment was discretized as 15-noded triangular elements. The piles and raft were modeled using plate elements. The side skin friction in the piles was taken into account by applying Rinter, i.e., interface reduction factor. Sub-soil thickness was considered up to a depth of 30m from the ground surface for all soil types. Non-uniform vertical loading was imposed on the piled raft in the form of concentrated column loads. Table 4.1 below discusses the type and properties of soil used in the study, while the type and properties of materials are given in Table 4.2.

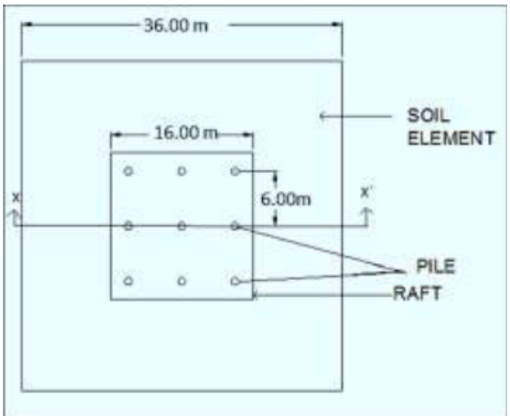
Table 4.1. Properties of the soil being used in the study

Particulars	**Layer 1 (depth: 0-6 m)**	**Layer 2 (depth: 6-15 m)**	**Layer 3 (depth: 15-30 m)**
Soil type	Silty Clay	Clayey Sand	Dense Sand
Material model	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
The angle of friction (ϕ_u)	8^0	28^0	37^0
Stiffness (E_{ref})	5000 kN/m^2	9600 kN/m^2	11250 kN/m^2
Cohesion (c_u)	20 kN/m^2	35 kN/m^2	0 kN/m^2
Poisson's ratio (υ)	0.45	0.4	0.3
Dilatancy angle (Ψ)	0^0	0^0	7^0
Saturated unit weight (γ_{sat})	20.45 kN/m^3	18.85 kN/m^3	19.6 kN/m^3
Unsaturated unit weight (γ_d)	17.25 kN/m^3	15.7 kN/m^3	15.7 kN/m^3
Drainage condition	Drained	Drained	Drained
Permeability(k_x=k_y=k_z)	0.000864 m/day	0.0864 m/day	0.864 m/day
Void Ratio (e_o)	0.85	0.75	0.55

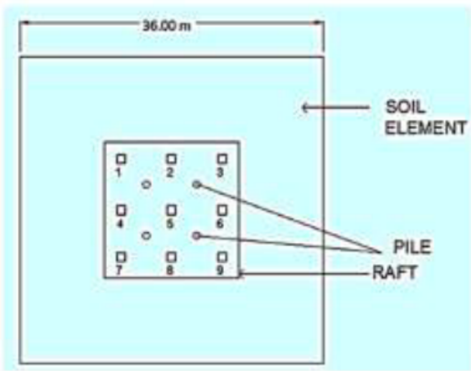
Table 4.2. Properties of the materials being used in the study

Material	Bored Pile	Raft (Floor)
Material model	Linear elastic	Linear isotropic
Material type	Non-porous	Non-porous
Poisson's ratio (υ)	0.30	0.20
Stiffness (E_{ref})	29.2 GPa	10 GPa
Unit weight (γ_{sat})	24 kN/m^3	24 kN/m^3
Permeability	0	0

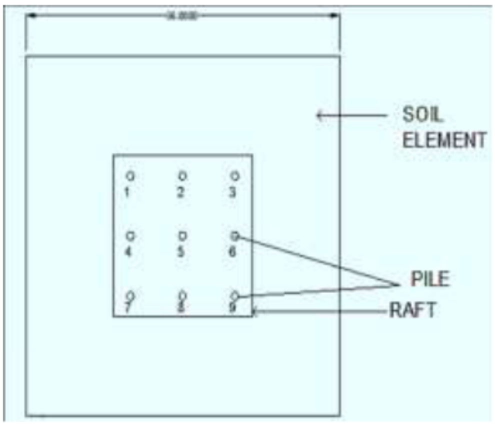
In this parametric study, different models are prepared with varying pile and raft parameters. Models have been prepared in a categorized manner with reference to pile position. Firstly, models without piles (i.e., raft-only models) have been taken into account. Then 4 number of piles are introduced at half of the bay between the column positions. Another model with 9 piles placed directly below the column positions has been generated. Thereafter, models with 16 piles placed at one-third of the bay and 24 piles placed at the column centerline in addition to one-third of the bay respectively have been prepared. All the above-mentioned models with a diameter of pile varying from 300-500 mm, the thickness of raft varying from 300-400 mm, and length of pile varying from 10-18m have been studied. The interface reduction factor R_{inter} (a property of soil-pile interface and soil-raft interface) has been taken as 0.75 for silty clay, 0.8 for clayey sand, and 0.9 for dense sand respectively. The chosen models are depicted in Figure 4.1 below.



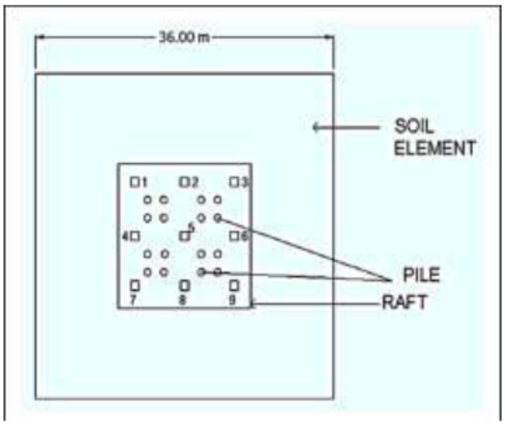
(a) Type A-Raft only (No pile)



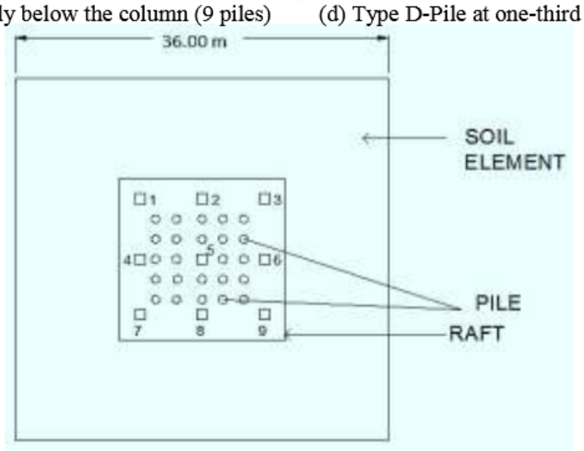
(b) Type B-Pile at half of the bay (4 piles)



(c) Type C-Pile directly below the column (9 piles)



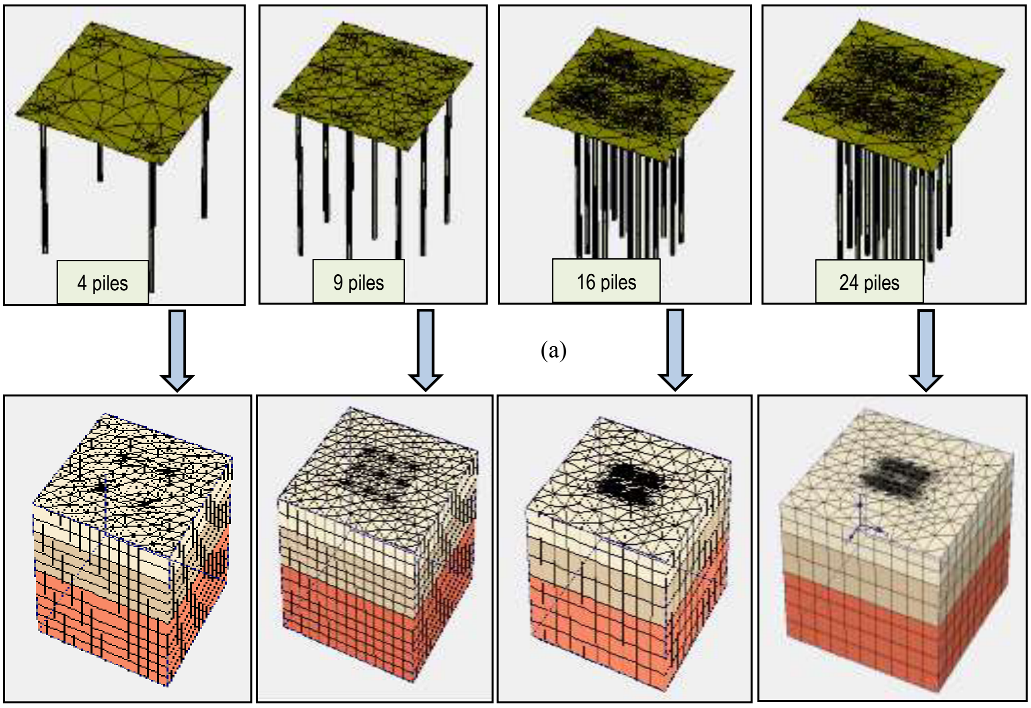
(d) Type D-Pile at one-third of the bay (16 piles)



(e) Type E- Pile at one-third of bay+ pile at column centerline (24 piles)

Figure 4.1. Position of piles in piled raft foundation

The images of different models of piled raft foundations with varied parameters along with their generated mesh are shown below in Figure 4.2. A total of 153 models have been created to check the effect of the raft and piled raft on settlement criteria.



(b)

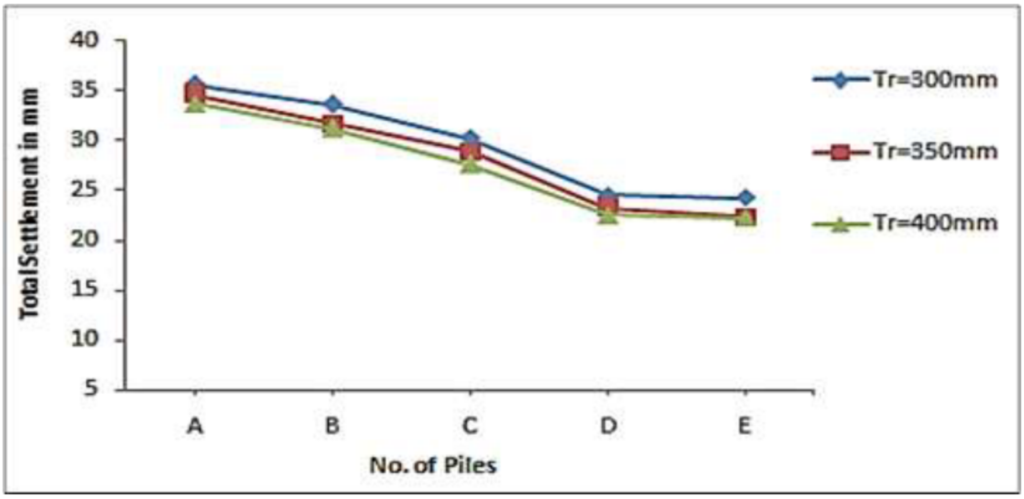
Figure 4.2. Different models exhibiting: (a) piled raft, and (b) generated 3D mesh

Results and Discussion

The total vertical load applied is 2470 kN which is unequally distributed on 9 equally spaced columns with 250 kN vertical load each on 4 corner columns, 280 kN on each of 4 intermediate columns, and 350 kN on a single central column. Figure 6 shows the variation of total settlement of the superstructure as well as a foundation before the introduction of the pile (i.e., only raft) and after the introduction of the pile (i.e., piled raft) on layered soil.

Here, (i) A represents N_p = 0, (ii) B represents N_p = 4 & P_p = Pile at half of the bay (iii) C represents N_p = 9 & P_p = Pile directly below the column (iv) D represents N_p = 16 & P_p = Pile at one-third of the bay (16 piles) (v) E represents N_p = 24 & P_p = Pile at one-third of bay+ pile at column center line (24 piles); where *Np* is the number of the pile, *Tr* is the thickness of raft, and P_p is the pile position.

The figures below show the variation in the total settlement of piled raft foundation after loading with an increase in the number of piles at a varied thickness of raft at a particular diameter and length of the pile (Figures 4.3 – 4.5). At a pile diameter of 300 mm, with an increase in raft thickness from 300 mm to 400 mm and subsequently an increase in pile length from 10 m to 18 m along with an increase in the number of piles from 4 to 24, a decrease in the settlement has been observed up to 33.96% for pile length of 10 m, 35.11% for pile length of 12 m, 40.93% for pile length of 15 m and 44.08% for pile length of 18 m, respectively, in comparison to the un-piled raft. At a pile diameter of 400 mm, with an increase in raft thickness from 300 mm to 400 mm and subsequently an increase in pile length from 10 m to 18m along with an increase in the number of piles from 4 to 24, a decrease in the settlement is noted up to 38.62% for pile length of 10 m, 42.68% for pile length of 12 m, 49.60% for pile length of 15 m and 51.83% for pile length of 18 m, respectively, compared to raft without any pile. At a pile diameter of 500 mm, a decrease in the settlement up to 42.33% is observed for a pile length of 10 m, 47.55% for a pile length of 12 m, 54.82% for a pile length of 15 m, and 60.82% for pile length of 18 m respectively, in comparison with an un-piled raft.


40
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30
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20
15
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Total Settlement in mm
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B
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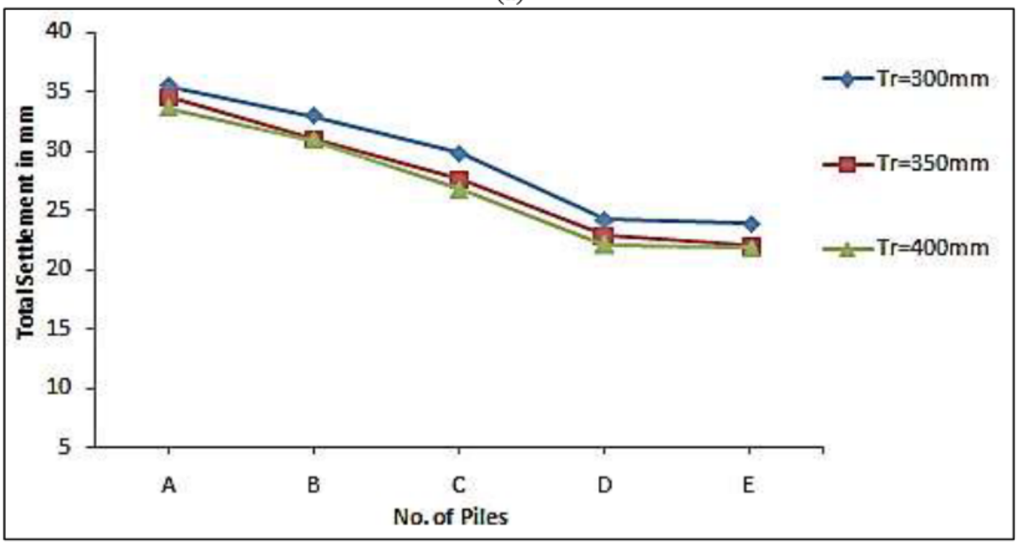
D
E
No. of Piles
Tr=300mm
Tr=350mm
Tr=400mm

(a)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Total Settlement in mm
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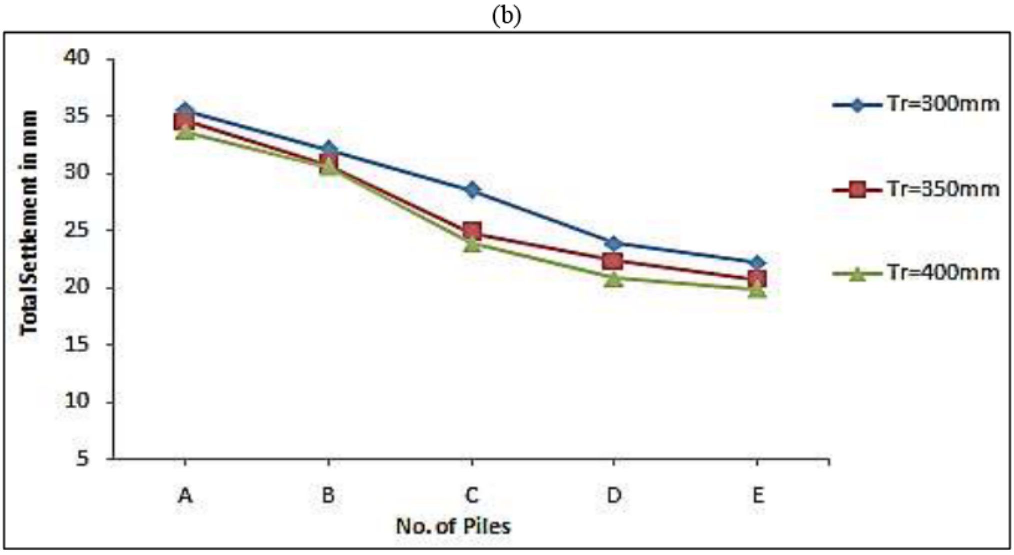
No. of Piles
Tr=300mm
Tr=350mm
Tr=400mm

(b)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Total Settlement in mm
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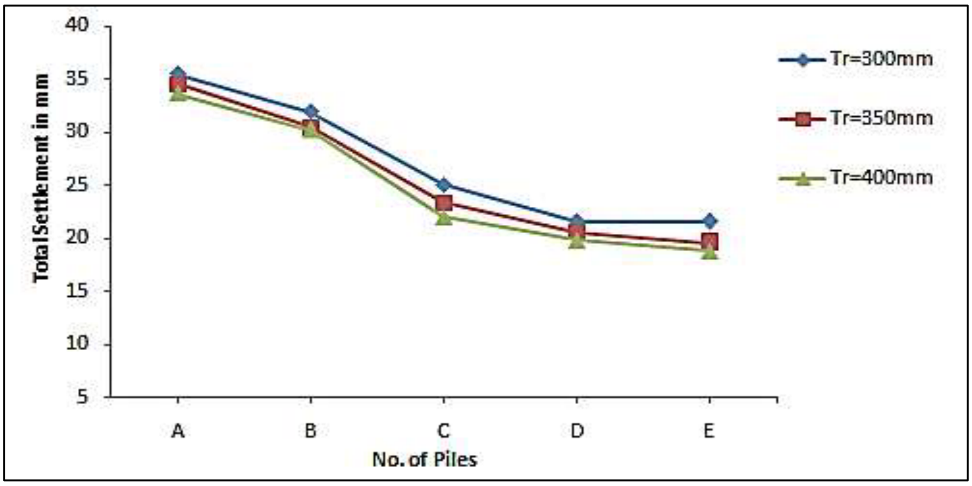
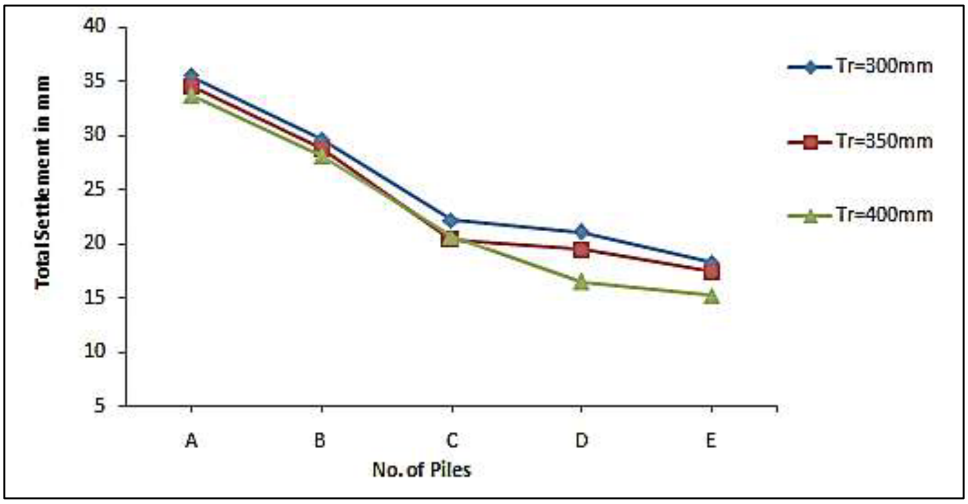
No. of Piles
Tr=300mm
Tr=350mm
Tr=400mm

(c)

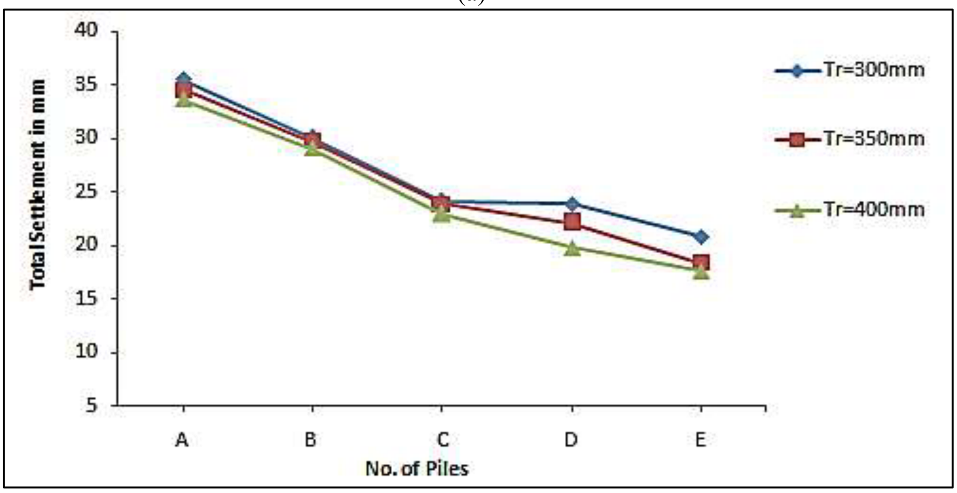


(d)

Figure 4.3. Variation of total settlement with a number of piles at varied raft thickness for pile diameter of 300 mm and pile length: (a) 10m, (b) 12 m, (c) 15 m, and (d) 18 m



(a)



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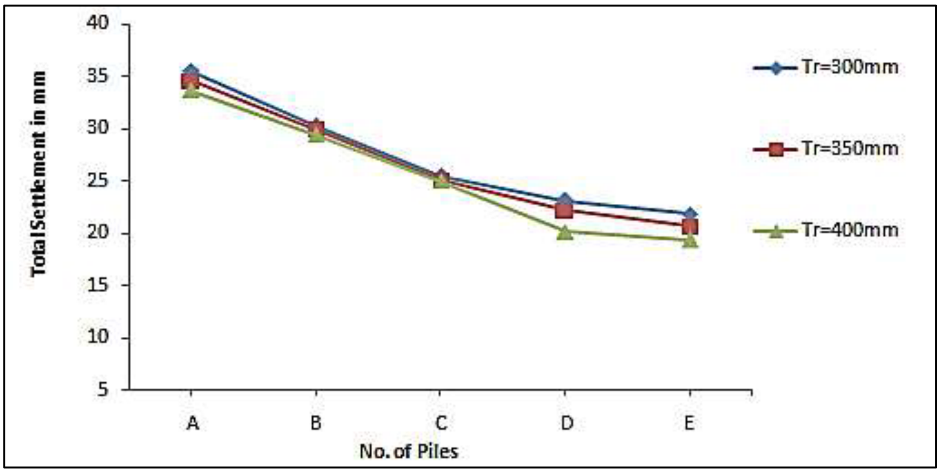

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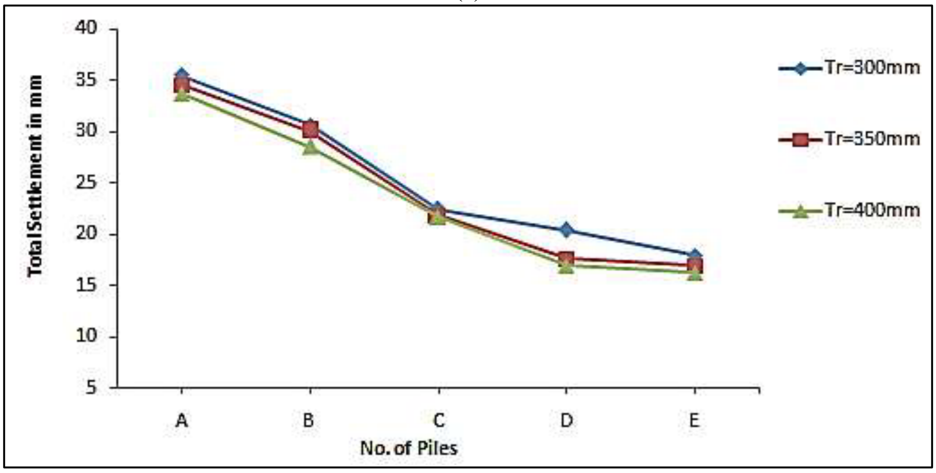
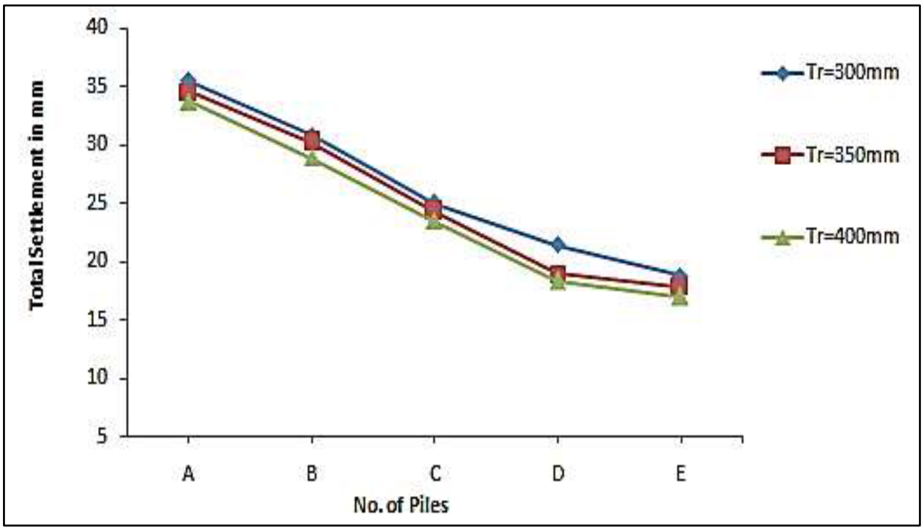
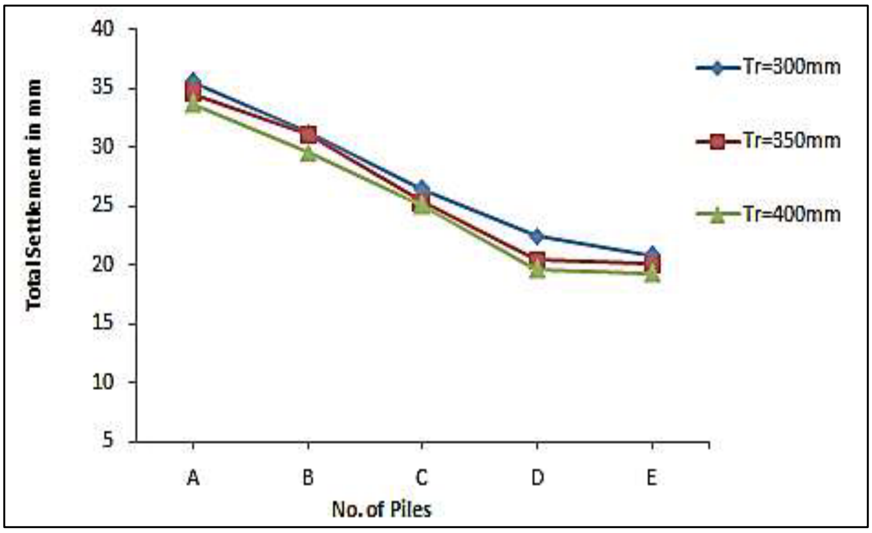


(d)

Figure 4.4. Variation of total settlement with a number of piles at varied raft thickness for pile diameter of 400 mm and pile length: (a) 10m, (b) 12 m, (c) 15 m, and (d) 18 m



(a)



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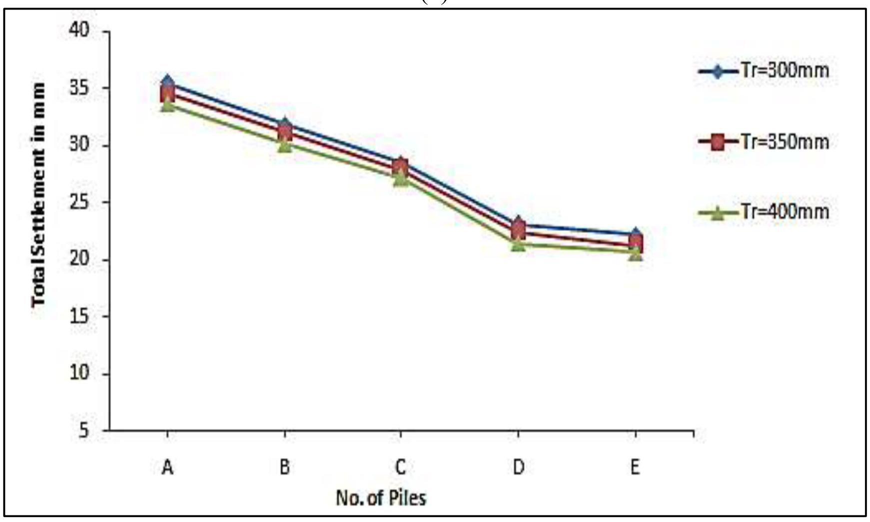

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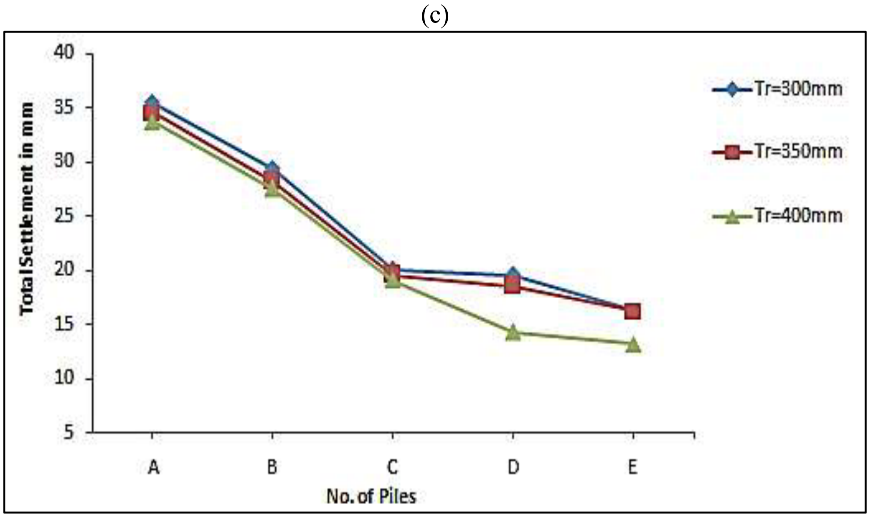
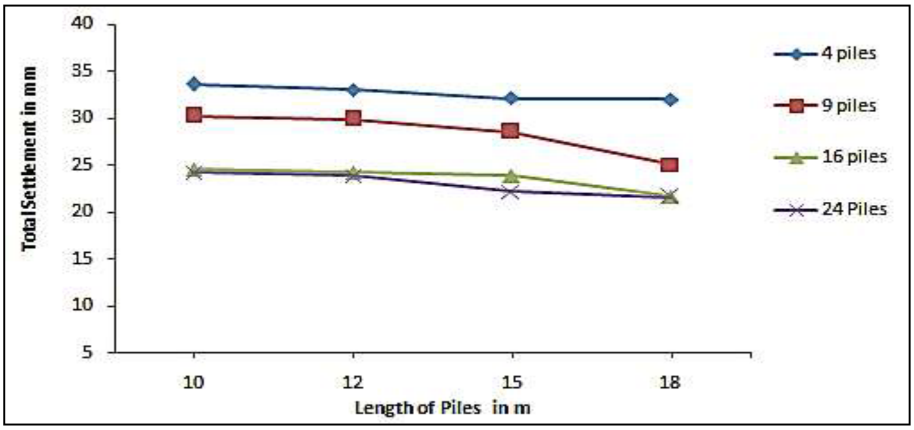


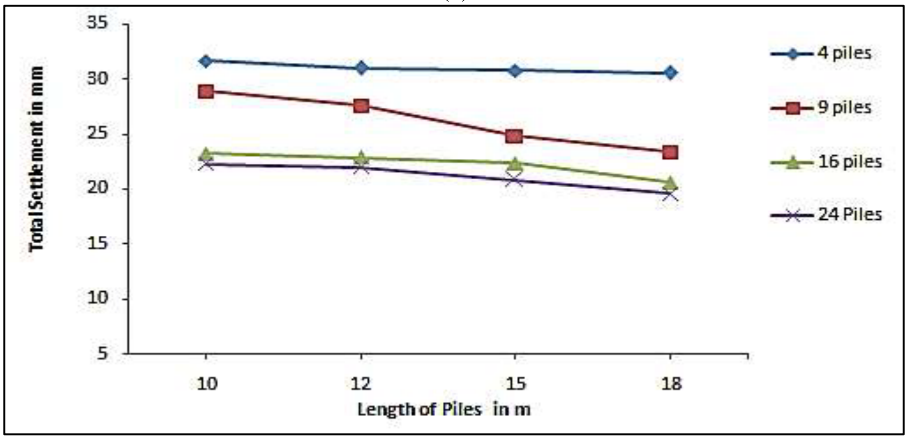
(d)

Figure 4.5. Variation of total settlement with a number of piles at varied raft thickness for pile diameter of 500 mm and pile length: (a) 10m, (b) 12 m, (c) 15 m, and (d) 18 m

Figures 4.6 - 4.8 below show the variation of total settlement of piled raft foundation after loading with an increase in the embedded pile length at a varying number of piles at a specified pile diameter and thickness of raft. At a pile diameter of 300 mm, raft thickness of 400 mm, and pile length of 18 m, an increase in the number of piles shows a decrease in the total settlement up to 10.24% for 4 piles, 34.57% for 9 piles, 41.22% for 16 piles and 44.07% for 24 piles respectively, in comparison to the un-piled raft. At a pile diameter of 400 mm, with identical raft thickness and pile length, an increase in the number of piles shows a decrease in the total settlement up to 15.25% for 4 piles, 35.7% for 9 piles, 49.68% for 16 piles and 51.82% for 24 piles respectively, compared to the un-piled raft. Lastly, at a pile diameter of 500 mm, the corresponding reductions in the total settlement were 18.22%, 43.39%, 57.55%, and 60.82% respectively.



(a)



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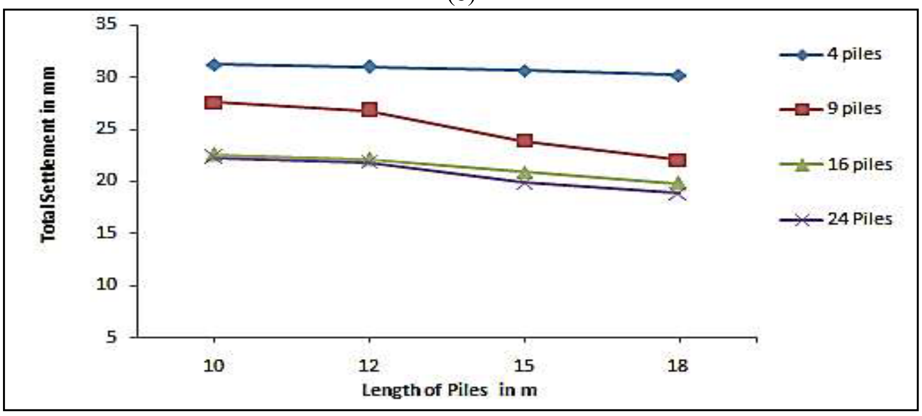
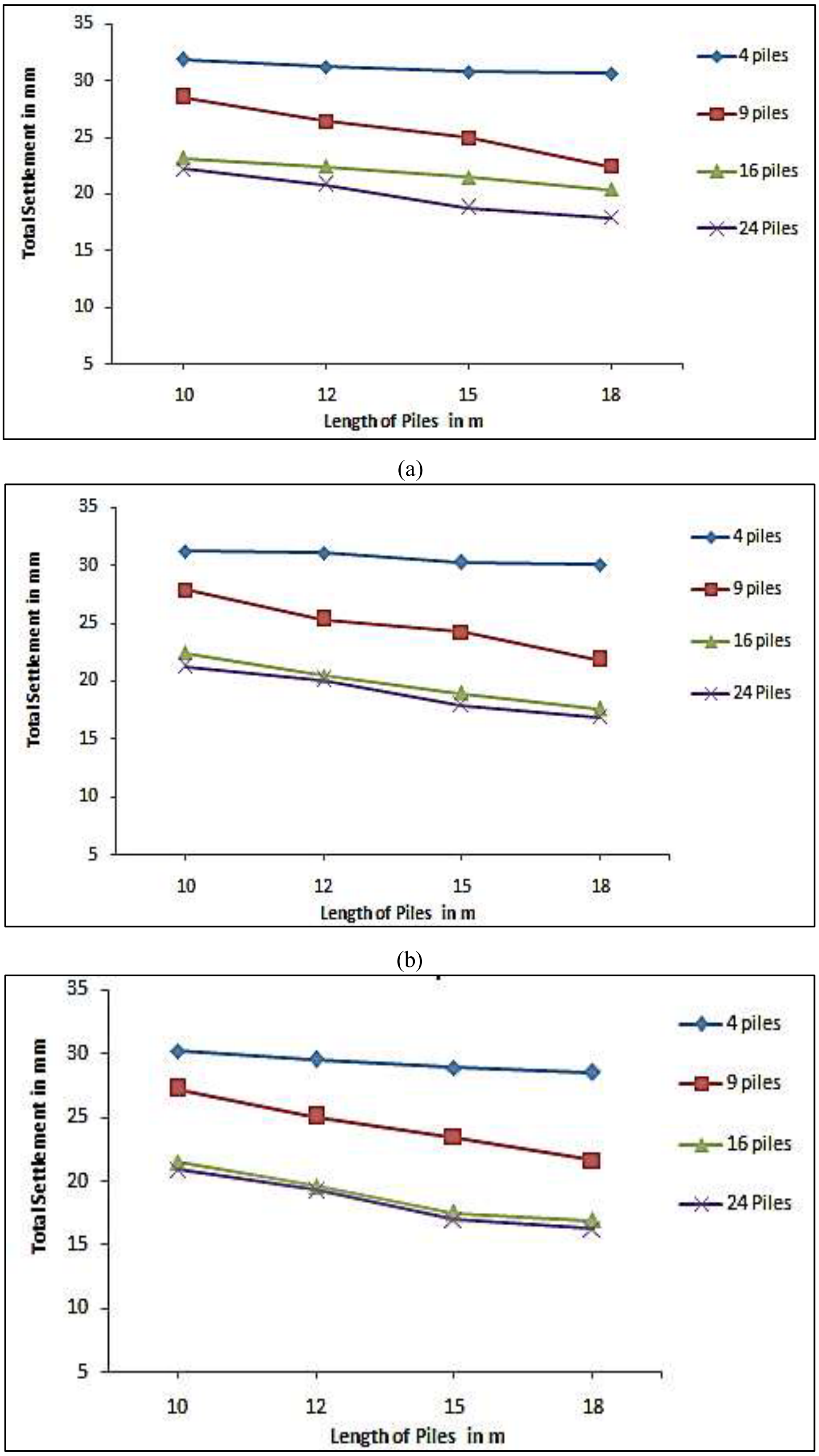


(c)

Figure 4.6. Variation of total settlement with embedded pile length at varying numbers of piles with pile diameter of 300 mm and raft thickness: (a) 300 mm, (b) 350 mm, and (c) 400 mm

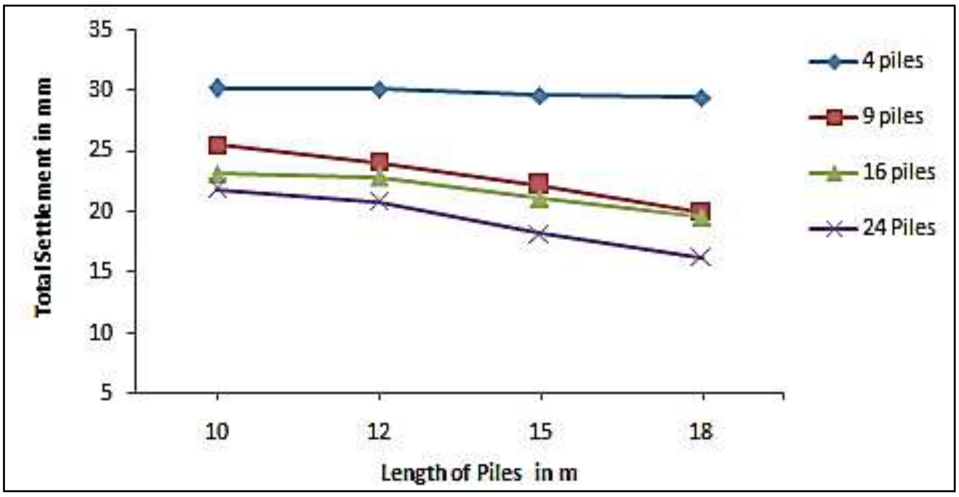


(a)

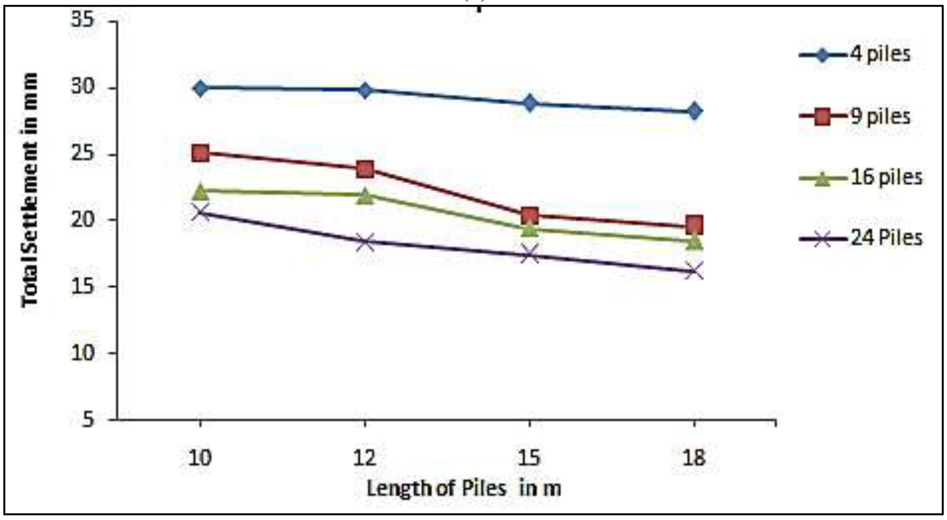
(b)

(c)

Figure 4.7. Variation of total settlement with embedded pile length at varying numbers of piles with pile diameter of 400 mm and raft thickness: (a) 300 mm, (b) 350 mm, and (c) 400 mm



(a)



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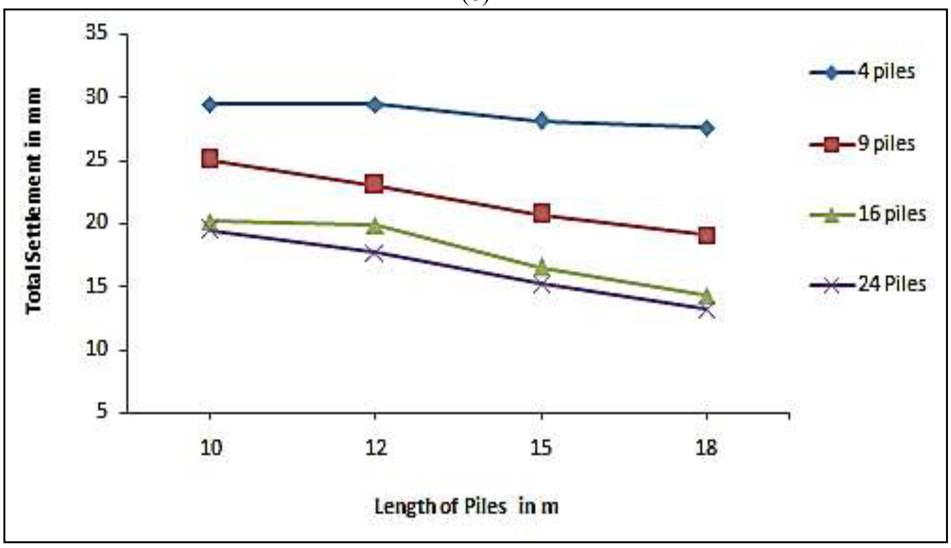

(c)

Figure 4.8. Variation of total settlement with embedded pile length at varying numbers of piles with pile diameter of 500 mm and raft thickness: (a) 300 mm, (b) 350 mm, and (c) 400 mm

Conclusions

The salient conclusions those can be drawn from the parametric study are as follows:

(i) As the pile length increases in piled raft foundation, the settlement decreases. The introduction of 9 piles to raft placed directly below the column position in layered soil with varied soil properties can reduce the total settlement up to 43.39%. The introduction of 16 piles to raft placed at one-third of the bay in between the column positions in layered soil with varied soil properties can reduce the total settlement up to 57.55%.

(ii) The introduction of 24 piles to raft placed at the column centerline in addition to one-third of the bay in layered soil with varied soil properties can reduce the total settlement up to 60.82% in case of vertical loading.

(iii) An increase in the number of piles up to 16 in piled raft foundation has a considerable effect in reducing settlement in layered soil. However, a further increase in pile numbers up to 24 does not contribute much to the further reduction of settlement of piled raft foundations, which justifies the findings of Clancy and Randolph (1993) and Poulos (1994).

(iv) The thickness of the raft has a nominal effect on the settlement of piled raft foundation. As the thickness of the raft increases, the settlement of the piled raft foundation decreases. However, the decrement is very nominal due to the increase in self-weight. So, it can be concluded that increasing the thickness of the raft does not contribute much to the reduction of settlement.

(v) In the case of pile groups, the position of piles has many effects on the reduction in settlement of piled raft foundations. The introduction of piles below the column at a considerable distance from the column center shows good results than piles positioned just below the column.

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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CHAPTER FIVE

PUSHOVER ANALYSIS OF PILE EMBEDDED IN LIQUEFIABLE AND NON-LIQUEFIABLE SOIL

ARUP BHATTACHARJEE[1,2*] BIDISHA BORTHAKUR[3]

Abstract

One of the main reasons for the collapse of bridges during an earthquake is the liquefaction of soil. In addition to the liquefaction of soil, the formation of plastic hinges on the pile can accelerate the failure of piles. Past earthquakes have resulted in the failure of piles due to the formation of plastic hinges at unexpected locations of the pile. Therefore, to predict the possible locations of plastic hinges in a pile, it is important to study the nonlinear behavior of the pile. Static pushover analysis is a method that can be conducted on piles to obtain the nonlinear behavior of a pile beyond its elastic stage. Additionally, considering soil-structure interaction during the analysis helps in obtaining a realistic response of the pile. In this research work, static pushover analysis has been conducted on single piles embedded in liquefiable and non-liquefiable soil using OpenSees PL. The advantage of conducting pushover analysis in OpenSees PL is that it enables the incorporation of soil-structure interaction, which helps to understand the influence of different types of soil on the pile subjected to incremental loading. From the results of the pushover analysis, the difference in the response of piles in liquefiable and non-liquefiable soil is studied. A pile embedded in liquefiable soil requires a lower pushover load for a specific displacement than a pile embedded in non-liquefiable soil. The bending moment developed in a pile is influenced by the type of surrounding soil. The yield moment of a pile surrounded by liquefied soil is lower than a pile in non-liquefied soil.

Key Words

Numerical modeling; Pile foundation; Pushover analysis; Yield moment

Introduction

There is evidence of severe damage to important structures such as bridges caused by earthquakes. The damage caused by an earthquake affects the serviceability of the bridge and ultimately disrupts normal life. Non-linear pushover analysis is an effective tool for evaluating the non-linear behavior of the bridge foundation subjected to earthquake excitation. The deformations of structures subjected to severe ground motion can be predicted by conducting static pushover analysis (Krawinkler 1996). This analysis can approximately account for the redistribution of internal forces occurring in the structure due to inertia force beyond the elastic range of the structure. The performance of the structure subjected to dynamic excitation can be predicted by conducting a pushover analysis (Krawinkler and Seneviratna 1998). Sun and Zhang (2004) predicted the maximum response of the structure along with the destruction of the structure after conducting a pushover analysis on the pier-pile-soil interaction of the bridge. The response of pile foundations in stratified liquefiable soil can be determined by applying force-based pushover analysis in OpenSees PL (Mukhopadhyay *et al.,* 2008).

The response of the pile subjected to seismic loads depends on the type of soil surrounding the pile in addition to the load from the superstructure. There is substantial literature that affirms the

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importance of incorporating soil-structure interaction in design to obtain an improved structure that considers the actual site effects on the structure. Zhang *et al.,* (2008) concluded that the response of a bridge foundation subjected to seismic loading is affected by the inelastic deformation of the soil surrounding the foundation. Brandenberg *et al.,* (2005) further concluded that the mode of pile deflection relative to the surrounding soil depended on the deformed shape of the soil profile, as well as the pile foundation stiffness and load from the non-liquefied crust.

It is well-known that the primary function of a pile is to transfer loads from the superstructure through weaker soil strata onto less compressible soil or rock. In addition to the load from the superstructure, the soil surrounding the piles, especially in earthquake-prone areas, influences the response of piles. Piles that are part of bridge foundations need to be designed against lateral load to prevent foundation failure when subjected to seismic forces. The main objective of this research work is to study the effect of different soil conditions on pile response when subjected to non-linear static force-based pushover analysis. In this research work, a non-linear static force-based pushover analysis has been conducted on a single 10m long fixed-head concrete pile embedded fully in different types of soils, while considering soil-structure interactions, to observe the responses.

Numerical Modeling of Soil-Pile System

The OpenSees PL is a graphical interface of OpenSees, a finite element program for non-linear static and dynamic structural analyses. The static and dynamic computations and pushover analysis can be performed using Openees PL (Wang 2015).

Pile

A 0.8 m diameter and 10 m long circular pile embedded in a soil domain are considered for numerical simulation. The soil domain comprises a single type of soil with a water table extended up to the top surface of the soil. A fixed head pile is considered for numerical simulation. The pile head is subjected to a dead load of 10 tons. The linear beam-column element is used to model the pile. The soil-pile interface is 10^4 times stiffer than pile elements both axially and flexural. The material properties used in the numerical modeling of a pile-soil system by Wang (2015) are considered in this study. The mass density of the pile is taken as 2400 kg/m3. Young's modulus is $3x10^7$ kPa and the shear modulus is 1.154x107 kPa. The moment of inertia of the pile and torsion constant is 0.020106 m^4 and 0.0402123 m^4 respectively.

Soil

The four different soil types are considered to study the influence of each soil on the pile. The soil types considered are as follows: (a) saturated cohesionless very loose sand, (b) saturated cohesionless medium sand, (c) saturated cohesionless dense sand, and (d) cohesive stiff soil.
Table 5.1 presents the material model used to model different soil types.

Table 5.1. The material used in numerical modeling

Soil type	**Material model**
Silt	Pressure dependent multi yield model
Sand	Pressure dependent multi yield model
Clay	Pressure-independent multi-yield model

The details about the soil properties, fluid properties, dilatancy properties, and liquefaction properties for the saturated cohesionless soil and cohesive soil are given in Table 5.2. The water table is extended up to the pile head for liquefaction analysis.

Boundary Conditions

The boundary condition is rigid box type and fixed at the bottom in all directions. Figure 5.1 shows the half-meshed pile-soil model as modeled in OpenSees PL. The model is fixed in the Y direction and free in X and Z directions.

Table 5.2. Soil Properties

Properties		**Soil type**			
		Very loose sand	**Medium sand**	**Dense sand**	**Cohesive stiff soil**
Elastic Properties					
Saturated mass density (Mg/m^3)		1.7	1.9	2.1	1.8
Reference values	Pressure (kPa)	80	80	80	100
	Shear modulus (MPa)	55	75	130	150
	Bulk modulus (GPa)	0.15	0.2	3.9	0.75
Non-linear properties					
Friction angle (^{o})		29	33	40	0
Cohesion (kPa) multiplied by $\sqrt{(3/2)}$		0.2	0.3	0.3	75
Fluid Properties					
Fluid mass density (Mg/m^3)		1	1	1	1
Permeability (10^{-6} m/s)	Horizontal	0.66	0.66	0.66	0.001
	Vertical	0.66	0.66	0.66	0.001
Dilatancy / Liquefaction Properties					
Phase transformation angle (^{o})		29	27	27	--
Contraction parameter		0.21	0.07	0.03	
Dilation parameter 1		0	0.4	0.8	
Dilation parameter 2		0	2	5	
Liquefaction parameter 1		10	10	0	
Liquefaction parameter 2		0.02	0.01	0	
Liquefaction parameter 3		1	1	0	

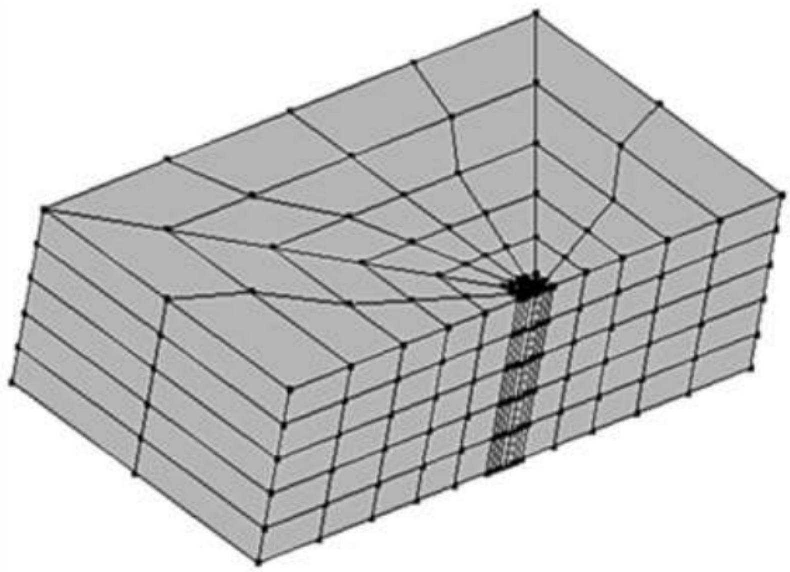

Figure 5.1. 3D view of half meshed pile-soil model in OpenSees PL

Pushover Analysis of Pile

Force-based pushover analysis is conducted on a 0.8m diameter pile by applying a stepwise incremental horizontal load of magnitude 10 kN at the pile head. The incremental horizontal load is applied until the pile head displacement reaches 0.2m, which is 2% of the pile length. The pile embedded in different types of soil requires different loading steps to reach 0.2m displacement of the pile head.

The excess pore pressure ratios of different soils increase with an increase in pushover loading. Figure 5.2 shows the variations of excess pore pressure ratio at different depths at the end of pushover loading. The maximum excess pore pressure ratio of cohesionless very loose sand is 1.43 at a depth of 1.25m, and that of cohesionless medium sand is 1. As the excess pore pressure ratio is greater than or equal to 1, the soil liquefies due to the application of pushover loading. However, the excess pore pressure of cohesionless dense sand is 0.52, implying that the soil does not liquefy on the application of pushover loading for a pile head displacement of 0.2m. For cohesive soil, which is non-liquefiable, the excess pore pressure ratio is a very low value of 0.23.

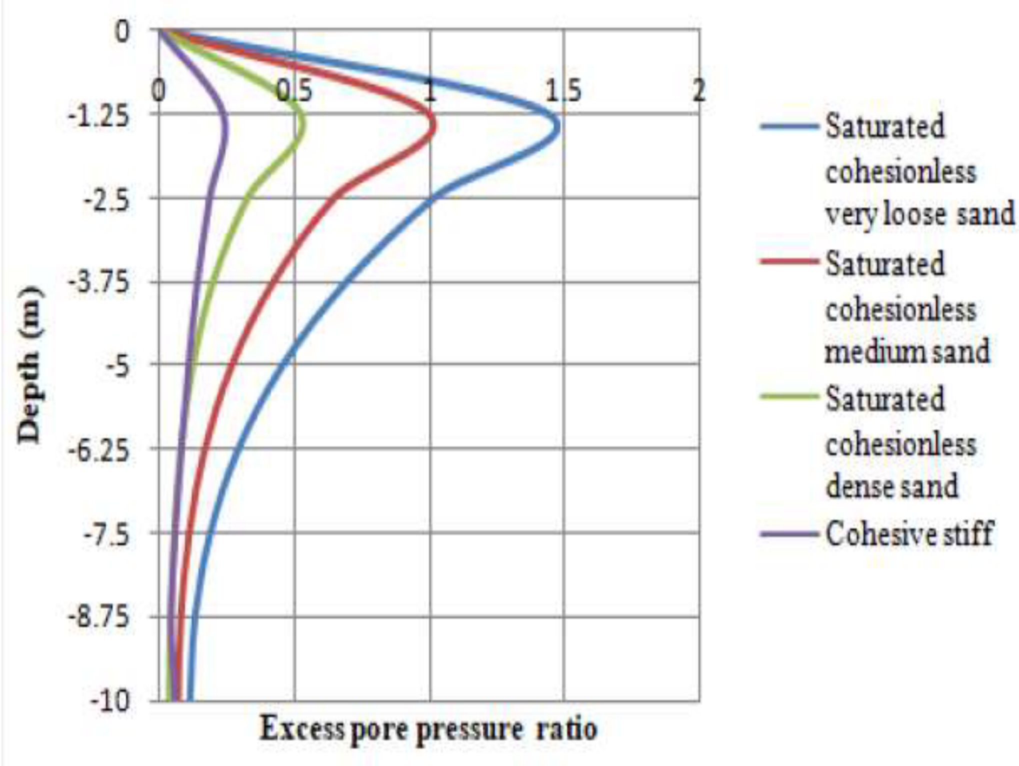

Figure 5.2. Excess pore pressure ratio-depth graph due to pushover analysis

Non-liquefiable cohesive stiff soil required the maximum number of loading steps for a pile head displacement of 0.2 m. However, the number of loading steps is lower for piles embedded in liquefiable soil as compared to non-liquefiable soil. The load versus pile displacement graphs for the pile embedded in different types of soil are shown in Figure 5.3. From the figure, it is observed that the load versus pile head displacement graph is non-linear. The pile behaves elastically under a small load, but as the load increases, the pile starts yielding, and the load-displacement curve becomes non-linear. The point on the curve that has the maximum curvature is usually referred to as the yielding point (Mukhopadhyay *et al.,*, 2008). The yield load at which the linear behavior of the pile changes to non-linear is determined by drawing double tangents. The yield load of the pile embedded in loose cohesionless soil and medium cohesionless soil is 2286 kN and 4200 kN, respectively. The yield load of the pile embedded in dense cohesionless soil and stiff cohesive soil is 5239 kN and 13103 kN, respectively. The load capacity of the pile is influenced by the density and type of the surrounding soil.

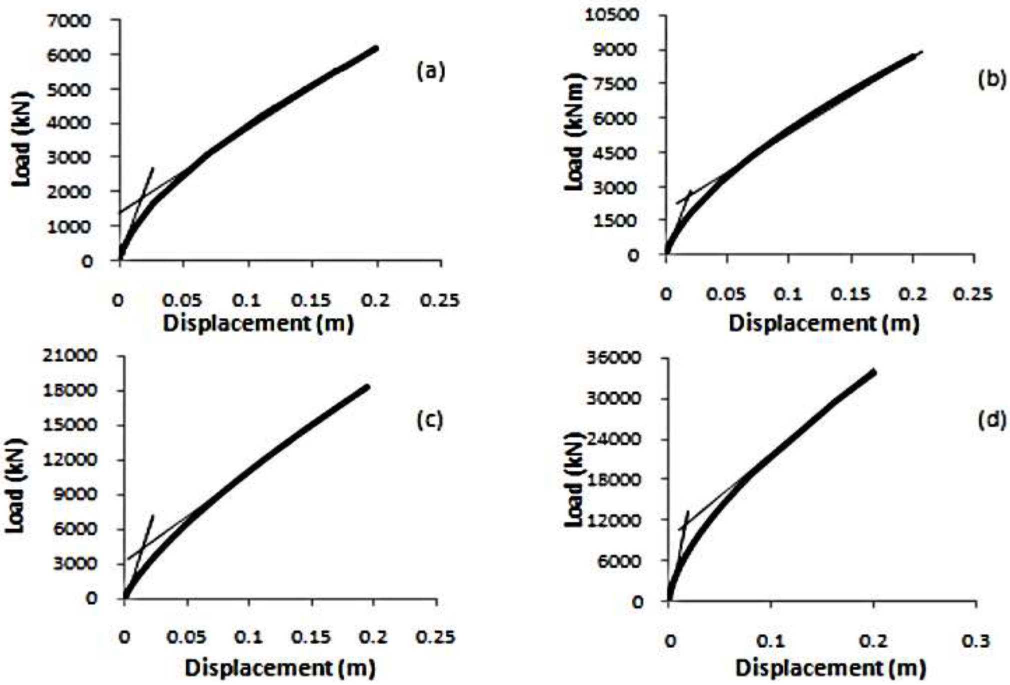

Figure 5.3. Load-displacement graph for pile embedded in (a) cohesionless very loose sand, (b) cohesionless medium sand, (c) cohesionless dense sand, and (d) cohesive stiff soil

The bending moment profile of the pile subjected to pushover loading is shown in Figure 5.4. The bending moment of the pile is maximum at the pile head for all cases of soil due to the application of load at the pile head. Piles in cohesionless very loose sand, medium sand, and dense sand are subjected to bending moments of 15504.8 kN-m, 19167 kN-m, and 28138.4 kN-m, respectively, at the pile head. The cohesive stiff soil has the highest bending moment at the pile head, with a magnitude of 39187.2 kN-m, which is more than twice the bending moment witnessed in piles embedded in cohesionless very loose sand and cohesionless medium sand.

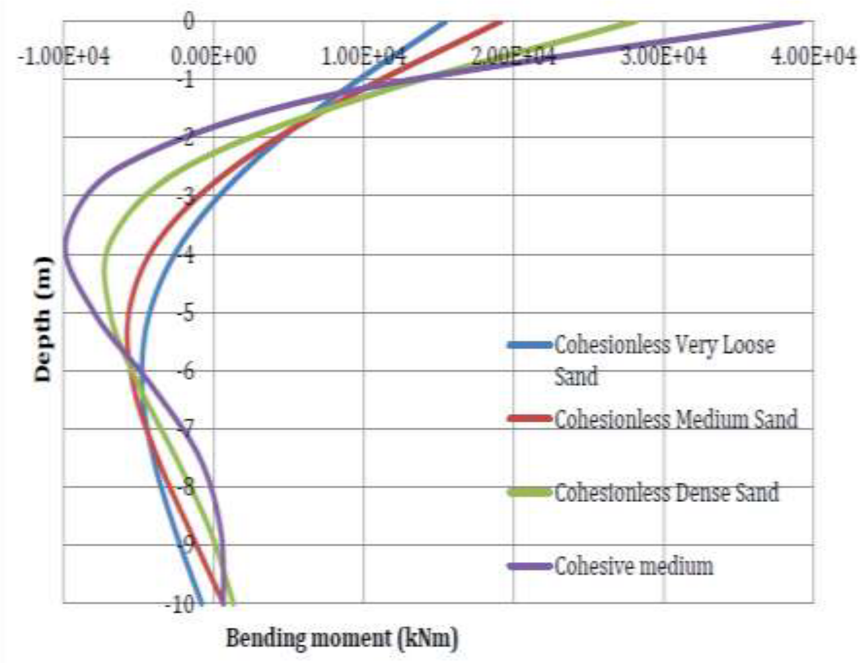

Figure 5.4. Bending moment profile of pile embedded in different types of soil

The moment-curvature graph is drawn to determine the yield moment. Figure 5.5 shows the moment-curvature curve at different depths of 1.25 m, 3.75 m, 6.25 m, and 8.75 m of the pile embedded in cohesionless very loose sand. The moment-curvature curve is non-linear at depths 1.25 m, 3.75 m, and 6.25 m. The yield moment can be determined by drawing double tangents. The yield moment of the pile embedded in very loose cohesionless soil is 1600 kN-m. The yielding of the pile will take place within depths 1.25 m and 6.25 m. The maximum bending moment of the pile is 8120 kN-m and 4850 kN-m at depths 1.25 m and 6.25 m respectively.

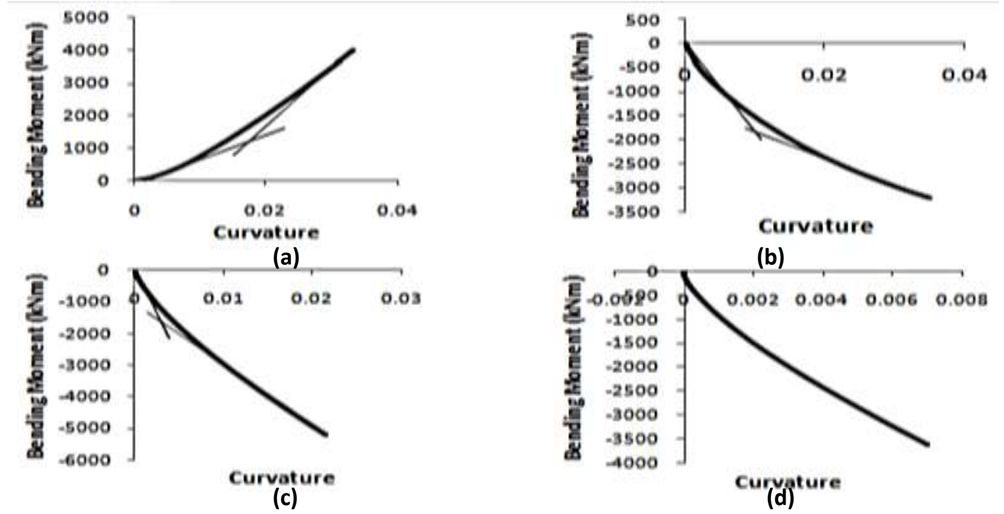

Figure 5.5. Moment curvature curve of the pile embedded in cohesionless very loose sand at depths of (a) 1.25 m, (b) 3.75 m, (c) 6.25 m, and (d) 8.75 m

Figures 5.6 and 5.7 depicts the moment-curvature relation at different depths of 1.25 m, 3.75 m, 6.25 m, and 8.75 m of the pile embedded in cohesionless medium sand and cohesionless dense sand respectively. The yield moment of the pile embedded in cohesionless medium sand and cohesionless dense sand is 2450 kN-m and 3000 kN-m respectively. In the case of a pile embedded in cohesionless dense sand yielding take place at depth of 3.75 m. The yielding moment of the pile increases with an increase in the relative density of cohesionless soil. Figure 5.8 shows the moment-curvature relationship for cohesive stiff soil. The yield moment of cohesive stiff soil is 3600 kN-m. The yielding of the pile occurs at 3.75 m depth. The yielding moment of non-liquefiable soil is more than liquefiable soil.

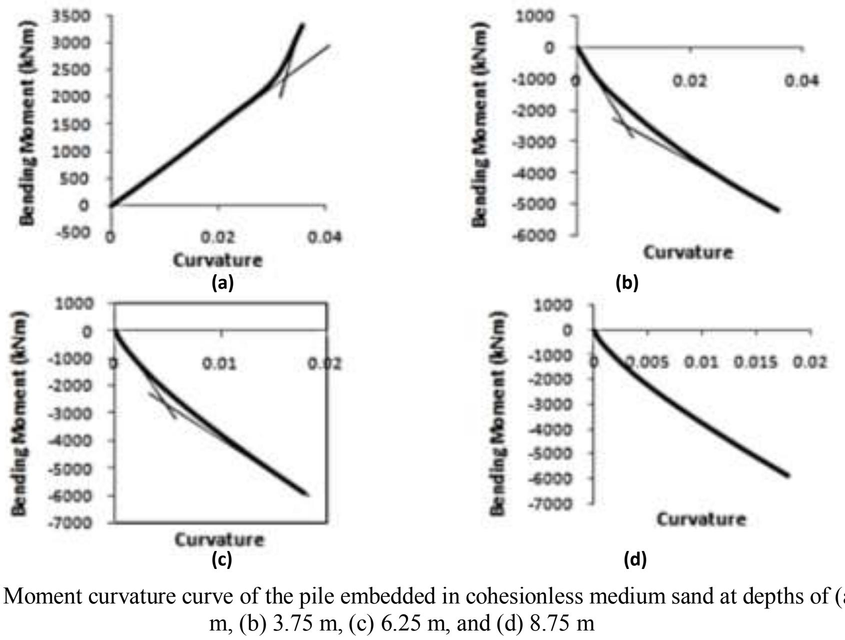

Figure 5.6. Moment curvature curve of the pile embedded in cohesionless medium sand at depths of (a) 1.25 m, (b) 3.75 m, (c) 6.25 m, and (d) 8.75 m

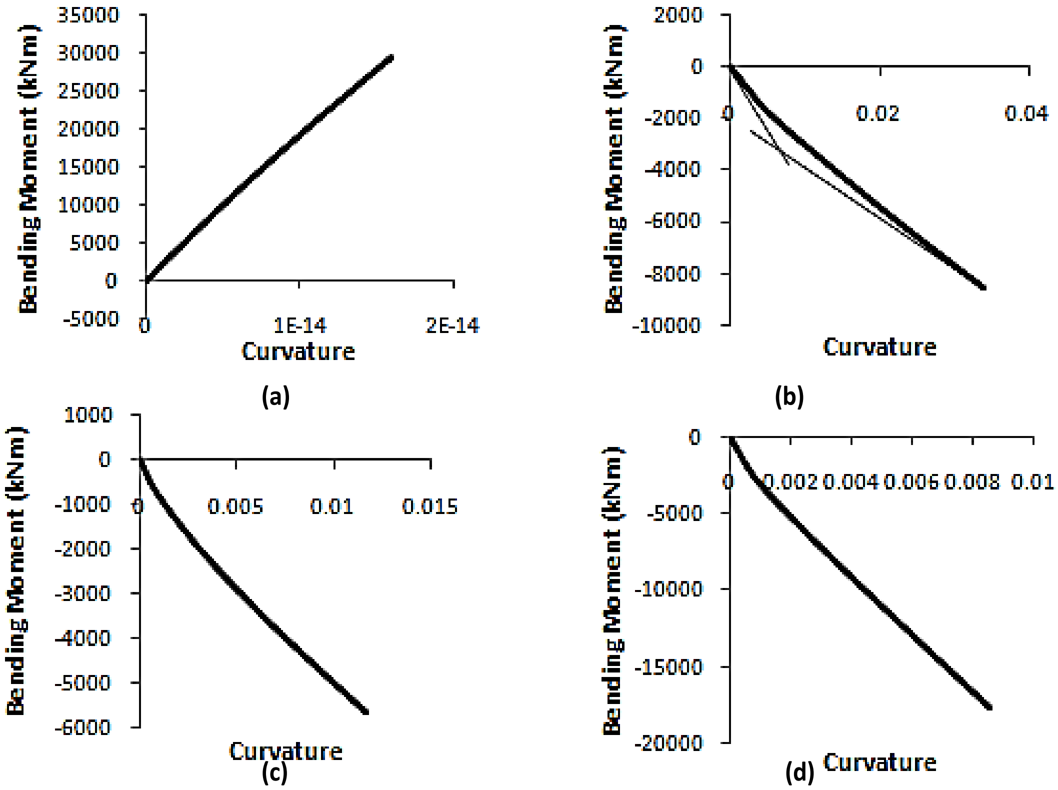

Figure 5.7. Moment curvature curve of the pile embedded in cohesionless dense sand at depths of (a) 1.25 m, (b) 3.75 m, (c) 6.25 m, and (d) 8.75 m

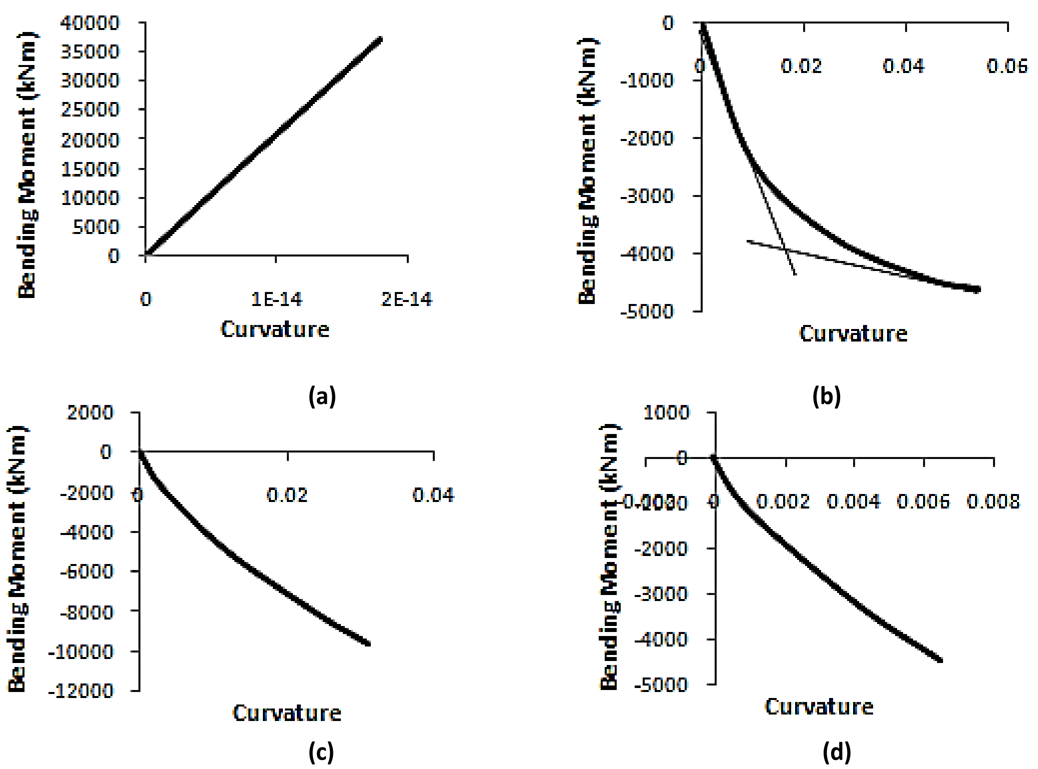

Figure 5.8. Moment curvature curve of the pile embedded in cohesive stiff soil at depths of (a) 1.25 m, (b) 3.75 m, (c) 6.25 m, and (d) 8.75 m

Conclusions

The responses of the pile for piles surrounded by liquefied soil and non-liquefied soil are investigated in this study through numerical analysis. The pushover analyses are conducted to find the effect of liquefiable soil and non-liquefiable soil on pile response. The following conclusions can be drawn from the entire investigation:

(i) The piles embedded in liquefied cohesionless very loose sand and cohesionless medium sand attained the required pile head displacement at a lesser pushover load as compared to piles embedded in non-liquefied soils.
(ii) The extent to which the pile behaved elastically is not only dependent on the load applied, but also on the surrounding soil type. The extent of elastic behavior is highest for piles embedded in cohesive medium soil followed by cohesionless dense sand and cohesionless medium sand and it is least for cohesionless very loose sand.
(iii) The bending moment is maximum at the pile head for all types of soil due to the application of load at the pile head. The bending moment of the pile surrounded by cohesive medium soil is maximum followed by the bending moment of the pile embedded in cohesionless very loose sand and cohesionless medium sand. Piles surrounded by cohesionless dense sand witnessed bending moments higher than these two soils as well.
(iv) The yield moment of a pile embedded in liquefied soil was much lower than the yield moment of a pile embedded in non-liquefied soil. The location of yielding of the pile is also affected by the surrounding soil type.

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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CHAPTER SIX

IMPACT OF DOMESTIC WASTEWATER ON SOIL CHARACTERISTICS FOR IRRIGATION

DEEPAK KUMAR POWREL[1,*] TADO GYADI[1]
DINKEN PAKSOK[1] RANJIT CHAKMA[2]

Abstract

Urbanization and industrialization have become increasingly significant, making the sewage system even more important for removing sewage and other waste from society. In many developing countries, however, sewage treatment plant design has not received adequate attention. The composition of wastewater is determined by the types and quantities of industrial effluents that are discharged into sewer systems. The use of domestic wastewater for irrigation has been shown to improve soil physicochemical characteristics, crop productivity, and nutrient status. With the exception of minor variations in alkalinity and salt solubility in clay soil with wastewater irrigation, no observable negative consequences were seen from the season-long application of domestic wastewater for irrigation.

Keywords

Irrigation; Soil characteristics (N, P, K); Soil texture; Specific gravity; Wastewater

Introduction

India is producing enormous amounts of effluent due to the transforming economic landscape brought on by widespread urbanization and industrialization. Both industrial and domestic wastewater is either utilized or dumped for irrigation on land, which presents both challenges and opportunities (Gupta *et al.,*, 1998). Such wastewater contains the majority of nutrients and can be used as irrigation water for a variety of plants, trees, and crops, potentially resulting in an improvement in agricultural output and plantations. It has the potential to provide micronutrients and macronutrients, including nitrogen (N), phosphorus (P), and potassium (K), which are essential for plant growth (Rutkowski *et al.,*, 2006). However, not all water sources have the quality required for irrigating crops. Water used for irrigation must be suitable for the crops and soils it will be used on. For optimal crop growth, appropriate amounts of nutrients must be present in the root zone of the crops. Therefore, domestic wastewater is typically used for irrigation in semi-arid and arid countries. These nutrients can be provided in part by the soil and should also be supplemented with organic fertilizers and manures (Agarwal *et al.,*, 2014). Depending on the parent material and variances in management histories, such as past harvests, management of crop residue, as well as the prior use of manure and fertilizer, different soils will contain different amounts of readily available nutrients. The nutrients that are accessible may also change due to climate change. In order to enhance crop output and productivity, it is necessary to determine how much N, P, and K should be added to organic or mineral fertilizer, and farmers must be aware of the NPK composition of their soil for yield (Dutta *et al.,*, 2000). However, N, P, and K should be present in sufficient, but not excessive, amounts in the soil. Low availability of nutrients will prevent growth

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and lead to low yields, while sufficient availability of nutrients may disrupt plant growth and have detrimental effects on harvesting yield and quality. Furthermore, N, P, and K availability need to be balanced, so it is essential to consider the availability of other nutrients when modifying the abundance of the considered nutrient (Singh and Kansal, 1985).

Due to increasing water demand, the practice of using domestic wastewater in agriculture is becoming more common. Water availability is dwindling daily as a result of rapid industrial expansion and population growth. Population growth has increased both the demand for water and the production of wastewater (Powrel *et al.,*, 2022). Low-quality water is often used for agriculture, while high-quality water is retained. In semi-arid and arid countries, where it is more affordable and accessible to use wastewater than freshwater, irrigation with wastewater has become a common technique (Blaha *et al.,*, 2000).

Engineering Properties of Soil Sample

"Soil is mostly made up of minerals, which are formed from parent material that has weathered or broken down. Both plants and animals play significant roles in soil. There are numerous ways in which soil composition and structure are altered by both plants and animals. Plants use their roots to draw nutrients and moisture from the soil (Piper 1966). Soil properties are characterized by physical, chemical, and biological factors. Additionally, soils can provide excellent construction materials for civil engineering projects. One of the goals of this study is to understand the engineering properties of soils and their importance in irrigation.

Soil Texture

The texture of soil is influenced by the size and composition of the solid particles that make it up, which can be mineral or organic in nature. To classify the texture of mineral soils, the relative fraction of particles smaller than 2 millimeters (mm), or 5/64 of an inch, is used. As illustrated in Figure 6.1, sand has the largest particles, clay has the smallest, and silt falls in between. The proportions of sand, silt, and clay in a soil sample determine its texture. If more than 15% of the particles are organic, the textural class may be altered, and it is not possible to assess soil texture using particles larger than 2 mm (Oyediran *et al.,*, 2011). However, if organic particles account for more than 15% of the soil volume, the textural class will still be affected. To determine the texture of a mineral soil sample, the amounts of sand, silt, and clay are separated and weighed.

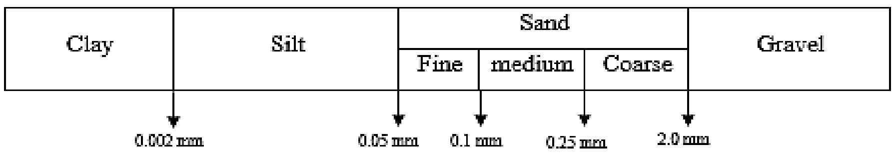

Figure 6.1. Particle size distribution of soil (Apparao et. al. 1995)

Moisture Content

Soil moisture is a crucial component for regulating the movement of water and heat energy between the ground surface and the atmosphere through evaporation and plant transpiration. The cycle of rainfall and the development of weather patterns heavily rely on soil moisture (Raj 2008). Knowing the soil moisture level enables the quantification of irrigation requirements before crop distress occurs, allowing for highly effective irrigation that supplies water as needed and avoids unnecessary water use when irrigation is not required (Wigneron *et al.,* 1998). Water stored in the soil is necessary for plant growth, and vegetation in a natural landscape is adapted to the soil type, climate, and soil moisture regime. The variation in moisture content over time, both within and between years, is called the soil moisture regime. Plants struggle to survive when water is scarce or soil moisture falls below the wilting point. Similarly, excessive watering can also be harmful. The availability of water is one of the main factors that influence the biogeography of plant species (Asner and Lobell 2000). The equation below can be used to determine the moisture content of the soil:

$$\text{Moisture Content, } w\,(\%) = \frac{W_2 - W_3}{W_3 - W_1} \quad (1)$$

where, W_1= empty weight of the container, W_2= weight of the container + weight of moist soil, and W_3 = weight of the container + weight of dry soil.

Specific Gravity

Specific gravity is the ratio of the mass of soil solids to the volume of water in an equivalent volume. It is a significant soil index characteristic that reflects the historical weathering and is directly related to the mineralogy or chemical composition (Tuncer and Lohnes 1977). Specific gravity is important for understanding the qualitative behavior of the soil and useful for classifying minerals in the soil; for example, iron minerals have a higher specific gravity compared to silicas (Bowles 1992). It also helps to determine whether the soil is suitable for use as a building material; soil with higher specific gravity values produces stronger foundations and roads. Additionally, specific gravity is used to evaluate other properties of the soil, such as void ratio, porosity, and saturation level. The equation below can be used to determine the specific gravity of the soil:

$$\text{Specific Gravity, } G = \frac{M_2 - M_1}{(M_2 - M_1) - (M_3 - M_4)} \quad (2)$$

where, M_1 = mass of empty Pycnometer, M_2 = mass of the Pycnometer with dry soil, M_3 = mass of the Pycnometer and soil and water, M_4 = mass of Pycnometer filled with water only. The typical values of the specific gravity of a few soil particles are given in Table 6.1.

Table 6.1. Typical values of specific gravity of soil (source: Bowels, 2012)

Types of soil	Specific Gravity
Organic Soil	1.00-2.60
Soil with Mica or Iron	2.75-3.00
Inorganic Clay	2.70-2.80
Silty Sand	2.67-2.70
Sand	2.65-2.67

Importance of Soil Water Relationship

Water can be stored and moved through soil. Approximately 45% of a typical silt loam topsoil's volume would be made up of mineral matter (soil particles), 5% would be made up of organic matter, and the remaining percentage would be pore space. The spaces between soil particles, known as the pore space, are occupied by either air or water. The texture, bulk density, and structure of the soil affect the number and size of the pore spaces. The two ways that soil holds water are in the pore spaces and as a thin layer on the exterior of soil particles. Some water will seep into the groundwater if the soil becomes saturated. The remaining water will be kept in the soil until it evaporates or is absorbed by plant roots, at which point it will finally transpire from leaves. Water transports sediment, organic materials, plant nutrients like nitrogen and phosphorus, insecticides, and other dissolved or suspended substances at each of these stages. Sediment and nutrients from the surface may be carried into lakes by water flowing over it. Pesticides or nitrate may be present in water that drains into groundwater (Gardner *et al.,* 1970). There are two types of soil water found in the pore spaces: Capillary and gravitational water (Corey and Klute 1985).

The force of gravity enables gravitational water to typically travel fast downward in the soil. The most important type of water for crop production is capillary water, in which soil granules withstand gravity. As water seeps into the soil, the pore spaces become saturated with water. Water travels through the soil by gravity and capillary forces as the pores are filled. Water continues to flow downward until the forces of gravity and capillary action are balanced (Gardner *et al.,* 1970). Capillary pressures cause water to be drawn around soil particles and through tiny pore holes in either direction. Capillary forces that raise water from a shallow water table upward may cause salts to precipitate and concentrate in the soil as water is absorbed by plants and evaporated (Richards and Wadleigh 1952).

The primary objective of this research is to determine the feasibility of using domestic wastewater for irrigation and to analyze the engineering properties of soil after wastewater application. This study aims to investigate the beneficial effects of domestic wastewater on soil properties by analyzing the N, P, K, pH, and engineering properties of soil samples containing domestic wastewater.

Methodology

Survey and Collection of Samples

An experimental setup was established to evaluate the impact of domestic wastewater on soil characteristics. Wastewater samples were collected from two locations within Assam Down Town University, Panikhaiti, Guwahati (refer to Figure 6.2). The selected sources were the drain outlets of the Boy's mess (Point 1) and the Girls' mess (Point 2). For this purpose, agricultural soil samples were collected from the paddy fields of Panikhaiti, Guwahati (latitude 26.2268° N and longitude 91.9041° E). Prior to applying wastewater, soil parameters such as N, P, K, pH, moisture content, and specific gravity were determined and are presented in Table 6.2.

Table 6.2. Characteristics of soil without application of wastewater

Soil sample (without application of wastewater	**Soil parameters**					
	N (ppm)	*P* (ppm)	*K* (ppm)	*pH*	Moisture content, w (%)	Specific Gravity, G
	2660	5.09	2850	6.7	31.2	2.44

(a) (b) (c) (d)

Figure 6.2. (a) Soil Sample - Location 1 (b) Soil Sample - Location 2 (c) Wastewater - point 1, and (d) Wastewater - point 2.

To determine whether the research's viability using domestic waste the characteristics of the wastewater sample generated from the Boys' mess (Point 1) and Girls' mess (Point 2) of Assam Down Town University, Panikhaiti have been observed as shown in Table 6.3

Table 6.3. Characteristics of wastewater Collected from Boys and Girls mess

Parameter tested	**Observed results**	
	Point 1	**Point 2**
pH	6.8	5.9
Turbidity	37 NTU	41 NTU
Hardness	98 mg/L	122 mg/ L
B.O.D.	312 mg/ L	336 mg/ L
COD	560 mg/ L	520 mg/ L

Analysis Technique

To assess the impact of domestic wastewater on soil, two wastewater samples collected from Point 1 and Point 2 of Assam Downtown University Campus were separately applied to the soil. The soil parameters, including N, P, K, pH, moisture content, and specific gravity, were determined using the Kjeldahl method, multiparameter photometer, Flame photometer, pH meter, Oven drying method, and pycnometer method, respectively, at 1 week, 2 weeks, and 3 weeks after the application of wastewater.

Results and Discussion

The test results with analysis and interpretations are presented in this section. The data relevant to pH, *N, P, K*, w, and G are given in Tables 6.4-6.9 and Figures 6.3-6.8, respectively.

Table 6.4. Determination of pH

Location	**pH**		
	1st week	2nd week	3rd week
Point 1 (Boys mess)	7.2	7.6	7.3
Point 2 (Girls mess)	6.6	7.1	6.9

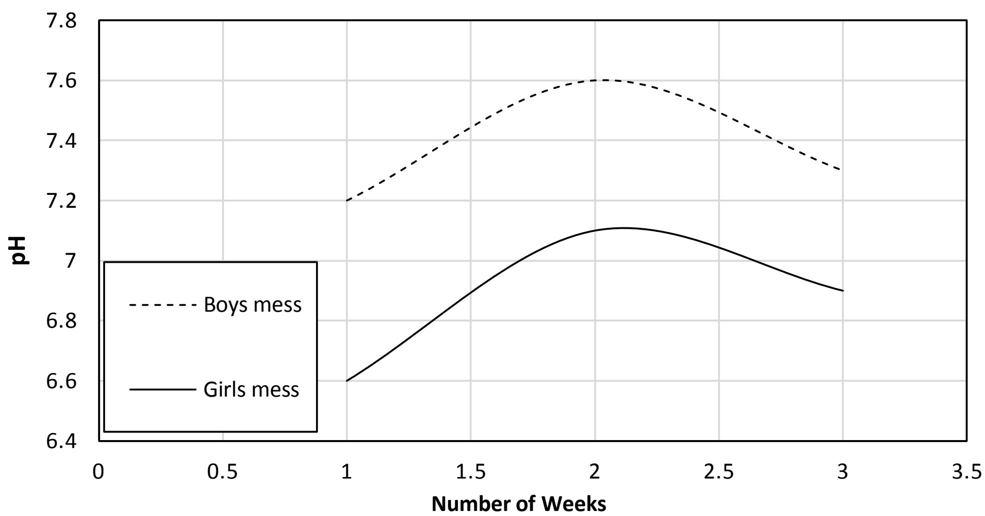

Figure 6.3. Variation of pH with the number of weeks

Table 6.5. Determination of N

Location	N (ppm)		
	1st week	2nd week	3rd week
Point 1 (Boys mess)	3210	2430	1980
Point 2 (Girls mess)	3000	2520	2160

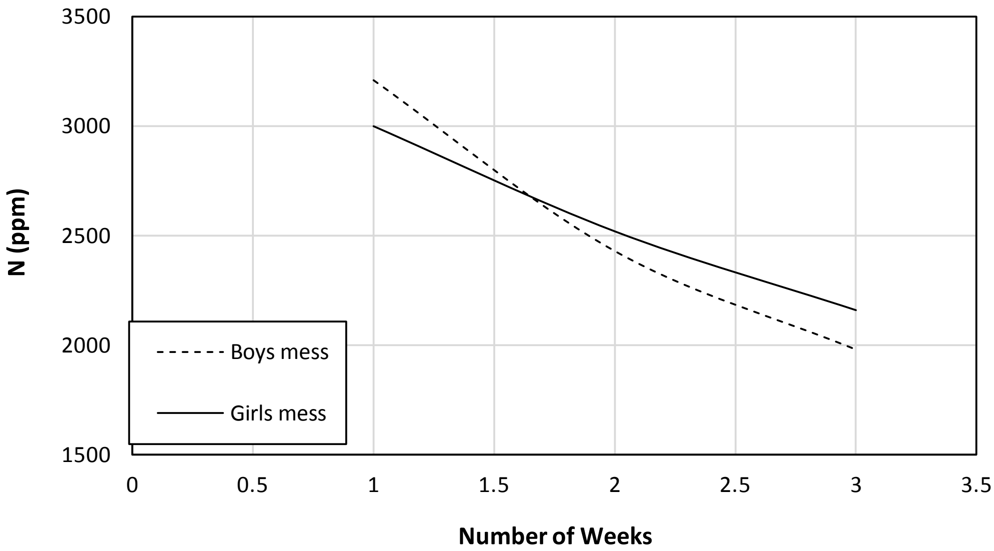

Figure 6.4. Variation of N with the number of weeks

Table 6.6. Determination of P

Location	P (ppm)		
	1st week	2nd week	3rd week
Point 1 (Boys mess)	18	18	12
Point 2 (Girls mess)	22	16	6

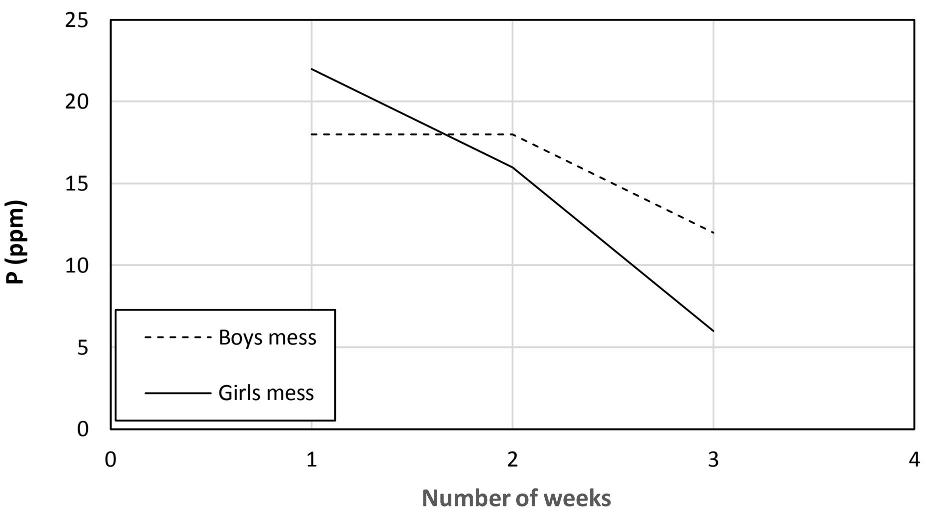

Figure 6.5.: Variation of P with the number of weeks

Table 6.7. Determination of K

Location	K (ppm)		
	1st week	2nd week	3rd week
Point 1 (Boys mess)	3710	3230	2970
Point 2 (Girls mess)	3550	3610	3060

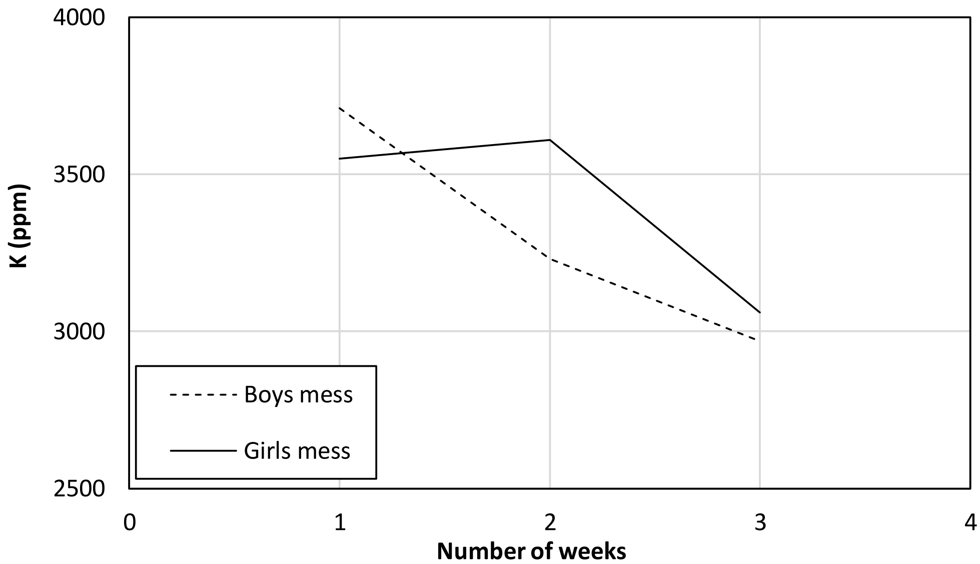

Figure 6.6. Variation of K with the number of weeks

Table 6.8. Determination of moisture content

Location	Moisture content (%)		
	1st week	2nd week	3rd week
Point 1 (Boys mess)	36.5	32.3	31.1
Point 2 (Girls mess)	34.5	32.4	30.6

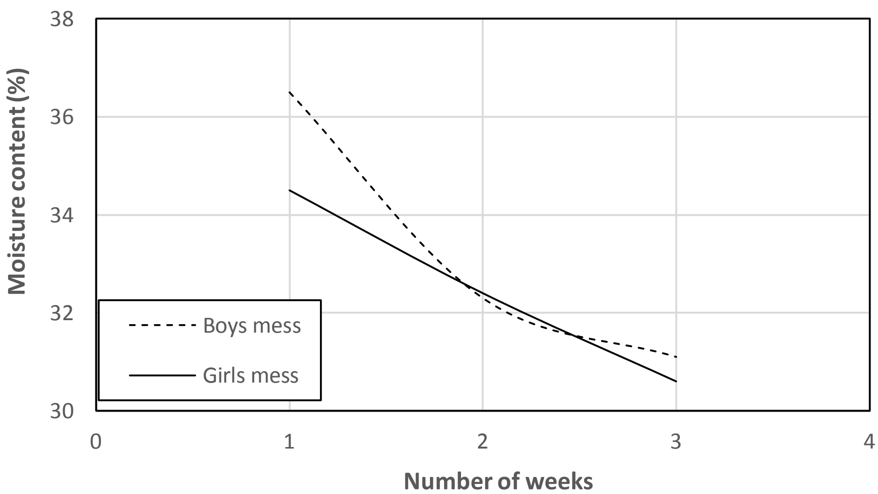

Figure 6.7. Variation of Moisture content with the number of weeks

Table 6.9. Determination of specific gravity

Location	Specific gravity		
	1st week	2nd week	3rd week
Point 1 (Boys mess)	2.13	2.16	2.16
Point 2 (Girls mess)	2.12	2.16	2.18

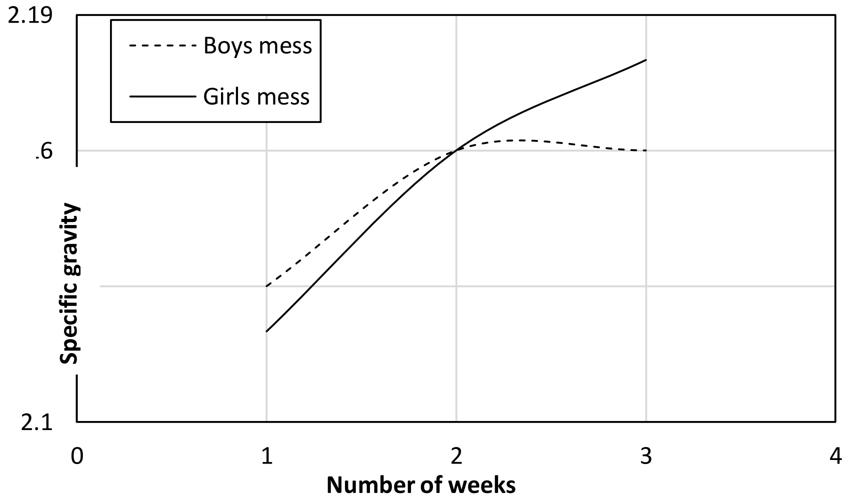

Figure 6.8. Variation of Specific gravity with the number of weeks

Domestic wastewater contains essential nutrients that can improve soil fertility and promote crop growth. As shown in Figure 6.2, the pH value increased in the soil containing wastewater collected from the Boys' mess compared to that from the Girls' mess. pH influences the availability of essential nutrients, making it significant. Horticultural crops can usually be grown in soils with a pH between 6 (slightly acidic) and 7.5 (slightly alkaline). In the first week, the N and K content was slightly higher in the soil containing wastewater collected from both sources, but in the second and third weeks, the N content was lower in the soil containing wastewater collected from the Boys' mess compared to that from the Girls' mess, as depicted in Figures 6.4-6.6. Plants require nitrogen to produce many leaves and have a vibrant green color, and they require phosphorus to develop new roots, seeds, fruit, and blossoms. It is also used to defend against diseases. Potassium helps plants form sturdy stems and grow rapidly. As shown in Figures 6.7 and 6.8, the moisture content of the soil gradually decreased, while the specific gravity of the soil increased over time. Moisture content reflects both the state of the field and the amount of water in a given area. As water is initially absorbed by plant roots, its quantity and aeration directly impact plant health. It is crucial to consider how soil moisture affects plants and productivity.

Conclusion

The presence of domestic wastewater in soil samples leads to higher values of nitrogen, phosphorus, and potassium, which can benefit plants and increase crop yields. Moreover, it can increase the overall phosphorus and potassium contents of the soil. As water resources are inadequate, using domestic wastewater for irrigation provides an alternative approach to wastewater management. According to the findings, the use of physically treated domestic wastewater can improve water supplies for irrigation, which could be beneficial for agricultural production. Therefore, it can be concluded that the use of domestic wastewater for irrigation has become more significant worldwide due to limited water resources and expensive wastewater treatment before discharge. If the land has the right terrain, soil, and drainage, domestic wastewater can be discharged as a source of irrigation water and plant nutrients. This approach can help conserve water resources and reduce the costs of wastewater treatment.

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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CHAPTER SEVEN

ECO-PLANNING OF TEXTILE CLUSTER FOR SUSTAINABLE DEVELOPMENT AT A SELECTED AREA IN WEST BENGAL, INDIA

BIMAN GATI GUPTA[1]

Abstract

The textile industry is one of the major product manufacturing businesses in India, providing a large number of skilled and unskilled employment opportunities, second only to agriculture. The production value of the Indian textiles industry was estimated to be around US$ 120 billion in the financial year 2016-2017 and is expected to reach about US$ 250 billion by 2023. According to the Ministry of Small and Medium Enterprises, Government of West Bengal, India, 1000 textile units were operating in the Maheshtala textile cluster in 2014, which has increased since then. However, industrialization has been found to cause severe environmental pollution due to the discharge of wastewater from the processing of textile products. This wastewater is heavily rich in organic load, toxic elements, and compounds. In the Maheshtala cluster's dyeing and bleaching units, the discharge of toxic effluent with no treatment affects the nearby agricultural lands, ponds, and canals due to the absence of a common effluent treatment plant. The objective of the study is to assess the quality of wastewater and air pollution caused in the Maheshtala region by the textile cluster and to develop an eco-planning strategy for sustainable development.

Key Words

Eco-planning; Health hazards; Remediation; Surface & Groundwater; Textile; Wastewater

Introduction

In India, after agriculture, the textile industry is the second largest employment-creating sector. The textile industry employs about 51 million people directly and 68 million people indirectly. India's overall textile exports during the financial year 2015-2016 stood at US$ 40 billion (IJT 2017). The Indian textiles industry is expected to reach an estimated production value of about US$ 120 billion in the financial year of 2016-2017 and up to around US$ 230 billion by 2023. The Indian Textile Industry contributes approximately 4% of India's gross domestic product and 14% to the overall index of industrial production (MOT 2019; Union Budget 2017).

In terms of jute production, India globally ranks first and secures 63% of the global garment and textile market and ranks second in global cotton and silk production. The raw cotton production in India grew from 28 million bales to 37.1 million bales during the years 2007 to 2021 (Statista; CCI). In the textile sector, 100% foreign direct investment is permitted via the automatic route. Bilsar, Nisshinbo, Rieter, Zara, Trutzschler, Soktas, Zambia, Levi's, Monti, CMT, E-land, Marks & Spencer, Promod, and Benetton are a few of the foreign textile companies that have invested or are working in India (Narayanan 2009).

The man-finished fibers include garment manufacturing using fiber or filament synthetic yarns produced in large power loom factories, covering the majority of India's textile production industry. About 4.8 million people are employed in this sector, which accounts for 62% of India's total production.

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The cotton sector is the second most developed sector in the Indian textile industry. Although it provides employment for a large number of people, its production and jobs are based on production seasonality. The handloom industry is fully developed and is largely reliant on self-help groups' resources. Only 13% of the total cloth produced in India is sold in its market. India is the seventh-largest producer of wool in the world, accounting for about 1.8% (Shakyawar *et al.,* 2018).

The export of manmade fiber textiles has rapidly increased in the last few decades. More than 140 nations, including Japan, the United States, the United Kingdom, Russia, France, Nepal, Singapore, and Sri Lanka, are the recipients of India's yarn exports. With 43.13 million spindles installed, India is in 2nd place globally in terms of spindle capacity (SRTEPC 2022).

India accounts for a sizable portion of the global commerce in cotton yarn but just 4% of the global trade in apparel. This is a result of the local spinning and weaving mills' inability to process yarn. Although there are some large factories, the majority of the output is split up into tiny units that serve the needs of the neighborhood. Apparel is produced by about 77,000 small-scale units classified as domestic manufacturers, exporters, and fabricators. This mismatch is a major drawback for the industry. As a result, many spinners export yarn, while the producers of textiles and clothing must import fabric. The machinery needs to be modernized, and the power supply is inconsistent. Other problems include low labor productivity and fierce competition.

In West Bengal, India, large, medium, and small-scale textile units are operating largely in South Bengal. Such industries have grown in the localities like Maheshtala, Budge Budge, Chatta, Kalikapur, and Khidirpur, in and around Kolkata and Howrah, and the semi-urban and rural clusters around them due to the availability of skilled manpower, raw materials (fiber, yarn), chemicals for bleaching and dyeing units, water, and power. Accessibility to seaport, airport, and railway connectivity with the rest of the country is quite advantageous as well. The locality Maheshtala is at a distance of about 19 km from Kolkata, belonging to the South 24 Parganas district of West Bengal. In the map of major textile clusters in India, Maheshtala occupies an equivalent status to Tirupur in Tamil Nadu, Bangalore in Karnataka, Rajasthan, Tripura, Nasik in Maharashtra, etc. Maheshtala had a total population of 448,317 comprising 51% male and 49% female (Census 2011).

Environment Pollution by Textile Cluster

Although the textile industry has immense potential for contributing to economic development and creating employment opportunities, its susceptibility to initiating severe environmental pollution is significantly high. This pollution is due to the discharge of wastewater from its processing of products, which is heavily rich in organic load and laden with toxic elements and compounds. In the study area of Maheshtala, bleaching and dyeing are done in small units as a partial job. To meet the increasing demand and production of garments, many new bleaching and dyeing units have been set up in Chatta, Kalikapur, Mahishgoat, and other adjoining panchayat areas. According to the Ministry of Small & Medium Enterprises, Government of West Bengal, India, about 1000 textile units were operating in the Maheshtala textile cluster in 2014, and this number has increased further in the present time.

Bleaching and dyeing processes are considered a part of wet processing, among other major processes of textile products. They are the most hazardous processes as they discharge toxic wastewater to the open land and adjoining canal without treatment due to inadequate infrastructure. They typically cover the end product's pretreatment, dyeing, printing, and finishing. Water serves as the necessary liquid medium for all of these phases. Each of the stages requires a significant volume of water. According to estimates, processing 1 kg of textile products uses about 100 gallons of water on average. For application in textile operations, the water used must have a few specific qualities in terms of physicochemical characteristics, color, and biological features. Therefore, water is a key consideration in wet process engineering.

The majority of the water used in the textile industry comes from deep wells and tube wells, which are located at depths of 25-35 m below the surface. The main issue with using water in textile processing is water hardness produced by the presence of soluble metal salts. Iron, aluminum, copper, calcium, magnesium, and other metals can increase water hardness, but their effects are less serious. The use of hard water in the wet method can cause scale buildup in boilers, reactions with soap and detergents, reactions with colors, and iron-related issues. Boiling, liming, soda lime, base exchange, or synthetic ion exchange processes can be used to soften hard water. Some textile manufacturing hubs have recently begun collecting rainwater to use in wet operations because rainwater is less likely to cause issues related to water hardness.

Aim and Objective

With an aim of environmental impact assessment, wastewater treatment and management, and eco-planning of the textile cluster for sustainable development, the study has been conducted with the following objectives:

(i) Quality assessment of water: (a) wastewater discharge from the bleaching and dyeing units.
(b) surface water (mainly from the canal) contaminated by a direct or indirect discharge of wastewater from the textile units.
(iii) underground water around 30 m below the ground level is used mostly by textile units.
(ii) To assess the quality of the soil of the adjoining agricultural field contaminated by either the direct discharge of wastewater or flooding of the canal (surface water) during monsoon season.
(iii) To assess the quality of fruits namely coconut, guava, papaya, coix grass, and water hyacinth in the study area.
(iv) To conduct a socio-economic study to present a profile of the area for population, education, occupation, earnings, and living standard of the people inhabiting the area.
(v) To conduct a health impact assessment among the population of the study area affected by environmental pollution namely water, air, soil, and fruits.
(vi) To design and develop the common wastewater treatment plant in the study area as mitigatory measures.
(vii) To develop eco-planning of the study area for sustainable development.

Textile Processing Methodology

Bleaching and Dyeing Process

Bleaching is a process that improves whiteness by removing natural coloration and remaining trace impurities from cotton, and sodium hydrosulfite is commonly used for this purpose. The process can also be used to clean materials like polyamide, polyacrylic, and polyacetal fibers. Optical brightening agents (OBAs) are often used after scouring and bleaching to make the textile material look whiter. These agents are available in the market in a variety of shades, including blue, violet, and red.

The process of dyeing involves coloring textile goods and materials. Following dyeing, the dye molecules still maintain intact chemical connections with the fiber molecules. Temperature and time are two parameters that regulate the dyeing process. Natural and artificial dyes are the two main categories of dyes. When dyeing yarn, the color is intensified. Yarns can be dyed using skein, package, beam, and space dyeing techniques. Skein dyeing is a long and relatively more expensive process, while package dyeing is somewhat quicker, although the dyeing uniformity might not be as excellent as in skein dying.

Cloth dyeing, commonly referred to as piece dyeing, is the process of coloring fabric after it has been produced. The most popular and economical way to dye materials is with solid colors. After the fabric has been created, an appropriate color decision can be made.

Printing and Finishing Process

Fabric printing and dyeing are similar, but during appropriate dyeing, the entire fabric is evenly covered in one color. When printing, one or more colors are put to it in precise patterns that are exclusively applied to specific sections. To apply colors to the fabric during printing, wooden blocks, stencils, engraved plates, rollers, or silkscreens might be utilized.

The object of textile finishing is to render textile goods fit for their purpose as well as the serviceability of the fabric. The manufacture and use of synthetic dyes for fabric dyeing have become a massive industry nowadays. Synthetic dyes have provided a wide range of colorfastness. However, their toxic nature has become a cause of serious concern to environmentalists. The use of synthetic dyes has a hazardous effect on the environment. The presence of chemicals like sulfur, naphthol, vat dyes, nitrates, acetic acid, soaps, enzymes, chromium compounds, and heavy metals like copper, arsenic, lead, cadmium, mercury, nickel, and cobalt, as well as certain auxiliary chemicals, all collectively make the textile effluent highly toxic and hazardous to the environment and public health. Other injurious chemicals present in the water may be formaldehyde-based dye-fixing agents, chlorinated stain removers, hydrocarbon-based softeners, and non-biodegradable dyeing chemicals. These organic materials react with many disinfectants mainly chlorine and form by-products that are often carcinogenic and therefore harmful. Many of these show different types of allergic reactions. The colloidal matter present along with colors and oily scum increases the turbidity and total dissolved solids, which in turn, interferes with the oxygen transfer method at the air-water interface, interfering with the self-purification process of water. This effluent, if allowed to flow in the fields, clogs the pores of the soil, which adversely affects agricultural productivity. If it is allowed to flow in drains and rivers, the quality of drinking water is adversely affected.

Environmental Impact from Textile Industries

Due to the lack of a single effluent treatment plant, the Maheshtala cluster's bleaching and dyeing facilities release toxic effluent into a canal, pond, and neighboring agricultural land without any treatment. In order to lower the cost of production, they have neither fully nor partially treated it on their property. High pH, turbidity, foul odor, total dissolved and suspended solids, biological and chemical oxygen demands, chloride, nitrate, sulphuric acid, heavy metals, and low dissolved oxygen are the characteristic features of untreated effluent. It contaminates recipient water bodies and surface water, pollutes soil, and releases nitrogen and sulfur dioxides into the atmosphere. In turn, the vegetables and fruits grown on the contaminated soil may also be contaminated with potentially toxic elements and compounds.

Additionally, during their numerous processes, textile units emit gases into the atmosphere. The second most significant source of pollution from the textile sector, after wastewater, has been identified as these gaseous emissions. Dust, oil mists, acid vapors, foul odors, and boiler exhausts are a few examples of such hazardous air emissions. Moreover, the combustion of diesel causes air emissions from two main sources: point sources such as boilers, ovens, and storage tanks, and diffusive sources such as solvent-based wastewater treatment, warehouses, and spills.

Both directly and indirectly, the surrounding area is impacted by air pollution. By spewing particulate particles into the air, diesel engines and generators exacerbate the issue. Additionally, they release SO2 and NO2, which in the atmosphere change into secondary particles. The incomplete combustion of diesel results in the production of particulate matter. Being carcinogenic, diesel exhaust damages the respiratory system. It contains a number of compounds that are also recognized individually as human carcinogenic by the International Agency for Research on Cancer. Public health has been put at risk due to diseases that spread through the air and water as a result of exposure to various pollutants and toxicants present in various mediums and materials.

Research Gap

As discussed above, wastewater, liquid and solid wastes, and effluent gases from textile industries may contain toxic substances and lead to environmental pollution. Hence, it is undeniable that pretreatment is required to minimize the interference with treatment works and negative impacts on receiving water quality, as well as health risks from contaminated water usage.

the case of large textile industries, but no systematic treatment facilities are employed in the case of small textile bleaching and dyeing units developed in an unplanned manner in India, such as in the Maheshtala textile cluster. Moreover, the growth of the latter cluster is presently mushrooming in Chatta, Kalikapur, Mahispota, and other adjoining rural areas. Although some sporadic studies have been undertaken for specific textile industries, no systematic study on the environmental fallout of such development has been conducted for any textile cluster, including the Maheshtala textile cluster. There exists a huge knowledge gap about the quality and quantity of the pollutants produced, their adverse impacts on environmental contamination, health risk assessment, and appropriate measures to mitigate the disastrous consequences.

Unplanned growth of textile units impacts the degradation of the ecosystem. Discharge of effluents from textile units leaves a severe environmental footprint on surface water, groundwater, soil, crops, and vegetables grown in the agricultural fields, ambient air, and above all, general public health (Balachandra *et al.,* 2010). Many such textile units lack effluent treatment plants, and the untreated wastewater is released to the canals, open sewers, and nearby land (Kant 2012; Odjegba *et al.,* 2012).

The study area herein is located in the district of 24 Parganas (South) in West Bengal, India, which is a complicated district that stretches from the urban centre of Kolkata to isolated riverside villages and all the way to the mouth of the Bay of Bengal. In addition to its enormous size and population, the district administration must deal with issues that are typical of metropolitan living in urban areas, such as high population density and overburdened civic infrastructure, and in stark contrast, the lack of transportation and communication infrastructure and inadequate delivery systems in rural areas. Government agencies must take appropriate steps to mitigate the environmental hazards caused by the unplanned development of textile industries in these areas.

Socio-Economic Status of Residents

Socio-Economic Status (SES) is a combined measure of a person's economic and social position based on their work participation, income, education, and occupation (Oakes and Rossi 2003). When analyzing a family's SES, the family income, earners' education, and occupation are examined, while for an individual's SES, only their attributes are assessed. Three levels of SES, namely high, middle, and low, are used to characterize the social groups to which a family or a person may belong. Low income and education have been strongly associated with a variety of physical and mental health issues, including respiratory disorders, arthritis, heart disease, and schizophrenia. These issues may be caused by the working environment or by mental illnesses that may be at the root of the person's social difficulties (Marmot 2004).

SES appears to have a substantial positive correlation with health and is a significant source of health disparities. Several types of research have demonstrated a clear relationship between economic position and healthcare, based on relative economic resources and affordability (Leigh *et al.,* 2012). It has been demonstrated that people with low SES are far more susceptible to illness (Bradley and Corwyn 2002).

Eco-Planning for Sustainable Development

Eco-planning is a significant factor that influences quality, regulation, cost, health and safety, aesthetics, durability, functionality, and ergonomics considered in a planning project. If products are eco-planned, they are innovative, eco-friendly, and of quality, not below market standards. This is why eco-planning has been gaining significant importance (Wang *et al.,* 2008).

Green products and services take care of the environment by using non-hazardous and non-toxic raw materials, processes, technologies, and waste management practices, thus minimizing environmental footprints and adverse health impacts. Eco-planning contributes to better workplace health and safety (Schwarz and Steininger 1997).

Eco-industrial parks can be planned, designed, and operated using the principles of industrial ecology. An eco-industrial park adopts a systemic approach, taking into account a holistic concept of resources, both materials and energy, and emphasizing recycling, closed-looping, and symbiosis (Allen and Behmanish 1994). It puts emphasis on waste exchanges and, to a lesser degree, energy cascading as dominant features. The goal is to achieve the three bottom lines of sustainability: environmental protection, economic development, and social security (Kuras *et al.,* 2020).

Study Area

The urban area of Maheshtala is located at global coordinates of 10.45°N and 75.9°E, having an area of about 44.77 $km^{2,}$ and the administrative headquarter at Alipore of 24 Parganas (South) district of West Bengal, India (Figure 7.1). The area of 1.85 km^2 situated around the Chatta canal, where the majority of the new bleaching and dying facilities are located, has been chosen for an intensive study on environmental impact assessment, environmental management, and eco-planning. These locations supply the majority of the bleaching and dyeing industries' wastewater to the canal. In addition, the canal also receives sewage and domestic wastewater from the neighborhood's various interconnected drains. Due to poor cleaning and siltation, the canal's water capacity cross-section and depth) is being declined with time. Along the stretch of Chatta to Kalikapur, two monitoring points, denoted as stations A and B, situated 1500 m apart, have been chosen for the collection of wastewater, canal water, soil, fruit, and vegetable samples, as well as air samples. The climate of the area comprises a temperature range of 13.6-40°C, annual rainfall of 1760- 1800 mm, and relative humidity of 47-88% (IMD 2023).

Figure 7.1. Study Area (.kmz map prepared using Google Earth)

Socio-Economic and Health Status

The economy of the Maheshtala textile cluster area and other dimensions of its social and health had always relied strongly on traditional and informal pillars; consequently, had never been reflected authentically neither in official records nor in other forms. Hence, a study survey was conducted with the following objectives:

(i) Conducting a socio-economic assessment study in the Chatta-Kalikapur area under the cluster.
(ii) Knowing the current socio-economic situation in the cluster to cover the sub-sectors of education, occupation, and income.
(iii) Performing health surveys of local residents regarding water and airborne diseases.

The Department of Ecological Studies, University of Kalyani, West Bengal, and the Environment Management Department, Indian Institute of Social Welfare & Business Management, Kolkata prepared the survey questionnaire for evaluating socio-economic studies and the health status of local residents in accordance with accepted standards. Two persons from each of the two Universities made up the team that organized the survey and managed the internal data for two months.

Design of Model Integrated Textile Park

Based on the survey study mentioned above, it was suggested to establish 3 to 4 textile parks in different key locations within Maheshtala. Efforts were made to develop the plan in a way that does not affect the relocation of existing units and small entrepreneurs' cost. The planned growth was aimed at maximizing the present environment's improvement. Careful consideration was given to utilizing the available space within the scope of a vacant campus surrounded by open green fields.

Efficient and sturdy road networks are crucial for any industrial estate's development. Therefore, emphasis was given to constructing new roadways with recommended specifications by the Public Works Department of the Government of West Bengal, providing better and wider roads. To ensure better vehicle maneuvering, all internal roads' Right-of-Way (ROW) was maintained at 10.5 m within the available space. Further emphasis was given to combining drainage-cum-sewerage systems with proper and adequate water supply through graded underground mains. The approach road was designed with a 12.5 m ROW to facilitate vehicle movement in both directions. Figure 7.2 shows the current growth of the textile park.

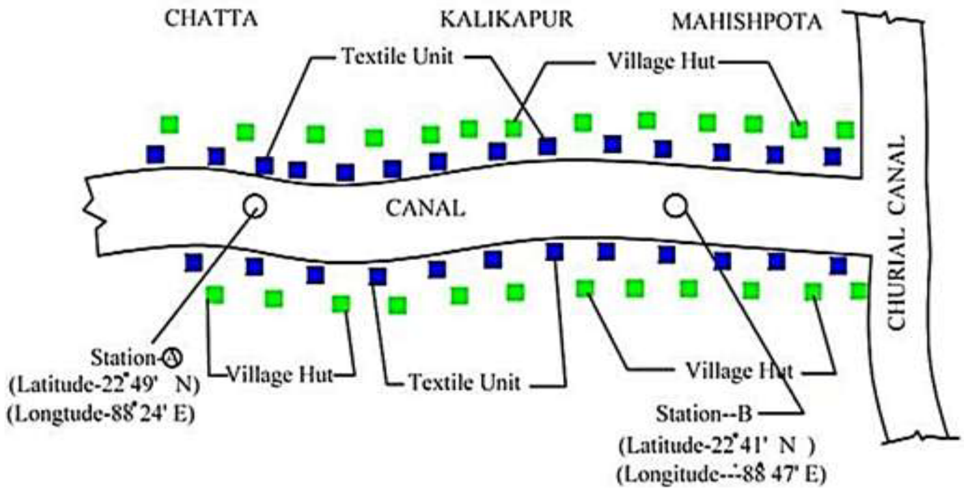

Figure 7.2. Present unplanned growth of textile units

Proposed Infrastructure Distribution Pattern of Plots

The industrial estate is proposed to be developed on approximately 93 bighas of land (Figure 7.3). The estate shall comprise mainly of plots for industrial entrepreneurs. All the plots shall be located in the central and peripheral portions of the estate.

The plots to be allotted shall have areas ranging between 175 - 788 m^2, the total number of plots being 219 with the total area covered has been 75410.77 m^2 (i.e., 62% of the total area). Common Facility Centre (CFC) has been proposed near the main entrance of the industrial complex in an area of 2902.55 m^2. CFC will contain three 2-storied buildings to accommodate the administrative office of the textile park and some other support services including a telecommunication center, bank, post office, and seminar/conference halls in one building, and the other building will be accommodated by the marketing center, canteen, crèche, etc. 50% of the CFC area will be utilized for this purpose. Balance 50% will be utilized for storing raw materials. Minor landfilling is considered for the proposed site because the area may be about 750 mm below the existing road level. One tank will be excavated in an area of 123.9 cottahs of land. This will help to fill up the remaining land to some extent, and the balanced earth will be carried out from the outside area. The proposed level of filling has been considered up to 450 mm from the existing ground surface. The level of the approach road, internal road, and main road will be fixed accordingly. The tank will act as a water reservoir by rainwater harvesting. The water will be utilized during firefighting and to keep the environment cool within the park. Different types of trees will be planted along the water tank and the boundary of the park to maintain ecological balance.

Internal Roads

There are two types of roads provided in the textile park for the movement of vehicles. Internal roads of 10.5 m width have been provided, and each plot is likely to have such a roadway in the front. A collector road of 12.5 m width will also be constructed, so there will be no difficulties in the movement of traffic inside the textile park for approaching the Maheshtala Road. It has also been proposed that the Maheshtala Road could be widened to at least 25m to cater to the needs of traffic originating from the garment complexes and other industries in the near future. Provision of a culvert on the canal by the side of the Maheshtala Road has been made for approaching the garment and textile park. Provision has also been made for one truck parking area in the textile park on the northern side.

The road width is proposed as 10.5 m for all internal roads as per the standard specifications of the Public Works Department, Government of West Bengal. These roads will have a 3.5 m hard crust and 1m hard shoulder on either side and a 1.5 m earthen shoulder on either side. The remaining 1 m wide space will be utilized for laying drainage, sewerage, water supply, telecommunication, and electrical distribution systems. Provision of afforestation has also been made in this area for greenery purposes. Construction of roads may be commenced simultaneously with water distribution and sewerage works. The 12.5 m wide road will have one lane of 5.5 m wide. The remaining area will be a 1 m wide hard shoulder and 1.5 m earthen shoulder for laying pipelines, etc. The remaining 1 m width will be utilized for drainage and afforestation purposes.

Internal Drainage

The combined system of drainage consisting of a network of open brick drains has been proposed to be adopted here for the efficient disposal of wastewater from different industrial units and administrative buildings and the Effluent Treatment Plant (ETP), as well as the stormwater of the proposed garment park. The majority of the industries to be located in this park will be undertaking bleaching and dyeing activities. Open brick drains will be provided on both sides of the road, and the network of brick drains is designed in such a way that they are capable of quickly dispersing the wastewater and stormwater of the corresponding tributary areas. Rainwater from the roads will flow to the open drains due to the cross slope provided on the roads. The combined drainage network will ultimately dispose of the wastewater into the existing canal network.

Internal Water Supply Scheme

The total water requirement for the proposed industrial estate will be drawn from groundwater sources through two separate deep tube wells to fulfill the total requirement of 900 kL/day (= domestic water of 400 kL/day + effluent of 500 kL/day). It is proposed that one deep tube well along with the pump house and overhead reservoir shall feed the water to individual plots on the northern side of the park and the other on the southern end of the park. Cast iron water distribution mains are to be laid from the underground reservoir to consumer points. The size of the main distribution pipe is 100 mm in diameter while branch pipes are 80 mm and rising main pipes are 150 mm in diameter. The total requirement of water has been calculated as per standard practice. Water requirements in other common facility buildings will be met by keeping an overhead reservoir on the top of the building with a safety factor of 2.0.

Sewage and Solid Waste Disposal

Sewers from the different units will be taken through sewer lines and will be treated in ETP along with effluent. As for solid waste disposal, garbage vats are proposed to be located at strategic points wherefrom disposal at regular intervals is to be arranged by trucks.

Power Supply

The high-tension power lines will be available from the Calcutta Electric Supply Company (CESC) main grid at point supply 6.6 KV, 250 MVA, 3 phases, 3 wires, 50 Hz. The 6.6 kV power supply is to be stepped down to 415 V, 3 phase, 50 Hz, 4 wire system through 3 numbers of 500 kVA, 6.6 kV, 433 V transformer to meet the expected requirements in the zone. This power supply system will be channelized in the underground distribution to different feeder Kiosks as primary distribution. In secondary distribution, consumers will be fed from the kiosk. The kiosks are interconnected among themselves through a coupler isolator along with a castle key interlock.

The complex has been divided into a 3-load distribution block to achieve an economic and optimum system. All roads crossing cable shall be protected suitably by Hume pipes. All cables shall be laid by the side of the road at a minimum of 750 mm depth for low-tension cables and 1000 mm for high-tension cables directly buried in earth covered with sand and bricks as per standard specifications. The total power requirement will be 4500 kVA including the power of the common facility center and operating pump for the water supply system and street lighting.

Common Facilities

An administrative building would be set up for the facilitation of administrative activities within the industrial park. A three-storied building covering an area of 2853.5 m^2 has been proposed to accommodate common facilities like a bank, IT center, and cafeteria which are located on the ground floor. The display room, training center, research center, and medical center are located on

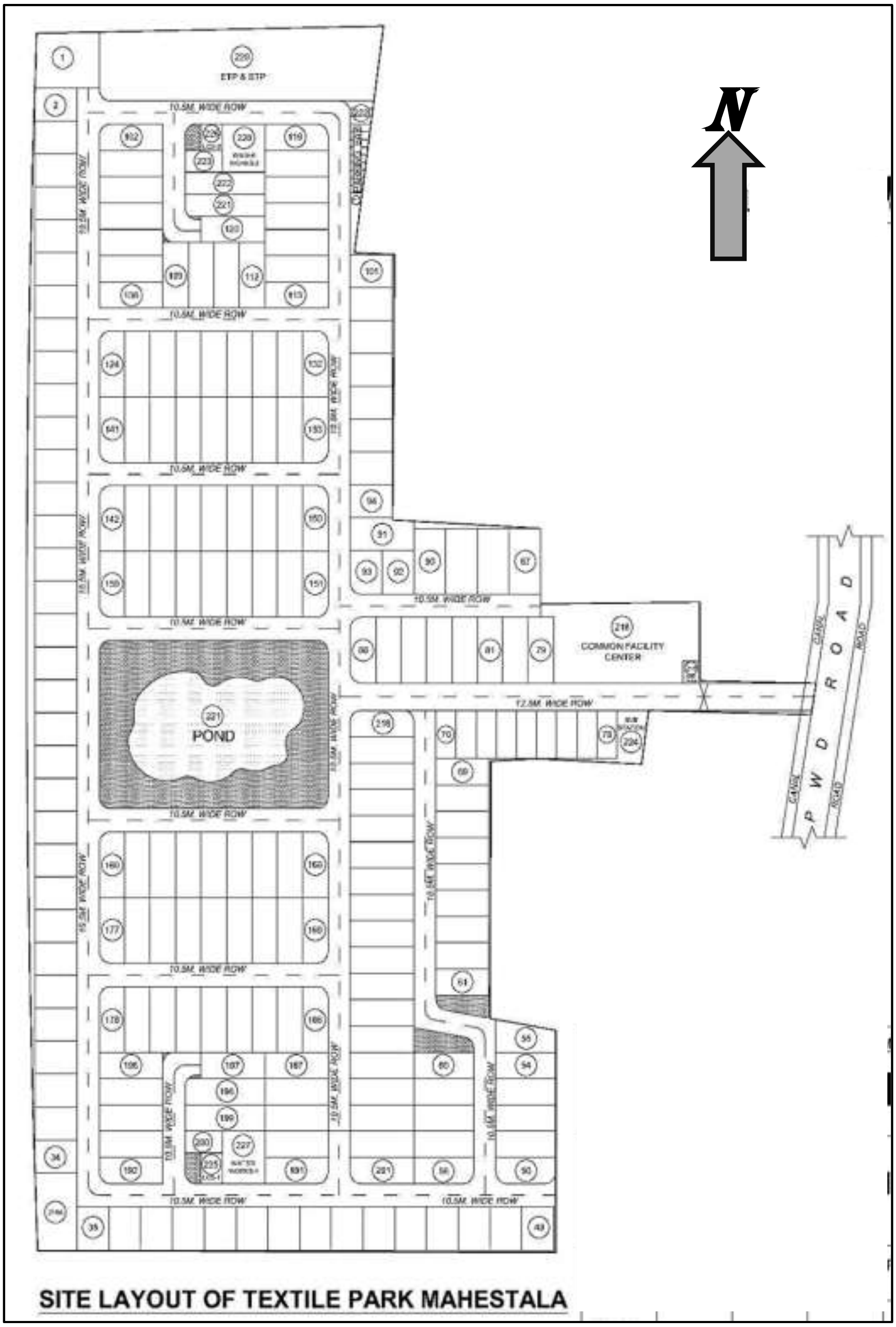

Figure 7.3. Proposed plan

the first floor. The conference hall and office of some industries have been accommodated on the second floor. Initially, the ground floor of the administrative office is to be constructed with a 1200 m^2 area to minimize the cost of the project. Afterward, two separate buildings will be constructed as per the requirement.

Commercial Complex

To minimize the procurement and storage cost, it is proposed to build a three-storied commercial complex in the common facility center in an area of 2853.5 m^2. The commercial complex will accommodate 11 shops, a medical center, a phone booth, a photocopy booth, and a raw material bank on the first floor (= 934.5 m^2), 23 shops on the first floor (=934.5 m^2), and office spaces on the second floor (= 984.5 m^2). The building will have a staircase as well as lift facilities for easy movement of public and materials.

The proposed textile park in the study area is portrayed in Figure 7.3. The details of the land usage plan, driver-pressure particular and stage, impact, and the response of the textile park have been presented in Tables 7.1, 7.2, and 7.3, respectively.

Table 7.1: Detail of land use plan of textile park

Detail Of Land Use				
Lot No.	**Use Pattern**	**Land Dimension**	**Areain Sq. M. of Each Plot**	**Total Area in Sq. M.**
1	Bleaching – Dyeing Unit		788 (11.75K)	788 (11.75K)
20 To 49		20 M. X 15 M.	300 (4.47K)	300 (4.47K)
50 To 54		28M. X 12M.	339.6 (5.06K)	339.6 (5.06K)
55			360.24 (5.36K)	360.24 (5.36K)
56 To 60		28.3 M. X 12 M.	339.6 (5.06K)	339.6 (5.06K)
61 To 69		25 M. X 12 M.	300 (4.47K)	300 (4.47K)
70 To 78		9.5 M. X 22 M.	209 (3.1K)	209 (3.1K)
79 To 86		30 M. X 12 M.	360 (5.36K)	360 (5.36K)
87 To 91		30 M. X 15 M.	450 (6.7K)	450 (6.7K)
92 To 93		20 M. X 15 M.	300 (4.47K)	300 (4.47K)
94 To 101		24.5 M. X 15 M.	367.5 (5.47K)	367.5 (5.47K)
102 To 120		30 M. X 12 M.	360 (5.36K)	360 (5.36K)
121 To 122		37.5 M. X 12 M.	450 (6.7K)	450 (6.7K)
123		17.5 M. X 10 M.	175 (2.6K)	175 (2.6K)
124 To 197		30 M. X 12 M.	360 (5.36K)	360 (5.36K)
198 To 199		37.5 M. X 12 M.	450 (6.7K)	450 (6.7K)
200		17.5 M. X 10 M.	175 (2.6K)	175 (2.6K)
201 To 218		30 M. X 12 M.	360 (5.36K)	360 (5.36K)
218 A			648.03 (9.65K)	648.03 (9.65K)
Total Area of Bleaching – Dyeing Unit			**74330.77 (1110.90K)**	**61%**
19 &79 TO 81	Common Facility Center	2902.55 (43.24k) +360 X 3	3982 (59.52K)	**3%**
220	Etp & Stp	4312 (64.24K)	4312 (64.24K)	**3.58%**

221	Central Landscape	8316 (123.9K)		8316 (123.9K)	**6.9%**
222	Parking Bay	58.79 (8.72k)		58.79 (8.72k)	**0.48%**
223	Gate Office	80 (1.9K)		80 (1.9K)	**0.06%**
224	Sub-Station	347.87 (5.18K)		347.87 (5.18K)	
225	LCS-1	100 (1.49K)		100 (1.49K)	
226	LCS-2	100 (1.49K)		100 (1.49K)	
Total Area of Electrical Works					**0.45%**
227	Water Works-1	400 (5.96K)		400 (5.96K)	
228	Water Works-2	400 (5.96K)		400 (5.96K)	
Total Area of Water Works				**800 (11.92K)**	**0.66%**
ROAD (12.5M. ROW)		220.5M. X 12.5M.	2756.25 (41.06K)	3737.4	
ROAD (10.5M. ROW)		2148.9. X 10.5M.	22563.45 (336.19K)	22563.45 (336.19K)	
Total Area of Roads				**26300.85 (391.88K)**	**23.04%**
Unorganized Green		1000(14.9K)	1000(14.9K)		**0.83%**

Table 7.2. Driver-Pressure particulars of the textile park

Driver	Mushroom growth of Textile units
	Bleaching and dyeing units
	Painting of fabrics
Pressure	Discharge of wastewater
	Drawing of groundwater
	Change of land utilization
	Soil tillage
	Contamination of surface water canals, ponds, and groundwater
	Contamination of vegetables and fruits
	Release of diesel exhaust

Table 7.3: Stage, impact, and the response of the textile park

Stage	Release of toxic chemicals and metals. Release of nutrients. Physical and chemical parameters of surface water and groundwater exceed permissible limits. Vegetables and fruits are degraded due to the presence of metals. Air polluted with PM 2.5 & PM 10.
Impact	Depletion of groundwater aquifer Health diseases due to water-borne viruses Health problems due to airborne diseases Damage to the aquatic system

Response	Wastewater treatment Recycle treated water. Eco- planning and setting up of Textile Park (4 nos) in the cluster. Introduction of bye-laws for setting up of units and other infrastructure. Maintaining regulation of boiler exhaust discharge Health checking system.

Conclusion

The textile industry is a major source of socioeconomic development in many countries, including India. The textile industry has been the second-largest industry in India, after agriculture. However, many small to medium textile manufacturing units in India have been inadequately designed, producing significant effluent discharge in the form of solid, liquid, and gas. If not disposed of appropriately, the waste materials are likely to produce enormous environmental pollution, which may adversely affect public health. Many unplanned small to medium textile manufacturing hubs are available in the state of West Bengal, India. The current study area focuses on the textile hubs existing in the Maheshtala region of the 24 Parganas (South) district. Appropriate eco-planning has been proposed in the study area to minimize such environmental pollution. The detailed activities to be undertaken in the study area have been described.

Conflict of Interest Statement

The author declares that there is no conflict of interest.

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Author Biography

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CHAPTER EIGHT

SURFACE WATER CHARACTERIZATION IN A NORTH-EASTERN INDIAN LOCALITY: A HYDROLOGICAL AND ENVIRONMENTAL STUDY

HABUNG BIDA1[1] BINI KIRON[1,*]
DINKEN PAKSOK[1] TINU LUSI[1]

Abstract

Fast construction, excavation, road cutting, and haphazard usage of chemical fertilizers and pesticides in agricultural work are polluting the aquatic environment in the Lower Subansiri District of Arunachal Pradesh. This pollution has led to a decline in water quality and aquatic life, which has further resulted in the spread of waterborne diseases such as diarrhea and typhoid in humans due to the consumption of contaminated water. Therefore, regular monitoring of water quality is required to assess its suitability for human consumption or other uses. The study presents the results of several water quality indicators from different water sources in the Lower Subansiri District of Arunachal Pradesh for both the post-monsoon (2018) and pre-monsoon (2019) seasons. The parameters tested and calculated include phosphate, nitrate, total dissolved solids, turbidity, pH, dissolved oxygen, and temperature. Based on these hydrochemical details, an attempt will be made to calculate the Water Quality Index (WQI) of the study locations. Additionally, water from various sources will be rated as excellent, good, fair, poor, or unfit for consumption based on the calculated data. According to the study, the water quality indicates a good status.

Key Words

eXact@ Micro 20; Water quality parameters; WAWQI; Water quality index; Multi-meter

Introduction

Arunachal Pradesh is considered one of India's least explored and remote states, with water preserved in its nascent stage in various parts of the state due to its vast green area and lack of pollution. However, in the Lower Subansiri District, fast construction, rapid excavation, road cutting, and haphazard use of chemical fertilizers and pesticides in agriculture are polluting the aquatic environment and leading to a decline in water quality and aquatic life. This, in turn, is causing waterborne diseases such as malaria, diarrhea, and typhoid, particularly in children, due to the use of contaminated water. Therefore, regular monitoring of water quality is essential. According to Meybeck and Helmer (1992), water quality assessment involves analyzing the biological, chemical, and physical properties of water with respect to natural quality, human consequences, and intended uses. Furthermore, Horton (1965) defines the Water Quality Index (WQI) as a metric that summarizes information about water quality in a single number based on several factors. WQI is a crucial and unique measure that summarizes the overall quality of water in a single phrase, making it easier to determine the best treatment options and address the challenges at hand (Tyagi *et al.,* 2013). Water quality indicators can be used to assess the water's condition.

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Sushmitha *et al.,* (2013) described the WQI based on the design given by the Canadian Council of Ministers of the Environment. They tested the method on the herbal Lake, located in Mysore, Karnataka, India, to see how it had influenced the livestock as well as aquatic life and to compute whether it was safe to use for amusement, irrigation, or drinking purposes. Overall, they concluded their findings that the water was not safe for use. By amalgamating the different water quality factors in a small lake, Tandel *et al.,* (2010) evaluated the WQI in a single number which indicated the quality of water. Furthermore, it was observed that the quality of water from the lake has decreased marginally for the winter season compared to the summer seasons due to an increase in the pollutant concentration resulting from the evaporation of water. Kosha and Geeta (2015) used data from three different locations along the Sabarmati River basin between 2005 and 2008 to measure the six different water quality parameters which included dissolved oxygen, total coliform, nitrate nitrogen, electrical conductivity, biochemical oxygen demand, and pH to create a water quality index (WQI). They observed that the station located in a highly urban area had the worst water quality, followed by the station located in a moderately urban area, and lastly by the station located in a moderately rural area. Furthermore, they concluded that the main causes of the worsening quality of water were probably due to the high involvement of anthropogenic activities, unwanted discharge of industrial effluent and sewage, urban runoff, unprotected river sites, and a lack of proper sanitation. Călmuc *et al.,* (2018) conducted a study comparing four alternative methods for calculating the Water Quality Index: CCME-WQI (Canadian Council of Ministers of the Environment -Water Quality Index), WAWQI (Weighted Arithmetic Water Quality Index), NFS-WQI (National Sanitation Foundation-Water Quality Index), and OWQI (Oregon Water Quality Index). They found that two of the methods were useful in determining the Danube water quality. A review of the mapping, WQI calculation, and hierarchical cluster analysis was also done by G.A. Aliyu *et al.,* (2019). They came to the conclusion that the WQI and multivariate environmental management techniques could be used to monitor river resources and that this type of research could aid in inadequate river system planning and management.

The study presents the outcomes of the water quality of different locations in the Lower Subansiri for the pre and post-monsoon seasons of 2018 and 2019, respectively. The study aims to assess water quality parameters such as fluoride, total dissolved solids, chloride, nitrate, pH, sulfate, magnesium hardness, total alkalinity, turbidity, total hardness, and calcium hardness in the study locations. Note that the above parameters are necessary for the Horton method or Weighted Arithmetic WQI method to determine WQI (Horton 1965).

According to Tyagi *et al.,* (2013), the WAWQI approach utilized has the following benefits:

(i) This method assigns a number to the overall health of a water body by incorporating data from various quality water parameters into a mathematical equation.

(ii) For a particular use, fewer parameters are needed than for all water quality parameters.

(iii) Useful for disseminating data on the overall quality of water to the concerned citizens and policymakers.

(iv) It reflects the combined impact of various parameters, making it significant for managing and accessing water quality.

Methodology

The sampling locations are given in Table 8.1 and Figure 8.1 below. For both the post-monsoon and pre-monsoon seasons, samples of water from different locations were taken following the required procedures. Only forty sample locations were selected for the study during the post and pre-monsoon seasons due to the unavailability of road connectivity in inaccessible areas and dense forest regions. Most of the testing was conducted in nearby populated areas. Samples of water were collected from different sources, such as wells, springs, ponds, and two major rivers in the district, namely the Subansiri River and the Kamle River. Sampling names have been presented as State/District/Source/number, such as AP/LS/SW/00X. Spring Water (SW), Well Water (WW), River Water (RW), and Pond Water (PW) are examples of water sample sources, where AP stands for Arunachal Pradesh, LS represents Lower Subansiri district, and 00X represents the source number. The data for the study included parameters such as calcium hardness, turbidity, pH, total dissolved solids, magnesium hardness, total hardness, nitrate, chloride, total alkalinity, sulphate, and fluoride. The data were recorded using various instruments such as a multi-meter, photometer, salt-meter, turbidity-meter, etc. The water samples were preserved and later tested in the laboratory.

eXact@Micro 20 meter

eXact@Micro 20 meter is a high-performance photometer of dual-wavelength. This instrument is used for testing water from various environmental locations such as wells, rivers, pools, spas, ponds, etc. The instrument measures parameters like fluoride, sulfate, hardness, alkalinity, chloride, nitrate, and phosphate. The parameters are presented automatically on its screen after the reading.

Multi-meter and Turbidity Meter

The multimeter is a device used for the measurement of the following parameters as Total Dissolved Solids, Dissolved Oxygen, Temperature, Conductivity, Oxidation-Reduction Potential, and pH (Manual book of multi-meter). A turbidity Meter is a device for measuring the turbidity of water (Manual book of Turbidity meter).

Water Quality Index (WQI)

It is an index that provides information regarding the quality of water in a unique number. Based on the data, the water from various locations will be rated as excellent, good, fair, poor, or unsuitable for consumption (Horton 1965; Kosha and Geeta 2015; Călmuc *et al.,* 2018; Aliyu *et al.,* 2019). Forty water samples were collected for both seasons to compute the WQI. An Excel sheet was used for the computation of WQI. The parameters used in the study include Total alkalinity, pH, Total Dissolved Solids, Calcium hardness, Fluoride, Magnesium hardness, Chloride, Nitrate, Sulphate, Total hardness, and Turbidity. Due to unforeseen conditions, biological parameters were neglected. Additionally, Table 1 was used to assist in determining the status of the samples.

Calculation of WQI

Using Horton's method also known as the Weighted Arithmetic WQI method, WQI was evaluated in this study (Horton 1965; Kosha and Geeta 2015; Călmuc *et al.,* 2018; Aliyu *et al.,* 2019). The parameters for WQI were secured for both the post-monsoon season (2018) and pre-monsoon season (2019), utilizing different instruments, which included Total alkalinity, pH, Total Dissolve Solids, Calcium hardness, Fluoride, Magnesium hardness, Chloride, Nitrate, Sulphate, Total hardness, and Turbidity.

using Equation (1) WQI was calculated (Horton's method)

$$WQI = \frac{\sum qn\, W_n}{\sum W_n} \tag{1}$$

Where, q_n is the quality rating of the nth water quality parameter and W_n is the unit weight of the n^{th} water quality parameter.

Table 8.1 Sampling locations

Serial number.	Location	Serial number	Location	Serial number	Location	Serial number	Location
1	Hapoli	11	Ring road 1	21	Yazali 1	31	Tajgi
2	Paraline	12	Ring road 2	22	Yazali 2	32	Tamen 1
3	Siibey	13	Tajang Kiile	23	Yazali 3	33	Tamen 2
4	Hong-Bridge	14	Sia-Piro	24	Poosa 1	34	Jara
5	Dilo-polyang	15	Aarambo	25	Poosa 2	35	Lower Tallo
6	St. Aug. School	16	Panjin	26	Ranganadi Dam	36	Upper Tallo
7	Siiro	17	Joram-top	27	Potin town	37	Ponla
8	Pange	18	Joram town	28	Dam Road	38	Pistana
9	Bakhang Anii	19	Yachuli 1	29	Raga 1	39	Lumri
10	Siitii Ading	20	Yachuli 2	30	Raga 2	40	Shally

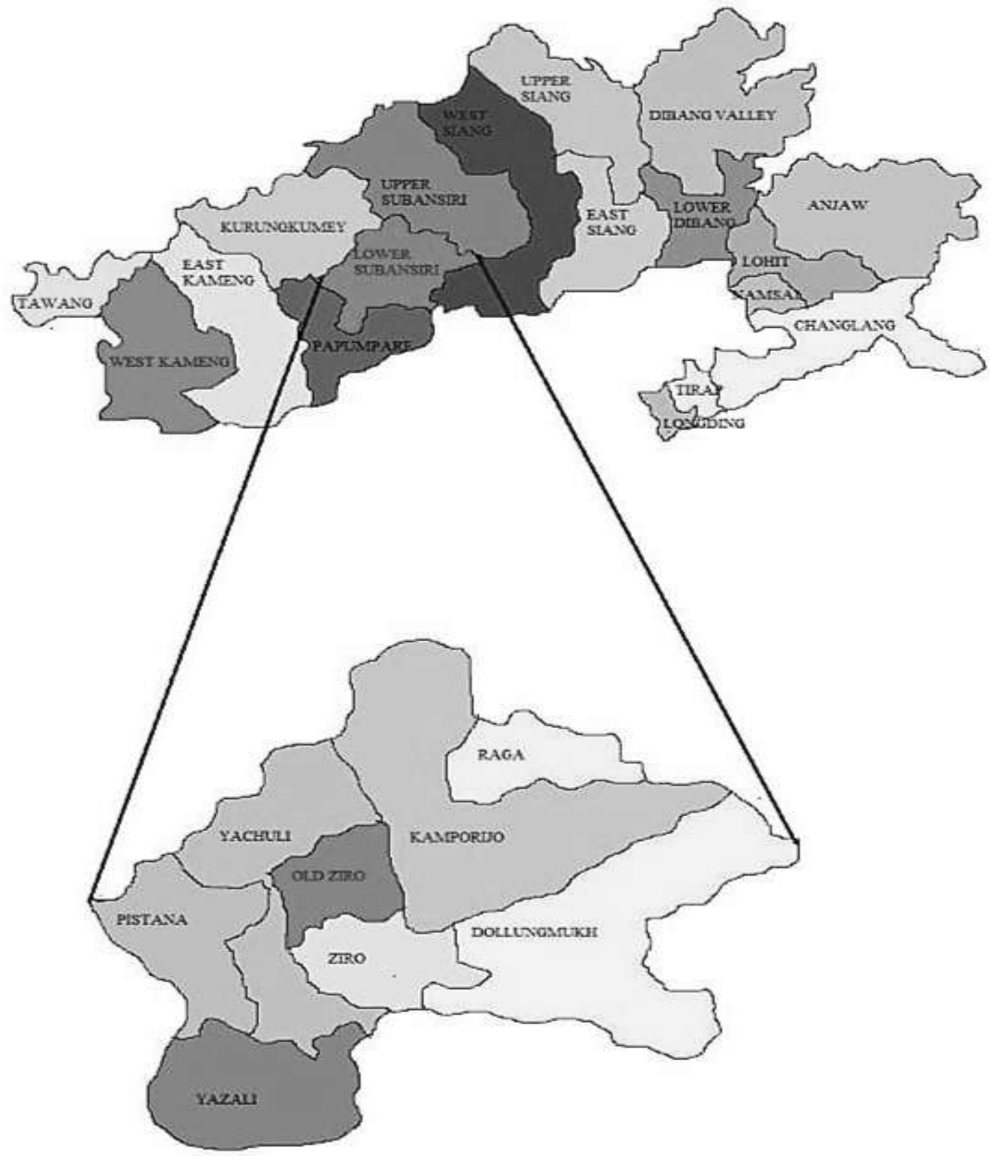


Figure 8.1. Water sample source map.

Quality rating (q_n)

Using Equation (2) the value of q_n is calculated.

$$q_n = \frac{(V_n - V_{id})}{(S_n - V_{id})} \times 100 \quad (2)$$

Where, V_n and V_{id} are the estimated value of the nth water quality parameter at a given sample location and the Ideal value for an nth parameter in pure water. (Note that V_{id} for pH is 7 and 0 for all other parameters)

S_n is the standard permissible value of the n^{th} water quality parameter.

Unit Weight parameter

Calculation of W_n value.

$$W_n = \frac{k}{S_n} \quad (3)$$

$$k = \frac{1}{\sum \frac{1}{S_n}} \quad (4)$$

Where, S_n is the standard permissible value of the n^{th} water quality parameter and k is the constant of proportionality and using Equation (4) it is calculated.

Status of the Water Quality

As per Horton's method, various ranges of WQI, the status of the quality of water at each range, and potential uses are outlined as shown below in the Table 8.2.

Table 8.2. Value of WQI and its quality status. (Source: Horton's Method or Weighted Arithmetic method of WQI (Horton 1965; Kosha and Geeta 2015)

WQI value	Quality Status	Usages
Above 150	Unfit for use	Proper treatment required
101-150	Very poor	Restricted use for irrigation
76-100	Poor	Irrigation
51-75	Fair	Industrial and irrigation
26-50	Good	Industrial, irrigation, and domestic
25-0	Excellent	Industrial, irrigation, and drinking

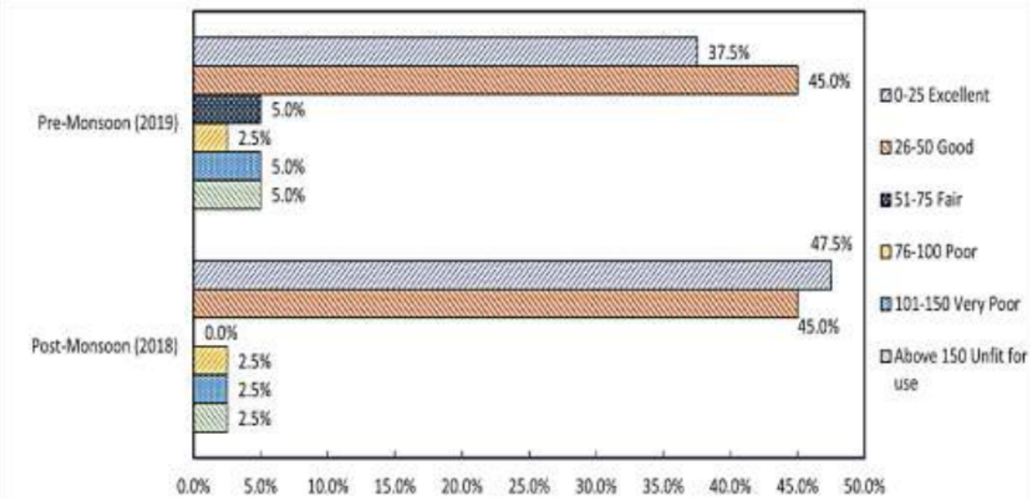
Results and Discussion

Based on Horton's method or the Weighted Arithmetic WQI (WAWQI), Table 8.3 represents the WQI ranges and water quality status.

Table 8.3. WQI for the Post Monsoon (2018) and the Pre-Monsoon (2019)

S. Number	Post monsoon (2018)	Pre-monsoon (2019)	S. Number	Post monsoon (2018)	Pre-monsoon (2019)
AP/LS/WW/01	23.70	22.49	AP/LS/RW/21	31.68	36.78
AP/LS/WW/02	46.85	60.55	AP/LS/SW/22	27.16	25.19
AP/LS/PW/03	28.14	120.83	AP/LS/RW/23	24.59	28.44
AP/LS/RW/04	22.80	26.94	AP/LS/RW/24	34.57	20.61
AP/LS/SW/05	25.95	30.37	AP/LS/RW/25	21.89	19.43
AP/LS/RW/06	17.77	26.54	AP/LS/RW/26	24.07	18.63
AP/LS/RW/07	46.74	75.31	AP/LS/SW/27	31.51	26.10
AP/LS/RW/08	13.75	26.31	AP/LS/SW/28	38.46	47.89
AP/LS/SW/09	14.17	21.48	AP/LS/SW/29	18.91	16.22
AP/LS/SW/10	46.51	14.45	AP/LS/PW/30	36.76	32.28
AP/LS/SW/11	40.55	34.54	AP/LS/SW/31	21.21	29.76
AP/LS/SW/12	9.92	16.54	AP/LS/SW/32	33.86	53.17
AP/LS/RW/13	75.83	113.60	AP/LS/SW/33	32.42	32.53
AP/LS/RW/14	14.18	13.56	AP/LS/SW/34	28.16	11.49
AP/LS/SW/15	37.87	25.61	AP/LS/RW/35	263.716	343.88
AP/LS/SW/16	40.55	33.07	AP/LS/SW/36	16.05	22.04
AP/LS/SW/17	16.13	15.73	AP/LS/SW/37	12.54	11.91
AP/LS/RW/18	17.67	27.54	AP/LS/SW/38	20.36	17.66
AP/LS/RW/19	18.87	18.57	AP/LS/RW/39	127.09	165.925
AP/LS/RW/20	17.37	32.48	AP/LS/PW/40	35.94	44.66

It is observed that the maximum number of samples falls under a rating 'Good', out of the total forty samples. The range of WQI for the Post (2018) and Pre-monsoon (2019) is shown in Figure 8.2. The mean value of the WQI for the Post-monsoon (2018) is obtained as 36.39%, which represents that the quality status of water is good (from table 2) and the mean value for WQI of the Pre-monsoon (2019) is obtained as 44.02%, which represents that the quality status of water as good (from Table 8.2)



	Post-Monsoon (2018)	Pre-Monsoon (2019)
0-25 Excellent	47.5%	37.5%
26-50 Good	45.0%	45.0%
51-75 Fair	0.0%	5.0%
76-100 Poor	2.5%	2.5%
101-150 Very Poor	2.5%	5.0%
Above 150 Unfit for use	2.5%	5.0%

Figure 8.2. Water sample percentage as per the quality status of water for the Pre-monsoon (2018) and the Post monsoon (2019)

Conclusions

As per the Weighted Arithmetic Water Quality Index (WAWQI) method, the quality of Spring Water (SW) is superior to that of Well Water (WW) and then followed by River Water (RW). Furthermore, samples collected from Lower Tallo village (AP/LS/RW/35) and Lumri village (AP/LS/RW/39) show a very high value of WQI which is 263.716, 343.88 in Lower Tallo village and 127.09, 165.925 in Lumri village for post and pre-monsoon seasons respectively, limiting their use for any purposes until and unless required treatment is done. This may be due to heavy rainfall in the area leading to high turbidity. Furthermore, it is observed that the majority of water sources in Lower Subansiri are in good condition because most of the Physico-chemical parameters of water are in the Bureau of Indian Standards (BIS) range of acceptable. For the post-monsoon period of 2018, 47.5% of water sample sources are fit for drinking, while 37.5% of water sample sources are fit for drinking for the pre-monsoon period (2019). Further, the majority of the sources of sample water tested could be utilized for irrigation and industrial purposes without treatment, as per Table 2. Unforeseeable rainfall in Arunachal Pradesh is the primary cause of WQI variation.

Furthermore, as per the Weighted Arithmetic method, it was observed that the average values of WQI for the post-monsoon season are lower than the WQI for the pre-monsoon season. Therefore, it could be concluded from the study that water from different sources during the post-monsoon season of 2018 is superior to the water from various sources during the pre-monsoon period of 2019. Around 80-90% of water sample sources are given the status of good quality.

Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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CHAPTER NINE

A REVIEW ON SALINE WATER INTRUSION RELEVANT TO THE COASTAL ENVIRONMENT

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Abstract

Coastal regions rely on local fresh groundwater supplies for household, irrigation, and industrial applications, which are subject to saltwater intrusion. Excessive fresh groundwater pumping causes the saltwater-freshwater interface to move inward owing to hydraulic equilibrium and continuity. This causes saline water intrusion (SWI) into coastal aquifers, which is a major geohydraulic challenge in the coastal environment. The geotechnical attributes of materials are altered by saline water, influencing coastal water resource planning and management. SWI is responsible for the deterioration of freshwater quality in aquifers. Storm surge, sea level rise owing to climate change, and the effect of human activities are the key factors influencing saline water incursion. High-intensity coastal hazards caused by climate change continue to render aquifers increasingly susceptible, negatively impacting coastal groundwater management. Understanding the phenomena is critical for incorporating proper coastal groundwater control and management approaches that are both effective and easily implementable. The current study assembles a comprehensive theoretical analysis of previous research, laboratory tests, and a case study. Brief research on risk assessment related to SWI in coastal regions was undertaken in addition to the theoretical analysis. The theoretical analysis identifies the key causes of SWI as well as mitigating strategies. The laboratory experiment demonstrated that the length of submergence and saline concentration had a substantial effect on the specific gravity, dry density, and permeability of fine sand. The specific gravity of sand particles increased almost linearly with submergence time and saline content. While sand dry density fell fairly linearly with submergence time, it was not appreciably impacted by saline concentration. Sand permeability increased nonlinearly with both submergence time and saline concentration. The case study was carried out in the coastal zone of West Bengal's Purba Medinipur district. A technology for withdrawing coastal freshwater via qanat-well constructions and artificial recharging by rainfall collecting helped by percolation ponds and recharge wells has been developed on the Contai Polytechnic campus in West Bengal.

Keywords

Coastal Aquifers, Flow Characteristics, Risk Assessment, Saline Water Intrusion

Introduction

The flow and management of coastal groundwater involve both the flow of seawater into the fresh aquifer zone and the discharge of fresh groundwater from the coastal aquifer back into the ocean. The former is known as saline water or saltwater intrusion (SWI), whereas the latter is known as submarine groundwater discharge (SGD). Many variables have been identified as causes of SWI, including notably higher groundwater loss from coastal aquifers that exceeds the rate of recharge. Second, SWI has been linked to the density differential between the denser saline water in the sea and the less dense fresh water in the aquifer. Throughout the study, it was discovered that researchers used a variety of approaches to SWI and SGD analysis and control, including

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theoretical modeling (numerical or analytical), laboratory-based studies, and field investigations. A few researchers also made valuable design suggestions. In this study, a quick summary of previous state-of-the-art contributions is discussed. The complicated hydrogeological system in coastal regions necessitates scientific groundwater management in coastal zones. Even in unconfined aquifers, a continual decrease of groundwater below sea level raises the possibility of saltwater incursion. Although several methods for controlling SWI are available, unregulated groundwater extraction and development are the two key causes that enhance saltwater incursion via the reverse freshwater gradient.

A coastal aquifer is an important supply of drinkable water that supports urban and agricultural growth in coastal regions. Because the end borders of coastal aquifers are in touch with the sea, saltwater rushes within, and denser saltwater with higher water pressure develops beneath the lighter freshwater. According to Allen and Klassen (2017), SWI is the primary cause of aquifer water-quality degradation because it elevates salinity over the permissible potability limit. SWI is mostly caused by natural and manmade disasters, which have varying degrees of influence on the vulnerability of SWI. Storm surge refers to the phenomenon of rising sea levels caused by low-pressure weather systems, such as coastal floods and tsunamis (Deng *et al.,* 2016). Such sea-level rise is anticipated to drive saltwater closer to the coast, resulting in SWI. Similarly, excessive pumping of coastal freshwater above the allowed limit causes the interface to extend inland, introducing SWI (Goswami *et al.,* 2020).

Extensive research has been published over the last few decades to better understand the complexities of SWI and to identify potential mitigation measures. SWI concerns have been examined by researchers across the world. However, a thorough review of the literature, including current progress in theoretical and experimental works, case studies, risk analysis, and management, is required to provide researchers and scientists with enough information. The purpose of this study is to systematically evaluate the recent developments in SWI in terms of theoretical investigations, experimental works, and design recommendations.

Methodology

The current study is divided into four categories, namely (a) Theoretical investigations, (b) Risk assessment, (c) Experimental works, and (d) Design recommendations. The theoretical investigation includes a critical review after extensively reviewing 25 research papers relevant to SWI, and for the risk assessment, 17 research papers have been reviewed. The experimental work includes a laboratory test conducted on soil samples submerged under saline water of different concentrations for different periods. The design recommendations include discussions on recent developments of techniques to mitigate SWI.

Theoretical Investigations

Verrjuit (1968) used the Ghyben–Herzberg relation to undertake physical modeling. Strack (1976) created an analytical model to address 3D interfacial problems. The developed model may be used to solve multi-zone aquifer concerns. Atkinson *et al.,* (1986), Basack *et al.,* (2010), Basack *et al.,* (2020), Soni and Pujara (2012), and Goswami *et al.,* (2020) conducted historical reviews to highlight SWI management difficulties. Singh and Stammers (1989) created an analytical model based on a finite element approach to address the issue of freshwater recharge from unconfined aquifers. Bobba (1992) assessed the applicability of various mathematical models and concluded that more study on aquifer features with different flow conditions is needed for improved coastal groundwater management. Sherif and Hamza (2001) employed finite element modeling to determine the precise position of pumping and the extent of the dispersion zone. Mantoglou *et al.,* (2004) created a theoretical framework for optimizing pumping rates. To alleviate the SWI, Abd-Elhamid and Javadi (2008) performed a historical study of mathematical models and created the Abstraction Desalinization Recharge (ADR) technique. Hubert and Morel (2009) created a 2D model using a numerical model integrated with MODFLOW and verified it using the Finite Difference technique. SWI caused by overexploitation, according to Post and Abarca (2009), has become a key study area in coastal hydrogeology. Haitjema *et al.,* (2010) investigated the use of horizontal wells in shallow aquifers and discovered that the Dupuit-Forchheimer model may be used to solve design challenges in groundwater withdrawal systems. Loaiciga *et al.,* (2010) used FEFLOW software to create a 3D-FEM model. Loaiciga *et al.,* (2012) created a technique to assess the consequences of fresh groundwater extraction on sea level rise. Mahesha (2011) summarized the important SWI research findings between 1960 and 2000. Kallioras *et al.,* (2013) reviewed numerous techniques for dealing with the saltwater incursion. Basack *et al.,* (2014) conducted analytical modeling and created a qanat well construction to manage seaward groundwater and control saltwater intrusion. Cai *et al.,* (2014) used a solute transport model to do numerical modeling. Klassen *et al.,* (2014) used statistical data analysis to find possible variables associated with SWI. Mahmoodzadeh and Karamouz (2017) devised a numerical technique for density-dependent flow. Roy (2017) did a thorough literature analysis and identified the primary parameters impacting the process of saline water incursions in coastal zones. White and Kaplan (2017) did a literature study and outlined two SWI drivers as well as the effects of saline water intrusion in the coastal zone. Maity *et al.,* (2018) suggested remedial measures for the restoration of the aquifer. Perera *et al.,* (2018) used a GIS-based model to identify the loss of agricultural resources in the coastal zone. Roy (2018) created a computationally simple and practical optimization technique for the coastal aquifer system. Zamrsky *et al.,* (2018) constructed a computer model to calculate aquifer thickness in unconsolidated sedimentary environments.

Risk Assessment

Canales *et al.,* (2001) identified risk-weighting elements using the Time Domain Electromagnetic Method. By analyzing groundwater monitoring records and system responses, Phreatos Limited (2001) determined the critical foreshore risk level of aquifer conditions. Lecca and Cau (2002) developed a stochastic simulation model for assessing risk in coastal aquifers. SWI risk charts were created by Ball and Campbell (2006) utilizing GIS-based techniques. Taclan (2011) conducted chemical analyses on groundwater samples from shallow tube wells and discovered that the Cl-2 level in groundwater exceeds the suggested limits. Altalmas (2012) evaluated risk and SWI reduction using FEM-MODFLOW modeling. Mazi (2014) created an analytical model for SWI to analyze the danger posed by groundwater exploitation. Simpson *et al.,* (2014) incorporated a risk assessment methodology based on SWI to analyze hazardous risks to coastal aquifers. Zaccaria *et al.,* (2015) used multi-year observations, data analysis, and modeling to determine long-term consequences on water resource management. Arumugam and Saraswathi (2016) used random samples to test the appropriateness of drinking water in coastal zones according to WHO standards. They discovered that the samples were unsuitable, indicating SWI. Holding and Allen (2016) created geospatial maps to rank the problematic water security zones. Klassen and Allen (2016) used a risk assessment framework to characterize hydrological systems and climate change to develop maps for monitoring coastal water management. Izaguirre *et al.,* (2017) investigated coastal danger and floods. Klassen *et al.,* (2017) created risk assessment tools for coastal hazard mapping. Eriksson *et al.,* (2018) prepared risk maps using GIS techniques. Morgan (2018) assessed risk in the study region using the Hutt Aquifer Model-MODFLOW and SEAWAT. Wen *et al.,* (2018) utilized a Bayesian mixing model to determine the source of pollution in the research region. Shammi *et al.,* (2019) used the DESIR method of impact response to evaluate the influence of salt in drinking water on human health. Basack *et al.,* (2021) and Basack *et al.,* (2022) conducted a historical review of qualitative and quantitative risks involved in SWI.

Laboratory Experiments

This section discusses many laboratory experiments used to simulate SWI. The experiments are carried out to assess the change in properties of locally available sand as well as the characteristics of locally available sand immersed for various periods and concentrations of salty water. The material is sieved using a 425-micron sieve and a 75-micron sieve after it is collected. All trials use sand that has gone through a 425-micron sieve but remains in a 75-micron sieve. The saline water solution is made with sodium chloride (NaCl) and distilled water. The standard saline water solution is made by dissolving salt in 200 ml of distilled water and stirring until completely dissolved, and then making the volume up to 3.14 L with distilled water. After acquiring the standard concentration, the amount of salt is multiplied by 2, 4, 6, and 8 to obtain the concentrations 2S, 4S, 6S, and 8S, respectively. Following sample preparation, the sand is submerged in a jar with varying concentrations of saline water (2S, 4S, 6S, 8S) for 1 day, 3 days, 7 days, 14 days, 21 days, and 28 days. The sand is removed from the jar after the specified submergence duration and oven-dried for 24 hours at 110°C. The laboratory studies are carried out when the sand sample has completely dried. This complete process is done six times to obtain results for various submergence periods.

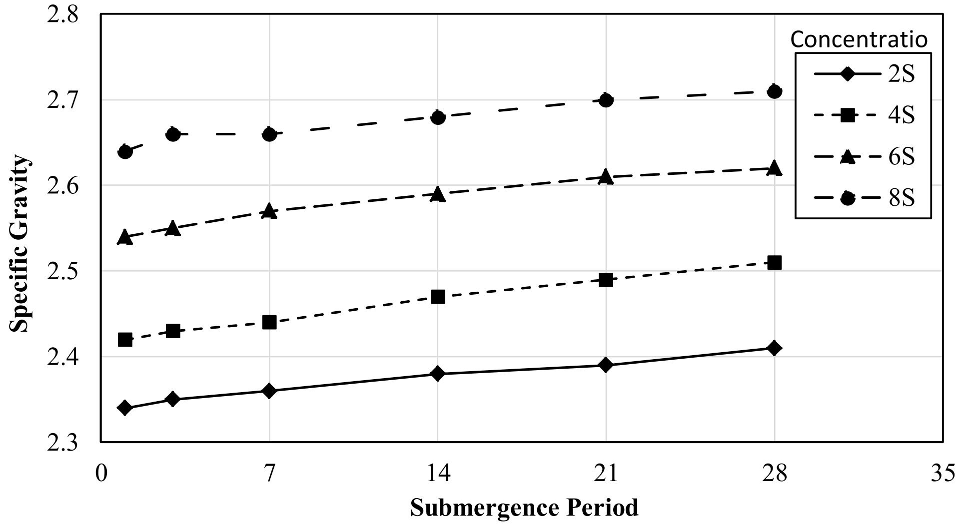

Figure 9.1. Graphical representation of specific gravity values of different concentrations and submergence period

Specific Gravity

Specific gravity (G) is defined as the ratio of the mass of a unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature. The knowledge of specific gravity is needed in the calculation of soil properties like void ratio, degree of saturation, etc. The Specific Gravity Test is conducted as per IS: 2720 (part 3) – 1980. From Figure 9.1, it is observed that the specific gravity (G) of the submerged sample increases with an increase in salt concentration and submergence period. The maximum specific gravity of the sample is 2.71, and the minimum specific gravity of this sample is 2.34, which occurred when the sample was kept in submergence for 28 days in 8S concentration and 1 day in 2S concentration, respectively.

Relative Density Test

Relative density is an important property of soil aggregates. The aim of the experiment is to determine the relative density of cohesionless soil. The relative density is defined as the ratio of the difference between the void ratio in the loosest state and the void ratio in its natural state to the difference between its void ratios in the loosest and densest states. This test is performed as per IS: 2720 (part 14) – 1983. Figure 9.2 shows a linearly increasing trend in relative density. It is evident that as the concentration of saline water and submergence period increase, the relative density increases, making the sample denser in nature. The relative density of the sample before submergence in saline water is 51.4%, which is classified as a medium-dense sample as per IS: 2720 (part 14) – 1983. However, when the sand sample is submerged in different saline water solutions for different durations, the values of relative density increase significantly. This is due to the presence of salt particles in the sample. The higher the concentration and submergence period, the more the presence of salt in the sand sample, thus increasing the overall density of the sample.

Falling Head Permeability Test

The hydraulic conductivity of a sample submerged in varying concentrations of saltwater and for varying submergence periods decreases as the sample's submergence duration and salt content in distilled water increase. However, a polynomial trend is observed for each concentration. The hydraulic conductivity increases linearly with concentration until the salt dissolves in the sample, which takes 1 to 14 days. After the initial dissolving time, the sample's hydraulic conductivity decreases dramatically (Basack *et al.,* 2021).

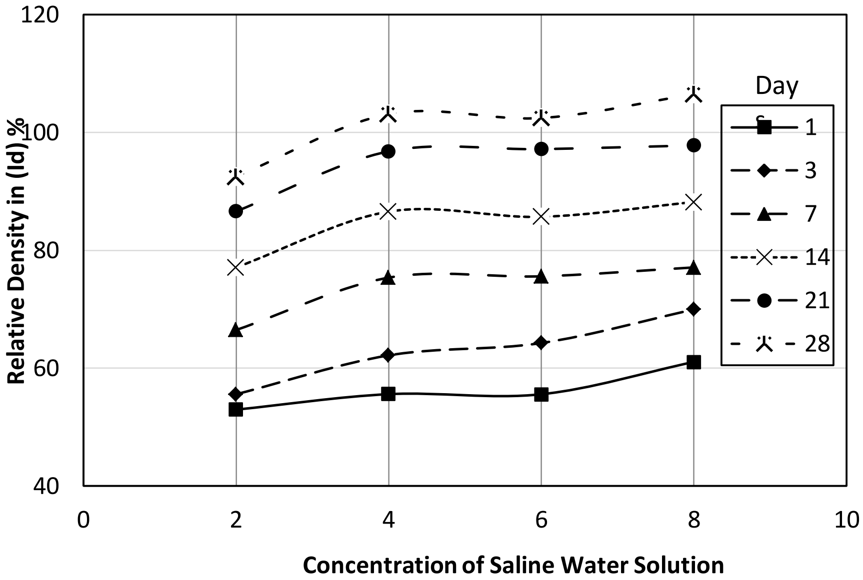

Figure 9.2. Relative density in percentage for different saline water concentrations and submergence days

Design Recommendations

This section deals with the techniques developed for the prevention and mitigation of SWI. The first method is ADR developed by Abd-Elhamid and Javadi (2008). In this technique, simple saline water is extracted and desalinated with a reverse osmosis process and then the treated water is recharged to the freshwater aquifer as shown in Figure 9.3.

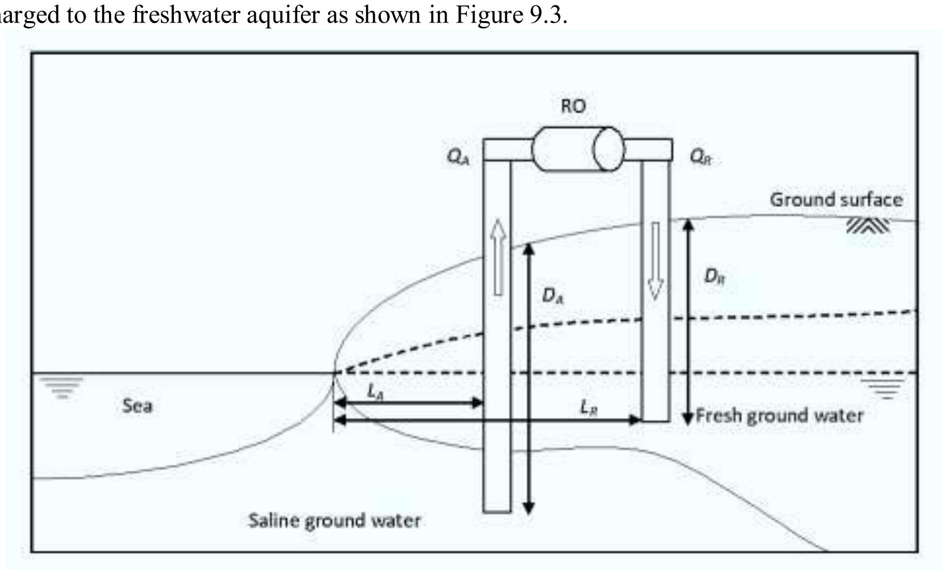

Figure 9.3. Diagram of ADR methodology (Modified from Abd-Elhamid and Javadi 2008)

The key advantages of the Abstraction, Desalination, and Recharge (ADR) approach are that it is cost-effective, has a low environmental impact, and has the potential to be utilized for the sustainable development of water resources in coastal areas. It is regarded as a cost-effective and environmentally friendly solution because desalinating brackish water using RO treatment involves less energy consumption, lower costs, and lower pollution and carbon emissions when compared to traditional methods of seawater desalination and wastewater treatment. It also supplies fresh water for recharging through the use of processed brackish water. The ADR can avoid saltwater intrusion because it increases the volume of fresh groundwater while decreasing the volume of saltwater while considering economic factors, environmental effects, and the long-term development of water resources.

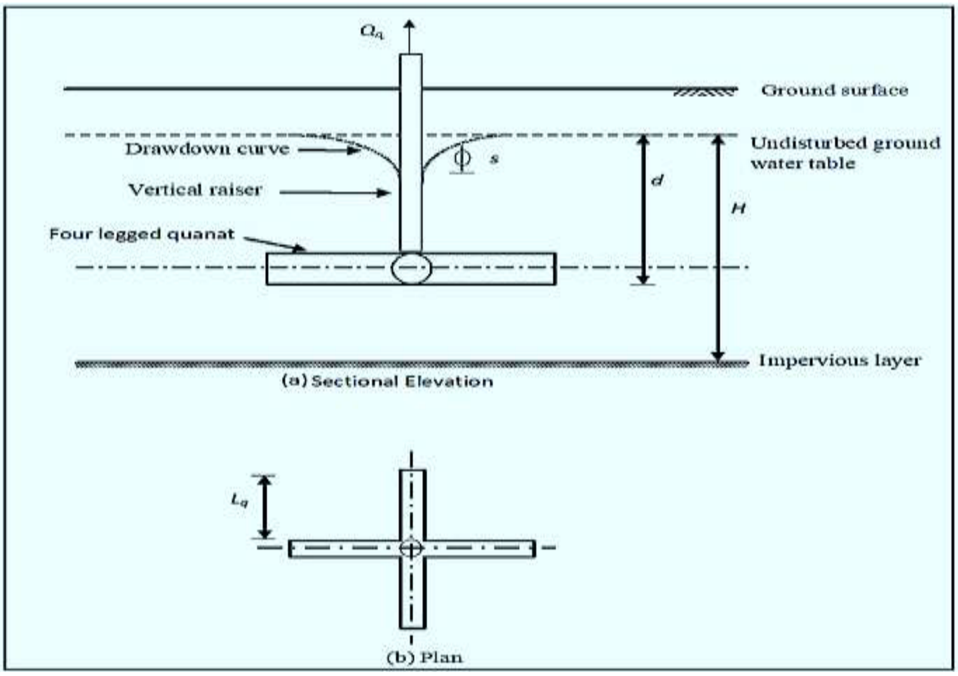

Figure 9.4. Four-legged Qanat well (modified from Basack *et al.,* 2014)

Basack *et al.,* (2012) proposed a model that uses qanat well structures to extract fresh groundwater from coastal areas. If the in situ parameters are appropriately assessed and applied, the model designed for coastal groundwater management can be easily implemented at any given site. A qanat-well structure is a combination of horizontal wells joined at their ends by a vertical riser (Figure 9.4) built in dry areas for groundwater extraction (Maity, 2011). Deep tube wells are not recommended due to saltwater intrusion and coning issues. However, the use of a shallow well is also not advisable due to the significantly reduced discharge.

Conclusion

Saline water intrusion is a critical factor that affects the quality of water in coastal aquifers, necessitating substantial research to monitor, predict, and prevent SWI. A critical examination and evaluation of the existing literature, as indicated above, reveal the following:

(i) More research is required to anticipate, prevent, and mitigate saline water incursion caused by rising sea levels. Continual groundwater removal from aquifers causes seawater to flow inland. Sea level rise is expected to move the interface inland, posing one of the most serious problems in coastal areas. Man-made topographical alterations will diminish the freshwater quality of the aquifer. Proper assessment of pumping and wastewater injection hydraulic properties can help forecast the consequences of human activities on water bodies.

(ii) The study of saltwater intrusion in freshwater reveals the potential risks to human and agricultural productivity. Rising sea levels have allowed seawater to flow into subterranean aquifers via hydraulic gradients or waves. A method that can help overcome the risk of salty water intrusion in freshwater is in high demand worldwide. SWI management mainly relies on a risk assessment that reveals vulnerabilities, economic losses, and the cost of implementing SWI measures.

(iii) The specific gravity (G) of the sample increases linearly with increasing salt content and submergence duration in saltwater solution in laboratory studies. The relative density shows that the soil sample becomes very dense from medium dense. The hydraulic conductivity initially increases until it reaches a critical threshold, which occurs during the 14-day submergence period, and then begins to fall dramatically, establishing a polynomial trend. Overall, salt particles significantly affect the engineering properties of soil, which in turn increases saline water incursion.

(iv) To mitigate SWI and safely withdraw fresh water, two novel methodologies (A.D.R. & Qanat well) have been found to be efficient and effective. A.D.R is the Abstraction, Desalination, and Recharge method efficient in areas where the extraction rate is high, and Qanat well, an innovative system comprises qanat-well structures withdrawing water with adequate compensation from rainfall collection via recharge ponds and recharge wells.

Conflict of Interest Statement

The author declares that there is no conflict of interest.

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CHAPTER TEN

EFFICACY OF EMBANKMENT AS A VIABLE FLOOD CONTROL STRUCTURE AND CAUSE OF FLOODING IN ASSAM, INDIA

JOYDEEP DUTTA[1]

Abstract

Naturally, a large portion of Assam is prone to significant and severe flooding, mostly from the Brahmaputra and Barak rivers. Embankments are only partially successful for several reasons, including the fact that they can only control floods of a specific size and there are usually openings where tributary streams reach the embanked river. Moreover, they are vulnerable to failure due to river erosion or geotechnical instability. The aim of this research is to examine the effectiveness of embankments as flood control structures and the factors that contribute to flooding in Assam, India, specifically concerning the Brahmaputra, Barak, and their tributaries.

Key Words

Barak, Brahmaputra, Embankment, Flood

Introduction

India's northeastern region is abundant in water resources, with one-third of India's runoff originating from the region and flowing through the Brahmaputra and Barak Rivers. Significant untapped groundwater resources are also present. However, the region's vast water resources also cause significant suffering and expenses due to regular flooding that must be controlled to boost economic growth. The Brahmaputra River basin, along with the Barak River basin, is among the most flood-prone on the continent. On average, floods damage 0.80 million hectares of land each year, but in certain years, they affect more than 4 million hectares of Assam's total land area of 7.54 million hectares. The situation is further aggravated by riverbank erosion, which results in the loss of around 8000 hectares of riparian land along the Brahmaputra each year. Within a few years of the formulation of the 1954 strategy, and before implementation had progressed very far, it became clear that further work was required in the areas of watershed management programs and flood warning systems. Furthermore, the suitability of embankments as a flood protection strategy was questioned due to perceived issues such as flow confinement, which raised flood levels and reduced natural damage, along with waterlogging.

In 1978, a new flood management working group echoed previous arguments while also recommending that flood-affected governments develop master plans for each river basin. This committee also found that while embankments provided some protection at a reasonable cost, the consequences of embankments on river regimes were not well known. As the construction of flood management infrastructure developed, it became clear that erosion control was closely intertwined with flood management, because embankments designed to limit overbank spills were being

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destroyed by river erosion. Concurrently, drainage improvements were necessary to address issues caused by embankment development. Significant infrastructure investment in the Brahmaputra and Barak basins has incorporated measures to reduce pollution.

While there are variations in hydrological parameters between the lower Brahmaputra and Barak, there is no scientific proof that the frequency of significant floods has risen over the previous 120 years overall (Hofer and Messerli 1997). Evidence suggests that overbank stages have risen; however, it is unclear if this is due to the sediment surge that moved down the Brahmaputra/Barak after the 1950 earthquake, the confining effect of the embankments, or some other factor. Embankments mainly work to confine regular floods while failing to prevent abnormal floods. As a result, they limit the favorable benefits of shallow floods on agriculture (Hughes, Adam, and Dala-Cleyton, 1994). The average annual flow levels in the Dihang and Subansiri rivers are around 180,000 and 55,000 million cubic meters, respectively. Thus, the planned dams on these rivers have a live storage capacity of around 20% of the mean annual inflows. The Dihang live storage would be around 30% of an average four-month monsoon flow volume from June to September. The Dihang River's yearly suspended sediment load is approximately 130 million metric tonnes or 80 million cubic meters. When compared to storage amounts, reservoir sedimentation does not appear to be a major issue unless another earthquake results in significantly higher sediment fluxes.

After the massive earthquakes in 1934 and 1950, when the entire river system in the Northeast suffered a massive jolt, the Brahmaputra and Barak River basins underwent a major character change and started experiencing major erosion and inundation problems in the entire basin, including problems with the stability of the bank line on both banks of almost all the rivers and tributaries. Due to geomorphological changes in the riverbeds coupled with human encroachment of the catchment areas, the river started carrying comparatively higher silt-loads from the hills to the plains, depositing them on the bed and resulting in the rise of the bed by decreasing flow depth. Due to the decrease in depth, the river tends to expand its width on both banks in the form of bank erosion and spelling of the bank as per contours of the ground to maintain its waterway for accommodating its inherent discharge. This phenomenon of erosion of the bank is continuing in the entire Assam in all the rivers.

Complete flood control is impossible, so the concept of flood management is given thrust to provide a certain amount of protection (Leopard and Maddock, 1964). This has led to the construction of large multipurpose dams. It is also noted that there is no statistical evidence that the frequency of major flooding has increased over the last 120 years (Hofer and Messerli, 1997). However, the movement of sediment due to earthquakes in 1934 and 1950 is uncertain. Although controlling flooding through embankment construction may be fairly successful, complete protection is not possible. Therefore, the concept of "living with the flood" put forward by the "Rashtriya Bar Ayogi" is commendable, as the public only has to face a flood for 7 days out of 365 days or in a year, which means only 0.01% of the year in total. Hence, flood control is impossible, and flood management is a more appropriate term.

The Brahmaputra and Barak Rivers in Assam

The Brahmaputra River, which flows across Assam from east to west for nearly 650 kilometers, is one of the world's biggest, most flood-prone, and most unstable rivers. Its major branch begins on the Tibetan plateau, running west to east as the Tsangpo River, and then swings south through the eastern Himalayas in a steep canyon as the Dihang River, entering the eastern section of Assam, where it is joined by additional branches from the northeast to create the Brahmaputra. The river swings south towards Assam's western border to enter Bangladesh, where it is known as the Jamuna below the offtake of the old Brahmaputra. The river's properties are fairly similar in Assam, and the river's drainage regions in Assam's east and west ends are around 290,000 and 530,000 square kilometers, respectively. The long-term mean discharge increases from roughly 8,500 to 17,000 cubic meters per second as flows are supplemented by 28 main tributaries on the north or right bank and 16 on the south or left bank as the river passes into Assam. Northern tributaries drain the southern Himalayan slopes and provide significantly more water and sediment to the river than southern tributaries.

The Barak River originates in the Indian state of Nagaland at an elevation of around 2300 meters and runs through the Manipur Hills of Manipur State for almost 400 kilometers. It then flows approximately westward from Lakhipur through Assam's Cachar Plains region for around 130 kilometers before entering Bangladesh at Bhanga. High flows in streams from the north and south have traditionally caused flooding on the Cachar plains. Heavy rainfall on the plains, along with inadequate slopes for depressional regions to drain by gravity to river systems, and obstruction of natural drainage by road and railway embankments and other infrastructure features, are additional primary causes of flooding in the Cachar plains. Overflooding has mostly been managed by substantial building of embankments along riverbanks. Design requirements call for agricultural land to be protected for 25 years and communities to be protected for 100 years. Because most embankments are near riverbanks, they are vulnerable to damage from bed scour and channel migration. Efforts have been made to withstand erosion in river areas by employing spurs and revetments as flood barriers in urban areas.

Flood Management Assets: Embankments

In Assam, there are around 4500 km of the embankment (including approximately 700 km along the Barak River), 85 large regulators (Sluices), 850 km of drainage canals, and over 680 erosion-control devices such as spurs, porcupine fields, and revetments. Embankments are typically built with 1V: 2H side slopes and Crest levels intended to handle floods with a return time of 25 years plus freeboard. The crest level is increased around cities and other economically vital infrastructure to accommodate floods with a 100-year return time. The embankments go for a significant distance along both banks of the river, as well as along chosen portions of tributary rivers coming from both the north and south.

In numerous places, the embankment needs to be repaired. Many embankments along the Brahmaputra and Barak Rivers have been susceptible to river erosion, and where the erosion has resulted in breaches, the embankment has been retired or set back farther from the riverbank, in some cases multiple times. Land acquisition, new embankment building, and impoverishment and displacement of the afflicted people have all been the results. The embankments are also prone to erosion from rainfall and settling as a result of poor compaction during construction. Human habitation atop the crest threatens the stability of the embankment in places. According to previous experience, the yearly cost of maintaining earthen embankments is between 2% and 3% of the original cost of earthwork. A typical sketch of a flood-control embankment is shown in Figure 10.1

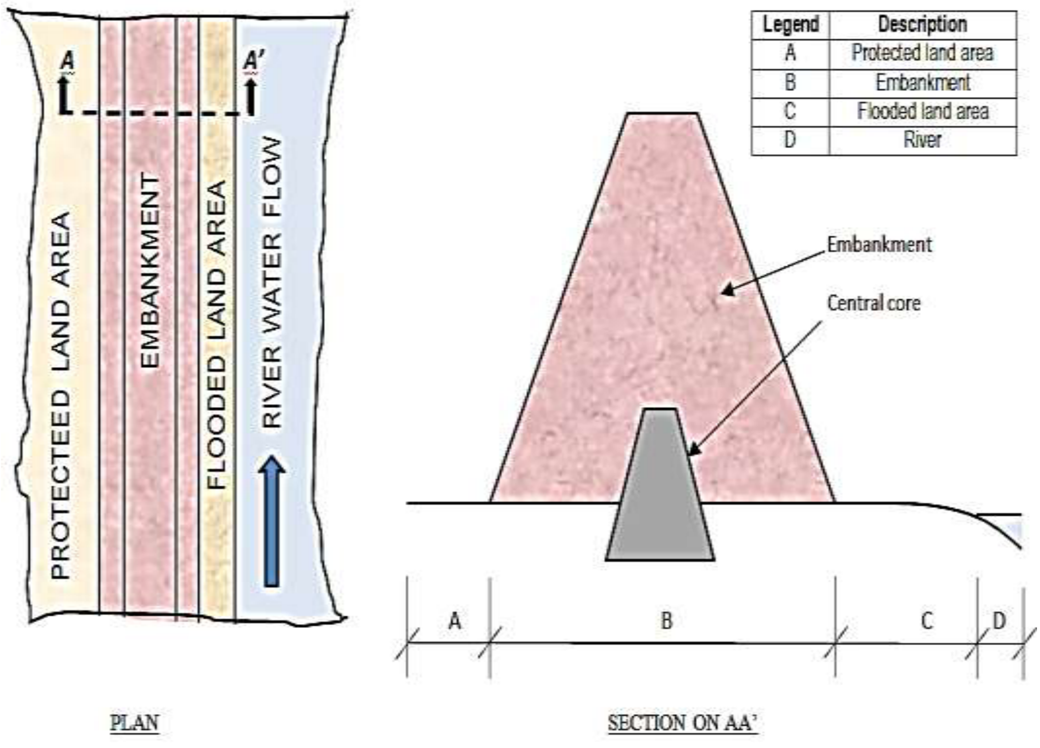

Figure 10.1. Sketch of a typical flood-control embankment

Efficacy of Embankment

There is substantial debate on the efficacy of embankments as a suitable form of flood management in the Brahmaputra and Barak River Basin (Leopold and Maddock 1954). It is asserted that devastating floods are becoming more frequent, that each subsequent flood affects a larger overall area, that embankments have become a significant cause of increased flooding, and that the implementation of flood control measures has given people a false sense of security, encouraging them to encroach more deeply into the floodplain. Furthermore, Leopold and Maddock (1954) highlighted the following: inadequate planning encourages fast expansion in high-risk locations, resulting in self-expanding projects; land management strategies have little influence on catastrophic floods; construction project advantages occur in one region while disbenefits exist in another, resulting in conflicts; benefit-cost calculations are risky because they rely on anticipating future losses and tend to overestimate benefits while underestimating costs. Because of the challenges with the embankments, experts researching flood-control solutions have tended to suggest the construction of huge multi-purpose dams. Proposed dams on the Dihang and Subansiri rivers in Arunachal Pradesh, with a live storage capacity of 35,500 and 10,600 million cubic meters, respectively, would supply enough power for the entire Northeast region. The Dihang Dam is predicted to flood Pandu peaks by up to 1.75m and the Subansiri Dam by 0.15 to 0.40m. Experts believe that control of a further 22 tributaries is also achievable, with analysts initially focused on the main rivers.

The details of an existing embankment in the study area have been sourced from a reliable technical report available, and shown in Table 10.1

Table 10.1 Details of the existing embankment (Source: Flood Damage Mitigation: Report, 2014)

River	**Left bank**			**Right bank**		
	From	To	Approx-imate length (km)	From	To	Approx-imate length (km)
Barak	Dilcush Village	Rajnagar	84	Barenga	Masughat	42
Rukni				Ujan Gram	Katigorah	40
Sonai	Baga	Nadir Gram	30.5	Gagla Ghat	Roy Para	24
Badri	Borali Basti	Jarul Gram Toal	33.5	Amraghat	Dungir Par	38
Madhura	Mach Para	Badri Basti	2	Old Lakhipur Road	Machpara	1.5
Gagra	Rongpur	Istampur	14	Dudhpatil	Pachmile	8
Jatinga	Rothur Gram	A.P Camp	19.5	Suktara	Srikona	2
Katakhal	Badripar	Dolu	3			
Longai	Kaligange	Rupacherra	71	Kaligange	Rupacherra Bagan	71

Conclusion

Existing embankments should be reinforced and expanded, and embankments in urban and other important areas should be built to higher standards. It is also suggested that before filling any gaps in the embankment, thorough research should be conducted because drainage problems are likely to arise. However, planning experts have reservations about the effectiveness of embankments and recommend that unless flood control systems include reservoirs, alternative techniques to embankments should be considered. These options are not described in detail.

Conflict of Interest Statement

The author declares that there is no conflict of interest.

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CHAPTER ELEVEN

SUSTAINABLE WATER RESOURCE DEVELOPMENT IN THE INDIAN SCENARIO

SATABDI SAHA[1]

Abstract

A period of increasing competition for water supplies has increased the risk of water contamination and environmental deterioration, and rising social, economic, and environmental expenses are all affecting water resources. The water shortage in India seems to be becoming worse rather than better. In order to meet the challenges posed by this situation, water professionals and managers need to adapt their thinking about water in a way that is sustainable. Due to the distinctive characteristics of water, which include its necessity for human existence, economic growth, and environmental conservation, as well as the large number of stakeholders involved, this is particularly challenging. A number of difficulties confront those in charge of these essential resources today, highlighting the significance of managing water resources sustainably. This study aims to provide an overview of water scarcity and its sustainable development in the context of India. The significance of this study is to avert this crisis by applying sustainable development, a water management concept that emphasizes the significance of using less water than could be produced or replaced, maximizing positive economic benefits, minimizing negative social and environmental impacts, protecting natural systems, and ensuring that future generations will not have to compromise on their water needs.

Keywords

Water Resources, Water Policy, Sustainable Development, Indian Scenario, Water Pollution, Environmental Deterioration

Introduction

Water is a precious natural resource that is being depleted more quickly than it can be replaced. As demand for this essential commodity continues to grow, the available water is decreasing at an alarming rate. India leads the world in terms of irrigated land, but one-eighth of its land is flood-prone, and one-sixth experiences drought. The main culprit behind India's water shortages is the monsoon season. Crops need a lot of water to grow, especially during the summer, and as a result, urbanization, industrialization, and modernization all contribute to increasing demand for this essential liquid. Along with household waste removal needs, issues such as sewerage infrastructure have made it difficult to meet demands without compromising our water supply. According to the World Bank, despite making some progress on poverty reduction in recent years, a shocking 52% of India's population still lives below the middle-class income level.

The excessive privatization of government solutions has also made them vulnerable as a result of India's rapid urbanization. Even if the quality of drinking water has improved, many more water sources are contaminated with chemical and biological contaminants, and over 21% of illnesses in the country are connected to water. Moreover, just 33% of the population has access to traditional sanitation. One worry is that India may not have sufficient long-term access to replenishable water supplies. As with other countries with substantial agricultural output, overuse of water for food

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production depletes the entire water table. Drilling wells is sometimes the only option for many rural villages in India located on the periphery of urban sprawl to access groundwater sources. However, any water system contributes to the overall loss of water. Increased corporate privatization, industrial waste, and personal waste are frequently blamed for India's water shortages.

There are still areas with a fairly rainy climate in India's driest regions. Nevertheless, the majority of the water is either lost through transfer or evaporation since there are no rain collection plans in place. In these areas, rainwater harvesting may be one method of obtaining water. With better filtration techniques to reduce the risk of water-borne infections, the collected water can also be made promptly available for human consumption.

Water Resources in India

One of a nation's most important resources is its water supply. India receives roughly 4000 BCM (Billion Cubic meters) of precipitation every year (Figure 1). The absurdity of the situation is that Mousinram, which is next to Cherrapunji and receives the highest rainfall worldwide, also experiences a water shortage during the dry season almost every year. India's rainfall is incredibly variable both geographically and temporally. 1953 BCM is thought to be the average annual flow for all Indian rivers. 432 BCM is estimated to be the total yearly replenishable groundwater resources (Pathak *et al.,* 2014). Surface water and groundwater resources that can be used annually in India are estimated to be 690 BCM (Figure 11.1) and 396 BCM, respectively.

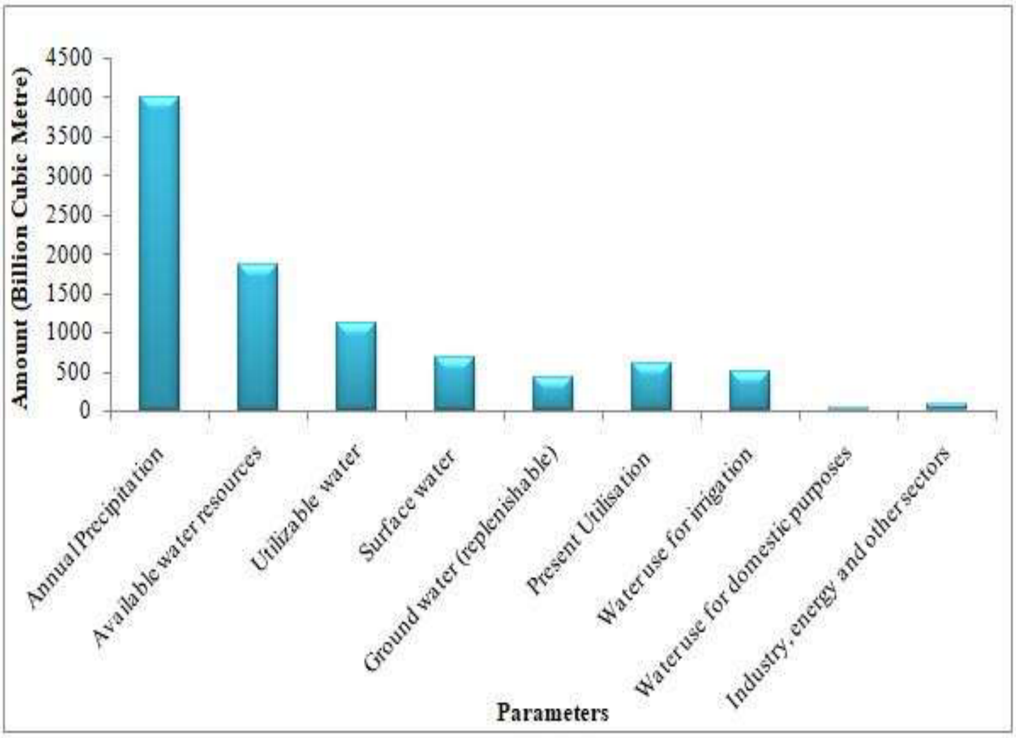

Figure 11.1. Indian water resources

There is increasing pressure on our water resources as the population continues to grow and economic conditions improve. The per-person availability of resources is decreasing day by day (Figure 3). Due to regional and temporal variations in precipitation, the issue of flood and drought syndrome exists throughout the country. The overuse of groundwater is causing groundwater supplies to decline, rivers to flow more slowly, and saltwater intrusion in aquifers near the coast. Waterlogging and salinity have occurred as a result of excessive canal irrigation in some of the command regions. Rising pollution loads from point and non-point sources are deteriorating the quality of both surface and groundwater resources. Precipitation and water availability are expected to be impacted by climate change (Kumar *et al.,* 2005).

Water holds a special place among all renewable resources in the world. It is necessary for the continuation of all living forms, the production of food, the growth of the economy, and overall health. Since it can be diverted, transported, stored, and recycled, water is also one of the most manageable natural resources. All of these characteristics provide water with tremendous human benefit. Agriculture, hydropower generation, livestock production, industrial activities, forestry, fisheries, navigation, leisure activities, etc. heavily rely on surface water as well as groundwater resources of the nation. According to National Water Policy (2012), irrigation, drinking water, hydropower, agro-sectors, ecology, non-agricultural industries, and navigation should be given priority in the development and operation of systems.

India receives 4000 BCM of precipitation annually, including snowfall. Rainfall during the monsoon is approximately 3,000 BCM. India's rainfall is influenced by the southwest and northeast monsoons, local storms, and shallow cyclonic depressions and disturbances (Bhattacharyya *et al.,* 2015). Except for Tamil Nadu, which is influenced by the northeast monsoon during October and November, the majority of rainfall occurs between June and September under the influence of the southwest monsoon. India has a river system that includes more than 20 major rivers and several tributaries. Some of these rivers are seasonal, while others are perennial (Gangwar, 2013). The Himalayas are the source of rivers like the Ganges, Brahmaputra, and Indus, which transport water all year round.

The Himalayan snow and ice melt, as well as the base flow, are responsible for the flows during the lean season. According to Lal (2001), the many tributaries of these river systems contain more than 50% of India's water resources. The average water supply per unit area of the Himalayan rivers is about twice as great as that of the southern peninsular river system, highlighting the significance of the high mountains' contribution to snow and glacier melt. In addition to the water found in the nation's numerous rivers, groundwater is another significant supply of water for drinking, agriculture, industrial applications, etc. It supplies more than 73% of all irrigation in the nation, as well as around 5% of the water needed for domestic use (Figure 11.2).

Water for irrigation is just as important as water for drinking since both are necessary to increase food production, care for livestock, and ensure enough food for the expanding population. Population expansion is a major concern, as everyone is aware, because it will further reduce future per capita water supplies (Kumar *et al.,* 2005) (Figure 11.3). Despite having a reasonable distribution of rainfall, the country currently struggles to effectively utilize rainwater due to a lack of understanding and inadequate infrastructure for building dams and reservoirs. In order to harvest 1-2 crops every year, just 35-40% of the cropland is irrigated. Numerous rivers in India are used for hydropower generation in addition to irrigation. Due to challenging sites, concerns about protecting forests, interstate problems, subpar execution, and a lack of commitment, the country is currently having a tough time realizing its full potential. It is also feasible to create projects with multiple uses, such as those for irrigation and power generation, which can increase water supply while enhancing project viability.

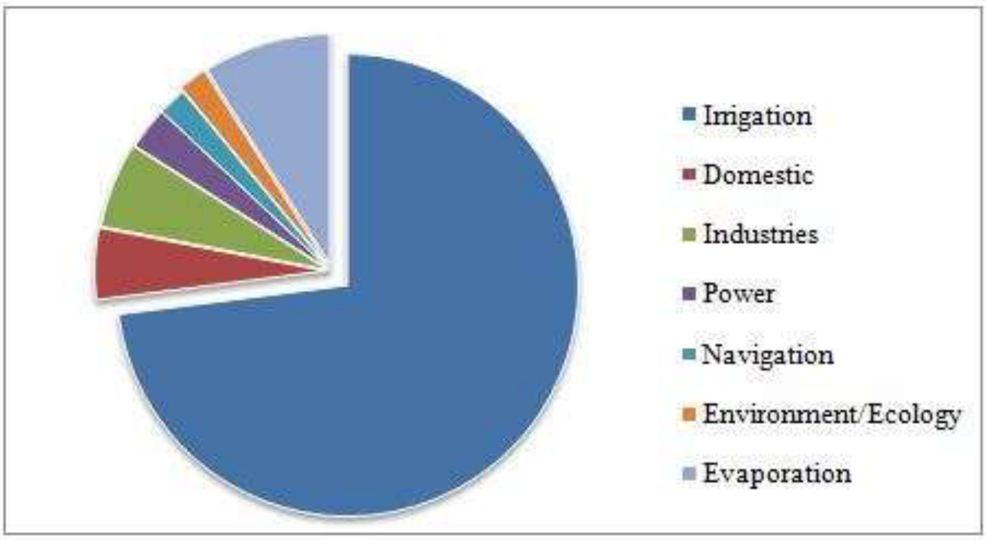

Figure 11.2. Demands of water for several uses in India

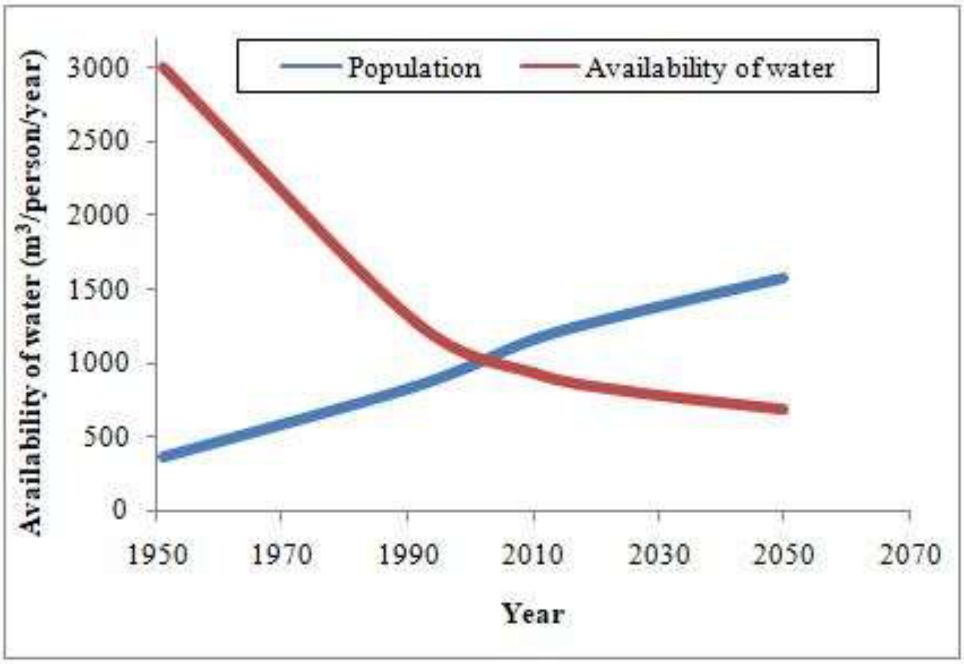

Figure 11.3. India's per-person water availability

human health and water supply. Although only 5% of the country's entire water is utilized for household purposes, 27% of India's villages and 4-6% of its urban population lack access to clean drinking water. In addition to the insufficient water supply, there is a big concern about water quality, which is negatively affecting people's health. The main contributors to water pollution are the release of untreated sewage as well as industrial pollutants into rivers, excessive use of fertilizers in agricultural land, and the inclusion of salts and minerals from lower soil profiles in groundwater. According to estimates, daily sewage production in New Delhi alone is 36 million tonnes, of which only 50% is treated before being released into the Yamuna River. The same is true for other remaining cities. 23 significant cities produce sewage, yet only 31% of it is treated; the remainder pollutes 18 significant rivers across the nation. Additionally, various hazardous metals, nitrites, and fluorides are present in the majority of the nation's rivers. More than 66 million individuals currently have fluorosis as a result of drinking water with a fluoride content of more than 1.5 ppm (Ayoob and Gupta, 2007). Another factor contributing to the contamination of drinking water sources is poor sanitation, both in urban and rural regions.

The amount of groundwater that has been contaminated by the excessive use of chemical fertilizers and pesticides cannot be determined with any degree of accuracy. Increased fertilizer application is simply one aspect of the issue; excessive irrigation water use is another. Because of this, nearly all well water utilized for drinking purposes in irrigated areas is contaminated. Due to water reaching lower soil layers and salts contained in this area being diffused in water, over-irrigation has also been reducing soil productivity. These salts then go through capillary action to the topsoil. High concentrations of such soils transform them into desiccated wastelands unsuitable for agricultural use. Currently, more than 9 million ha of rich irrigation-based lands have degenerated into wastelands, where the water is highly salinized and unsuited for both human consumption and agricultural productivity. The prevalence of ailments is great because those who live in these communities use such hard water in a helpless manner.

Water Resources Development

Water is essential for life, as it is necessary for the survival of both plants and animals. Water serves various purposes, including food security, livestock care, maintaining organic life, conserving biodiversity, and preserving the environment. Without it, life on Earth would not exist. Geological evidence suggests that water has never dried up on our planet, and it exists in different forms, including as plant life. However, due to reckless human behavior, many areas around the world face severe water shortages. Without appropriate corrective measures, India alone will soon experience a crisis in food and water security. Due to the burgeoning human population and various other factors, water has become increasingly scarce in India. This necessitates swift action by those responsible for managing the country's water resources. Water has been abundant for centuries, but with population growth and technological advances, water consumption has become more rampant, and a shortage of good-quality water is now looming. The world is facing a water crisis, with some countries having too much water while many others are running out. This problem is only going to get worse as the population continues to grow in different parts of the world. Over the years, water usage has been largely dependent on culture, lifestyle, and industrial development, and water was never seen as a serious concern. In addition to being used for fisheries, hydropower generation, transportation, conserving biodiversity and ecological balance, agriculture, industrial production, and home uses account for the majority of water usage (Integrated water resources development (1999).

The National Water Policy (NWP)

India updated NWP in 2012 (National Water Policy, 2012) with key elements listed below:

(i) Facilitating the conversion of existing water resources into usable water
(ii) Establishing data banks at the national and state levels to track demand and supply.
(iii) In order to ensure sustainable development, water should be wisely allocated for different uses and prices.
(iv) Groundwater extraction should be regulated, and the water table should be closely monitored utilizing the latest scientific approaches.
(v) All interested parties and neighborhood groups should be included in maintaining the current water bodies.
(vi) PPP (Public Private Partnership) for water projects should be used.
(vii) A comprehensive flood control strategy that promotes soil conservation measures and links several rivers.
(viii) Improvement of drought-prone areas through the creation of watersheds, reforestation, and sustainable agricultural methods
(ix) A policy for interstate water sharing and prompt resolution of issues.

The environment has radically changed over the past ten years, and the water sector's development has not kept pace with expectations. Therefore, it was deemed necessary to make additional revisions to the policy, especially in the following areas:

Proposed modifications to NWP

1) ***Agriculture Industry***

(a) Increasing the efficiency of water use
(b) Acquisition of watershed management and rainwater collection as well as storage strategies
(c) Reducing subsidies for electrical supply, especially for water pumping
(d) Groundwater exploitation can be stopped by implementing differential prices, incentives, and penalties.
(e) The National River Link project is now being implemented. The project will connect 30 rivers as well as canals in order to provide water amounting to 175 trillion liters.

2) ***Industrial Sector***

(a) Encourage the development of new water-saving technology
(b) Promote industrial wastewater recycling as well as treatment through regulations and financial incentives.

3) ***Domestic Sector***

(a) The acquisition of legislation mandating that cities collect rainwater
(b) Spreading water efficiency
(c) Raising public awareness of the need for water conservation

Elevation of Water Resources

The majority of people, particularly those who depend on agriculture and live in poverty, will be most negatively impacted by India's increasing water use. The ecosystem, biodiversity, and food production will all be affected by water scarcity. The degradation of the environment will accelerate global warming, which will in turn worsen the water crisis. This deadly cycle exists, and the only way to solve this problem is to utilize every accessible source of water, save it for future use, and improve water use efficiency. The aforementioned can be accomplished by attending to innumerable issues and launching appropriate activities for the creation of new sources of water, the expansion of current resources, the protection of water from contamination, and the enhancement of water usage efficiency across all provinces. According to Integrated Water Resources Development (1999), the following projects should get underway in order to increase the availability of water resources.

Growing the Storage Capacity of Water

Percolation tanks, farm ponds, small and medium-sized dams, water reservoirs, and rivers can hold additional surface water during groundwater recharge, which increases. A series of contour bunds, especially in sloping landscapes, will enhance the groundwater table and promote water percolation through the soil while lowering soil erosion. Insufficient soil and water conservation efforts are causing acute erosion of soil, silting of riverbeds, and reservoirs, and recurrent flooding throughout the nation, since precipitation cannot be collected in forests and deforested high terrains. Serious deforestation is one of the main causes of soil erosion and river silting. Many rivers have been altering their courses virtually annually as a result of soil erosion, harming productive agricultural fields. A notable example is the Brahmaputra, whose breadth varies from 3 to 4 km in the summer to 10 to 12 km in the wet season. The aforementioned demonstrates the amount of river flooding and harassment of those who live along the river. 22 billion m3 of this river's water only can be utilized, however, more than 607 billion m3 of water are squandered as a result of inadequate management (National Water Policy, 2012). Other rivers, like the Ganga, Mahanadi, Godavari, Narmada, etc., are subject to comparable conditions.

The country's water distribution will be improved while floods are prevented by connecting the rivers. Soil erosion can be avoided by controlling floods and water flow. Currently, our forests and valuable agricultural fields are losing billions of tonnes of rich soil together with priceless nutrients. In actuality, the quantity of nutrients lost as a result of the erosion of soil is about equal to the amount of artificial fertilizers made in the nation. This demonstrates how controlling soil erosion affects food output. Reforestation of damaged forests and the creation of wastelands through afforestation will assist in soil and water conservation. Water scarcity can be avoided by a careful distribution of water among various users. Strong lobbyists and entrenched interests have an influence on how water is distributed for various reasons. At the expense of other sectors, many receive more water than is necessary. The sites for framework development are frequently impacted by individuals who possess political clout and have vested interests, even in the same industry, such as agriculture irrigation, depriving others in poor regions. Proper investment strategies must be created based on demands and profits from investing to combat such inefficiencies and resource waste. With the implementation of a program with a transparent procedure and frequent quality control checks, the projects' pace and quality can be boosted.

Efficient Irrigation Practices

If a nation desires to address the dilemma of the crisis of water, irrigation efficiency is crucial. Over 70% of the water utilized for irrigation is lost because flood irrigation is used to irrigate the majority of crops. Farmers also have the propensity to flood the field with excessive amounts of water without incurring any additional costs because the water provided is not metered. Such a method has an adverse effect by increasing the cost of leached nutrients, contaminating groundwater, increasing soil salinity, and increasing pests and illnesses. The farmers should use micro-irrigation techniques, which will expand the area irrigated while lowering production costs and reducing the amount of water needed. Metered irrigation water supplies, cost recovery for water usage, promotion of micro-irrigation techniques, and participation of users' groups for water in the distribution of water would all greatly improve the efficiency of water use while lowering agricultural production costs.

Watershed Development

To maximize the application of rainwater for agricultural output while enhancing soil and biodiversity conservation, watershed development is a crucial initiative. Under the watershed development program, a basin's catchment area is treated as a group in an endeavor to treat the soil from the ridge to the valley to capture rainfall. It is projected that more than 63% of the land area used for agriculture in rain-fed regions needs to be included in the development of watersheds to conserve soil and water, increase agricultural yields and groundwater levels. In the final year of the tenth five-year plan, the watershed development program, which was first implemented nearly thirty years ago, covered more than 51 million acres. However, due to subpar soil conservation work done in the past and the deficiency of coordination to further agricultural development operations, a significant number of watersheds continue to experience high soil erosion.

Water Pollution Management

Excessive use of water in homes, industries, and agriculture is contributing to water contamination as this extra water is converted into effluent, sewage, or saltwater. Therefore, it is important to design rewards and penalties to motivate people to make judicious use of the few water resources available. In addition to pursuing and enforcing wastewater recycling, it is required to forbid the discharge of effluent and sewage into bodies of water and rivers. This will keep water sources clean and reduce the future need for water. Agriculture and industrial output can benefit from the use of treated sewage and effluent.

Desalination of Sea Water

The looming shortage of freshwater can be addressed by economically desalinating seawater, especially for human consumption, as more than 70% of the world's water resources are already salty. Seawater desalination (Figure 11.4) is currently costly and unpopular. However, desalination can be a practical solution with solar power to address water needs in coastal locations.

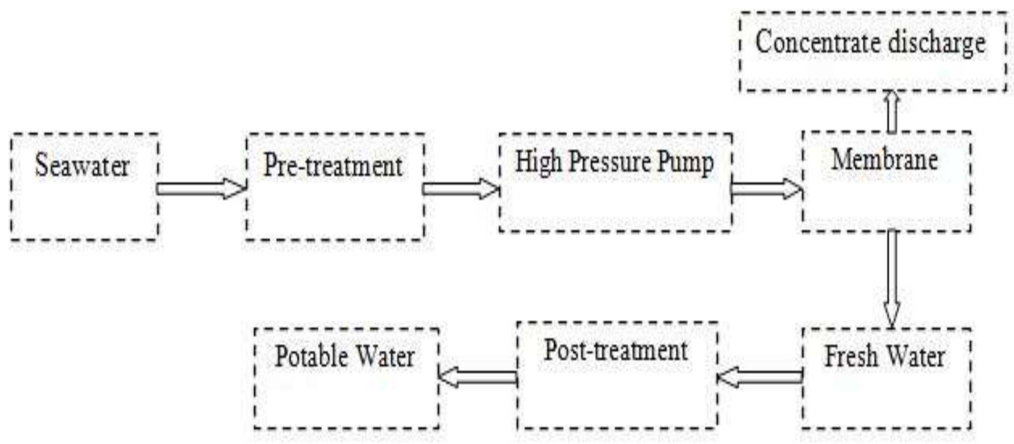

Figure 11.4. Flow chart of desalination of seawater

Research and Development

In order to create crops and varieties that can withstand the changing climatic circumstances brought on by global warming, it is important to fund studies on weather prediction, breeding water efficient as well as drought-resistant crops, and groundwater monitoring.

Actionable areas of Priority

The following actions must be taken immediately because time is running short:

(i) Irrigation projects should be carefully designed, and a number of programs should be started at the same time, such as providing aid as well as rehabilitation to project-affected populations, managing land usage at the microscale, and enhancing farmer capacity.

(ii) To encourage the conservation of soil, recharge of groundwater, and prevent flooding of rivers, and silting of water reservoirs, priority should be given to replanting on degraded wastelands, riverbanks, and woodlands.

(iii) If careful forethought is placed into water meter distribution, water is priced sensibly to cover costs, and investments are made in micro irrigation systems, irrigation efficiency can be increased with ease. Farmers should be educated on the necessity of water judicious use and conservation, which is required for achieving sustainability.

(iv) Development of the 80 million hectares of wastelands, which is accelerating erosion of soil, and surface runoff water, as well as increasing productivity in these arid regions, will aid in water conservation while enhancing food production and biodiversity.

(v) Enhancing local capacities by training the next generation of water management managers and professionals to carry out various innovative projects more successfully. Additionally, there is a need to support multidisciplinary researchers that are interested in researching several facets of water resources, including conservation, effective storage, loss reduction, and sustainable use.

(vi) Both Farmers' Organizations and Civil Society Organizations can assist small farmers in implementing cutting-edge technologies and creating the forward and backward linkages necessary to boost their income.

(vii) Diverse developmental programs coming together can increase outputs. The Ministries of Water Resources Development, Agriculture, and Rural Development carry out several development programs that are coordinated at the local level by a single organization to promote efficient resource use and greater impact.

Conclusions

India's water supply is going to present significant challenges for several reasons. The biggest worry is the population growth, which is expected to reach 1.66 billion by 2050. Another issue is excessive groundwater use. In many coastal areas, fertile agricultural grounds have been rendered unsuitable for cultivation due to the excessive intrusion of seawater. Even though India has enough water resources to meet the country's expanding demand, it is nevertheless imperative to solve these pressing challenges that are limiting the supply of water. According to estimates, more than 70% of irrigation water is lost since other dry areas aren't given irrigation. To significantly alleviate water shortage, it is important to move from flood irrigation to micro irrigation and to enhance water usage efficiency (Rosegrant *et al.,* 2002). Water scarcity can be avoided by carefully distributing water among various users. India falls well short of the majority of affluent nations when it comes to the efficiency of water use in agriculture. This is caused by a variety of factors, including inefficient water conservation techniques, crop varieties that require more water, flood irrigation, and overwatering. Crops will require more water because increased evapotranspiration will come from global warming. The nation's denuded wastelands and forestlands, which total more than 60–80 million ha, are unable to collect rainwater, which would have ensured groundwater replenishment and biodiversity preservation. Because of this, the rivers that run from these mountains are unable to maintain their water flow all year long. Heavy soil erosion is causing floods, which have also forced rivers to modify their paths. In the future, such rivers won't be able to support agricultural development.

Therefore, it is essential to avert this crisis by utilizing all available technology and resources to preserve water resources already in place, transform them into usable forms, and effectively utilize them for human consumption, industrial production, and agricultural usage. Water conservation will benefit from the implementation of legislative restrictions to stop water waste and the introduction of rewards and penalties to promote wise water use. It is also necessary to conduct hydrological studies to evaluate water resources under different climatic situations. The country can eventually weather the water crisis if all water consumers are made aware of it and encouraged to adjust their lifestyles to conserve water. The difficulty can be overcome as long as we have effective policies and tools to urge our population to change their way of life.

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CHAPTER TWELVE

STRATEGIES FOR ADVANCING BENGALURU AS SMART CITY: A CASE STUDY

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Abstract

The concept, origin, development, and history of Smart Cities were studied in conjunction with the backdrop, town, and economic characteristics of Bengaluru. The idea of Smart Cities is a "booming" global phenomenon, with Smart City initiatives being implemented worldwide. After the 2000s, the term "smart" gained popularity in urban policymaking to describe the skillful use of information technologies (IT) to improve a city's infrastructure and service functionality and efficacy. With significant contributions from various technologies, including computer science, information technology, remote sensing, and enhanced multimedia, the idea of Smart Cities is a recent one in our country. This project explores the foundation of a Smart City by examining existing relevant parameters, such as electricity, solid waste management systems, water supply, and transportation, in Kondashettihalli and Chikkaballapur areas only due to the vastness of the city and the deciding parameters. Bengaluru's spatial expansion is examined, the shortcomings of the current situation are contrasted with those of a Smart City, and lastly, planning plans and recommendations are provided.

Key Words

Information technology; Smart city; Spatial Growth; Transportation; Water supply;

Introduction

The notion of a "Smart City" is not new, but the phrase originated with the "Smart Growth" movement at the end of the 1990s, which advocated for new urban planning principles (Harrison and Donnelly, 2011). The idea of Smart Cities is a booming global phenomenon, with over 2000 Smart City initiatives started in Europe, Asia, Africa, and America. By 2013, there were more than 1500 projects underway, with a compound annual growth rate of 20%. After the 2000s, the term "smart" became widely used in urban policymaking to describe the clever application of information technologies (IT) to increase the effectiveness and productivity of a city's services and infrastructure (Robin Hodkinson 2011). Detailed explanations of the "smart city" phenomenon's elements are provided below. With substantial contributions from various technologies, including computer science, information technology, remote sensing, and enhanced multimedia, the idea of a Smart City is a recent one in our country. These new systems improve the efficiency, agility, flexibility, and sustainability of Smart City operations. India's first Smart City, GIFT (Gujarat International Finance Tec-City), was established in Gujarat in 2011 with the assistance of experts

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from CISCO and ABB. Other Indian cities with Smart City initiatives include Haldia (West Bengal), Amanora (Maharashtra), Pune, Lavasa (Maharashtra), and Electronic City (Bangalore).

Definition of Smart City

The concept of a "smart city" refers to a city that can achieve long-term economic growth, a high quality of life, and responsible resource management by investing in social and human capital, conventional (transportation), and modern (ICT) communication infrastructures. (Caragliu *et al.,* 2009). While the idea of applying information technology (ICT) to future cities has become popular in recent years, the focus of a smart city is not just on the role of ICT infrastructure but also on human capital/education, relational and social capital, and environmental challenges. These are considered significant drivers of urban growth. Smart cities are defined as "innovative, knowledge-intensive tactics designed to improve cities' competitiveness, logistical efficiency, and socioeconomic success. These 'smart cities' are supported by a promising combination of human capital (such as a skilled labor force), infrastructural capital (such as high-tech communication facilities), social capital (such as intense and open network links, and entrepreneurial capital) (Kourtit *et al.,* 2012). Smart computing technology can be applied to key municipal services and infrastructure, such as real estate, public safety, transit, and city administration, to make them more intelligent, networked, and effective. (Washburn *et al.,* 2010). There are various definitions of "smart cities" in use today, depending on the region and focus area. The UK Department of Business, Innovation, and Skills defines it as a process that improves a city's livability, resilience, and capacity to deal with challenges through increased hard infrastructure, citizen engagement, digital technologies, and social capital. The British Standards Institute defines it as "the effective integration of physical, digital, and human systems in the built environment to produce a sustainable, prosperous, and inclusive future for its residents," while IBM defines it as a city that makes the best use of interconnected information to better understand and govern its operations and optimize the use of limited resources. Cisco defines smart cities as those that implement scalable solutions that make use of information and communications technology (ICT), which boosts productivity, lowers costs, and improves the quality of life. Accenture defines it as a city that "delivers public and civic services to citizens and companies in an integrated and resource-efficient manner while enabling innovative collaborations to improve quality of life and expand the local and national economy." In summary, a city is considered "smart" when it successfully integrates information and communication technology (ICT) and the Internet of Things (IoT) into critical infrastructure components and services of the city, including education, public safety, city administration, transportation, healthcare, real estate, and utilities.

Need for Study

Globally, urbanization is rapidly accelerating. For the first time in human history, there were more urban residents than rural ones in 2008, and indications suggest that this trend will continue. By 2030, the majority of the world's population is expected to live in "megacities" (10+ million), major cities (5-10 million), medium-sized cities (1-5 million), and smaller cities and peri-urban villages, with a growing concentration in Asia, Africa, and Latin America. By 2050, this percentage could reach two-thirds. According to a recent report by the Intergovernmental Panel on Climate Change (IPCC) on Spatial Planning, Human Settlements, and Infrastructure, the expansion of urban areas (urban centers and suburbs) is, on average, twice as fast as the growth of the urban population, and the expected growth in the first three decades of the 21st Century will be greater than the total urban expansion throughout human history. As a result of this rapid urbanization, there is a greater need for resources like energy, water, and sanitation as well as for services like education and healthcare. This highlights the necessity of developing "smart" cities that can meet the needs of city dwellers while also utilizing resources effectively or "smartly."

Infrastructure development on all fronts - institutional, physical, economic, and social - is necessary for this. Improving the quality of life in cities, attracting tourists and investors, and igniting a cycle of growth and expansion all require these elements. The development of smart cities is a step in that direction. To meet the benchmarks, civil engineers must provide planning ideas and realistically implement them through infrastructure.

Smart City Evolution

"Smart Growth" emerged in 1992 as a concept aimed at providing an alternative model to detached homes, urban sprawl, and reliance on motor vehicles. Planners, architects, community organizers, and advocates for historic preservation were the primary drivers behind this movement. Innovative approaches to urban planning and design began to emerge, emphasizing that the expansion of a city should occur in compact, mixed land-use, and walkable urban centers, offering a range of transportation and housing options. In these areas, the community is involved in making decisions about development that are reasonable, anticipated, and economical. This idea gained widespread popularity in the 1990s before losing momentum as "Intelligent Cities" took its place. The concept of intelligent cities focused on how data and information technologies could impact the functioning of cities. The concept of a "Smart City" grew out of these discussions on intelligent cities and smart growth. Many of these conversations were led by "intelligent" and "smart" companies such as IBM, Siemens, and CISCO. Other digital giants, like Hitachi and Microsoft, have also developed "smart" technologies for cities. Contributions to this conversation have also come from MIT laboratories (Townsend, 2014; Harrison, 2011).

The discussion of smart cities became more prominent with the end of the global economic crisis in 2008. During this time, in order to offer public urban services, there were drastic cuts to urban finances and social welfare (Paroutis *et al.,* 2014). As a result, the concept of a "smart city" evolved, offering an interface that treats the city as a system of intricate information flows. The model assumes that there is an overarching objective for the city that can be amended to boost productivity in several industries, including transportation, healthcare, and others, for the benefit of the city as a whole (Steiner and Veel, 2014).

History of Smart City

The Smart City Mission (SCM) was launched by the Ministry of Urban Development (MoUD), Government of India on June 25, 2015, to be implemented in 100 cities dispersed throughout the country. The objective of the SCM is to create livable cities that provide employment opportunities, a sustainable and clean environment, and "Smart" solutions. To achieve these objectives, the SCM has strategic elements of area-based development, such as place improvement (Retrofitting), city renewal (Redevelopment), and city extension (Greenfield Development), as well as a pan-city initiative in which smart solutions are implemented across larger areas of the city. To be considered for SCM, each city must pass a two-stage city challenge selection process. In the first round of the selection process, competition was held among the state's cities based on the prerequisites and scoring criteria specified in the SCM standards. Seven cities in Madhya Pradesh, including Bhopal, Indore, Gwalior, Jabalpur, Sagar, Ujjain, and Satna, were shortlisted in the first stage and are among the 100 cities identified by MOUD as potential smart cities. Each of the 100 shortlisted cities must prepare their ideas for the "City Challenge" in accordance with the Smart City Guidelines and submit them by the deadline specified by MOUD to participate in the second round of the selection process.

As part of the process of creating Indore's Smart City Plan, the Urban Development and Environment Department's Madhya Pradesh Urban Infrastructure Investment Programme (MPUIIP) team conducted a diagnostic study. The study examined a variety of smart solutions for different sectors of the plan based on secondary research, best practices from around the world, and the applicability of specific smart solutions. Based on the most important lessons learned from these studies, the MPUIIP team has created a manual of sector-specific "Smart Solutions." The handbook is intended to serve as a ready reference for local governments in creating smart solutions, ensuring that each city's smart city plan adheres to international standards and quality requirements and is developed in accordance with the Government of India's Smart City Guidelines.

History of Bengaluru City

Before Kempe Gowda, the feudal lord of the Vijayanagara Empire, constructed a fort made of mud, which is regarded as the precursor to modern-day Bangalore, in 1537 CE, the region that is now Bangalore was ruled by a sequence of South Indian kingdoms, including the Cholas, the Western Gangas, and the Hoysalas. The Marathas ruled Bangalore from 1638 until the Mughals retook the city and gave it to the Wadiyar dynasty of the Mysore Kingdom. The British gained control of the city after winning the Fourth Anglo-Mysore War (1799), and then gave authority back to the Sultan of Mysore. Mysore, which was a region of the British Raj that enjoyed some measure of autonomy, was given the old city as its official capital. Around the British cantonment, which was transferred from the old city to Bangalore in 1809, a town that was ruled as a part of British India rose. After India's independence in 1947, Bangalore was chosen to serve as the capital of Mysore State. This designation was retained even after Karnataka was added to the Indian state system in 1956. The city and the cantonment, which had grown as self-supporting urban communities, merged in 1949 to form a single urban center. The city's present Kannada name, Bengaluru, was chosen as its official name.

Physical Characteristics of The City

Bangalore is located in the southeast of Karnataka state, India. It is situated in the Mysore Plateau, which is a part of the larger Precambrian Deccan Plateau, at an average elevation of 900 meters (2,953 ft). With an area of 741 km^2, it is located at 12.97°N 77.56°E. The majority of Bangalore lies within the Bangalore Urban district of Karnataka, while the surrounding rural areas are included in the Bangalore Rural district. The former Bangalore Rural district was converted by the Karnataka government into a new district called Ramanagara. Bangalore's morphology is primarily flat, with some hilly areas in the western parts of the city. Vidyaranyapura Doddabettahalli, at a height of 962 meters (3,156 ft), is the highest peak located to the northwest of the city. There aren't any significant rivers that flow through the city, although the Arkavathi and South Pennar rivers meet up to the north in the Nandi Hills, 60 kilometers away. Basavanagudi is the source of River Vrishabhavathi, a minor tributary of the Arkavathi, which runs through the city. Many of Bangalore's sewage flows jointly through the rivers Arkavathi and Vrishabhavathi. Five sewage treatment facilities are connected to Bangalore's sewerage system, which was built in 1922 and covers 215 km^2 of the city. The largest freshwater lakes and tanks in Bangalore are the Madivala tank, Hebbal lake, Ulsoor lake, Yediyur Lake, and Sankey Tank. Groundwater is found in layers of alluvial sediments ranging from silty to sandy. The most prevalent rock type in the region is the Peninsular Gneissic Complex (PGC), which is made up of granites, gneisses, and migmatites. Bangalore's soils consist of red laterite and red, fine loamy to clayey soils. Large deciduous canopies and a few coconut trees make up most of the city's vegetation. Despite being a member of seismic zone II (a stable zone), Bangalore has experienced earthquakes as powerful as 4.5.

Economic Profile of The City

The metropolitan region of Bangalore has been estimated to have the third- to fifth-most productive metro area in India, with a fluctuating GDP ranging from US$45 to US$83 billion. Bangalore is India's second-fastest-growing metropolitan city, with an economic growth rate of 10.3%, and the fourth-largest market for fast-moving consumer goods (FMCG) in the country. Forbes has identified Bangalore as one of "The Next Decade's Fastest-Growing Cities." It is also the third-largest hub for high-net-worth individuals and is home to around 10,000 millionaires who have made over $1 million, as well as over 60,000 super-rich people who have assets worth a combined total of $45 million (US$668,700) and $5 million (US$74,300). Bangalore has the corporate offices of several public sector organizations, including Hindustan Aeronautics Limited (HAL), Bharat Heavy Electricals Limited (BHEL), Bharat Earth Movers Limited (BEML), Bharat Electronics Limited (BEL), Central Manufacturing Technology Institute (CMTI), National Aerospace Laboratories (NAL), and HMT (previously Hindustan Machine Tools). The Indian Space Research Organisation (ISRO), which was founded under the Department of Space, has its headquarters in the city and was created in June 1972. Bangalore also houses numerous R&D facilities for various companies, including Airbus, ABB, Toyota, Bosch, GE, GM, Nokia, Google, Microsoft, Philips, Boeing, Mercedes-Benz, Oracle, Shell, and Tyco.

Bangalore is known as the Silicon Valley of India due to the high concentration of information technology firms in the city, which in 2006-07 accounted for 33% of India's 1,442 billion (US$21 billion) in IT exports. The three primary IT clusters in Bangalore are Electronics City, International Tech Park, Bangalore (ITPB), and Software Technology Parks of India (STPI). High-end commerce can be found in UB City, which is the headquarters of the United Breweries Group. Bangalore is home to many international SEI-CMM Level 5 Companies, including Infosys and Wipro, which are the third and fourth largest software companies in India, respectively. However, the city is facing specific challenges due to the growth of the IT sector. The city's IT tycoons often clash with the state government, whose voting base is mainly made up of residents of rural Karnataka, as they call for an upgrade to the city's infrastructure. The promotion of the high-tech sector in Bangalore did not help local employment growth; instead, it raised land values and drove away small businesses. Additionally, the state has not made significant investments to prevent the significant decline in urban transportation, which has already begun to push new and expanding companies to other hubs across India. Bangalore is also a center for biotechnology-related businesses in India, and in 2005 it was home to Biocon, the country's largest biotechnology company, as well as around 47% of the country's 265 biotechnology firms.

Steps involved in the Research work

(i) A survey of the key research articles that have influenced the area of sustainable smart cities.
(ii) Review of the Most Important Policy Literature, Including Initiatives, Experiences, and Recommendations from the World's Major Organizations and Experts in the Subject.
(iii) Building a repository of such efforts through the process of gathering documentation of Smart City ideas as well as the execution performance.
(iv) To assist in planning, implementation, and assessment of smart city ideas, create a framework based on contributions derived out of case study development, research, and policy literature review;
(v) Due to time restrictions, four parameters - transportation, water supply, solid waste management, and electricity, are taken into consideration.
(vi) Data collection and analysis:
(a) Revised Master Plan 2015
(b) BBMP Solid Waste management system data of the required areas
(c) Land use in 2004
(d) Existing land use 2015
(e) Final proposals: After analyzing all the data shortfall is calculated, issues and strategies are found, and the final proposal is prepared.

Limitations of the study

Limited to two intermediate areas (Kondashettihalli) and outer areas (Chikkaballapur) the study is limited to physical infrastructure viz., (a) Traffic and Transportation, (b) Water supply, (c) Solid waste management, and (d) Electricity.

Reviews of literature

The article reports on the findings of the EADIC research project on enterprise planning of smart cities (Kakarontzas *et al.,* 2014). The study reveals that interoperability, availability, usability, recoverability, security, and maintainability are the most crucial requirements for smart cities. The article presents a conceptual framework based on these criteria. Khan *et al.,* (2014) suggest a cloud-based architecture and service framework for context-aware services in smart cities. They argue that integrating various applications and enabling them to interact with intelligent information is necessary to produce intelligent information for efficient smart urban governance. Paroutis *et al.,* (2014) developed a novel method for developing and distributing technology to address urban challenges, particularly in the context of a recession. They constructed a conceptual framework based on recessionary literature to assess the case study of IBM on smart cities. Mulligan and Olsson (2013) discuss the two primary system architectures for smart cities: communications and ICT. They also explain how the system architecture must change to produce fresh and creative business models for smart cities.

Glebova *et al.,* (2014) studied the three largest cities in the Volga Federal Region with the idea of a "smart city" as a foundation (Karzan, Samara, and Nizhniy Novgorod) and offer suggestions for putting a smart city into practice. Vilajosana *et al.,* (2013) identified the reasons why smart cities are struggling to take off and presented a big data approach based on the concept of an API store to make smart cities a reality. Herschel (2013) introduces the smart city-regionalism concept to address the competing agendas and policy objectives of sustainability and competitiveness principles. Smart growth and modern regionalism combine to create smart city regionalism, serving as both an analytical framework and a process for formulating policy. Neirotti *et al.,* (2014) present a taxonomy for smart cities based on application domains, such as natural resources and energy, buildings, transportation and mobility, and the economy of people. The article also seeks to comprehend the potential effects that urbanity, economy, and demography may have on the execution of a smart city. Lazaroiu and Roscia (2012) propose a smart city model that enables the calculation of a city's smartness index based on "smart" indicators. The authors argue that the suggested model could aid local management in formulating policies and making a final choice among the several possibilities that are on the table. Ojo *et al.,* (2014) develop a "Smart City Initiative Design Framework" based on an examination of ten cities with smart city initiatives, providing a tool for designing smart city projects. Piro *et al.,* (2014) focus on information for smart city services and develop a platform that falls back on common use cases, including business operations and water management. The article mainly emphasizes the technological aspects of smart cities that relate to ICT infrastructure and services.

Methodology

Case Study 1- International model

Seoul, South Korea is leading the way in e-governance by integrating IT with service delivery. In 2004, the government launched the u-City initiative, and in 2011, it unveiled Smart Seoul 2015 as its strategic plan to retain Seoul's competitiveness and solidify its position as a global technological leader. The plan aims to address several issues such as traffic, aging, and sustainability since people's expectations were rising.

The Smart Seoul 2015 strategic plan proposes using IT with service delivery as the solution, with most services funded by the city or the federal government. Most master plan-based services are contracted out to the private sector. For example, Seoul and three wireless service providers have signed a joint MOU to deploy public Wi-Fi, which will cover 13.5% of the Seoul region. Some of the initiatives under the plan include:

(i) Increasing ICT accessibility and closing the digital divide: The plan aims to provide IT training to low-income and senior groups, benefiting around 200,000 people every year. The city also donated smart devices, resulting in tax deductions of between $50 and $100 for each donated item. As of March 2012, all of Seoul's subway trains have Wi-Fi access, and the goal is to provide free, reliable Wi-Fi service to residents.

(ii) Enhancing public health and safety: Parents can monitor their children's travel patterns and alert the appropriate authorities in case of an emergency, thanks to U-Seoul Safety Services that use location-based services and CCTV. Another initiative is U-Health Care, intended to provide health examinations and priority medical care to the elderly and disabled with limited mobility.

(iii) Effective public service delivery through participatory governance: The plan aims to construct infrastructure such as data centers based on cloud computing that use less energy and smart work centers that allow government personnel to operate from ten offices. More than 60 services are available through the Mobile Seoul app, which also allows users to vote yes or no on proposals to enhance the city and locate nearby public bathrooms. Citizens can get information on all public services through a single platform on the Seoul Metropolitan Government's new website. The city's new Information Open Square online feature enables the proactive publication of official data and documents.

(iv) Improving commuting: Open 311 interfaces and the implementation of a touch card payment system based on GPS will help collect real-time traffic data for the 25,000 taxis in the city. This method is more affordable than adding sensors to the road infrastructure. To promote public transportation, TOPIS (Transport Operation and Information Service) integrates data from all forms of mass transit and connects with the traffic signal system. Additionally, when a starting point and destination are input, digital view terminals that have been installed in Seoul subway stations show thorough navigation and the best routes to travel. T-Money, an electronic payment system in the form of a card, can be used to pay for all types of public transit. Lastly, online shops are available for users to make purchases while waiting at bus stops, using a smartphone app that can read product barcodes.

(v) Increasing energy efficiency: The plan includes providing smart home electrical controllers and smart meters that show power usage and encourage energy-saving measures.

Streetlights automatically adjust the lighting depending on the outdoor luminance. To cultivate organic food, hydroponic pavilions have been created.

Some of the benefits of these initiatives are:

(a) Service delivery and access to public information: Seoul reports that the percentage of public service reservations made online has increased from 26% to 85%. Additionally, Seoul has released more than 35% of the total 400 datasets, with 150 datasets available compared to only 40 in 2011.
(b) Economy: The availability of public information has enabled the private sector to create innovative solutions to meet public demands, such as the Seoul Bus app. The disclosure of public information has also contributed to the growth of the knowledge information and content market, which is expected to double in size by 2015, thanks to the estimated economic value of 1.2 trillion KRW. Seoul aims to increase the number of application developers from 2,000 in 2011 to 6,000 by 2015.
(c) Environment: In Seoul, energy-saving apps have been downloaded by 4 major banks, 22,000 buildings, and 479,000 homes. Seoul aims to reduce energy use by 10% and CO2 emissions by 2% by 2015. Smart sensors and informed electrical information are expected to help achieve these goals, resulting in a potential 10% reduction in power use and savings of 500 billion KRW.

Case study 2- National Model

Gujarat International Finance Tech-City or GIFT is a city that is currently under construction in Gujarat, India, located about 12 kilometers away from Ahmedabad International Airport. The construction is starting on a 2.0 km^2 block of land, and its main objective is to provide top-quality physical infrastructure such as gas, water, electricity, roads, broadband, and telecoms to financial and technology companies relocating from other locations like Bangalore, Mumbai, Gurgaon, etc., where the infrastructure is either insufficient or very expensive. The development will include a Special Economic Zone (SEZ), a Global Education Zone, Integrated Townships, Hotels, Convention Centers, Global Techno Parks, Stock Exchanges, Software Technology Parks of India (STPI) Units, an Entertainment Zone, Retail Stores, and Service Facilities. GIFT aims to develop a transportation system that ensures accessible, easy, and speedy mobility, with no traffic fatalities. This will be achieved by using a multimodal mix of transportation systems (MRTS/LRTS/BRT, etc.) for both intra-city travel and inter-regional transit (connecting Ahmedabad, the airport, Gandhinagar, and the city). Efficiency will be achieved by incorporating the "walk-to-work" idea into urban planning and adopting a 10:90 nodal divide for private and public transportation. GIFT will also use electric Personnel Rapid Transport systems within the city. Currently, it is connected to Ahmedabad BRTS, run by Ahmedabad Janmarg Ltd. The city will eventually be connected to other areas as well.

The first of its kind in India, GIFT is envisioned as an IT service and global financial center that will compete favorably with other financial hubs across the world like Tokyo, Shinjuku, London Dockyards, La Defense, Lujiazui, Shanghai, Paris, Shanghai, etc. Its Target Business Segments are KPO Services, IT services (Software Application development and maintenance), BPO Services, ITeS, Capital Markets and Trading, Financial Services Operations (Back-office of banking, Insurance, and Asset Management Companies). The land leveling work for GIFT city has completed its first phase, and construction is currently underway on two 29-floor commercial skyscrapers. They were finally finished in December 2016 following a three-year delay. The project's second phase involved creating roadways and building foundations from 2011 to 2013. The development and start dates for the third Phase were set for 2013 to 2017.

Guidelines and Features for Smart City

The Smart Communities Mission seeks to assist communities that provide a solid foundation for their citizens, a high standard of life, a healthy, sustainable environment, and the use of "Smart" Solutions. The goal is to analyze compact geographic areas and create a replicable model that would serve as a beacon for other aspirational communities. Sustainable and equitable development are the main priorities. A report, according to the Ministry of Urban Development, Government of India, 2015, some common characteristics of the extensive growth of smart cities are listed below:

(i) Encouraging mixed-use development in localized areas - planning for "unplanned regions" that have a variety of appropriate applications and activities close to one another to maximize the use of available land. The States will allow some wiggle room in their land use and building bylaws to accommodate change.

(ii) Inclusivity and housing- increase access to homes for everybody.

(iii) Creating walkable localities - increases the local economy, encourages interactions, and provides security while reducing traffic, air pollution, and resource depletion. All crucial administrative tasks are located nearby, and roads are constructed or refurbished not only for automobiles and public transportation but also for pedestrians and cyclists.

(iv) Preserving and developing open spaces - playgrounds, parks, and recreational areas to improve the standard of living for residents, lessen the effects of urban heat in some areas, and overall promote eco-balance.

(v) Encouraging a range of transportation choices - Public transportation, last-mile connectivity, and transit-oriented development (TOD) for paratransit.

(vi) Making government more cost and citizen-friendly - There is a growing reliance on online services to promote accountability and transparency, particularly when using mobile devices to lower service costs and deliver services without requiring residents to visit municipal offices; setting up online focus groups to hear from the public and gather feedback; and using online monitoring of programs and activities with the help of virtual site visits.

(vii) Giving the city an identity- based on its primary economic activity, such as its regional cuisine, education, sporting goods, arts and crafts, culture, health, furniture, hosiery, textiles, dairy products, etc.

(viii) Improving area-based development's infrastructure and services through the application of smart solutions. Using less energy, fewer resources, and offering less expensive services are a few examples.

Spatial Growth Analysis

Cities worldwide are undergoing various changes due to natural and human activities. The population growth of a city over time can result from socioeconomic changes, improved livelihoods, etc., which in turn leads to migration of the workforce into the city, drastically affecting land use patterns. To provide for the living needs of the workforce, land areas need to be developed, requiring proper planning and execution. Due to the already crowded nature of cities, intricate ideas are required to develop the necessary amenities within the limited space. The growth of urban population takes different forms, and to determine them, we must consider various land uses dedicated to the general public, such as residential, commercial, or industrial areas, parks and playgrounds, open spaces, and transportation and communication infrastructure. The challenges posed by the spatial growth of cities were first noticed in the 1980s (Kaya *et al.,* 2009).

In the context of urban planning, "Land Use" refers to the purpose for which a particular zone is designated, which may include residential, commercial, or industrial purposes, as well as parks, playgrounds, open spaces, and transportation and communication infrastructure. Over the past ten years, cities have seen development almost everywhere. Assuming all developments are relatively close to each other, the total built-up area of the city is taken into account. Spatial growth analysis provides accurate data for identifying and interpreting land use dynamics and urban growth tendencies. This involves analyzing and comparing the total built-up area of a city at different stages, such as 2004 and 2015.

Analysis of Land Use Data in 2004

The analysis of land use data in the year of 2004 has been portrayed in Table 12.1. the relevant pie chart has been depicted in Figure 12.1.

Table 12.1. Land use data, 2004*

Land use type	Area (Hectare)
Industrial	1874778.836
Commercial	714721.9277
Residential	2493468.931
Park and Open space	225865.321
Civic Amenities	198254.9356
Transport	2346891.684
Total	**7853981.634**

*Land Use 2004 data is obtained from Revised Master Plan (RMP) 2004

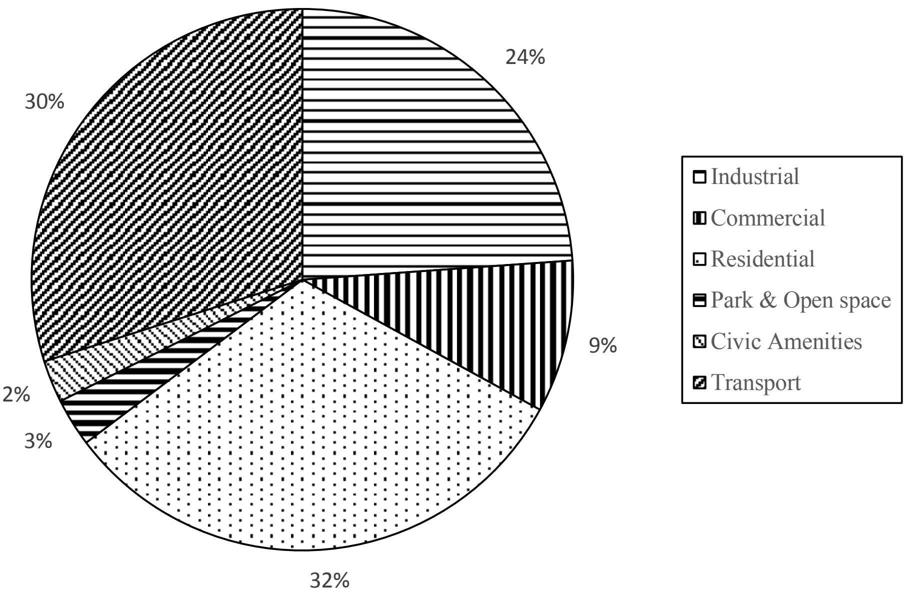

Figure 12.1. Land use pattern 2004

Analysis of Existing Land Use Data, 2015

The analysis of land use data in the year of 2004 has been portrayed in Table 12.2. the relevant pie chart has been depicted in Figure 12.2.

Table 12.2. Existing land use data, 2015**

Land use type	Area (Hectare)
Industrial	1518940.631
Commercial	1098771.663
Residential	2193468.931
Park and Open space	208997.6717
Civic Amenities	346366.8219
Transport	2487435.916
Total	**7853981.634**

**Land Use 2015 data is obtained from Revised Master Plan (RMP) 2015

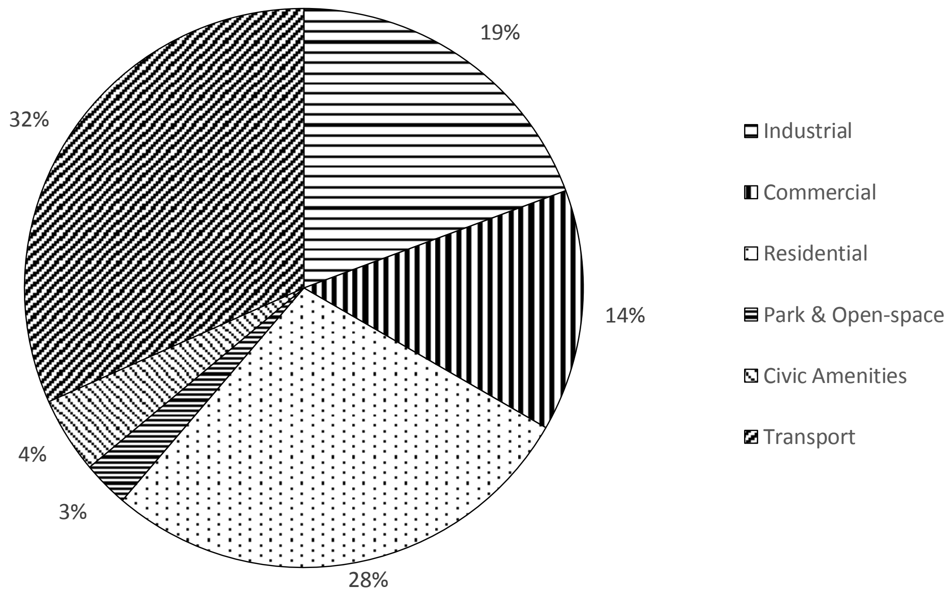

Figure 12.2. Land use pattern 2015

Comparison of Spatial Growth

The comparative study of the spatial growth has been made herein. The study analysis has been presented in Table 12.3 and Figure 12.3.

Table 12.3 Difference in 2004 and 2015 land use data

Land use	Land use data, 2004 (ha)	Existing land use data, 2015 (ha)	Difference (%)
Industrial	1874778.836	1518940.631	-4.53
Commercial	714721.9277	1098771.663	4.89
Residential	2493468.931	2193468.931	-3.82
Park and Open space	225865.321	208997.6717	-0.21
Civic Amenities	198254.9356	346366.8219	1.89
Transport	2346891.684	2487435.916	1.79
Total	**7853981.634**	**7853981.634**	**-**

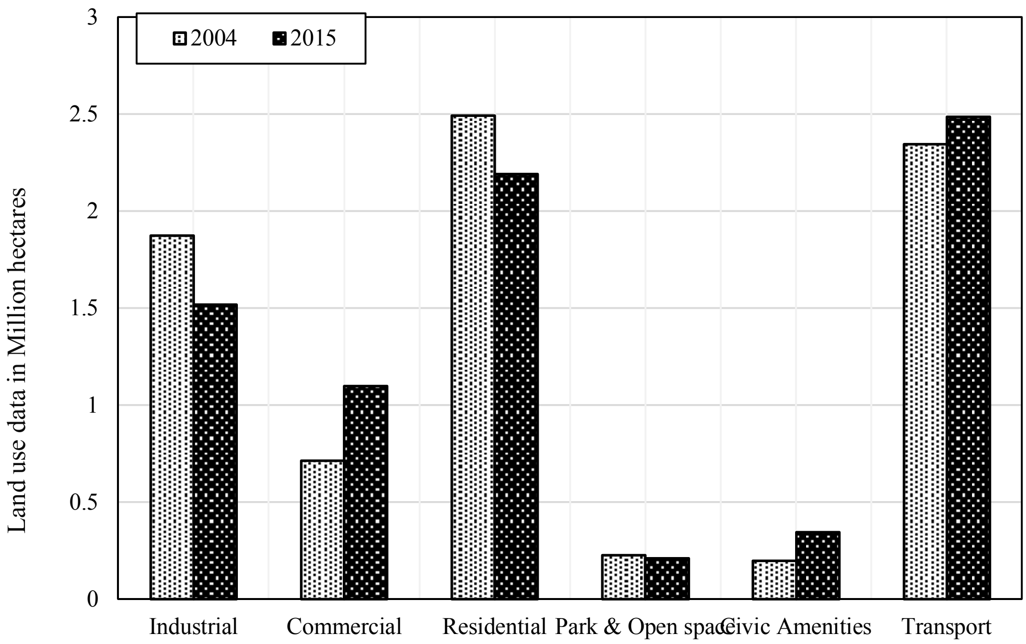

Figure 12.3. Comparison of land use data 2004 and 2015

Factors Affecting Growth of Bengaluru City

Future growth is greatly influenced by the growth figures in the Bangalore Metropolitan Region besides Bangalore's swift socioeconomic growth, which has had a substantial impact on the city's urbanization. The following are important initiatives promoting socioeconomic growth in the city and peri-urban area:

(i) Bangalore-Mysore Infrastructure Corridor (South-West Bangalore).
(ii) Information Technology (IT) Corridor (South-East Bangalore).
(iii) Bangalore Metro Rail (cross-cutting Bangalore City).
(iv) Bangalore International Airport (North Bangalore).
(v) Power supply and energy projects that are responsive.
(vi) Location of large-scale/manufacturing industries (East and North Bangalore).
(vii) Location of IT/ITES/Biotech Industries (East and South Bangalore).
(viii) Five Integrated Townships are being built in the BMR.
(ix) Power supply and energy projects that are responsive.
(x) Proposed Peripheral Ring Road (around Bangalore); and
(xi) Projects for delivering urban basic services presented by the city's local self-government organizations (funded through the Jawaharlal Nehru National Urban Renewal Mission)

Several local self-government organizations are in charge of handling the city's expansion, including Bangalore Metropolitan Transport Corporation (BMTC), Bruhat Bengaluru Mahanagara Palike (BBMP), Bangalore Development Authority (BDA), Bangalore Water Supply and Sewerage Board (BWSSB), Karnataka Slum Clearance Board (KSCB), ITBT, Karnataka State Road Transport Corporation (KSRTC), Bangalore Metropolitan Region Development Authority (BMRDA), Heritage Board, Karnataka Housing Board (KHB), Bangalore International Airport Area Planning Authority (BIAAPA), Bangalore Electricity Supply Company (BESCOM), Tourism Department, and the Karnataka Urban Infrastructure Development and Finance Corporation (KUIDFC). Numerous systemic problems related to the aforementioned institutions are brought on by the presence of multiple agencies, including problems with planning for service delivery, accountability, organizational development, and others. These problems have an impact on how services are provided in the city.

Identification of Indicators and Benchmarks

Indicators and benchmarks of core infrastructures viz. Solid waste management (SWM), Transport, Water supply, and Power are identified, and the shortfalls are calculated.

Transport

To improve the quality of life in smart cities, it is necessary to expand the public transportation system and implement smart parking integrated multimodal transportation. This is highlighted in Table 12.4.

Table 12.4. Service level benchmark on Transport #

Sl. No.	Indicators and Benchmark	Present Status	Shortfall
1	Maximum journey time is 45 minutes in metropolitan areas and 30 minutes in small and medium-sized cities.	Not efficient	100%
2	All streets with a row of 12 meters or more must have an uninterrupted, 2 m-wide walkways on each side.	Not efficient	100%
3	On all streets having a roadway wider than 10m, there shall be two dedicated bicycle lanes, one in each direction, that are at least 2 meters wide.	Not efficient	100%
4	All houses in places with a population density of more than 175 people per square meter of a constructed area must be within 800 meters (10–15 minutes walking distance) of high-quality, frequent mass transit.	Not efficient	100%
5	Para-transit Road is 300 meters away on foot.	Not efficient	100%

#The present status is obtained from the Revised Master Plan (RMP) 2015

Water Supply

To monitor adequate water supply, smart metering, leakage identification, and water quality monitoring are the smart solutions to 24/7 water supply with 135 litres per capita per day (lpcd). The scenario has been portrayed in Figure 12.5.

Table 12.5. Service level benchmarking on Water Supply $

Sl. No.	Indicators	Benchmark	Present Status	Shortfall
1	Households with direct water supply	100%	75.75%	24.25%
2	Per capita water supply	135lpcd	85 lpcd	50 lpcd
3	Metering of water connections	100%	0%	100%
4	Quality of water supply	100%	100%	-
5	Continue water supply	24 hrs	2 hrs	22hrs
6	Efficiency in the collection of water charges	100%	0%	100%

$ The present status is obtained from the (RMP) 2015

Solid Waste Management

The practical approaches to managing solid waste include recycling and waste reduction, waste to electricity and fuel, waste to compost, and wastewater treatment. The details are shown in Figure 12.6.

Table 12.6. Service level benchmarking on SWM [#$]

Sl. No.	Solid Waste Management	Benchmark	Progress Achieved	Shortfall
1	Coverage at the family level	100%	0%	100%
2	The effectiveness of MSW collection	100%	0%	100%
3	Size of the segregation	100%	0%	100%
4	The extent of the recovery	100%	0%	100%
5	The scope of scientific disposal	100%	0%	100%

[#$] The present status from Burhat Bengaluru Mahanagara Palike (BBMP) Zone-wise Solid Waste Management process.

Electricity

Electricity and adequate electrification is the key for smart city development. So far as the electricity is concerned, the actual scenario is portrayed in Figure 12.7.

Table 12.7. Service level benchmarking on Power [$$]

Sl. No.	Description	Benchmark	Progress Achieved	Shortfall
1	Household electric connection	100%	98%	2%
2	Supply of electricity	24hrs	22hrs	2hrs
3	Metering of electricity supply	100%	90%	10%
4	Recovery Cost	100%	85%	15%

[$$] The present status is obtained from the RMP 2015

Issues, Strategies, and Proposals

Traffic and transportation

Issues:

(a) Rapid motorization, severe congestion, a growing number of traffic collisions.
(b) Inadequate public transportation and poor infrastructure.
(c) Poor infrastructure for other motor vehicles.
(d) Poor Infrastructure for Non-Motorized Transport (NMT).

Strategies:

(a) Improvements in public transport,
(b) Ring roads, by-passes, underpasses, elevated roads, improvements to the current roadways, and parking are all examples of additions to the infrastructure for other vehicles.
(c) Infrastructure upgrades for non-motorized transportation (walking, cycling).
(d) Information, communication, and technology (ICT) implementation in the transportation sector.

Proposals:

(a) Enhancements to public transportation, including BRT, Metro Rail, LRT, Trams, and Monorail.
(b) In the smart transportation system, using a personal automobile is strongly discouraged and public transportation is prioritized as the major mode of transportation.
(c) Access to public transport: All homes in the built-up region are within 800m (10–15 minutes' walk) of high-quality, frequent mass transit.
(d) Within a 300-meter walking distance should have a paratransit station.
(e) Discouraging personal motor vehicles, by introducing more tax on vehicles.
(f) Mandatory group pooling with a minimum of 1 person in cars.
(g) Minute parking charges.
(h) Infrastructure upgrades for various types of vehicles include parking, ring roads, underpasses, elevated highways, and bypasses.
(i) The bottlenecks in the road and rail networks must be examined as well, and underpasses, elevated roadways, and extra rail networks must be promptly installed where necessary.
(j) Improvement of circles at Shivkote, Hesaragatta, and Subbanahalli.
(k) Road widening: From Shivkote to Aivarakandapura and from NH44 to Subbanahalli road.
(l) Improvements in infrastructure for walking, and cycling.
(m) Introducing ICT in the transport system.
(n) Proposal to introduce a Smart card system in public transport.
(o) Proposal to introduce a Synchronous signaling system.

Water Supply System

Problems:

(a) Water supply covers 77 % while 23 % was not covered in the city.
(b) The piped water supply in the city covers only 75.75%.
(c) whereas the duration of drinking water 2 to 4 hrs is more i.e., 74%.
(d) While in slums water supply through public tapes amounts to only 73.3% and individuals 24.3%.
(e) Cost recovered only 20%.
(f) Per capita water supply 85 lpcd.
(g) A lot of distribution loss due to the old pipeline (18%).

Strategies:

(a) All inhabitants have access to a safe and sufficient water supply.
(b) A sufficient supply of piped water that is also widely available and satisfies standards for water quality, pressure, etc.
(c) Two separate water supply networks (that serve the needs of drinking water and other needs that would help in recycling water and conserving it.
(d) Covering 100% of the water supply to the entire city. Now it has been covered 75%, so the remaining 25% needs to be covered.
(e) Achieving 135 lpcd and 24/7 ware supply as per the smart city benchmark

Proposals:

(a) Use of modern techniques, particularly smart metering, to cut down on waste and energy use in water networks.
(b) Installing sensors in the supply system to continuously monitor water flow rates, water levels, and water use. These models will aid in not only finding and locating leaks but also in maximizing the network's energy usage. Smart water meters may also be installed to measure water usage more accurately and to give water consumers data to manage their water use and cut expenditures.
(c) Replacing deteriorated pipes which are installed long back.
(d) Collection of water charges, 100% efficiency.
(e) Training for staff who are involved in the water supply system by technical exports.
(f) Water tanks at Kurubarahalli, Shivakote, and Subbanahalli.

Solid Waste Management System

Issues/problems:

(a) Efficiency of collection of MSW is only 0%.
(b) Extent of segregation is only 0%.
(c) The extent of scientific disposal is only 0%.
(d) Household-level coverage is only 0%.
(e) Lack of technical knowledge and proper institutional setup.
(f) Dumping and burning in open spaces.

Strategies:

(a) The system of daily doorstep collecting reaches every family.
(b) 100% of municipal solid garbage is collected.
(c) Totally separating biodegradable and non-biodegradable trash at the source.
(d) Solid trash is recycled entirely.

Proposals:

(a) Separation of dry and wet trash, as well as recyclable and non-recyclable waste, at the source to enable complete recycling of solid waste.
(b) Decentralized areas should use the appropriate technology for waste treatment. Set up a method for collecting and disposal that works well.
(c) Promote the use of items made from recycled materials, particularly those for building materials, compost, and power (based on the cycling of debris and construction materials).
(d) Composting at home and product subsidies for compost.
(e) Development of sanitation with the involvement of the private sector and NGOs.
(f) community involvement, hygiene promotion, and awareness-raising .
(g) Building institutional strength and sanitation management capabilities in order to improve service standards.
(h) creating a recycling facility at Subbanahalli and the Mavallipura dump.

Electricity

Issues/problems:

(a) Up to 98 percent of households have power connections.
(b) Power losses in 2014 were 16%.
(c) There were 22 hours of electrical supply, and (d) there is a lack of knowledge about renewable energy sources.

Strategies:

(a) Making 100% of households have an electricity connection.
(b) All residents in smart cities must have constant access to electricity.

Proposals:

(a) Proposal to make 100% metering of electricity supply.
(b) Proposal to ensure full cost recovery.
(c) Tariff slabs designed to cut down on waste.
(d) Incentives for the adoption of the solar system, and mandatory issuing of building licenses.
(e) establishing a smart grid and integrating it with renewable energy sources like solar and wind energy to meet demand.
(f) It is necessary to improve the current distribution system.
(g) Systems for power banking must be built.
(h) To decrease the need for electricity, it is necessary to construct green structures and green transportation.
(i) Awareness of the use of the solar system in street lighting, use of LED, etc. Use of the solar system in public buildings like stadiums, theatres, etc.

(j) a shared customer service center and an integrated billing system for many services, such as water, electricity, gas, internet, and property taxes.
(k) Online payment system that is simple to use. (l) Encouraging Renewable sources such as solar and wind energy.

Limitations of Proposal

(i) The study was limited to two intermediate areas (Kondashettihalli) and outer areas (Chikkaballapur) in Bengaluru city.
(ii) The study is limited to physical infrastructure viz., a) Traffic and Transportation, b) Water supply, c) Solid waste management, and d) Electricity as the data were relatively available on the government websites and offices. Several other parameters such as availability of capital, ease of proposal for smart city, etc., were not taken due to time constraints and can be used as a future scope consideration.
(iii) The data used in the study is relatively old due to inaccessibility to the newer data from government machinery.
(iv) The Technology capital expenditures required must be substantial for a smart city assumed in this project.
(v) The per capita income of the population of the region could not be documented which would draw back the implementation of this sophisticated smart city as technology service providers are relied upon the most in a well-planned smart city which means that the everyday activities are mostly done in a relatively easy manner. And this increase in technology dependence can take a toll on the mental and physical well-being of the residents in the near future.
(vi) Real estate prices rise as construction and development become more challenging due to the technological inclusion in most of the buildings to provide for an easy and comfortable living which could lead to difficulty in implementation due to lack of the exact revenue data of the state to build a smart city.

Conclusions

The pillars of a smart city include transportation, social infrastructure, stormwater drain, sewerage, solid waste management, power, telecommunication, and water supply. Due to the vastness of the area of study, only four pillars have been studied and planning strategies proposed for them. Further research can be done on the remaining pillars to generate a more concise proposal for the development of a smart city. Based on the spatial growth analysis of 2004 and 2015, it is forecasted that the land use for industrial, residential, parks and open spaces will be reduced while commercial and civic amenities and transportation will increase. To achieve economic growth and a healthy environment, there should be an increase in industrial, parks, and open spaces, and a reduction in commercial land use. Transportation facilities should be conveniently planned with the proposed infrastructure. In the solid waste management system, the shortfalls should be checked by the proposed plans and timely monitoring. In the water supply segment, losses and usage of water should be regulated according to the proposed plans. Uninterrupted power supply is a major factor in urban activities and can be achieved through the proposed harvesting method. The planning strategies and proposals aim to overcome the shortfalls of the selected smart city pillars. Thus, a general proposal for all smart city projects is established.

Conflict of Interest Statement

The author declares that there is no conflict of interest.

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CHAPTER THIRTEEN

DEVELOPING ANTI-FUNGAL AND ANTI-BACTERIAL MORTAR USING ZINC OXIDE NANORODS

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Abstract

Fungal and bacterial growth are two factors primarily responsible for the degradation and breakdown of the surfaces of buildings and structures. Fungi, which cause molds in buildings, develop rapidly in humid places like Assam and can cause deadly diseases such as Histoplasmosis. Remedial measures for these molds are expensive and cumbersome. Bacteria can result in Sick Building Syndrome (SBS), which causes acute health problems in people living in these buildings. Bacteria mostly grow in the damp walls of hospitals and cause acute diseases in people, which is a worldwide problem in humid countries. Nanotechnology can be utilized to solve these problems to a great extent, providing relief to the world's population. Tests with Zinc Oxide (ZnO) Nanorods grown on prepared mortar samples using hydrothermal techniques revealed dense growth of Nanorods deep into the pores of the mortar samples on scanning electron micrographs. This anti-fungal and anti-bacterial study was done on the prepared Ordinary Portland cement mortar sample with fungus Aspergillus Niger and bacteria Escherichia coli (gram-negative) and microorganisms samples collected from local hospital buildings.

Key Words

Mortar, Zinc Oxide, Nano Rods, Aspergillus Niger, Escherichia Coli

Introduction

Nanotechnology has made significant advancements in almost all aspects of technology, including the construction industry in civil engineering. It has provided many benefits and possibilities to the construction sector. The use of nanotechnology has helped to produce stronger and more durable materials than conventional ones, like concrete, which occupies nearly 70% of the materials by volume in construction. Researchers have incorporated Nano-sized particles into concrete using appropriate methods in suitable proportions to improve compressive and flexural strengths at an early age, along with enhancing the pore structure of concrete. Nano-sized materials absorb less water and require less cement content than conventional concrete. Extensive studies have been conducted on the use of nanotechnology in civil engineering, and its possible effects (Redlich *et al.,* 1997). Research has shown that traditional construction materials, such as concrete and steel, can perform better when nanotechnology is applied. The use of metal/metal oxide nanoparticles and engineered nanoparticles, such as carbon nanotubes and carbon nanofibers, has resulted in achieving remarkable improvements in concrete strength, durability, sustainability, and environmentally responsive anti-corrosion coatings formed using Nanoencapsulation techniques, showing promise in laboratory settings (Yu and Crump 1998). Advancements in the development of novel materials and technologies have been observed in the field of nanotechnology and the

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world's construction industry. The obvious advantage of applying nanotechnology is to promote the use of more efficient nanomaterials to make building structures and infrastructures "smarter" (Pelczar *et al.,* 2001). A review has also been conducted on the knowledge of nanomaterials and nanotechnology used by the construction industry. The areas covered include the nanoscale analysis of Portland cement hydration products, the use of nanoparticles to increase the strength and durability of cementitious composites, the photocatalytic capacity of nanomaterials, and the risks of nontoxicity (Ananthnarayan and Paniker 2009). Fungal growth, bacterial growth, VOCs (volatile organic compounds), and formaldehyde are primarily responsible for the degradation of structures. Remedial measures are being taken using nanotechnology. These problems must be addressed appropriately; otherwise, they have a strong probability of resulting in Sick Building Syndrome (SBS). VOCs and formaldehyde, which originate from building and finishing materials and consumer products, can cause adverse health effects to building occupants and may contribute to symptoms of SBS when emitted continuously over prolonged periods. The demand for low-emission VOC products has increased. Studies have been conducted on the emission of VOCs from polymeric building materials, the level of emissions in the indoor environment, and the requirements for testing the materials (Crook and Burton 2010). Exposure to a large number of mold spores is attributed to symptoms of asthma, rhinitis, or bronchitis.

Some methods have been described that were used to investigate exposure to indoor mold contamination. Strategies for remediating mold-contaminated buildings were discussed, taking examples of the after-effects of flooding in the UK in 2007 and Hurricane Katrina in the USA in 2005 (Harold Zeliger, 2011). It has been observed that mucous membrane (nose, throat, and eye) irritation, skin symptoms, for example, itching, and sensory irritation (primarily odor) are some health issues that can occur due to SBS. SBS has its presence in office structures, warehouses, and homes. The association of SBS has also been observed with airborne biological and chemical components, including bioaerosols, volatile organic compounds released from building materials and furnishings, personal use products (e.g., perfumes), and environmental tobacco smoke (Torgal and Jalali, 2011). The sensation of dry mucous membranes, red skin, headaches, mental fatigue, nausea, and dizziness have also been observed to have a direct link with SBS. The World Health Organization has recognized SBS as a group of symptoms that occur due to exposure to building variables like indoor air quality, lighting, noise, and psychological factors (Monica *et al.,* 2013). Studies related to SBS suggested that on-site assessment had proved to be very useful. The patient and the building were both involved in the treatment. Initiation of works like reduction of sources of environmental contamination and ventilation improvements were highly recommended (Srikanth *et al.,* 2013). Researchers have compared the biological resistance of green and conventional building materials (BMs) before and after nano-metal treatment. They have also explored the best Nano-metals to improve the fungal growth resistance of building materials. It was observed that Nano-zinc was probably the most favorable Nano-metal for wood and wood composite materials. Green materials were less resistant to fungal attack relative to their conventional counterparts treated by Nano-metals. A few building materials were selected with specific proportions, and it was seen that all test Nano-metals failed to provide complete protection against fungal growth. However, it was concluded that the higher the Nano-metal concentration was, the longer the lag period until growth began, and fewer fungi grew on the materials (Huang *et al.,* 2013). Researchers have tried to establish an advantageous position in the field of nanotechnology. In this matter, a special mention should be given to China as it is the second-largest producer of research papers on nanotechnology. The first place belongs to the United States of America. It has been observed that a lot of emphasis has been given to the incorporation of nanotechnology in the construction sector (Pacheco-Torgal, 2019). Recent studies have focused on antimicrobial surfaces with functional material coatings, such as cationic polymers, metal coatings, and antifouling micro-/nanostructures. These studies provide insights into the development of virus-inactivating surfaces, which could be particularly useful in controlling the currently confronted pandemic coronavirus disease 2019 (COVID-19). Additional recent studies have been conducted on the beneficial role of zinc oxide nanoparticles in improving the performance of cement composites. Zinc oxide (ZnO) nanoparticles have unique optic, antimicrobial, and photocatalytic properties. These ultra-fine nanoparticles have a filler effect and have been found to impact the hydration reaction in the cement matrix, as well as impart photocatalytic properties in the cement structures. The impact of ZnO nanoparticles on setting time, microstructure, and strength has also been studied in detail in recent years. Studies reveal that with an optimized dosage of these nanoparticles, mortars and concrete with increased antimicrobial properties can be prepared, which provides an innovative pathway in the construction industry to build self-cleaning, durable, and eco-friendly structures.

Importance and Objectives

Experimental results show the possibility and prospect of using such treated and smart building materials or anti-fungal/anti-bacterial materials for the construction of structures. This will be particularly attractive for structures in humid areas, hospitals, etc., as it would be helpful and effective in increasing the longevity and performance of the structures.

Our study aims to find a unique preparation technique for the ZnO nano-rods-based mortar sample, which has not been done previously in any related study. Moreover, we will ascertain the performance of the prepared sample against specific microorganisms, which has not been done in any previous research.

Methodology

Materials and Methods

Bacterial growth is one of the factors primarily responsible for the degradation and breakdown of building surfaces. Hence, smart building materials are increasingly being used in the construction of structures nowadays. Tests with Zinc Oxide (ZnO) Nanorods grown on prepared mortar samples using the hydrothermal technique revealed a dense growth of Nanorods deep into the pores of the mortar samples in Scanning Electron Micrographs. These Nanorods exhibit anti-bacterial properties.

The steps adopted are described below:

(i) Firstly, samples of mortar (Figure 13.1) were prepared using cement and sand in a proportion of 1:2 and with a 0.45 water-cement ratio. 50 grams of cement and 100 grams of sand were used and cast using Le-Chatelier's apparatus. They were then cut into three equal pieces with the help of a hacksaw blade.

(ii) For the synthesis of ZnO Nanorods in the prepared samples, the seeding process was initiated. The samples were dried at 120°C for 15 minutes. In 250ml of distilled water, 1mM of Zinc Acetate (C4H6O4Zn) was added and stirred for 10 minutes at normal temperature. (Figure 13.2)

(iii) The heated samples were dipped for 1-2 minutes in the solution. Then they were dried at 120°C. This process was repeated 3 times. The samples were then annealed at 250°C for four hours.

After the seeding process, the Nanorod growth process was initiated. For this, equimolar solutions of Zinc Nitrate and Hexamine were prepared, where 10 mM Zinc Nitrate (ZnNO3) was added to 300 ml distilled water, and 10mM Hexamine or Hexamethylenetetramine (C6H12N4) was added to 300 ml of distilled water. Equimolar solutions of Zinc Nitrate and Hexamine were added to the mortar samples and heated for 5 hours in the oven at 250°C. After this, the Nanorods synthesized mortar samples were again heated at 250°C on a hot plate for 1 hour. Similarly, the same process has been followed for the growth of Nanorods for 30 hours.

Figure 13.1. Mortar sample

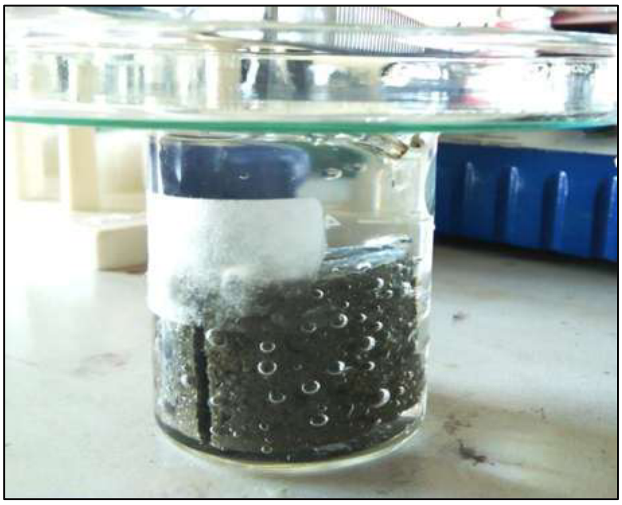

Figure 13.2. Immersed sample in 10 m Zinc Acetate Solution

Anti-Bacterial Test

The antibacterial test is carried out using two types of bacteria: Escherichia coli, commonly known as E.coli, and Streptococcus pneumoniae. E.coli and Streptococcus pneumoniae are the most common bacterial species and have therefore been selected for the experiment.

E.coli is a gram-negative bacteria commonly found in the lower intestine of warm-blooded organisms. They can cause food poisoning in their hosts and are expelled into the environment within fecal matter. They do not form spores (Rao *et al.,* 2014). Streptococcus pneumoniae is a gram-positive bacteria that resides colonizing in the respiratory tract, sinuses, and nasal cavity. It spreads from person to person via contact with the respiratory tract. It can also cause neonatal infections and is the main cause of pneumonia and meningitis in children and elders. Pneumonia is the most common and serious disease, which shows symptoms such as fever and chills, cough, rapid breathing, difficulty breathing, and chest pain. It affects the lungs. Pneumococcal meningitis is an infection that affects the brain and spinal cord and shows symptoms of a stiff neck, fever, headache, confusion, and photophobia. Sepsis caused by an overwhelming response to infection leads to tissue damage, organ failure, and even death. The symptoms of sepsis are confusion, shortness of breath, elevated heart rate, pain or discomfort, over-perspiration, fever, shivering, or feeling cold (Mendes and Teixeira, 2014).

E.Coli Treatment

Two 200 mL Luria Bertani Broth samples (one for the control sample and one for the Nano-synthesized sample) were prepared. The control and Nanorods-synthesized samples were immersed in the L.B. Broth samples in the beakers and sterilized using an autoclave process. In the incubation process, equal amounts of bacteria were added to the conical flasks after cooling down and then placed in a shaker for 24 to 48 hours (Figures 13.3 and 13.4). Afterward, the optical density (O.D.) values were measured using a colorimeter.

Before treatment, the samples were kept in the Luria Bertani broth samples and E. Coli bacteria was added to both beakers. After incubation for 48 hours, the sample with the Nano-synthesized sample is less turbid than the one with the non-treated sample. (Figure 13.5 and Figure 13.6). Results are shown in Figures 13.7 and 13.8.

Anti-Fungal Test

A series of experiments are performed successively for this test taking Aspergillus Niger fungus and Potato Dextrose Broth (PDB) as the media. A.Niger is the most common species and causes a disease called black mold on certain fruits and vegetables and acts as a common contaminant of


Figure 13.3. Incubation process


Figure 13.4. E.coli treatment


Figure 13.5. After incubation


Figure 13.6. Streptococcus treatment

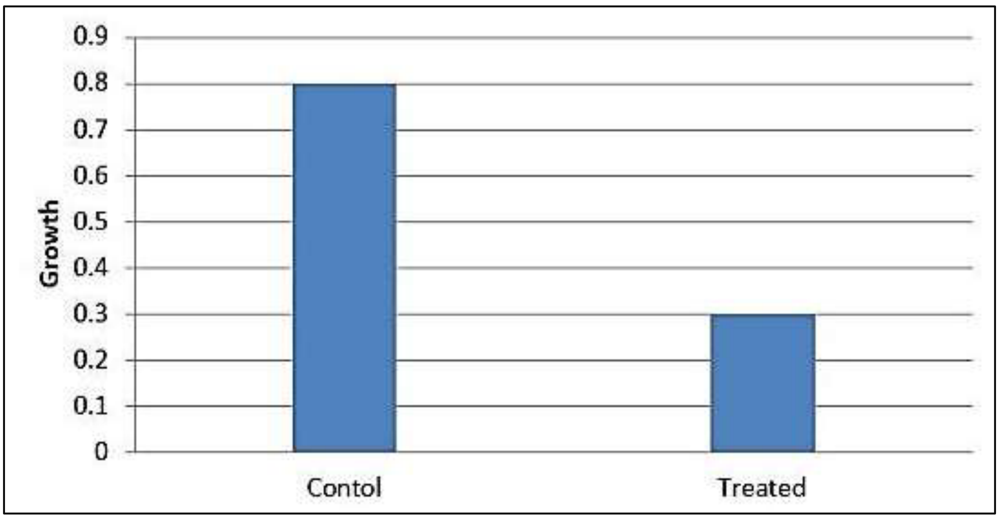

Figure 13.7. O.D. Results for E.Coli

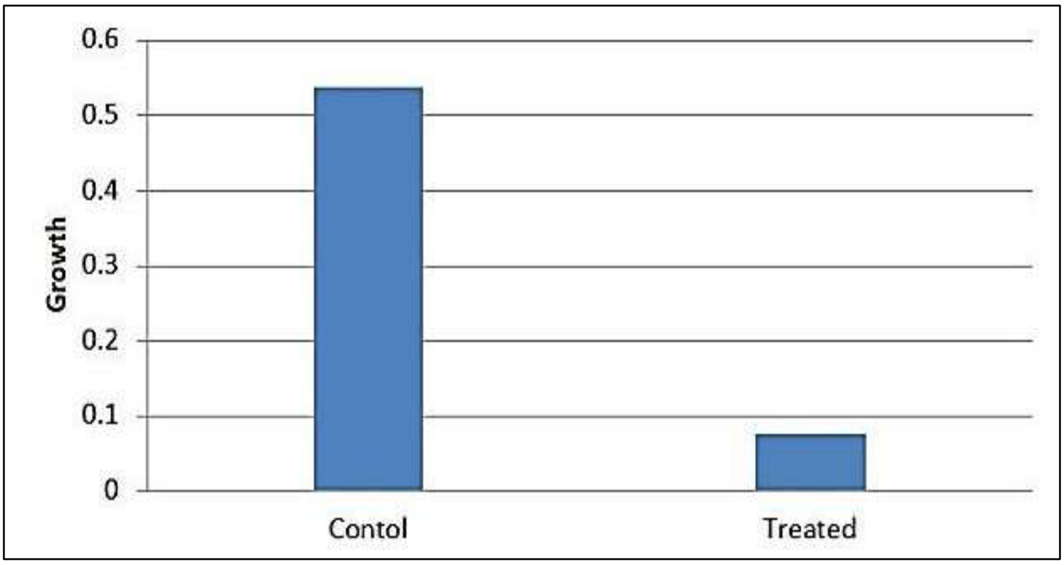

Figure 13.8. O.D. Results for S. pneumoniae

food. This fungus is pre-dominant in the walls of damped buildings and can easily affect the occupants. The ZnO nanorods were synthesized at 10mM concentration for 15 hours initially. The following are the steps taken for performing the test:

(i) 100ml of PDB samples are made in triplets (i.e, 3 treated samples, 3 untreated, and 3 control.) The media is prepped on 9 conical flasks. (Figure 13.9)
(ii) All the samples are autoclaved for 30min @121^{0}C to sterilize the samples.
(iii) The grown fungus on the agar plates is taken into 'laminar air flow' and is then transferred to a flacon tube and 10ml is weighted. Next, 1ml of liquid is poured (containing fungus) into 9 conical flasks 3 treated samples, 3 untreated, and 3 controlled. (Figure 13.10)

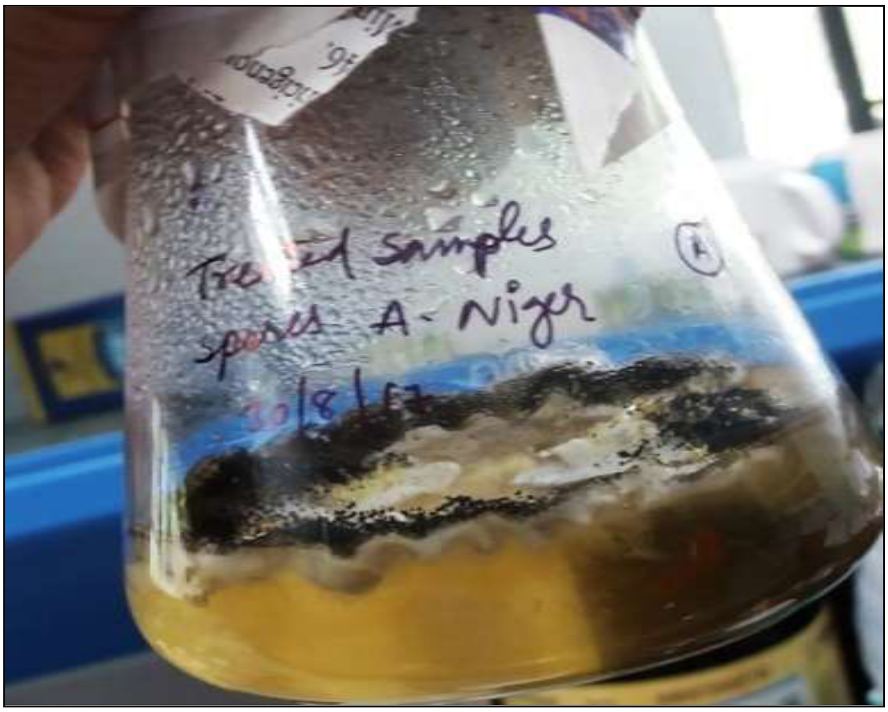

Figure 13.9. Fungal growth over a treated sample in PDB

Figure 13.10. Fungal growth over an untreated sample in PD

For spore counting, the aspergillus niger mycelia were extracted by using forceps and suspended in 14ml of autoclaved distilled water in a falcon tube. The solution is vertexed, mixed, and filtered using filter paper and 100µl of the filtrate was taken in a sterile Eppendorf tube and 10µl of lactophenol cotton blue was added to the Eppendorf. It is then observed under a hemocytometer by compound microscope. The spores are then mixed in a 2ml Eppendorf tube. From there 213µl solution is poured into each conical flask by using a micropipette.

Satisfactory results were not found on the first attempt. It has been seen that the treated as well as the untreated samples settled to the bottom of the conical flask due to gravity and the since the fungal growth is reliable even in anti-gravitational directional, it remained floating at the top of the conical flask, and the nanorods samples couldn't resist the growth of fungus.

Similarly, the successive experiment was carried out in agar triplets (Figure 13.11 to 13.13). This time the mortar samples were first placed and then sterilized agar solution was poured into them. It was then allowed to get thickened and solidified. 12.7ml of spore solution was prepared for 9 agar plates. The samples are then incubated for three days.

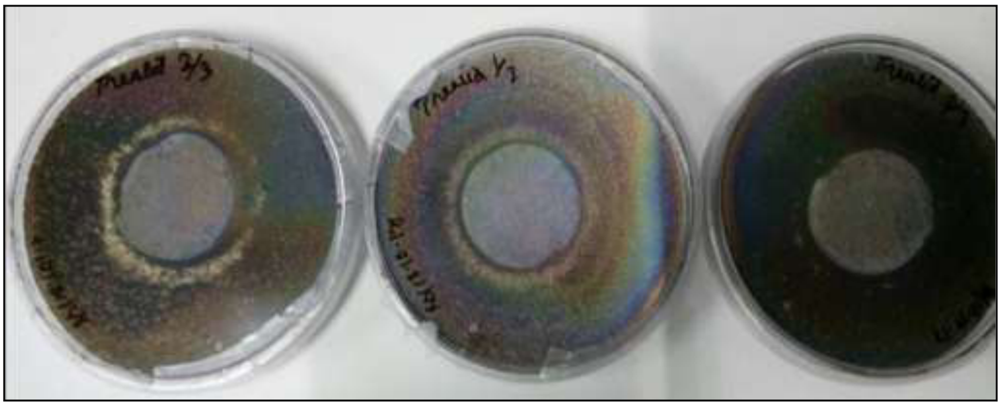

Figure 13.11. After the experiment treated samples in PDA

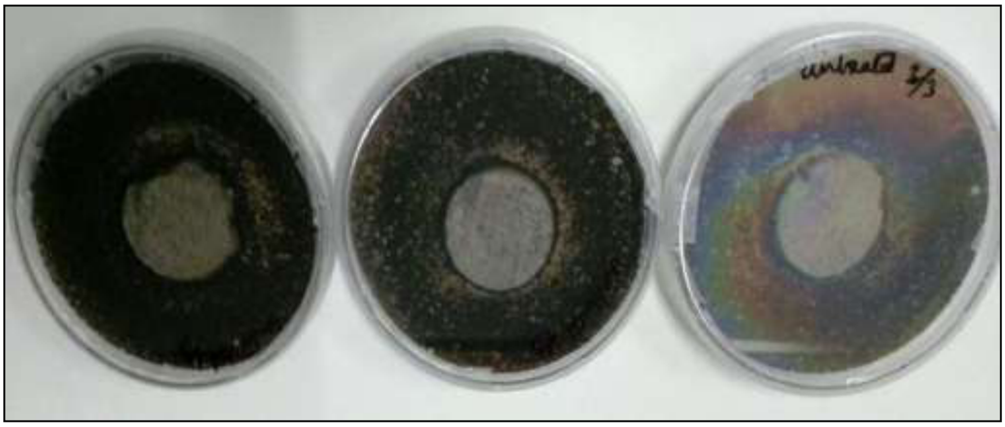

Figure 13.12: After the experiment untreated samples in PDA

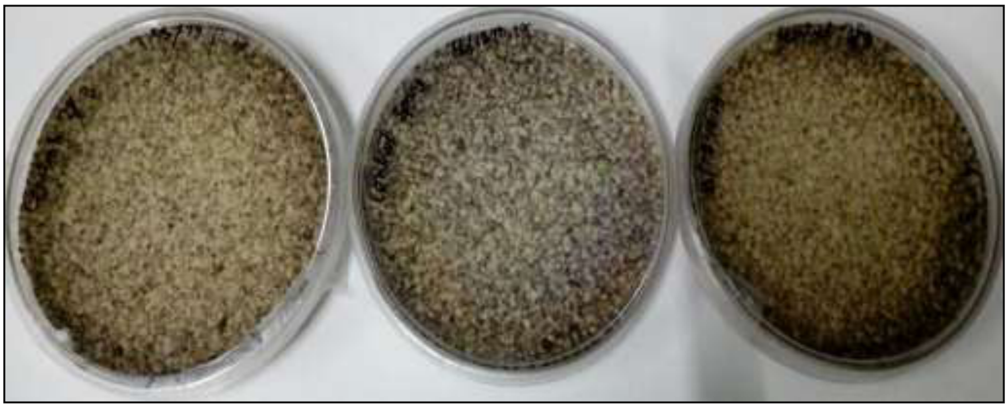

Figure 13.13. Controlled samples

The expected results were not very positive. The Aspergillus niger interaction has repeatedly come negative with a minimum concentration of fungal inoculum in the PDA medium. This one might be a very aggressive strain. Further, fungal experiments were carried out with fungal samples collected from local hospital buildings in North Lakhimpur, Assam. A total of 26 microbial colonies were obtained on PDA plates from three hospital buildings. Samples were collected by taking wall samples from these hospital buildings. The respective colonies were named in numbers. Two colonies were picked up. Experiments based upon their rapid growth pattern, fast sporulation, surface texture, and color. The colonies taken were colony numbers 18 and 26 (Figures 13.14 and 13.15).

Nanorods were grown on mortar samples strictly for 20 hours, changing the solution at 5-hour intervals. The experiment was carried out in triplicates with nano-treated and untreated samples in PDA plates. Since this experiment is focused on fungal growth and resistance, streptomycin antibiotic is used for bacterial treatments. Streptomycin is used mainly to kill any bacterial contamination in the fungal experiments to be performed so that only fungi can survive. It is a substance that exhibits antibiotic activity against gram-positive and gram-negative bacteria. It is water soluble and is effective against bacterial growth.

Figure 13.14. Colony number 18

Figure 13.15. Colony number 26

The spore counting for the respective colonies was done under a compound microscope using a hemocytometer. The spore counting for colony 18 was found to be 7.9×105 spores /ml and spore concentration was taken for 104 spores /ml (Figure 13.16). However, no spores for colony 26 have been seen when observed under a microscope (Figure 13.17). Since it has a glistening surface texture the spores are absent. So, an optimal amount of the sample was taken for test experiments. For the antibacterial streptomycin, a stock solution of 100mg/ml was prepared in autoclaved distilled water weighing 100mg of streptomycin in 1ml of water and filter sterilizing the solution. For performing the experiments the required working concentration was taken from the preserved stock solution.

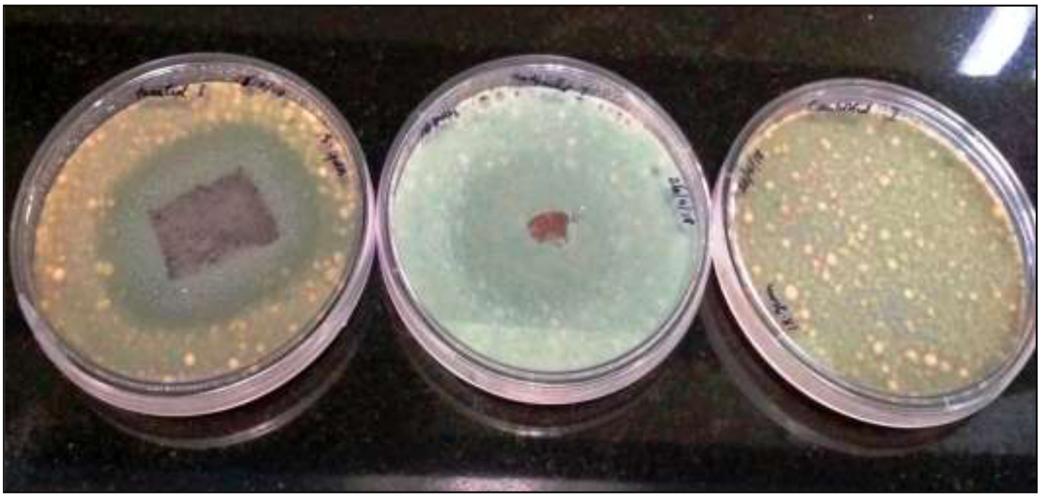

Figure 13.16. Experimental results with colony 18

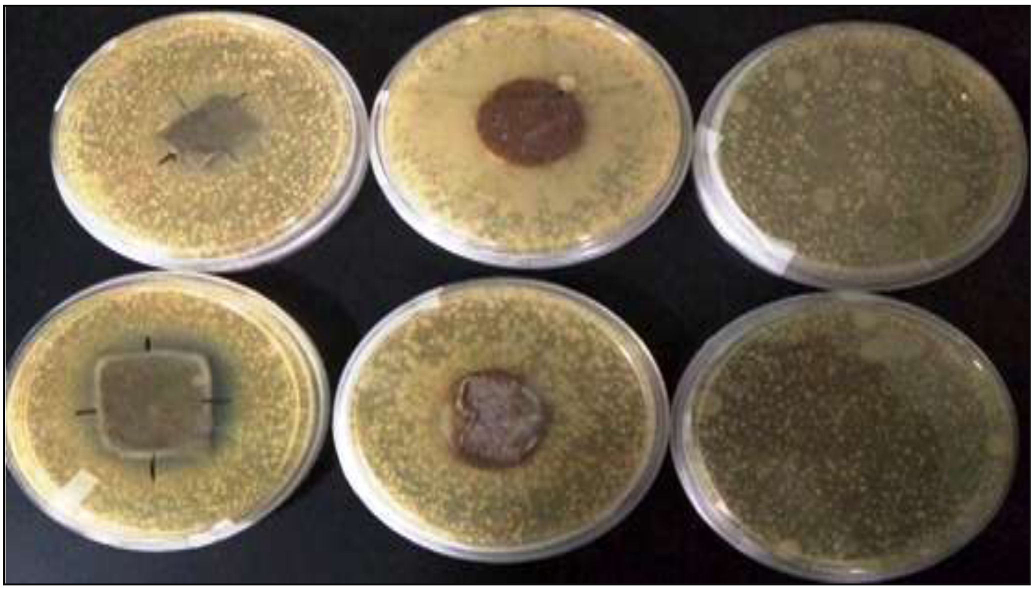

Figure 13.17. Experimental results with colony 26

Interpretation and Analysis

In the bacterial analysis, the growth of E. Coli and S. Pneumoniae has been inhibited by the Zinc Oxide nanorods coated samples. The optical density (OD) value obtained, in the case of E. Coli is 0.299 and 0.077 in the case of S. pneumoniae when observed under wavelength 600nm. The decreasing value of OD indicates lower microbial growth, indicating inhibiting their growth.

It was seen from experiments that out of the two microbial species taken for observation, Colony number 18 showed a clear zone of teal green around the mortar sample but did not show a clear zone of inhibition. The nanorods have likely to reduce the sporulation around the treated mortar sample. The untreated sample as shown above has been engulfed by the species. The complete zone of minimum sporulation is 5.7 in the circumferential area. Colony number 26 showed a zone of inhibition of area 0.45cm when measured from the edge of the sample.

The samples previously taken for experiments were examined with Scanning Electron Microscopy (SEM) and it was observed that the growth of zinc nanorods was not uniform and was not straight enough to directly act upon the microbial action (Figures 13.18 and 13.19). There might be two possible reasons. One, the time required for growth was not strictly followed as a lapse of half an hour came into intervention. Secondly, the required chemical composition might be quite low for the rods to grow up to certain nanometers, and maybe their resisting capacity was weaker. It was also reported that organic matter was present in the samples in large amounts.

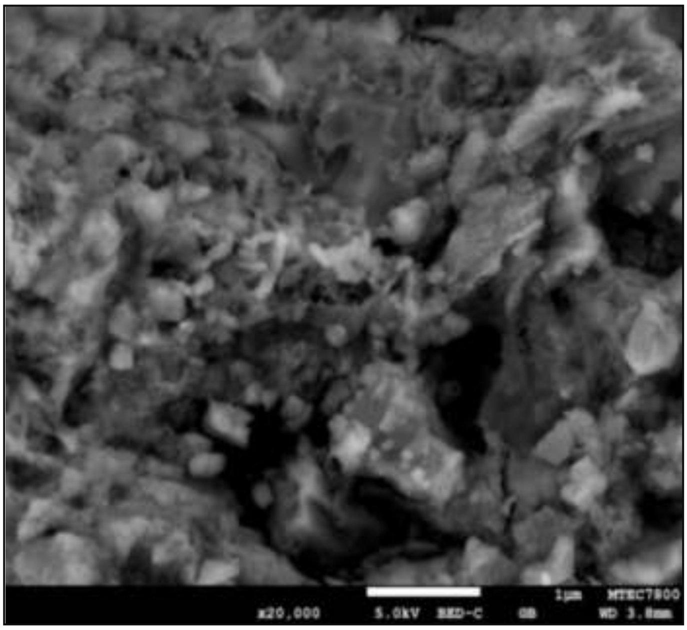

Figure 13.18. SEM image at 20,000x

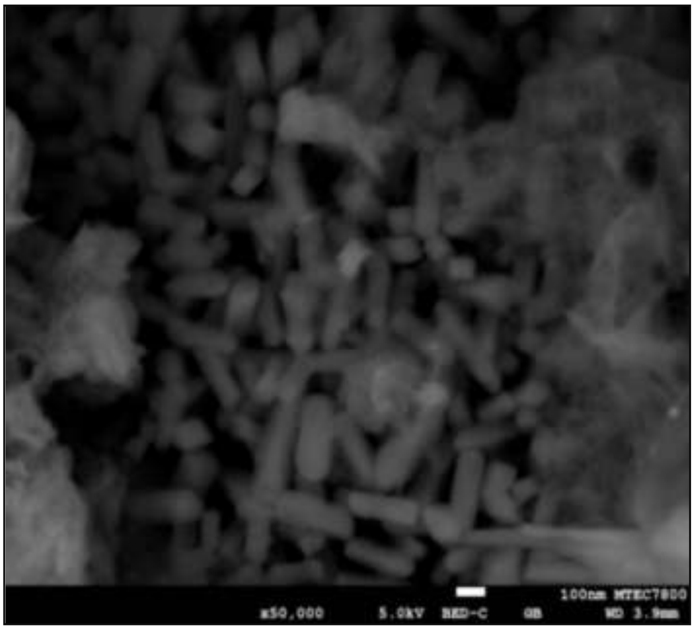

Figure 13.19. Nanorods at 50,000x

Figure 13.20. Mortar samples with reduced samples

The sample sizes and thickness has been reduced lately for the next experiments and this time the nanorods were synthesized at 20mM for 20 hours straight strictly maintaining the time variation and changing the solution every 5-hour interval (Figure 13.20). The rods were grown at 900C with the same chemicals used earlier, Zinc Nitrate and Hexamine solutions.

Conclusions

The test for anti-bacterial experiments was done with E.coli and Streptococcus pneumoniae. Experiments showed that the mortar samples with ZnO Nanorods possess anti-bacterial properties. This is evident from the decrease in the O.D. value of the bacterial cells in the Luria Bertani (L.B.) medium with time. The ZnO Nanorods embedded samples showed 63% and 85% anti-bacterial activity on E. coli and Streptococcus pneumoniae respectively. Mortar structures embedded with ZnO Nanorods offer promise as a possible anti-bacterial building material.

The test for anti-fungal properties of ZnO Nanorods was performed with fungal species which grow commonly on walls of buildings. The treated mortar samples were tested with Aspergillus Niger initially in triplicates. The test with A. niger was not successful. The test was performed on a conical flask, and it was observed that the mortar samples settled at the bottom of the conical flask due to gravity and the fungal biomass remained afloat at the top of the broth media. From Scanning Electron Microscope (SEM) images it was observed that too much of organic deposits were present on the surface of the mortar samples. The growths of Nanorods were nonuniform and were not in perpendicular alignment.

The fungal species collected from hospital buildings of North Lakhimpur district, Assam, were cultured. Out of the 26 colonies obtained, two colonies tested against the treated mortar samples using an anti-bacterial streptomycin solution to terminate the growth of bacterial species if in case present in the colonies, it was observed that colony number 18 showed a zone of minimum sporulation, insisting that Nanorods have reduced the rate of sporulation near the treated sample area and 26 showed zone of inhibition of area 0.45cm as measured from edges.

Limitations

The primary limitation of the work lies in the cost of preparation of the mortar sample with ZnO Nanorods grown on them. In this study, a small volume of samples was prepared. Whereas for large-scale production of the same sample proper research must be done in order to finally arrive at a manufacturing procedure which will also have to be cost-effective. Moreover, Nanotechnology is a comparatively costly area which ultimately leads to an increase in the price of the final product.

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Conflict of Interest Statement

The author declares that there is no conflict of interest.

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CHAPTER FOURTEEN

ROLE OF ROBOTICS AND AUTOMATION IN CONSTRUCTION SECTOR

RAKESH KUMAR[1]

Abstract

Construction is one of the major industries in the world. The construction industry is labor-intensive and performed in hazardous situations. Hence, the importance of Construction robots has developed rapidly. The research discovers the latest advances in robotics and sensor-based technologies that are leading developments in the construction sector to attain improvements in construction quality, efficiency, and safety. Although automation in construction was first introduced in the year 1980. It has seen little advancement in the level of application. The present study attempts to identify the recent developments in automated robotic systems and their scope in the construction sectors, namely with respect to construction robots. The application of robotic technologies in the construction industry has been known as one of the most challenging tasks. Automation in the construction industry can help to ensure production without compromising the quality of the construction products. This may be due to the fact that workers can become tired over time.

Key Words

Robot; Automation; Construction; Technology; Building

Introduction

One of the most unexplored research and development fields in the robotics and automation sector is the construction industry. It is one of the oldest and major industries. The economy of developed and developing countries are substantially influenced by the construction sectors. Up to 10% of the Gross domestic product (GDP) in developed nations and more than 25% in underdeveloped nations is contributed by the construction industry (Kim *et al.,* 2015). Construction work is labor intensive and is performed in perilous circumstances, also materials and the work content alter as often as possible. In recent years, innovation in robotics and automation technology has been developed progressively and applied to various industries directly or indirectly. The robot market is considered to be extensively large. However, the application of robotics and automation in the construction sector is much lower than in other industries such as manufacturing industries. This leads to both poor productivity and hazardous operating conditions. The application of Automation and robotics are the possibilities to resolve such problems in the construction industry (Bademosi *et al.,* 2019). Due to the rapid development of computer hardware and software in the past few decades, major enhancements may be found in robotic control, sensing, vision, localization, mapping, and planning modules (Kim *et al.,* 2015). In this regard, a variety of robot technologies have been developed and have been applied in actual construction sites. However, a great number of research topics still exist in the application of robotics technologies in the construction industry.

At the end of the 20th century, it was considered to be lagging behind the significance of

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automation and robotics technology development in the construction industry as compared to that of other industries. The main difficulty of robotics and automation in construction is related to on-site outdoor environment situations that are very unstructured. The manipulation of heavy sections, big tolerances, low level of standardization, medium level of industrialization and pre-fabrication, and involvement of numerous non-coordinated people (architects, builders, suppliers, etc.), etc. are other significant features of this sector (Bademosi *et al.,* 2019).

The research and development in automation and robotics in the field of construction have been divided into two categories i.e, hard robotics, and soft robotics. Japanese companies and universities pioneered Research and development activities in the field of robotics and automation in construction in the 90s, focusing on the development of a teleoperated robotic system in existing machinery automation.

This era of robotics and automation in construction research is known as hard robotics. These were used for interior building finishing, bricklayer masonry, modular industrialized building construction, road paver's sensor-based guidance, excavator's control, infrastructure inspection, tunnel, and bridge construction, etc.

After Japan's economic crisis, new research trends have been launched in the field of robotics and automation in construction. The research and development activities are focused on soft robotics. It defines not only software but also hardware, but not in the machinery sense. It includes on-site sensory data acquisition and processing, human operator field safety and security, chip-based process control, etc. (Balaguer 2004).

In the present study, an attempt has been taken to identify the benefits and recent developments in robotics and automation in the construction sector. In collective terms Construction involves the identification of requirements, project planning, design and engineering, construction, operation and maintenance, and decommissioning. The study explores technological interventions in the construction part of the all-inclusive classification.

Advances in Robotics and Automation in Construction

Robotics is a major part of automated construction. Robotics may be defined as the "science of designing, building, and applying robots" which aims to improve product quality and the life of workers in the industry through incorporating the "background knowledge, and mechanical creativeness, electrical, computer, industrial, and manufacturing engineering" (Jackson 1990). Autonomous machine used in automation in construction is the most common example. These are basically self-driving machines that can be used to transport materials across the work site and to haul heavy objects without posing a risk to employees.

Machine equipped with Robotic technology that allows forklifts, trucks, diggers, etc. operate without a driver. Many researchers stated that construction robots as intelligent machines operated by smart controls with varying sophistication levels and utilized by the industry to enhance speed and construction process precision (Buswell *et al.,* 2007).

Previous research activities have been shown to identify the benefits of implementing robotics, categorize the associated challenges and barriers, and develop solutions to overcome these problems. Aghimien *et al.,* conducted an extensive literature review on the implementation of robotics in construction (Aghimien *et al.,* 2019).

Seo *et al.* (2011) developed a robotic excavator to enhance quality productivity and safety; robots control and information system which is mostly related to research that focuses on the control systems and programming of robots to perform work independently and autonomously, in addition to integrating Building Information Modeling (BIM) and 3D manufacturing with robots (Seo *et al.,* 2011).

The application for automation in concrete floor finishing is shown in Figure 14.1. This robot was developed by the Japanese construction Kajima Corp in collaboration with four Singaporean institutions. The concrete floor finishing robot can reduce construction manpower and labor cost by 30% while enhancing construction quality and safety.

Further, Artificial intelligence is the latest technology and advancement in the field of the construction industry. Implementing this technology enables high accuracy and quicker construction, saving time, money, and other resources.

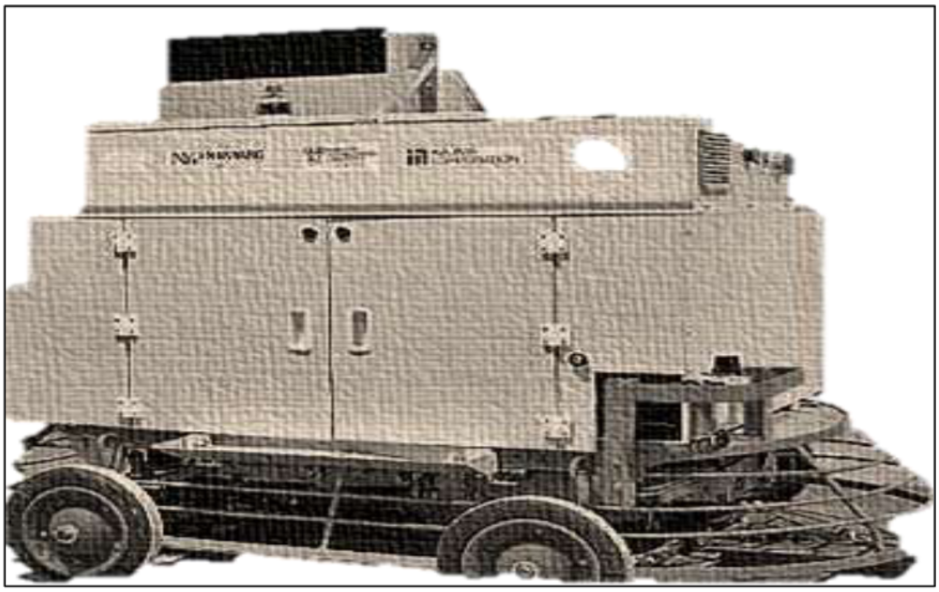

Figure 14.1. Concrete Floor Finishing Robot
(modified after https://www.constructionkenya.com/10841/concrete-finishing-robot)

Benefits of Robotics in Construction Sector

The requirement for robotics in the construction industry is vital for various reasons as it would yield different tangible and intangible benefits. Carra *et al.,* have discussed the reasons to use robotics in construction including the scarcity of building material resources (increase in cost while availability decreases), urbanization (construction within densely populated areas), aging workforce (increase in fatigue and injuries while trades suffer from a shortage of labor), enhanced connectivity and convergence (especially with workers becoming more familiar with technology and connectivity), environmental reasons (robots can be environmentally friendly and use green energy instead of electric power-strain systems), and safety purposes (reduce the number of accidents on construction sites) (Carra *et al.,* 2018). Therefore, various studies tended to research the benefits of using robotics in the construction industry. Banik and Barnes (2002) saw automating the construction industry as a solution for the shortage of skilled labor. Elattar (2008) considered implementing robotics as a solution to deal with the increase in construction demand due to the heavy migration into cities worldwide.

Löfgren has suggested the implementation of robotics as a financial investment with tangible benefits in the perspectives of efficiency, effectiveness, and performance (Löfgren 2006). Martinez *et al.,* have proposed that implementing robotics can increase productivity, increase cost savings, and enhance safety. Robots have the ability to increase production speed, eliminate human limitations, and reduce variability in operations, all of which reflect on the quality of the end product. Robotic operations can also help engineers better control the project, which can lead to faster problem findings and an increase in quality (Martinez 2008).

In addition, robots reduce the reliance on human labor and increase cost savings as they have the potential to reduce difficulties related to quality and rework. The decrease in dependency on humans can lead to a decrease in the number of human resources needed, which usually contribute to 30-50% of a total construction project cost. This saves cost and improves time performance and better end quality (Balaguer 2000; Dabirian *et al.,* 2016; Bakir and Balchi 2018). Also, Martinez *et al.,* have advised that safety can be improved, especially with the robot's ability to work in dangerous and hazardous regions (Martinez 2008). This strengthens previous studies that indicated that robots could decrease human needs in high-risk activities and the incidence of trauma disorders in activities that need repetitive motion (Tucker 1988; Demsetz 1990).

In automated construction, lasers are used for dimension analysis, computer-aided designs are used to promote design specifications, construction products are improved by ensuring required standards, and cost-effectiveness is achieved by maximizing the value for money. Material wastage can be eliminated due to accurate and precise estimates of material requirements. Construction accidents can be reduced due to the use of the machine during hazardous construction activities, working conditions can be improved as workers are more secure and safety is guaranteed and labor costs can be reduced due to the deployment of machinery.

Barriers to Robotics in Construction

Due to high capital costs, there is a shortage of investment in heavy machinery and mechanized construction systems, which could impede the process of industrialization (Rahman and Omar 2006). Stewart *et al.,* 2004 documented the challenges of implementing information technology (IT) for robotics (Stewart 2004). The significance of these challenges depends on the fact that automating construction, especially by using robotics, will be heavily dependent on the use and expansion of IT across the construction sector. The researchers studied the challenges in a top-down effect that starts from the industry, then the organization, and down to the project. At an industry level, challenges comprised client leadership deficiency, poor operability between applications and organizations, the disintegration of the industry, and the little unveiling of IT. The challenges at the level of the organization comprised of limited resources mainly for medium and small enterprises, traditional business practices and resistance to change, and redundancy for IT investments. Fear of change, low technology, project time tightness, and security concerns were some challenges enumerated by the study at the project level.

Mahbub 2008, categorized the challenges into five classes:

(i) Economic and cost comprise the high cost of investment and implementation, high-risk investments, and high costs of holding and consuming.
(ii) The structure and organization of the industry barriers include the need for compatibility between robotics and existing design, management capabilities, labor practices, and site operations.
(iii) Construction product and work processes challenges comprise the complexity and standardization of construction products, and local conditions like weather, labor supply, and building codes.
(iv) Technology barriers include the nature of construction projects and layout, causing robots to be robust and flexible with high mobility and versatility.
(v) Cultural and Human Factor barriers call for a requirement of new people with experience in handling robots.

Robots may also be a threat to workers because it is a one-time investment that pays itself and doesn't need workers, wages, or healthcare. The author identified that the problems associated with the construction industry such as decreasing quality and productivity, labor shortages, occupational safety, and inferior working situation have highlighted the need for an innovative solution within the industry, including the push for further use of industrialization and construction automation and robotics application on-site (Mahbub 2012). The study also revealed the harsh working environment of the construction site and the risk of a cyber breach and the low awareness level of technology. Other social issues also affect the implementation of robotics (Burke, 2015; IRRSS 2015; Ruggiero *et al.,* 2016). Struková and Líška (2012) conducted a survey to rank problems against robotics. Contractors reflected "high acquiring, maintenance and updating costs" as the biggest challenges, followed by local unavailability and difficulty to acquire, incompatibility with current practices and construction operations, not considered effective in construction sites, low workforce awareness, difficulty in handling robots, and finally rejection from workers and/or management. However, Benefits such as productivity, quality, communication, innovation, and safety can result in rewarding long-term benefits at the organizational level.

Mahbub has studied "Framework on the Barriers to the Implementation of Automation and Robotics in the Construction industry" (Mahbub 2015). By examining and constructing the barrier variables, the liaison between features of the construction industry and the qualities of existing technologies and basing the schemes on data from three nations Japan, Australia, and Malaysia. The research's goal was to identify and elucidate the barriers to the application of construction automation and robots. The results and conclusions of the research, including the ranking schemes developed for the four primary categories of construction attributes on the degree of usage, barrier variables, different levels of usage between nations, and future trends, have identified a number of possible areas for further research that may have an impact on the level of implementation both globally and for specific countries.

Effects of Robotics and Automation on Construction

Unemployment and increased total cost are the main two impacts of the implementation of robotics and automation in construction. It was seen that the greatly applied automated method in the construction industry has annoyed a significant number of workers from this industry.

Kaplinski *et al.,* suggested that robotics and automation considerably rise work efficiency, with upgrading in working situations and safety of the workforce and enhancement in the quality of work done (Struková and Líška 2012). The other impacts of automation and robotics in the construction industry are:

Reduced Labour cost: The usage of robotics in the construction industry is the replacement of labor. This drops the cost associated with labor such as labor wages, health insurance, and benefits. This ultimately reduces the risk of labor accidents and hence improves work conditions and lowers the insurance cost while accelerating productivity (Kapliński *et al.,* 2013).

Increased Productivity: The use of robotics in construction has increased productivity due to the replacement of labor. Robots can do more work in a day as compared to a human. However, Human fatigue plays a negative role in productivity in construction.

Robotics can produce and reproduce building components very rapidly and maintain constant productivity which reduces loss. High productivity of the product can be analyzed by software such as computer-aided design and computer-aided manufacturing (Xia *et al.,* 2019; Yang *et al.,* 2019; Manley 2018).

Robotics have high accuracy as compared to a human. The amalgamation of robotics technology excludes the possibility of human errors, delivering highly precise results.

Recommendations for Robotics

There is a need to overcome the various barriers that are described by researchers for the successful implementation of robotics and automation in the civil infrastructure sector. These challenges mostly centered around the short-term investment of commissioning robotics, confrontation for conversion from organizations, and the nature of the civil infrastructure projects. The study documented that automation helps in reduced labor charges, increased productivity, reduced accidents, cost-effectiveness, material saving, improved working situations, and increased accuracy (Bohner *et al.,* 2019).

The author suggested the crucial recommendation for three different aspects: Organisation which encompasses management and processes, People which incorporates engineers, working labor, administrative staff on and off construction sites, and technology.

The researchers recommended that the genetic algorithm is the most dominant approach in tackling the scheduling challenge and the applicability of the genetic algorithm to various aspects of managing a project schedule, cost, and quality (Oke *et al.,* 2019).

Figure 14.2 depicts an overview of the conceptual framework for automation and robotics implementation in the construction industry as proposed by (Mahbub 2015). In terms of laying the foundation for research on the widespread use of construction automation and robotics technologies, the contributions made through the ranking of the important categories defined within the four areas were realized.

Since the schemes may be used to establish whether a country is more likely to utilize the technologies based on the characteristics of the construction sector, they can be used to determine the potential of any country in terms of adopting the technologies.

The implementation hurdles for a nation that is deemed to be likely to adopt the technology but has not yet done so might be investigated. Some experts think that some countries don't get the most effective solutions to their problems with labor or construction by using new, innovative technologies.

This is especially true if the costs of these technologies are high. If there is a place where using technology can give you an edge, then future trends can help predict what might happen in that area.

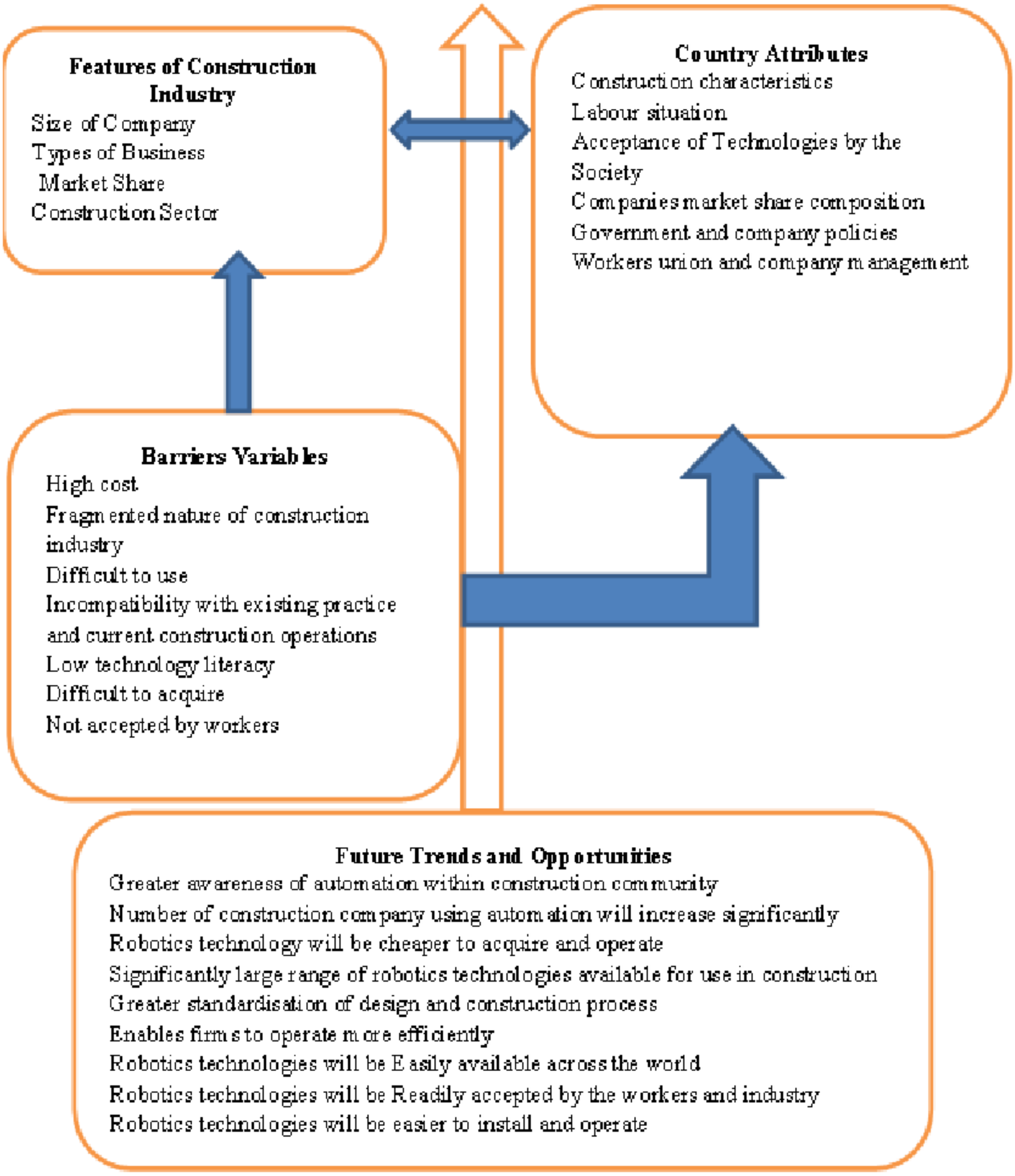

Figure 14.2. Conceptual framework on automation and robotics implementation in the construction sector

Conclusions

In this study, attention is given to the application of robotics and automation in the construction sector. The implementation and incorporation of automation and robotics, and therefore the extensive use may be the best opportunities for the construction industry to bloom in the coming future. The major impact of using robotics and automation in the construction industry will have improved project performance, improved work quality, time-saving, improved working situations, improved safety, and high productivity. This paper reviewed various investigations done on barriers and challenges and the benefits of robotics and automation in the construction sector. The associated challenges with the construction sector, such as declining quality and productivity, labor scarcities, industrial safety, and inferior working situation, have highlighted the requirement for innovative resolutions that impulse further usage of automation and robotics in construction on site. In spite of the various challenges, research is being conducted on various applications in construction and tasks in an effort to gradually move from traditional industry practices into the new era of automation. However, automation or automated machines may be a substitute for workers, thus reducing fatality. Also, the generated dust from the construction sector frequently leads to deadly diseases like tuberculosis and other respiratory complications thus hampering work. Construction stakeholders should be prepared to take financial threats in implementing the usage of construction automation and robotics for the gains. Further, studies can be carried out on the various scope of applying automation and robotics in the civil infrastructure sector.

Conflict of Interest Statement

The author declares that there is no conflict of interest.

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CHAPTER FIFTEEN

OPTIMISING BUILDING CONSTRUCTIONS AND CONDENSATION DETECTION IN AN ENCLOSED SPACE USING NUMERICAL STRATEGY

SHANTANU DUTTA[1]

Abstract

The primary function of a construction building is to ensure operational comfort to the dwelling people and nevertheless to provide safety and thermal comfort to the maximum extent. In Rajasthan and Gujarat which are very hot states of India, and where moisture is less, there are a lot of dwellings that are primarily built with exterior cavity walls which control heating and moisture. These double walls provide stability to the structure and separate the controlled indoor climate from the outdoor fluctuating environment. In this paper, we will present the thermodynamical evolution of moist air in a room with the aim of detecting whether saturation occurs when the external environment's properties change. The model uses meteorological data for the air temperature, pressure, and relative humidity, measured at Dum Dum Kolkata(less moisture-prone zone) and Dibrugarh station(more moisture-prone zone). The property data correspond to high conditions of dew point temperature and the average conditions of dry bulb temperature as observed on the 1st of June 2022.

Key Words

Room Enclosure; Building Construction; Heat Transfer; COMSOL Multiphysics

Introduction

Many systems, for example, food components kept inside in an open room, risk being deteriorated if there is exposure to condensation. When there is a definite amount of moisture in the air, saturation will definitely take place when the temperature goes on decreasing and reaches or touches the dew point, and condensation may occur on surfaces. Practical experimentations and obviously easy and reliable computer simulations can lead us for obtaining knowledge pertinent to avoiding the creation and generation of more than acceptable condensation. Further while working on the comfort and thermal parameters of building insulations special care is to be taken for several internal and external weather influences.

As we all know that an insulation material for a building material needs to be tested for 8-20 years. The subsequent numerical procedure might help in building insulation as it might allow us in detecting the condensation process beforehand and this way it can provide a boon to prevent several thermal and comfort problems as well as create an enabling environment for the spread of microorganisms that thrive in a moist environment.

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Antonyová and Antony, 2013 in their experimental research article presented testing reliability of building polystyrene insulation considering 1680 points by resorting to statistical analysis and pointed out that the humidity in the enclosure space between the wall and insulation is linearly dependent on the factors temperature (T) and time (t) and pointed out that it also depends between the space between the wall and insulation.

The authors also pointed out the fact that the temperature in the enclosure between the insulations and room walls is again a function of linear dependency of temperature (T) and time(t) outside the ambient surrounding of the building as well. Lucuik *et al.,*2006 in their paper presented an environmental "payback" associated with differing operational differences between the various roof insulation options, and the development of the operational environmental effects of these different options. In another paper concerning heat transfer in buildings Balaji *et al.* (2014) provide an appreciation of building-material thermal performance primarily depending on the lines of microstructure.

The authors proposed that the constituent pores and particles of constituent building materials are important parameters that influence how a building envelope regulates indoor thermal comfort. With a large increase in population in Europe and Asia, there has been a vast increase in commercial buildings and office space and there is an urgent need for stringent designing and performance monitoring of innovative building arrangements, structure shapes, and techniques.

Numerous documentation on heat transfer in enclosures with different geometry and porous materials frequently used in building construction has been done in the past and are well documented earlier (Dutta *et al.,* 2018, Dutta *et al.,* 2021, Dutta *et al.,* 2019, Dutta and Biswas, 2018; Dutta and Biswas, 2019).

In this context, there is a requirement for more knowledge of heat and moisture transport through building structures and joints as reported by De Wit,2009. On the other hand, there is also an urgent requirement of building construction houses in lines of climate-responsive design and construction as well which will moderate the climate for human good and well-being, as was reported in Hyde 2013.

Motivation and Objective

From the following literature survey, it is observed(though not exhaustive) we find that a detailed investigation of the building envelope needs to be done for understanding the thermal, moisture, and condensation characteristics of individual materials/elements. The manuscript presents a figure (Figure 15.1) the overview which can be considered for the thermal performance of a typical building envelope.

In this following research paper, we present the thermodynamical evolution of moist air in a 2D square room enclosure with the primary purpose of comprehending whether saturation occurs when the extraneous environmental property states alter.

The model uses meteorological data for the air, its temperature, its pressure, and relative humidity measured at Dum Dum Kolkata(less moisture-prone zone) and Dibrugarh station (more moisture-prone zone).

The property data correspond to high conditions of dew point temperature and the average conditions of dry bulb temperature as observed on the 1st of June 2022. The following assumptions are taken into consideration before we proceed with the presentation of results by numerical finite element COMSOL, Multiphysics, 1998 simulations.

The salient points are as follows:

- The water vapor concentration is considered homogeneous inside the square 2 D enclosure such that it is an outside concentration.
- Also, the simulations consider disregarding diffusion but take into consideration the outside concentration variation during the numerical investigation and simulation mode.
- In this simulation, we try to assume that the moist air concentration inside the box is closely matching the external concentration.

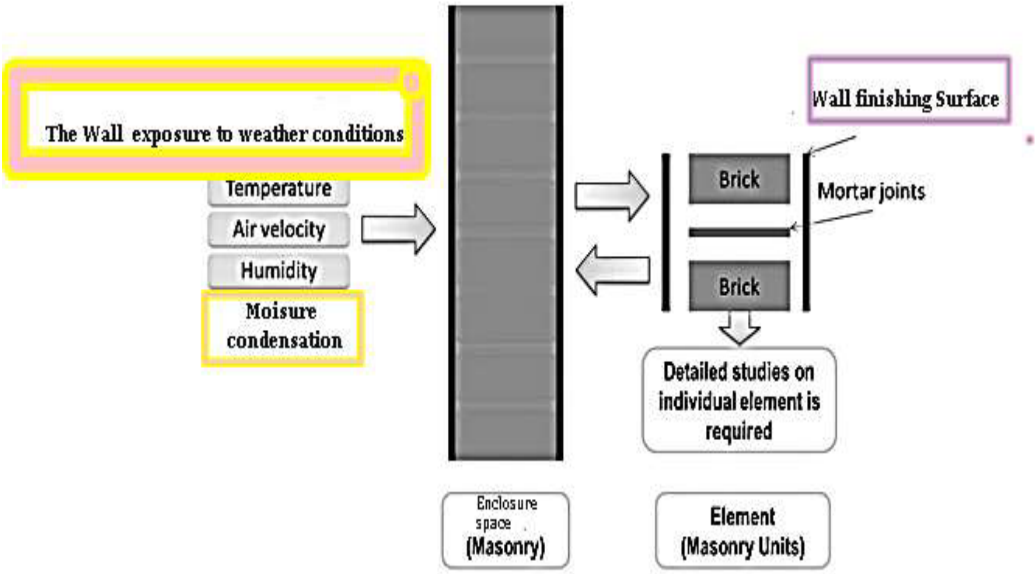


Figure 15.1. Thermal performance monitoring in line with the building envelope (Modified from Balaji *et al.* 2014)

Model Description

A square enclosure section (assumed to be a section of a room) having a dimension of 50 cm is carefully positioned in the air (having misty nature) environment. The enclosure has a rectangular heating element at the bottom of the room along with two very small opening cut-outs (thickness ≤ 1mm) positioned in the enclosure at vertical wall (LH and RH) sides (as shown in Figure 15.2). The two-dimensional numerical investigations are carried out accordingly, considering the fact that the enclosure has a sufficiently long length along the orthogonal side of the dimensional direction. It is made of aluminum (1050) and the heating section is made of Silicon, as adopted from COMSOL Multiphysics library (Aspnes and Studna 1983).

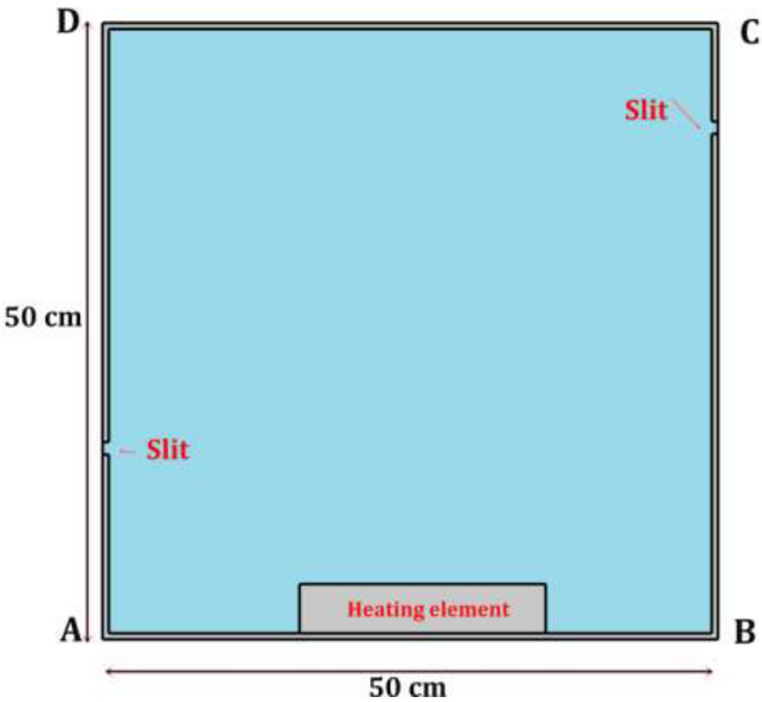


Figure 15.2: 2 D schematic of the room enclosure

We can observe clearly that the 2-D enclosure in Figure 15.2 virtually simulates a section of the room. The simulation takes into account the wall temperature fluctuations in an unsteady moist dynamic environmental situation. This means that during the simulation, temperature and relative humidity change along the walls of the room over a 24-hour period. Outside the 2 D section of the room, we consider the fact that there is an external cooling condition application with a heat transfer (convective in nature) coefficient =50 W/(m^2·K) and an obviously a temperature(varying with time)which closely manifests to the ambient temperature. The main enclosure opening of slitting boundaries is set to a BC of open type nature, which means it allows passage of air (moist)in a free manner through it by entering or exiting from the enclosure room wall.

Mathematical Formulations

The time-dependent fluid properties are modelled as per the following equations.

$$\rho\frac{\partial u}{\partial t}+\rho(u.\nabla)u=\nabla.[-pI+K]+F+\rho g \tag{1}$$

$$\frac{\partial \rho}{\partial t}+\nabla.(\rho u)=0 \tag{2}$$

$$K=\mu(\nabla u+(\nabla u)^{T})-\frac{2}{3}\mu(\nabla.u)I \tag{3}$$

The time-dependent heat transfer equations applicable to moist air can be represented as follow:

$$d_z\rho C_p\frac{\partial T}{\partial t}+d_z\rho C_p u.\nabla T+\nabla.q=d_zQ+q_{0_0}+d_zQ_p+d_zQ_{vd} \tag{4}$$

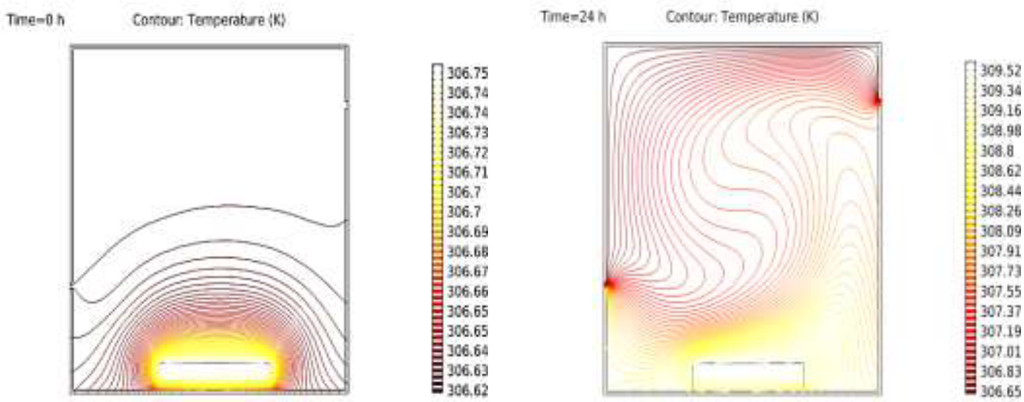
$$q=d_z k\nabla T \tag{5}$$

$$\left.\begin{aligned}\rho&=f(\rho_a;\rho_v;p_A;T;c_v)\\ C_p&=f(C_{p,a};C_{p,v};T;p_a;c_v)\\ k&=f(k_a;k_v;p_A;T;c_v)\end{aligned}\right\} \tag{6}$$

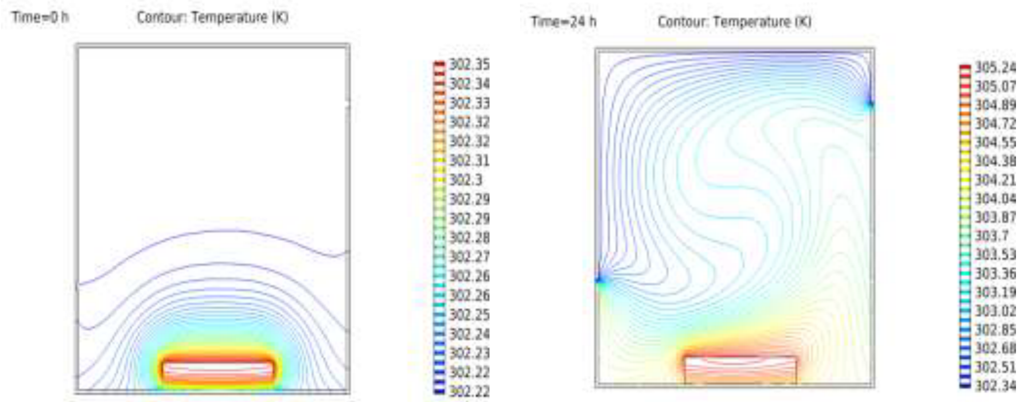
The definition of abbreviated symbols can be referred to as COMSOL Multiphysics and also in the Heat Transfer Module of COMSOL Multiphysics.

Results and Discussion

Let us now present the results and discussion. We represent the isothermal contours, relative humidity, and velocity contours for Dum Dum Kolkata (less moisture-prone zone) and Dibrugarh station (more moisture-prone zone) in Figures 15.3 to 15.6.

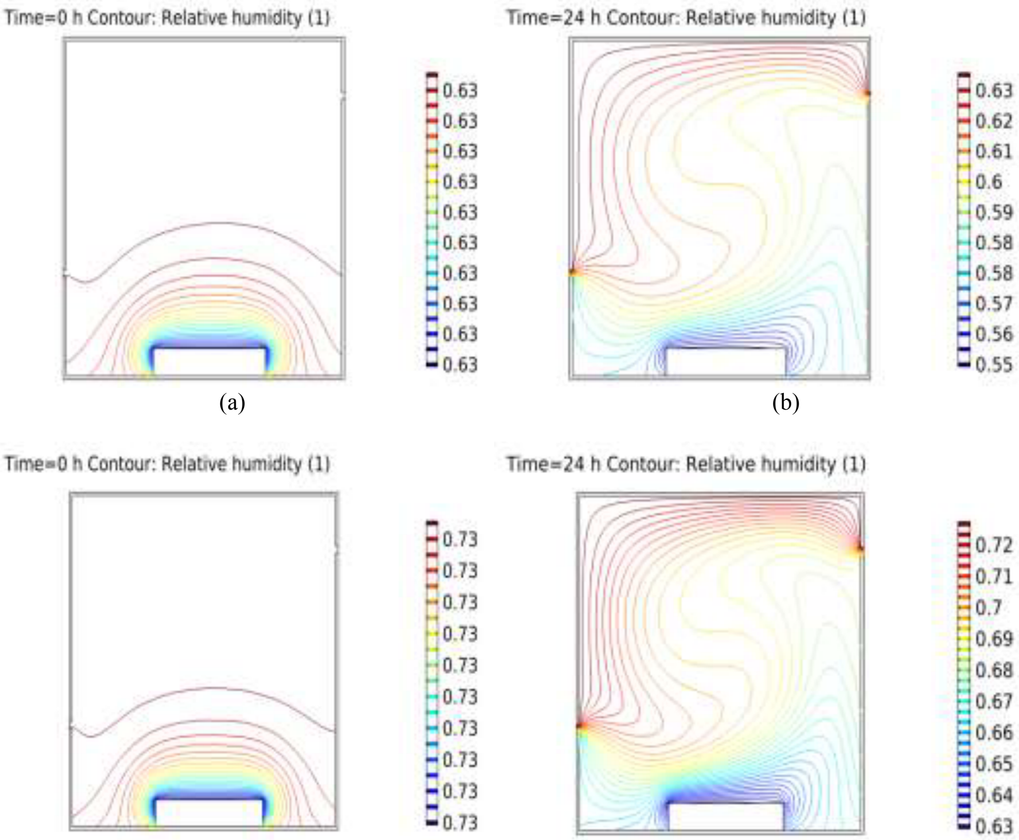


(a) (b)



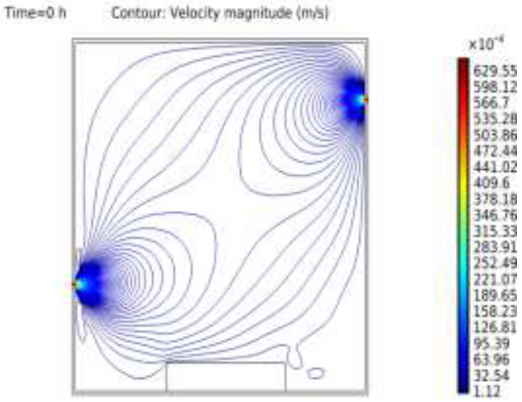
(c) (d)

Figure 15.3. Isothermal contour plots as per meteorological data for the air temperature, and pressure, measured at (a-b) Dum Dum, Kolkata, West Bengal station (c-d) Dibrugarh (Assam) station.

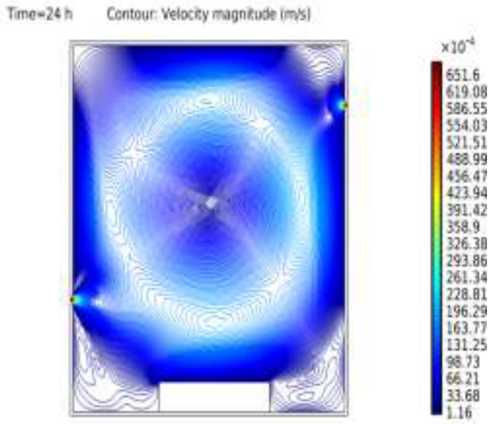


(c) (d)

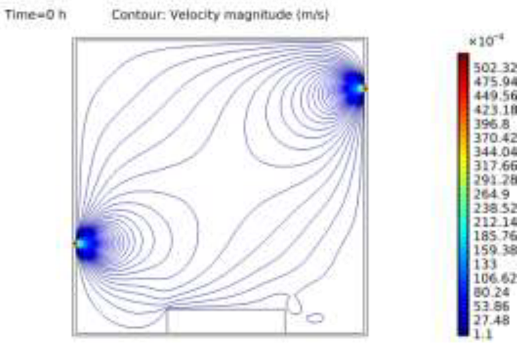
Figure 15.4. Relative humidity plots as per meteorological data for the relative humidity, measured at (a-b) Dum Dum, Kolkata, West Bengal station and (c-d) Dibrugarh, Assam station.



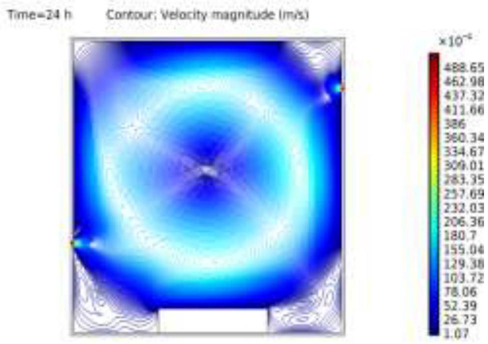
(a)



(b)

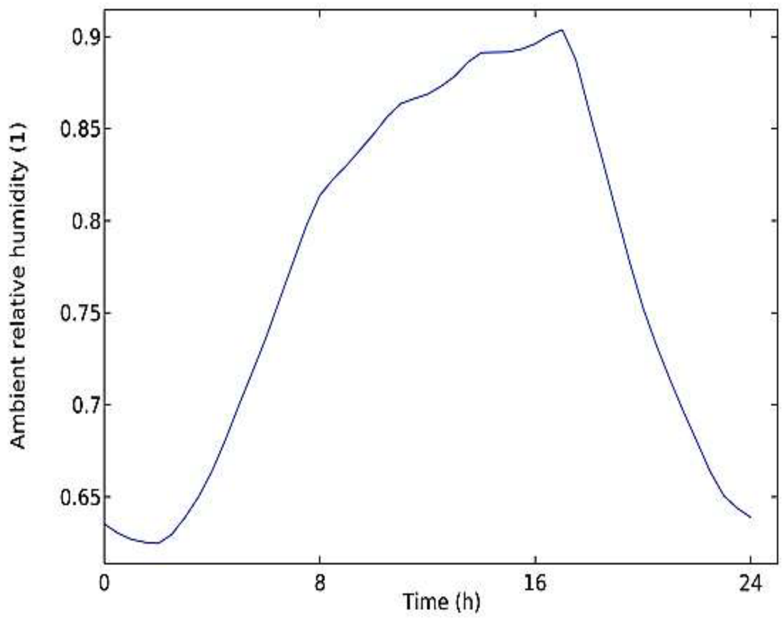


(c)

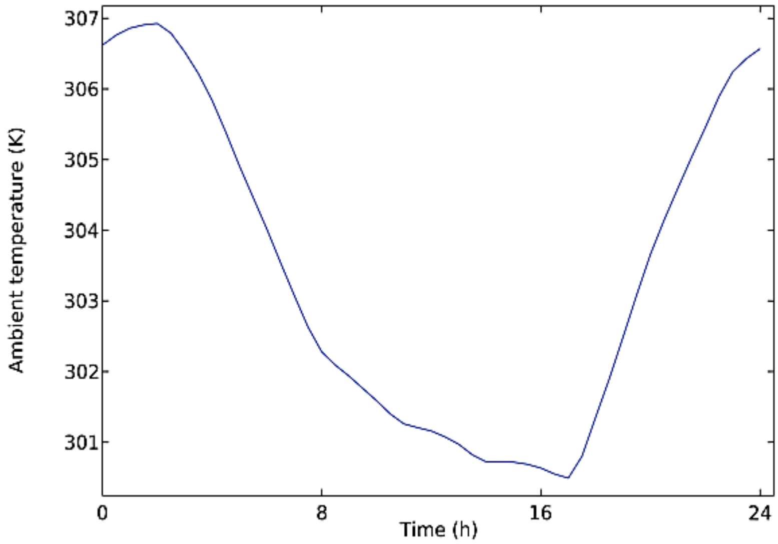


(d)

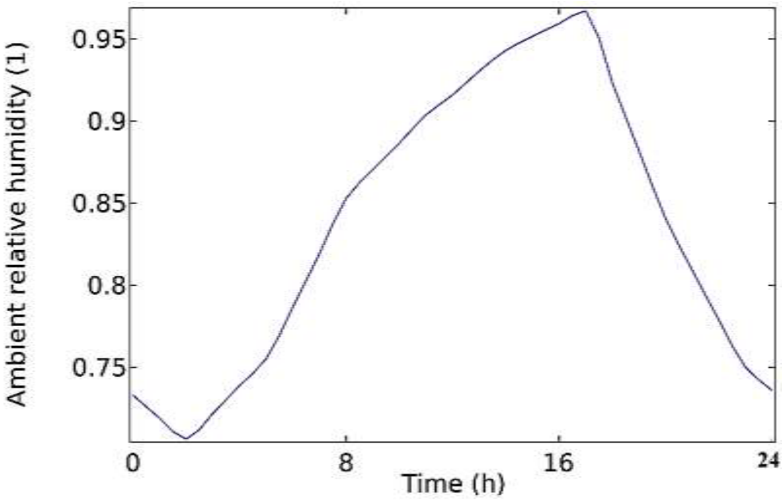
Figure 15.5. Velocity contour plots as per meteorological data measured at (a-b) Dum Dum, Kolkata, West Bengal station and (c-d) Dibrugarh, Assam station.



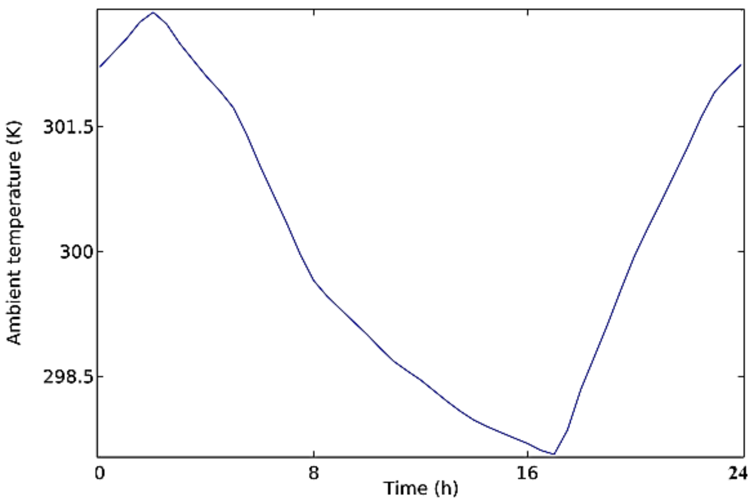
(a)



(b)



(c)



(d)

Figure 15.6. Time variation of ambient relative humidity and ambient temperature as per meteorological data measured at (a-b) Dum Dum, Kolkata, West Bengal station (c-d) Dibrugarh, Assam station.

The numerical model is developed in such a manner that it presents the numerical result over a period of 24 hours and the numerical results can be capable of storage (every ½ an hour). The goal is to observe if some saturation appears to detect the risk of condensation. Suitable validations could not be undertaken because of the dearth of similar work in literature.

Figure 15.3 (a-b) shows the isothermal contour plots measured at the 0th hour and 24th hour time period respectively for Dum Dum Airport, Kolkata, West Bengal station and Figure 15.3(c-d) shows the isothermal contour plots measured at the 0th hour and 24th hour time period respectively for Dibrugarh, Assam station respectively. Qualitatively they do not vary too much but the numerical values are more for Dum Dum Airport Kolkata station as compared to Dibrugarh station because of its inherent latitude longitude and geographical location which is quite evident.

It is quite evident that we cannot distinguish much from the aspect of gradients of temperature from the results for Dum Dum Airport Kolkata station and Dibrugarh station, but definitely, the isothermal contours do get affected for both the cases because of natural convection and heating effects and from the enclosure wall, because there is a dissipation of power from the heating source. Cold air enters through the slits by convection. In addition, the air inside the building is also cooled by conduction through the building walls.

Figure 15.4 (a-b) shows the relative humidity contour plots measured at the 0th hour and 24th hour time period respectively for Dum Dum station and Figure 15.4 (c-d) shows the relative humidity contour plots measured at the 0th hour and 24th hour time period respectively for Dibrugarh (Assam) station respectively. Qualitatively they also do not vary too much but the numerical values are more for Dibrugarh station as compared to Dum Dum station because rainfall is more at Dibrugarh geographical location which proves the fact from geographical data as well. The results and atmospheric conditions, it justifies the fact that the parameter of relative humidity attains a maximum value when the cold temperature prevails (lowest value) with a maximum concentration of vapor in moist air. The saturation threshold (where relative humidity=1), is not reached even after a 24 hour simulation period for both these cases, meaning that saturation has not occurred, with minimal risk of condensation inside the building block walls and inside surface which is a pertinent observation for this research done. Thus here we do not require the Boolean saturation indicator for this present simulation for denoting the true saturation values.

Figure 15.5 (a-b) shows the velocity contour plots measured at the 0th hour and 24th hour time period respectively for Dum Dum station and Figure 15.5(c-d) shows the velocity contour plots measured at the 0th hour and 24th hour time period respectively for Dibrugarh station, respectively. The maximum values obtained are more for Dum Dum station as evident from the numerical simulations.

Figure 15.6 (a-d) represents the evolution of the ambient relative humidity and ambient temperature on the basis of meteorological data measured at Dum Dum and Dibrugarh stations inside the 2D building room for the 24 hour period. It is observed that maximum relative humidity is more for Dibrugarh station inside the 2D building room as compared to Dum Dum station.

Conclusions

We have carried out a comparative study of isothermal contour plots, relative humidity contour plots, and velocity contour plots along with important indicators of ambient relative humidity, ambient temperature, maximum relative humidity vs. saturation indicator plots at Dum Dum Kolkata station, and Dibrugarh (Assam) station for a 24 hour numerical simulation time frame.

The following are the important revelations:

(i) The isothermal contour plots qualitatively don't vary too much but the numerical values are more for Dum Dum Airport Kolkata station as compared to Dibrugarh (Assam) station.

(ii) The relative humidity contour plots also qualitatively don't vary too much but the numerical values are more for Dibrugarh (Assam) station as compared to Dum Dum Airport Kolkata station.

(iii) The maximum relative humidity is more for Dibrugarh (Assam) station inside the 2D building room as compared to Dum Dum Kolkata station.

(iv) The saturation threshold, (where relative humidity=1), is not reached even after a 24-hour simulation period for Dum Dum Airport Kolkata station as well as Dibrugarh (Assam) station, meaning that saturation has not occurred, with minimal risk of condensation inside the building block walls.

Conflict of Interest Statement

The author declares that there is no conflict of interest.

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