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Deepankar Kumar Ashish
Jorge de Brito *Editors*

Environmental Restoration

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Preface

The F-EIR Conference 2021—Environment Concerns and its Remediation was held on October 18–22 in Chandigarh, India. The event was aimed to bring research professionals from multi-disciplinary fields to cross established sub-disciplinary divides, encouraging the exchange of ideas between scientists, engineering professionals, architects, environmental scientists, academicians, economists, and students. The conference focussed on the most interesting and relevant critical thinking on environmental issues with a wide array of quality technical presentations.

Over 400 abstracts and 300 full papers were received by the organizing committees, and about 140 papers were finally accepted for presentation in 27 sessions of F-EIR Conference 2021. These papers were presented by world-renowned experts from 30 countries during the event.

This volume contains 22 papers presented at the conference. Some other selected papers will appear in the Science of the Total Environment, an Elsevier Journal, Environmental Science and Pollution Research a European Chemical Society's journal published by Springer, Sustainability a MDPI Journal, Macromolecular Symposia a Wiley Journal, Materials Today Proceedings an Elsevier journal, and a book volume in Springer.

As the chairman of the conference, I would like to extend my appreciation to all the participated authors for their valuable contributions to the conference which made F-EIR Conference 2021 the most successful one. Special thanks are due to the keynote speakers and scientific and advisory committee members for their hard work and time spent to make this conference more interesting.

Baddi, India — Deepankar Kumar Ashish
Lisbon, Portugal — Jorge de Brito
October 2021

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Contents

Review on Bacteria Based Cementitious Matrix for Sustainable Building Construction

Krishna Kumar Maurya, Anupam Rawat, and Rama Shanker

Abstract Sustainable construction is obligatory for the development of the infrastructures to facilitate structural integrity. Incorporation of bacteria in cementitious materials is likewise a technique for sustainable concrete construction development and structural strengthening. The inclusion of bacteria in the cementitious-based matrix is prominent for microbial induced calcite precipitation through the respiratory metabolism process, environmentally friendly biodegradable material. This review paper is focused on parameters that are significant to develop bacterial concrete. In this paper, the bacterial concrete phenomenon and its effect on concrete have been presented. Further, the consequences of bacteria types, application methods, growth media for bacteria, and optimal cell concentration were deliberated. The advantages and disadvantages due to different kinds of bacteria on concrete have been discussed. The incorporation methods of bacteria viz., direct and indirect were enlightened, further their suitability was analyzed. Moreover, the effects of bacteria application on the mechanical properties of concrete were examined. Crack healing phenomenon in concrete due to microbial-induced calcite precipitation has been elaborated. The reviewed article will result in innovative research directions to the civil industry and valuable for environment friendly sustainable concrete construction of real-life infrastructures.

Keywords Bacterial concrete · Bacteria types · Incorporation methods · Optimum cell concentration · Crack healing · Culture media

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1 Introduction

The construction of sustainable buildings is requisite suitable cementitious materials. The easily available cementitious materials for the concrete matrix are cement, aggregates, water and admixture. Initial progression of damages/cracks occur in the concrete buildings are due to several environmental factors [1, 2]. Hence, the performance of damaged structures reduces. Nowadays, the different kind of materials have been used for the remediation of structural damages viz., resins, epoxy cement, cement slurry [3, 4]. Application of these organic repairable materials has negative impact on environment, because these are non-biodegradable materials. The concept of crack healing was studied from the decades; however Malinskii was investigated the progression of crack healing using polymeric resources in 1973 [5]. Generally, the self-healing of cracks are divided into two parts named as autogenous and autonomous [6]. If the self-healing was triggered without any kind of external action, the process is termed as autogenous, although autonomous process is the self-healing through the external operations like addition of engineered admixtures [7]. The incorporation of microorganism in cementitious matrix is an innovative concept for remediation of damaged/cracked concrete infrastructures. Thus, the properties of concrete buildings can be enhanced through applying different kinds of bacteria cells into the cementitious based matrix. Therefore, this novel concept is significant for the environmental friendly sustainable building construction [8]. Further, the properties of cementitious matrix can be improved through microbial induced calcite precipitation (MICP). The presence of CO_2 and H_2O are the main constituent for the MICP. The produced calcite through metabolism process is a solid substance, which is useful to fill the pores and healing of cracks present in concrete systems [9].

This review article is concentrated on bacteria incorporation in cement based matrix and their effect on mechanical properties viz., bacteria types, method of application, culture media, optimal cell concentration, incorporation methods, and positive and negative impact due to kinds of bacteria. Further, the impact of microbe application on strength, carbonation, corrosion of reinforcement, water absorption and crack healings have been enlightened. The presented review will be valuable for construction of sustainable buildings and provide novel research directions for the real-life infrastructures. The best type of bacteria that can be used in cementitious materials, incorporation methods suitability, nutrient for culture, positive and negative impact of bacteria, healing phenomenon, and chemical reactions, is the uniqueness of the review paper. Further, it will be helpful for researchers working in this area.

2 Types of Bacteria Used in Cementitious Based Materials

Addition of microbes in cementitious based materials introduces microbial or bacterial concrete. The focal alarm of bacteria application in concrete is the MICP to improve concrete properties along with crack healing. MICP depends on factors such as the availability of moisture and carbon dioxide. Numerous types of microbe are available that can be used in the cementitious based materials. The different types of bacteria are used in cementitious matrix to improve the properties. The researchers used several kinds of Genus and species of bacteria in sustainable building constructions based materials as listed in Table 1. From the previous research, it is observed that the Genus 'Bacillus' and its species have been considered to improve the performance of cementitious based matrix. Figure 1 shows the statics about bacteria application in the cementitious based materials. It was observed that the Genus 'Bacillus' is most suitable for the application in cementitious based materials.

Table 1 Types of Genus and species of bacteria

Genus	Species	References
Bacillus	alkaliphilic	[2, 11–15]
	sphaericus	[16–24]
	pasteurii	[4, 25–27]
	alkalinitrilicus	[28, 29]
	pseudofirmus	[2]
	cohnii	[2]
	subtilis	[10, 30–46]
	megaterium	[38, 47]
	cereus	[26]
	aerius	[48]
	flexus	[47]
	licheniformis	[47]
	sp. ct-5	[9, 49]
Halothiobacillus	neapolitanus	[50]
Lysinibacillus	boronitolerans ys11	[51]
E.	coli	[52]
Diaphorobacter	nitroreducens	[21]
Sporosarcina	ureae	[53]
	pasteurii	[22, 42, 53–58]
	–	[4]
	ginsengisoli	[59]
–	shewanella	[52, 60]
–	halomonas sp.	[61]
–	salinicoccus sp.	[46]
Desulfovibrio	species	[62]

'–' Not specified in the research articles

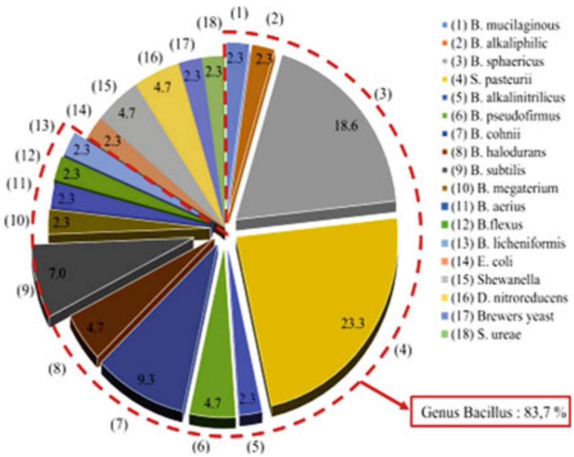

Fig. 1 Statics about bacteria application in the cementitious based materials [10]

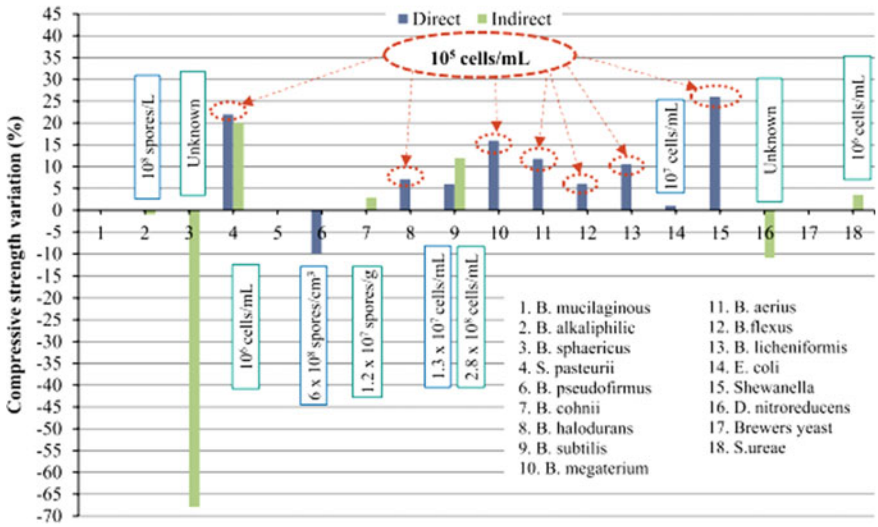

Fig. 2 Effect of types of bacteria and cell concentrations on compressive strength [10]

It was observed that about 83.7% Genus 'Bacillus' bacteria are used by the researchers in the cementitious materials. The applications of different kinds of bacteria have positive and negative impact on the concrete. Several researchers reported the types of bacteria incorporation have positive influence, however limited of them investigated that the few kinds of bacteria resulted negative impact on the properties of concrete [10]. The effects of different types of bacteria having positive and negative impact were shown in Fig. 2.

3 Methods of Incorporation of Microbe in Cementitious Matrix

The core defiance in making of microbial based concrete is detecting a mode to add bacteria in the cementitious based materials. Two methods are available for the incorporation of bacteria in the cement-based matrix, namely direct method [10, 14, 21, 36, 63, 64] and indirect method [10, 47, 48, 52, 60]. Direct method covers the applications of bacteria cells in concrete by cells/ml through the water used for concrete mix. Direct method is more frequently used by several researchers want to easy application of bacteria cells in cementitious materials. Thus, the direct addition of microbes is easy method equated to other application methods, like indirect method. In the indirect method the microbe spores are addend in cementitious based materials and these spores are placed inside the clay pallets. Since, the bacteria will be inserted in harsh medium like concrete matrix or cement paste, therefore it is significant to search a strain which can abide these extremely alkaline media. Subsequently, it can live the mixing practice and can remain viable with inadequate availability to growth media. Further, one of the key benefit of direct addition of cells into the cementitious based matrix is the decrease in porosity, that leads increase in compressive strength and durability [10, 65].

Ramachadran et al. [25] investigated the effect of Pseudomonas aeruginosa and S. pasteurii on compressive strength when they were directly incorporated to the mortar matrix. The increasing trend in compressive strength has been found after 7 and 28 days, however the optimum strength was found after 28 days. Ghosh et al. [52, 60] added anaerobic Shewanella and E. coli species in mixing water without any other nutrients. The compressive strength was increased because of gehlenite decomposition when Shewanella cells are incorporated in the mortar and addition of E. coli was found not any effect on strength. Achal et al. [49] studied the application of B. megaterium cells in fly ash-amended mortar to increase compressive strength and reduce porosity through the application of bacteria cells in the mix by replacement of mixing water content. Furthermore, Achal et al. [66] determined the consequence of microbial cells on the pull out strength of the reinforced concrete by the application of B. sp. CT-5 and the bacteria culture was replaced by mixing water. Achal et al. [67] used direct method of bacteria application in the cementitious based matrix and observed that B. megaterium survive upto 28 days. Basaran [68] considered the S. pasteurii bacteria and directly added to cementitious based material. It has been found that the viable of bacteria upto 330 days.

4 Bacterial Cell Concentrations

The different bacterial cell concentrations used by researchers have been shown in the Table 1. The impact of kinds of microbe and cell concentrations on compressive strength has been shown in Fig. 2 and observed that the incorporation of microbe cells increases the compressive strength of cementitious based matrix. Formation of bacteria based cementitious matrix depends on the cell concentration incorporated in cementitious materials. The higher cell concentration leads to lower compressive, whereas it is significant for automatically healing of cracks. The basic principle is that at higher cell concentration of microbe produce huge quantity of calcite on the surface of cementitious based materials. The pores available on the surface of cementitious based materials filled by produced calcite, however the pores that present inside the cementitious materials are not filled because of the interlocking at the surface of concrete, the required favourable condition for the formation of calcite inside the cementitious materials is prevented. Thus, the required compressive strength is reduced at the higher cell concentrations. Therefore, the optimal cell concentration can be used for the sustainable construction (Table 2).

Whereas, for healing of cracks the required cell concentration is higher as compared to the cell concentration required for compressive strength. The optimal cell concentration 10^5 per ml can be considered for maximum compressive strength determination of cementitious based materials. For the crack healing the optimal cell concentrations 10^7 to 10^9 per ml can be used. The cell concentration of bacteria can be calculated using the Eq. (1). Where X is the reading at OD_{600} (optical density at wave length of 600 nm) measured by UV spectroscope [25].

$$\text{Cell concentration/ml, Y} = 8.59 \times 10^7 X^{1.3627} \tag{1}$$

Table 2 Different cell concentrations for compressive strength and crack healing

Cell concentrations per ml	Reference	Description
10^2	[52, 60]	Used to determine compressive strength of cementitious materials
10^3	[23, 25, 30, 52, 60]	
10^4	[40, 41, 52, 60]	
10^5	[10, 23, 25, 28, 30, 40, 41, 47, 52, 56, 60, 69]	
10^6	[40, 41, 52, 53, 57, 60, 70]	
10^7	[23, 25, 30, 40, 52, 60]	
10^4	[41]	Used to investigate the self-healing of cracks
10^5	[30, 41]	
10^6	[41, 54]	
10^7	[30, 54, 71]	
10^8	[4, 12, 14, 30, 36, 54, 71, 72]	
10^9	[1, 4, 30, 39, 58, 63, 73]	

5 Growth Medium for Bacteria

The different culture media can be used for the survival of microorganism in the cementitious based materials. Several researchers used culture media viz., urea, sodium chloride, meat extract, peptone, yeast extract and/or combinations of these based on the purpose. The culture media for bacteria contains different quantity of urea in the cementitious based matrix [10, 17, 18, 21, 27, 48, 53, 56, 57, 69]. Several researchers have not been considered urea as culture media for the bacterial growth [10, 36, 52, 64, 72, 74]. Reddy et al. [40] used culture media for the bacterial growth as peptone 5 g/l, yeast extract 5 g/l and sodium chloride 3 g/l. Achal et al. [49] considered the culture media for the growth of bacteria in the cementitious material named as 8 gm nutrient broth, 25 mM calcium chloride and 2% urea. Nugroho et al. [41] used the combination of 5 g/l peptone, 5 g/l sodium chloride and 3 g/l yeast extract nutrient media in cement mortar. Luo and Qian [72] experimented the two types of bacteria based additive, the type one includes calcium lactate and microbe spores powder, whereas type 2 contains calcium formate and microbe spores powder. The growth media for microbe's 5 g peptone and 3 g yeast extract per liter were used. Mondal and Ghosh [30] increased the performance of cement mortar by incorporation of Bacillus subtilis bacteria cultured in the combination of 1 g/l beef extract, 5 g/l peptone, 2 g/l yeast extract and 5 g/l sodium chloride. Karimi and Mostofinejad [43] used 13 g of nutrient growth media which was consisted 5 g peptone, 2 g yeast extract, 1 g beef extract and 5 g NaCl per liter for the culture of bacteria. Abdulkareem et al. [39] used the culture media consist of 10 g sodium chloride, 10 g tryptone and 5 g yeast extract in 0.95 L of water. Hence, these nutrients can be used as culture media for the growth of bacteria.

6 Bacterial Phenomenon and Bio-Chemical Mechanism

The process of bacterial phenomenon is the bio-mineralization through bio-chemical reaction. It is assumed that bacteria are effective of developing $CaCO_3$ precipitation and chemical compounds that are developed by biological phenomenon in which a bacterium produces an optimum extracellular micro-environment of mineral phases, termed as bio-mineralization. MICP is induced by bacteria with metabolic process using different kinds of nutrients. The decomposition of urea by bacteria produced calcite which is due to the hydrolysis of urea in presence of enzymes breaks into ammonium and carbonate. During the initial bio-chemical phenomenon the one mole of urea is hydrolysed into one mole of carbamate (NH_2COOH) and one mole of ammonia (NH_3). Subsequently, the NH_2COOH hydrolysed into one mole of NH_3 and one mole of carbonic acid (H_2CO_3) as shown in Eqs. (2) and (3). Further, these formed products react with water and develop carbonic acid into carbonic ion and hydrogen ion, and the ammonia into two mole of hydroxide ion and two moles of ammonium ions as shown in Eqs. (4) and (5). These ions react to each other and develop the carbonate ion. The surface of the bacteria is negatively charged, thus the calcium ions attached with bacteria cells on the surface. Hence, the carbonate ions react with calcium ion and forms calcium carbonate on the surface of bacteria as shown in Eqs. (6), (7) and (8) [4, 10, 19, 23, 25, 49, 54, 65, 75–77]. The phenomenon of calcite precipitation on the surface of bacteria is shown in Fig. 3 [78].

$$CO(NH_2)_2 + H_2O \rightarrow NH_2COOH + NH_3 \quad (2)$$

$$NH_2COOH + H_2O \rightarrow NH_3 + H_2CO_3 \quad (3)$$

$$H_2CO_3 \rightarrow HCO_3^- + H^+ \quad (4)$$

$$2NH_3 + 2H_2O \rightarrow 2NH_4^+ + 2OH^- \quad (5)$$

$$HCO_3^- + H^+ + 2NH_4^+ + 2OH^- \rightarrow CO_3^{2-} + 2NH_4^- + 2H_2O \quad (6)$$

$$Ca^{2+} + \text{ Cell } \rightarrow \text{ Cell } - Ca^{2+} \quad (7)$$

$$\text{Cell} - Ca^{2+} + CO_3^{2-} \rightarrow \text{Cell} - CaCO_3 \quad (8)$$

Subsequently, the organic compounds can be used as bacterial nutrient growth media for the development of cementitious materials. The calcium lactate can be used because of less negative impact on cementitious based materials. These materials oxidized and formed calcium carbonate with CO_2, further developed CO_2 reacts with hydra oxide of calcium and forms $CaCO_3$ as shown in Eqs. (9) and (10) [13, 35, 73, 79, 80]. However, other materials like sodium chloride, beef extract, peptone and yeast extract can be considered as culture media. In this case the lime

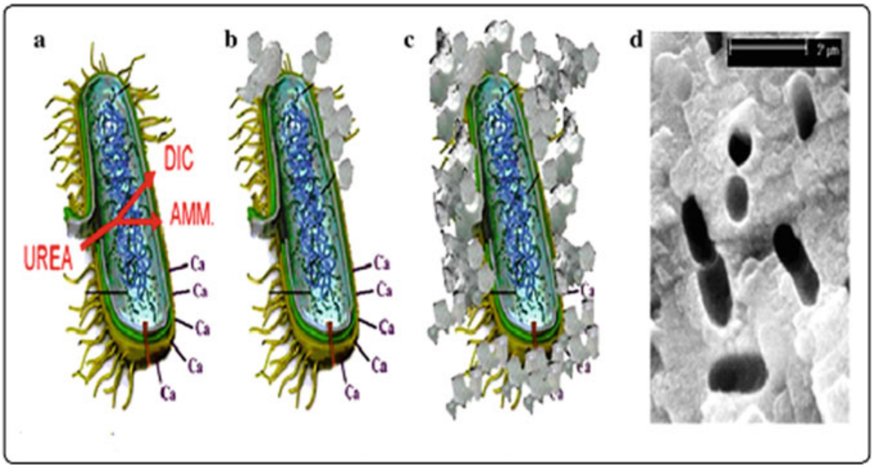

Fig. 3 Ureolysis-driven calcite precipitation [78]

reacts with moisture and formed calcium hydra oxide. Further, the formed compound reacts with carbon di-oxide present in the environment and produced calcite as shown in Eqs. (11) and (12) [10, 11, 32, 35, 41].

$$Ca(C_3H_5O_2)_2 + 7O_2 \rightarrow CaCO_3 + 5CO_2 + 5H_2O \quad (9)$$

$$5CO_2 + 5Ca(OH)_2 \rightarrow CaCO_3 + 5H_2O \quad (10)$$

$$CaO + H_2O \rightarrow Ca(OH)_2 \quad (11)$$

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (12)$$

7 Impact of Microbes on Properties of Cementitious Matrix

Addition of microbes in cement-based matrix improves properties of matrix due to induced calcite precipitation, thus the durability can be enhanced. The properties viz., permeability, compressive and tensile strength, water absorption, and crack healing can be advanced the performance of concrete structures.

7.1 Compressive and Tensile Strength

Strength is the significant property of any structural system, hence the additive added in any cementitious based matrix have positive impact. Addition of bacteria mostly results positive impact on the strength parameter, however addition of few kinds of microbes have negative on the strength of cementitious based materials. Figure 2 shows the consequence of kinds of microbe and cell concentrations on compressive strength. It has been observed that the Bacillus sphaericus, Bacillus pseudofirmus and D. nitroreducens were played negative impact on the compressive strength [10]. Several researchers applied microbes in cementitious based matrix and the strength was determined [2, 4, 9, 13, 20, 25, 30–33, 38, 45, 54, 55, 81]. The compressive strength was improved by investigators using Bacillus subtilis bacteria [10, 30–35, 45, 65, 82], Bacillus pseudofirmus [2, 15, 73], Bacillus sphaericus and Bacillus pasteurii [20, 22, 23, 79]. Further, many authors incorporated several kinds of microbes for the quality advancement of cementitious based materials [9, 11, 13, 28, 38, 75, 76, 83–86]. Figure 4 shows the compressive strength v/s age of testing, it has been perceived from the Fig. 4 that the enhancement in strength with the addition of bacteria, however the optimum strength was observed at 10^5 cell concentration per ml [30].

Nain et al., applied three types of bacteria in the concrete named as Bacillus subtilis, Bacillus megaterium and consortia and the strength of concrete has been

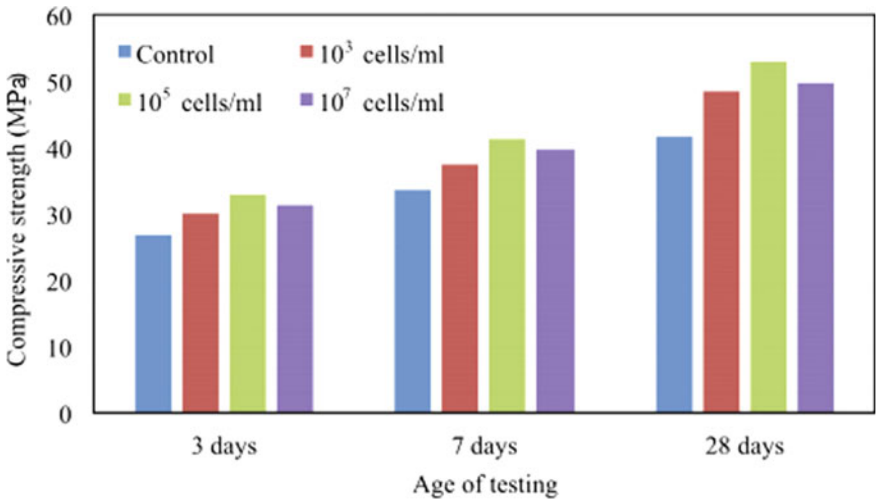

Fig. 4 Compressive strength v/s age of testing [30]

investigated after 7 and 28 days. It was observed that the compressive strength was enhanced with 14.36, 22.58 and 15.86% in 28 days using these bacteria, subsequently the split tensile strength was enhanced by 25.3, 18.29 and 19.51%, respectively [38]. Mondal and Ghosh [30] investigated mortar specimen by the incorporation of Bacillus subtilis bacteria and found that the maximum compressive strength of 27% than standard specimen after 28 days at 10^5 cell concentration/ml. Nugroho et al. [41] examined the mortar specimen by the application of Bacillus subtilis bacteria of different cell concentrations. It has been perceived from the evaluation that the optimum compressive strength of 34.85% than control specimen was achieved at 10^5 cell concentration/ml after 28 days. Another author investigated the bacterial concrete and found that the compressive strength has been enhanced with 36% by incorporation of Bacillus subtilis bacteria [49]. Further, the improvement in the strength was observed by another investigator and found that the strength was increased than control specimen by 25.38%, 21.40%, and 17.97% at different days [41]. Further, the incorporation of bacillus subtilis bacteria in the cementitious based material was examined and improvement in specimen than standard specimen was observed by 16.15% [40].

7.2 *Permeability, Water Absorption and Crack Healing*

Presence of the cracks in the structures reduces the structural strength, hence required a lot of attention and fund for remediation. Cracked structures allows ingress of harmful ingredients through the cracks/or pores present in the concrete. Further, the permeable cementitious based structures absorb water and thus reduce

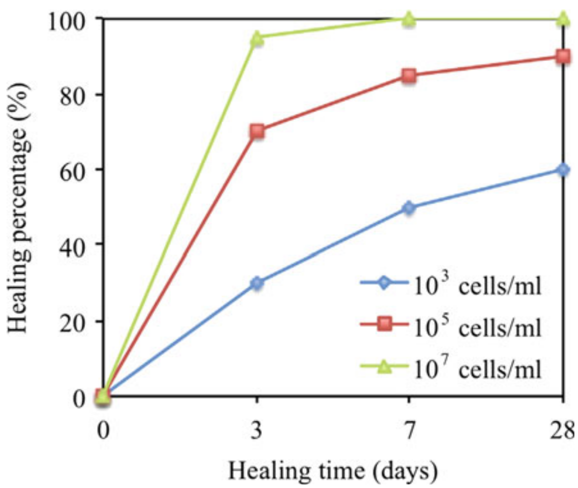

Fig. 5 Rate of crack healing w.r.t. initial crack width at different bacterial concentrations

the performance of infrastructures. Several crack healing materials are available in the market, however crack healing by incorporation of bacteria in cementitious based matrix are more significant than other materials because of biodegradable and environment friendly in nature [28]. Several researchers incorporated the bacteria cells for healing of cracks to improve the structural sustainability. Many authors investigated the healing of cracks, the permeability and the water absorption by the inclusion of bacteria [2, 4, 10, 11, 13, 14, 19, 23, 25, 28, 30, 34, 35, 45, 49, 54, 64, 65, 75, 79–81, 87, 88]. Figure 5 shows the percentage rate of crack healing w.r.t. initial crack width at different bacterial concentrations and the maximum healing was observed at higher cell concentration. Subsequently, the corrosion and carbonation can be minimised by the addition of microbes in the cementitious based materials because of the produced calcite densify the materials. Thus, the pores does not allow the ingress of water, therefore corrosion can be minimised [42]. Moreover, the crack healing percentage can be quantified using the Eq. (13). The crack closure percentage can be determine using Eq. (14) [58].

$$\text{Crack healing, \%} = (A - B)/A \times 100 \tag{13}$$

$$\text{Crack closure, \%} = (C - D)/C \times 100 \tag{14}$$

Where, A and B are the early crack width and the crack width determined after healing of cracks after a days. The C and D represent area of early crack and area of crack after healing of the cracks, respectively.

8 Needs and Future Scopes

Development of damages/cracks in the concrete structures causes reduction in the serviceability criteria and allows the ingress of harmful ingredients. The small crack in the liquid retaining structures develop big problem to the structures, thus the performance of structures can be reduced. The incorporation of bacteria in the cementitious based matrix is significant for the reduction of damages/cracks and resulted the sustainable building. The induced calcite is environment friendly material which is not harmful to the environment like epoxy resins and non-biodegradable materials. All the bacterial parameters were evaluated by the experiment and the tests were conducted in laboratory only. In future the bacterial concrete can be investigated using structural health monitoring and non-destructive evaluation techniques. Further, the different kinds of sensors can be a futuristic technology for the monitoring of real-life bacterial concrete structures. The quantity of calcite material deposited corresponding the incorporated cell concentration can be studied. Its specific properties can be studied for the modelling in different kinds of software, thus in future the bacterial concrete structures can be analysed through software.

9 Conclusions

Review article entails the detailed summary of microbial concrete phenomenon and impact of bacterial incorporation on cementitious matrix to reflect state-of-the-art. The different kinds of bacteria have been abridged and observed that the Bacillus Genus bacteria are used more frequently in the construction of sustainable buildings. One of the significant parameter, methods of application of bacteria and their suitability were discussed. Thus, it was observed that the direct method is easy way of bacterial application, whereas indirect method is more reliable to preserve the bacterial spores for long duration in structures open to the aggressive environment. For the survival of the bacteria in cementitious materials the nutrient growth media have been reported. Several researchers used different types of nutrient media which are advantageous for crack healing and strength development in the cementitious matrix. Further, the optimum cell concentration of microbial for self-healing of cracks and strength enhancement in cementitious matrix were discussed. Consequently, for the sustainable concrete construction the bacterial cell concentration of 10^7 to 10^9 per ml can be used for crack healing; however for the optimal strength determination, the 10^5 cells per ml can be used. The bio-chemical reactions were included that resulted the formation of calcite, which is useful substance for the concrete matrix. Through the inclusion of microbe in the cementitious based matrix the parameters like corrosion of reinforcement, permeability, aggressive environment, carbonation, and water absorption can be minimised, thus the catastrophic failure of structures can be avoided. Further, the review paper will induce novel investigation ways for the construction of sustainable infrastructures.

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Physical and Mechanical Properties of Concrete Made with Glass Sand

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Abstract It is important promoting less generation of urban waste not only for the economy of raw materials, but also for the lesser deposition of waste in landfills. Glass is among the most frequently used materials in packaging and is the easiest to be recycled. Being aware that the construction industry is one of the largest consumers of natural resources in the world, the present study deals with the possibility of replacing part of the fine aggregate of concrete by glass sand. Concrete was produced with the conventional aggregates and then the fine aggregate was partially replaced by glass sand for the percentages of 10, 15 and 20%. The experimental study sought to evaluate the physical and mechanical properties. The slump, compressive strength, tensile strength and water absorption by capillarity and void index testing were measured. Results showed that when replacing the fine aggregate by 10, 15 and 20% of glass sand the results are satisfactory, especially for the substitution of 20% of glass sand which presented an increase of 18% in the compressive strength.

Keywords Glass sand · Fine aggregate · Concrete

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1 Introduction

The concern with the reuse of waste generated in urban centers, in order to reduce the consumption of raw materials, is an alternative for society, both for the preservation of natural resources and to avoid the deposition of waste in the environment.

As it is known that the adversities linked to solid waste are still recurrent in society, it is necessary not only to find solutions for the correct disposal of these materials, but also to create procedures capable of systematically reinserting them in production. The circular economy emerges at a time when the value of resources, materials and products is preserved as long as possible in the economy, and waste generation serves as a tactic to develop low-carbon resource efficiency and competitive sustainability [1].

Solid waste management and municipal solid waste management are the basis for the circular economy to achieve greater waste recovery and better resource management, extending and closing material cycles creating stockpiles of economic flows [2–4].

The civil construction sector is one of the main pillars of the economy, generating solid waste and consuming natural resources [5]. The concrete industry uses more than 4.2 billion tons of cement per year (in 2016, its worldwide consumption is 4.13 billion tons [6]). Concrete is one of the most used construction materials, with a consumption annual total of approximately 25 billion tons, which equates to more than 3.8 tons per person per year [7]. In this context, some alternatives, including the use of waste as an aggregate in the manufacture of mortar and concrete exist to minimize the consequences of the impact of this sector.

The largest industry with the capacity to be a sustainable alternative for the disposal of various residues is the production of concrete [8]. The replacement of aggregate by some residues can be used to improve the physical and mechanical properties of concrete, as demonstrated by other research the use of some materials, such as pozzolanic substances (materials of volcanic origin, fly ash, among others).

For a material to be considered as an aggregate, the general requirements are that the grains must be hard, compact, stable, durable and clean, and must not contain substances of a nature and in amounts that alter the hydration and hardening of the cement, the protection of the reinforcement against corrosion, the durability and the external visual appearance of the concrete [9].

Glass has several applications, such as being a super-cooled transparent metal oxide of high hardness, essentially inert and biologically inactive, with low porosity, absorptivity, expansion and conductivity thermal and capable of withstanding pressures from 5800 to 10,800 kg/cm^2 [10].

According to CEMPRE—Consortium Business for Recycling (2011), Brazil manufactures around 980 000 tons of glass packaging per year, and only about 47% of the packaging was recycled in 2011. Brazil can further expand the recycling of glass as what happens in other countries, for example, Switzerland with 95%, and Germany with 87%. Glass recycling is extremely useful all over the world, but it is far to be fully recycled in Brazil [11]. At present most of unrecycled glass it becomes glass that ends up in landfills. That must change. Its reuse enables the conservation of materials, reducing energy consumption and the volume of waste sent to landfills [12].

Despite of being a subject studied for decades, the disposal and reuse of glass waste is still a current issue [13–15]. Research on the use of glass waste in concrete to partially replace sand is always relevant to reinforce the incentive of its use and provide improved results from new methodologies with different natural states of waste in different world regions. It is expected that studies such as this one justifies the investment and contribute to increase recycling and use of glass waste in countries like Brazil, especially in regions where glass waste is a problem, with no recycling, with no perspective for the circular economy.

In order to contribute to solve the problem of the large amount of sand extracted and the improper disposal of glass waste, this work explores the feasibility of partially replacing fine aggregate by glass sand in concrete. In this exploratory study 10, 15 and 20% of the fine aggregate was replaced by glass sand in concrete compositions tested. Here, this document regards to the part of the study wherein the physical and mechanical properties of concrete are investigated. The workability in assessed through the slump test, the compressive and tensile strength are measured to discuss the effect of the glass sand on the mechanical properties and the water absorption was determined to compare the effect on the physical properties. Issues regarding to the pozzolanic activity or related to the alkali-silica reactions are not addressed in the present document.

2 Environmental Problem and the Glass Waste

2.1 Environmental Impact

The most used mineral inputs in the world is the construction of aggregates [16]. Concrete production consumes large amounts of natural aggregates, about half of world production [17]. Therefore, eliminating or reducing the consumption of concrete aggregates can produce eco-friendly building materials. Figure 1 shows the graph of the evolution and projection of aggregate consumption in Brazil in the period 1997 to 2022, which was a survey carried out by Anepac (National Association of Aggregate Products for Construction Companies).

Mineral exploration will never be a sustainable activity, as the extracted material will never be replaced. The environmental impacts are not only due to the extracted material, but are also directly associated in the exploration phases, such as the opening of the pit, (removal of vegetation, excavations, earth movement and modification of the local landscape), to the use of explosives in the blasting from rock (under atmospheric pressure, ground vibration, ultra-release of fragments, fumes, gases, dust, noise), to the transport and processing of ore (generation of dust

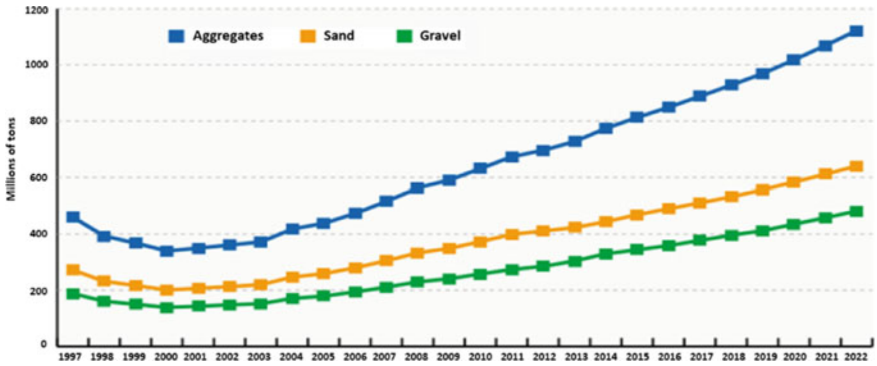

Fig. 1 Consumption of aggregates in Brazil

and noise), affecting the media such as water, soil and air, in addition of the local population.

CONAMA Resolution No. 01 [18], of January 23, 1986, in its article 1, considers that environmental impact is any change in the physical, chemical and biological properties of the environment, caused by any form of matter or energy resulting from human activities that directly or indirectly affect: (i) The living conditions of the population; (ii) The economy; (iii) Social relationships; (iv) Any set of living beings; (v) The characteristics of environmental resources; (vi) Environmental property aesthetically or sanitary. Some of the environmental impacts arising from the mining of aggregates for civil construction, especially sand, are listed in Ref. [19], such as: (i) Silting, which is caused by the high content of suspended sediment; (ii) Removal of vegetation cover; (iii) Change in relief; (iv) Change of watercourse; (v) Emergence of holes; (vi) Sedimentation of materials in water courses; (vii) Destruction of permanent preservation areas; (viii) Biota destruction; (ix) Erosion; (x) Gullies; (xi) Changing hydrogeology.

2.2 *Glass Waste*

Glass waste has several applications, one of which is its insertion in civil construction as an aggregate, which is feasible due to the characteristics shown in Tables 1 and 2. According to CONAMA Resolution No. 431 [20], glass is classified as Class B of solid waste, in the document it is reported that all material in this class is considered recyclable for other destinations. All Class B waste must be reused, recycled or sent to temporary storage areas, being arranged in such a way as to allow for its future use or recycling. However, the glass, in Brazil, ends up being, most of the time, destined to sanitary landfills or simply discarded in sanitary landfills. Therefore, the best alternative for the final disposal of the glass would be recycling. Recycling involves manufacturing the product from a used material, that

Table 1 Main physical properties of glass

Physical properties
Excellent resistance to water and salty liquids as well as organic substances, alkalis and acids, with the exception of hydrofluoric and phosphoric acid
High durability
Low electrical conductivity
Very low thermal expansion

Source Adapted from Ref. [21]

Table 2 Glass's biggest attractions

Attractions
Transparent
Inert
Practical and versatile
Reusable
Waterproof
Returnable

Source Adapted from Ref. [21]

is, transforming the materials. In this context, it would be possible to fully reuse glass packaging with enormous ecological, economic and social benefits, for example, providing less waste disposal, increasing the life of landfills, which would help preserve the environment and increase economic viability through reducing the costs of urban collection, promoting the generation of jobs with the installation of a collection process that does not require specialization.

2.3 Pozzolanic Reactions

Pozzolanic materials are siliceous or silicoaluminous compounds that have little or no binding activity when isolated, however, when they are transformed into fine particles and added with water, they react with calcium hydroxide at room temperature forming substances with binding properties [22]. Glass can contain a large amount of silicon and calcium, making the material, in theory, pozzolanic [23].

According to the research carried out by [24], the results of the performance index with Portland cement indicate pozzolanic activity for the glass fractions #200 and #325 in the criteria of the American standard. Although the strength gain was slower in concrete with glass powder, as mixtures containing glass powder have a satisfactory performance in relation to drying shrinkage and alkaline reactivity, and there were indications that glass powder reduces the penetrability of the chloride ion of concrete, as well as the risk of chloride-induced corrosion of steel reinforcement in concrete [25].

The insertion of glass powder in cementitious composites presents positive results in several aspects [12, 25–27]. Research shows that the incorporation of glass powder is satisfactory in concrete at dosage rates of up to 30% to replace cement without adverse effects [25, 27]. The greatest strength improvement reported is 17% for a 30% cement replacement [27].

2.4 Alkali-Silica Reactions

The use of recycled glass dust residues in civil construction as a substitute for cement or even natural aggregates will bring double benefits, with environmental and economic advantages. The use of glass dust provides a value-added use of reinforced glass residues in concrete and reductions connected in the production of greenhouse gases by the cement industry and natural aggregate extraction [25, 27].

However, there is a durability problem with concrete with glass aggregates, that is, an Alkaline Silica Reaction (ASR), as the glass contains a large amount of alkalis [28]. It is well known that the ASR of glass particles depends on particle size. An incorporation of glass slag as a fine powder can benefit the concrete in terms of improved strength and reduced porosity [28, 29]. The ASR fine/coarse glass particles can be reduced by adding particles or mixed minerals. For example, metakaolin, fly ash and lithium compounds have been used to control the expansion of ASR in glass concrete or to be pretreated with three different solutions: $Ca(OH)_2$, NaOH and a mixture of $Ca(OH)_2$ and NaOH [28–31].

Studies have shown that the use of glass powder is a viable alternative to ultrafine silica sand, as its addition favors the durability of the mixture [28–31]. As the glass powder increases the porosity, absorption percentage, absorption depth, sensitivity and chloride penetration of the mixture decrease. This enhancement effect is attributed to the physical properties of the glass. In this regard, although there are concerns about the use of glass in cementitious materials, confirmed that the use of glass with a smaller particle size will not cause harmful ASR.

3 Experimental Program

3.1 Aggregates

The materials were chosen taking into account NBR 15,900-1/09 and NBR 6118/14. The materials used in this work are: Portland cement CP II Z 32; Standard sand with 5% humidity; Crushed gravel; Tap water; Glass sand.

The specific gravity tests were carried out in accordance with the provisions of NBR NM 27/01 and NBR NM 52/09. The glass sand was donated by Eco Vidros, which was ground to a granulometry ranging between 0.15–1.18 mm, specified

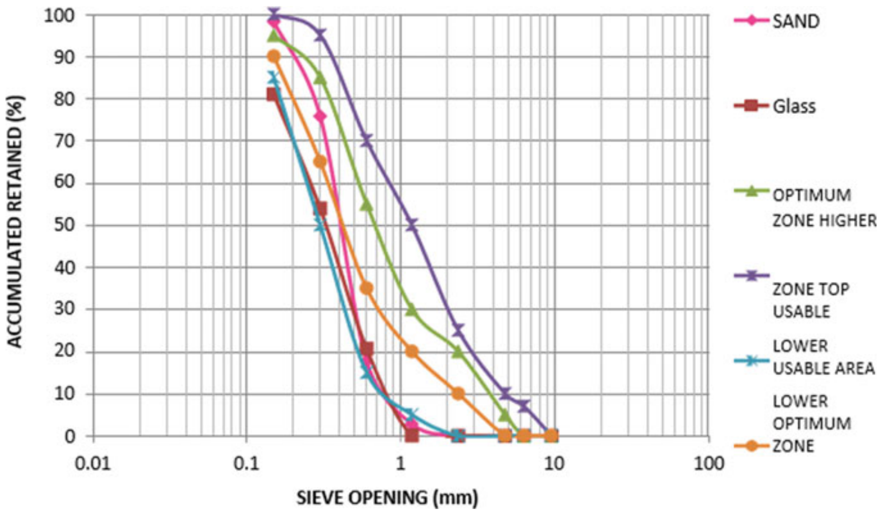

Fig. 2 Granulometric curve of fine aggregates (NBR 7211/09)

following the guidelines of NBR 7217/87, NBR NM-ISO 2395/97 and NBR 7211/09. The granulometric tests were carried out according to NBR NM 248/03, NBR 7211/09. The particle size analysis, which were performed on the fine aggregates used in the composition of the concrete mixtures, are shown in Fig. 2. As shown in the granulometric analysis, most sand and glass sand are within the range stipulated by NBR 7211/09. However, there are small percentages outside the use zone, which can generate problems in the microstructure of the concrete studied, such as greater porosity, lower resistance and high-water absorption, among others.

3.2 Concrete

The mix with 355 kg of cement, 1030 kg of gravel, 745 kg of sand and 195 kg of water was chosen to produce a 25 MPa concrete (reference mix). The tests were carried out on specimens with proportions of 10, 15 and 20% of replacement of the fine aggregate by glass sand. To enable the comparison between the traits evaluated, constant factors were adopted, such us: origin of materials; milling procedure and waste granulometry; preparation, molding of specimens; three-day immersion cure of specimens; ages of 7, 21 and 28 days to break the specimens in the compressive strength test; 10 × 20 cm cylindrical specimens; C25 concrete grade. These parameters were stipulated with the help of NBR 7215/96, NBR 6118/14 NBR 12,655/15 and NBR 5738/15. The specimens were classified according to the change of the mix in relation to the percentage of glass sand existing in its

Table 3 Concrete compositions

Mix	Glass sand (%)	Cement (kg)	Gravel (kg)	Sand (kg)	Water (l)	Glass sand (kg)
G0	0	10.1	29.98	21.10	5.3	–
G10	10	10.1	20.98	18.99	5.3	2.11
G15	15	10.1	20.98	17.93	5.3	3.17
G20	20	10.1	20.98	16.88	5.3	4.22

composition, whose nomenclatures were G0, G10, G15, G20, respectively, the reference mix and the partial replacements of the sand by glass sand in 10, 15 and 20%.

3.3 Mix Compositions

During the molding of the cylindrical specimens in accordance with standard NBR 5738/03, the slump test was carried out following the guidelines of NBR NM 67/98. To determine the void index of the samples, it was necessary to discover the specific mass of the dry and saturated specimens, this test was carried out following NBR 9778/05. To identify the absorption of water by capillary action, the test was carried out according to NBR 9779/12.

For the test of compressive strength of the specimen, the guidelines of NBR 7215/96 and NBR 5739/18 were used. The tensile strength test was carried out with the consent of NBR 7222/11, which was carried out through the diametral compression of the cylindrical specimens. Table 3 shows the mix compositions.

4 Results and Discussion

4.1 Slump and Compressive Strength

The slump test revealed that the concrete composed of vitreous sand presents a decrease in its workability. The slump test results were 90, 65, 45 and 35 mm for the G0, G10, G15 and G20 mixtures, respectively. The trend is likely due to the roughness of the glass sand surface compared to conventional sand. The reference concrete (G0) showed 90 mm slump, which was in the range of targeted slump of 80–100 mm. However, the workability decreased significantly with an increase in the quantity of glass sand. Although for [32] the angular nature of the glass waste can provide a better bond with the cement paste in concrete, this decreasing trend agreed with the study by Adaway and Wang [33].

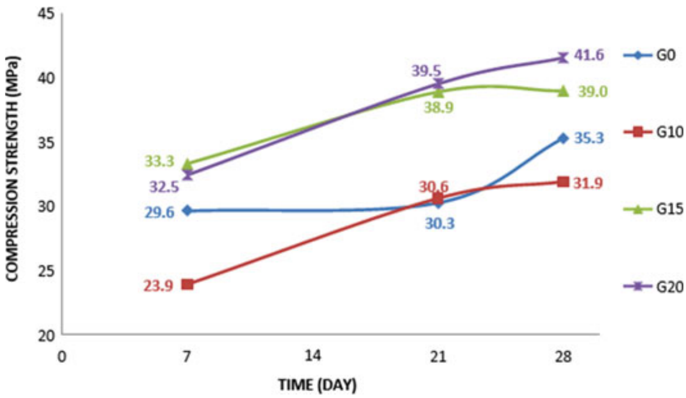

Fig. 3 Compressive strength evolution

The G10 e G15 exhibited 28 and 50% slump values of reference concrete, respectively. The G20 showed even lesser slump compared to any other mixtures, only 39% slump value of reference concrete. Similar decrease pattern was observed by Tan and Du [34] and Tamanna et al. [13] on the flowability of mortar.

Regarding to the compressive strength, Fig. 3 presents the results obtained. In Fig. 3, it is observed that the highest strength was from G20 (20% of glass sand), which had an improvement of 17.85% in relation to the G0 (reference mix). For the mix G15 the compressive strength improvement was of 7.65% when compared to G0.

These results are in agreement with the compressive strength results of Adaway and Wang [33] that for 15 and 20% replacements obtained results superior to the control concrete. Tan and Du also obtained results superior to the control concrete for 25% replacement [34].

The increase of the concrete strength in mixes wherein the fine aggregate was replaced is probably due to the angular shape of the glass waste, which affects the connection between the glass sand and the cement matrix [13, 33].

Concerning to the tensile strength by diametrical compression (NBR 7222/11), the tensile strength obtained were 2.5, 2.8, 3.1 and 3.2 MPa for the mixes G0, G10, G15 and G20, respectively. The results found are according to the ones of Ref. [35] —the higher replacement of sand by glass sand, the higher tensile strength. The higher mix being the G20 (20% of replacement) obtained an increase in its tensile strength by 27.77% compared to the reference mix.

4.2 Water Absorption

Table 4 presents the relation of the water absorption by capillarity as a function of time. Roughly speaking, results show that the higher glass sand replacement, the lower absorption by capillarity. Bearing in mind that specimens that reaches higher

Table 4 Relation water absorption by capillarity (g/cm^2) as a function of time (NBR 9779/12)

Mix	Cross height (cm)	Time (h)				
		3	6	24	48	72
G0 (ref.)	5.5	0.0001401	0.0002419	0.0005220	0.0007385	0.0008531
G10 (10%)	6	0.0001655	0.0002547	0.0005475	0.0007512	0.0008658
G15 (15%)	5	0.0001146	0.0001910	0.0004456	0.0005730	0.0006621
G20 (20%)	4	0.0001019	0.0001783	0.0003820	0.0005093	0.0006112

Table 5 Relation of water absorption by immersion, void index and specific masses of specimens (NBR 9778/05)

Mix	Water absorption by immersion (%)	Empty index (%)	Specific gravity dry (g/cm^3)	Specific saturated gravity (g/cm^3)	Specific gravity real (g/cm^3)
G0 (Ref.)	10.00	14.29	1.429	1.571	1.667
G10 (10%)	10.14	14.89	1.468	1.617	1.725
G15 (15%)	8.45	12.50	1.479	1.604	1.690
G20 (20%)	8.22	12.24	1.490	1.612	1.698

compressive strength are assumed as those that have lower open porosity, the obtained results were the expected ones. Table 5 shows the results obtained in the void indices test, in this test it is possible to determine the void indices, the specific masses and the water absorption by immersion of the specimens.

By analyzing the Table 5, water absorption by immersion promoted the same conclusion as the capillary absorption test, which reported that the highest percentages of absorption were in traces of lower strength. It was observed, also, that the lowest percentages of absorption of water by immersion are those that have lower void rates.

These results diverge from the observations of Turgut and Yahlizade [36] and Limbachiya [37] that the water absorption of glass concrete increases with increasing percentage of glass waste. Penacho et al. [38], also reported similar behavior of increased water absorption used in mortar mix.

5 Conclusions

From the results observed it is concluded that the mix that had the highest water absorption, was the one with the worst performance in its tensile and compressive strength.

Through a special analysis of the results of the tests carried out with the G10 mixture (10%), it can be seen that at 28 days, its compressive strength was lower than that of the reference, however it exceeded the expected 25 MPa. One of the factors that may have influenced this result was its microstructural composition, as the void index test concluded that it was the structure that presented the most porosity.

With the concrete slump test, it was observed that the workability of concrete decreases as the replacement of fine aggregate by glass sand increases. Therefore, for replacements greater than 20%, there would be a need to add water, which would promote a change in the water/cement ratio.

Despite the experimental variants, glass with a partial substitute for sand in concrete promoted satisfactory results, as it managed to achieve all the objectives of this work. With the analysis of all tests, it can be seen that the best results obtained in ascending order, in relation to the reference mix, were G10 (10%), G15 (15%) and G20 (20%).

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Utilization of Waste Granite Powder in Cementitious Composites: Perspectives and Challenges in Poland

Slawomir Czarnecki and Lukasz Sadowski

Abstract In this research, the authors emphasize the need for sustainable waste management due to the possible environmental danger in Poland. It is mainly due to the maintenance of a very high level and even the increase in the mining of rock raw materials. Along with Poland's accession to the European Union, more and more restrictive regulations on environmental protection were introduced, including those related to habitat and bird areas, which prevent the use of approximately 500 exploited deposits, which is a reduction of approximately 35% of the extraction possibility, and those related to detailed waste management planning. They oblige all producers to design entire production processes to improve the environmental preparation of waste for reuse, recycling, recovery, and disposal of waste. Through a sufficient literature survey and statistical data, the analyses of possible waste granite powder production is presented. The waste granite powder is used more often as a admixture in cementitious materials, which is also beneficial for the eco-friendly way of their utilization. In the article, advantages and disadvantages of using granite as a by-product in the production of cementitious materials have been presented. The presentation included the influence of the addition of granite on the physical, mechanical, and chemical properties of cementitious materials.

Keywords Mineral waste powders · Sustainable development · Cementitious materials · Granite

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1 Introduction

In recent years, granite has become one of the most purchased materials used in construction. Its functionality and attractive price are the main reasons for its popularity [6]. Therefore, in recent years in Poland and the world, the stone industry has developed significantly, including the processing of granite. As more than 75% of Polish deposits of this raw material are located in Lower Silesia (mainly in Karkonosze Massif: Sudets [22]). Granite, the main constituent is quartz, but second there could be find alkali feldspar. The chemical composition of granite has been presented in Fig. 1 on a QAFP diagram [17].

Along with the political transformation of Poland after 1989, this industry developed very dynamically. According to the report of the Polish Geological Institute, “Balance of mineral deposits in Poland according to as of December 31, 2018” the stone industry recorded a 14.78% increase in 2018 compared to 2017, and in 2019 it was expected to increase by another 10% (forecast), which is related not only to the consumption of their own granite resources, but also to the increasing import of blocks of rockeries from countries such as China or South Africa. The process of forming waste granite powder, which begins with the extraction and then the formation of the granite rock, in addition to the final

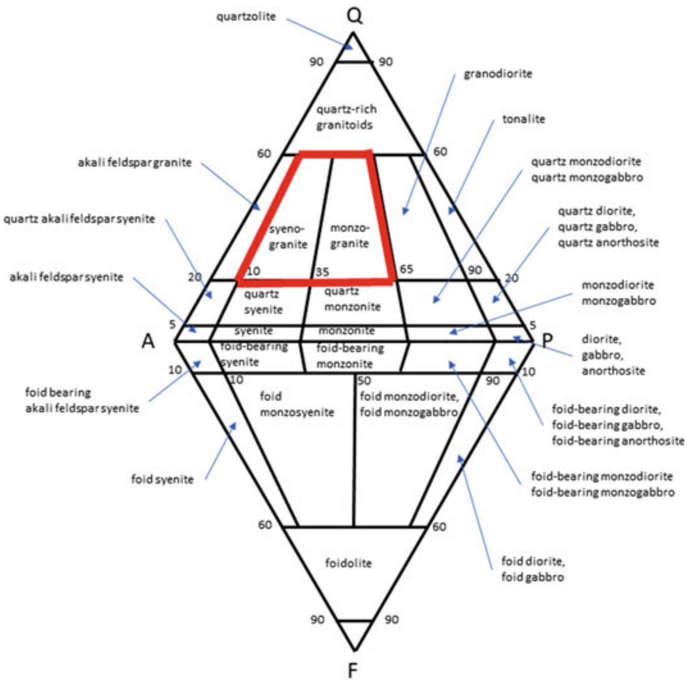

Fig. 1 QAFP diagram with emphasis on the chemical composition of granite

product, results in a waste in the form of granite powder, which is usually stored in piles [7].

Therefore, a significant problem related to granite powder is its limited use in industry. Basically, apart from storing waste granite powder in heaps, it is now sometimes utilized as a backfill for concrete or paving stones and as a filler for backfilling mines. However, the filling of old open-cast mines with this waste is controversial. Until now, it has allowed entrepreneurs dealing with the processing of granite blocks to eliminate this waste material almost at no cost, but it has resulted in a significant pollution of the natural environment. Granite powder does not contain any chemicals that are hazardous to the environment, but the fact that it is a dust causes it to spread over many kilometers in unfavorable winds, and thus significantly pollutes the surrounding areas [15].

It should be mentioned that apart from the negligible use of granite powder in industry, additionally after the last change in the regulations on waste management, its disposal has become significantly more complicated. The requirement to have a waste registration number (BDO) for entrepreneurs will significantly reduce the area of waste disposal, but will also significantly aggravate the problems of entrepreneurs dealing with the processing of materials, which result in a large amount of waste. This situation affects entrepreneurs associated with the mining sector, which can cause a stagnation in the development of waste materials management. Therefore, it is necessary to constantly search for new applications for waste materials in accordance with the idea of sustainable development, which may not only improve the condition of the Polish economy but, above all, allow the situation of the natural environment to be improved. One of the possible applications of granite powder is its addition to cement composites and epoxy resin, which are the main construction products used for making floors.

Currently, construction is the third strength of the Polish economy (according to stat.gov.pl). Cement production plays an important role in this. According to the Concrete Producers Association, in 2014, the concrete production in Poland reached a level of 19,181 Mm^3 and the cement production—16.5 million tons, which was 7% higher than in 2013. A large part of this production belongs to floor producers and contractors. Furthermore, the share of pollutants from the cement industry is significant, as it exceeds 5% of the total emission of pollutants in Poland. One of its main ingredients is cement.

Cement production requires around 15 billion tons of mineral resources annually and around 1 billion tons of water. It is also responsible for 5 to 7% of the world's CO_2 emissions and causes noise, dust, and vibration. Limiting these phenomena could result in partial replacement of cement and modification of concrete with the addition of waste granite powder. The use of this type of waste in the production of cement composites means not only lower energy consumption for the extraction and recovery of natural resources but, above all, a reduction in the share of clinker in the cement. In addition, this type of waste is completely harmless to health. Current environmental protection requirements have obliged waste producers to regulate waste management primarily through recovery or disposal.

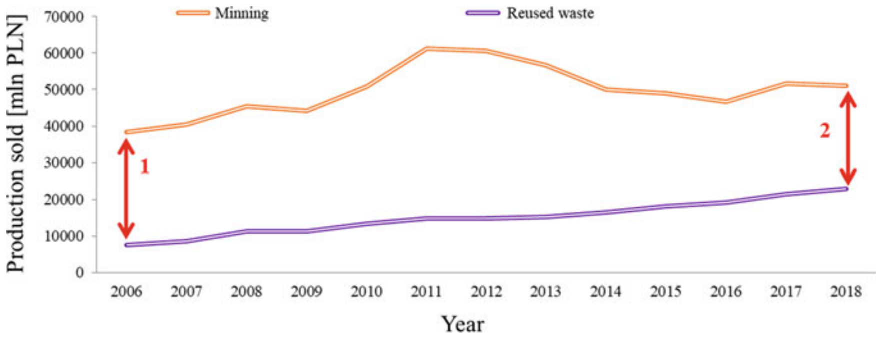

Fig. 2 Mining production and waste management in Poland in years 2006–2018, based on the database of the Polish Geological Institute statistics (assessed 20.07.2021)

Only unless there are economic reasons and technical reasons to use the waste, they should be deposited. The chart below (Fig. 2) also shows a comparison of two branches of industry, mining and waste management. It can be concluded that over the last dozen or so years the awareness of the need to use waste materials has changed significantly—(+200%) more waste is used now than 10 years earlier, which is a positive trend. It should be emphasized, however, that the broadly understood mining is still developing intensively, and the balance between production in mining and waste management unfortunately does not change significantly (the value of vector 1 is close to vector 2). The authors have not analysed the situation after this period due to the pandemic situation.

From the point of view of cement composites, it is important that, according to information from the Association of Cement Producers (SPC), a constant increase in cement consumption of 6–7% has been maintained in Poland since 2017. In 2017, consumption was 17 million tons, while in 2018 it was 18 million tons. This tendency means that cement plants in Poland not only constantly maintain a high production rate, but even have to constantly expand because in the event of difficulties in the availability of Polish cement, concrete producers willingly reach for cement from other countries (mainly from the Czech Republic and Germany).

This is due to the fact that most of the cement plants in Poland are located in the southern part of the country, so this cement often has to be transported several hundred kilometers to the concrete plant. As a result, almost every possibility of its partial replacement with the use of materials available locally (such as granite powder in Lower Silesia) is extremely valuable. In turn, data from the Central Statistical Office show that Poland is the third cement producer in Europe (after Germany and Italy), and the annual production currently exceeds 19 million tons. With the increasing production of cement, the related CO_2 emissions to the atmosphere also increase. According to the BP Statistical Review, Poland in 2018 achieved the world's largest increase in emissions of this compound per person (7%), overtaking China (2.8%) and the United States (2.2%). It is estimated that during the production of 19 million tons of cement (i.e. the amount forecasted for

2019), CO_2 emissions reach about 11.3 million tons, which exceeds the permissible European standards and causes Poland's deficit of about 2.7 million tons. It is connected with the need to buy additional CO_2 emission allowances in the amount of almost EUR 27 million. It is also the reason why the scientific world is also paying more attention to the potential use of granite powder for construction purposes.

2 Influence of the Use of Granite Powder in Cementitious Composites

Because the use of granite powder in cementitious composites is becoming more attractive in terms of chemical-mechanical properties, the investigation of the properties affected by granite powder is presented in this section.

2.1 Physical Properties of Granite Powder

2.1.1 Bulk Density

According to Velumani and Manikandan [21] it has been stated that the bulk density of the concrete mixture containing the granite waste powder decreases slightly until it reaches the replacement value of the fine aggregate of sand of 40% when it stabilizes at approximately 2300 kg/m^3. However the lose bulk density of granite powder is less and ranges from about 1350 kg/m^3 [9] to about 1400 kg/m^3 [10] and is affected by the size of the grains which diameter in research ranges very often used from 1 to 200 μm [23].

2.1.2 Roundness and Blaine Specific Surface Area

According to Chajec [3], the analyzes performed show that the granite powder is characterized by 15% higher roundness, which was equal to 1.520, while in comparison to the cement, it was 1.342. Furthermore, the granite powder-specific surface area value equal to 3950 cm^2/g is greater by approximately 10% compared to these values evaluated for cement equal to 3650 cm^2/g.

2.2 Chemical Properties of Granite Powder

2.2.1. Chemical Composition

As presented in a study dedicated to investigating the chemical composition of granite powder in Karkonosze [11], it can be observed that the main chemical compound is silicon dioxide (SiO_2), the average percentage value of which is approximately 70.23%, then the next highest amount of compound is alumina oxide

III (Al2O3), which is approximately 14.25% and other compounds: potassium oxide (K_2O—5.26%), sodium oxide (Na_2O—2.61%), iron oxide III (Fe_2O_3—2.91%), calcium oxide (CaO—0.89%), magnesium oxide (MgO—0.80%), titanium dioxide (TiO_2—0.42%) and phosphorus oxide (P_2O_5—0.14). Thus, according to the QAPF diagram. the rocks of Karkonosze massif are classified as quartz-rich granitoids or syenogranite due to the rich content of quartz and alkali feldspar [12].

2.3 Mechanical Properties of Cementitious Compounds Containing Granite Powder

2.3.1 Compressive Strength

The most common mechanical property of cementitious composites is the compressive strength. It is also known from different studies that there is a strong correlation between the concrete compressive strength and pull-off adhesion, elastic modulus, flexural strength, and other mechanical properties.

According to Velumani and Manikandan [21] it has been shown that replacing sand with waste granite powder even up to 30% significantly increases the compressive strength value up to approximately 20%. Similar observations were made in [16] where replacing silica sand with granite waste up to 30% was even more effective with increasing the compressive strength value by an average of 30%. These increases were also affected by the silica fume to binder ratio, thus, the real effectiveness of using waste granite powder might not be clear.

Investigating the development of compressive strength, the addition of granite powder does not differ this property compared to other waste mineral admixtures as presented in Binici et al. [1]. It is very promising in the case of the durability of such a composite if the long-term compressive strength increment is comparable to the other admixtures.

In the case of mortars, the replacement ratio of even 40% is the most effective; however, the increase in compressive strength of 5% is not as impressive as in the case of concrete mixtures [9].

It is opposite in the case of self-compacting concrete, where the possible increase in compressive strength is visible even for the 50% addition of waste granite powder to cement, where [15] states that it is more than 50% of the increase in strength than concrete with only 400 kg/m^3 cement content. It is also worth highlighting that with an overall amount of cement + waste granite powder equal to 600 kg/m^3, it is less effective than in comparison to concrete made of mixture with 600 kg/m^3 cement content.

However, when replacing the cement content by granite waste, it is important to observe if the potential substitute is a polished or unpolished mineral, as it can strongly affect the compressive strength. As presented in [18], when using polished granite as a substitute, a decrease in the compression strength value might be observed.

As can be seen from the investigations of the aforementioned works, the replacement ratio of cement by waste granite powder up to 30% has a positive effect on the compressive strength. In addition, while using waste granite powder as a filler in combination with cement, it is still possible to obtain satisfactory results. However, the most efficient in terms of waste granite consumption are the mixtures in which granite is a substitute for coarse aggregate, because such prepared concretes are characterized by increased compressive strength even for the 100% replacement ratio of origin aggregates [2].

2.3.2. Dynamic Young's Modulus

The dynamic Young modulus is very often calculated based on compressive strength [20]. However, it can also be calculated on the basis of the ultrasonic pulse velocity measurements [14].

It was observed that with increasing replacement ratio of sand aggregate by granite powder, the dynamic Youngs modulus increases significantly in mortars to 66% for a replacement ratio of 40% [9].

2.3.3. Flexural Strength

It is stated that the replacement of aggregate with granite powder from waste can increase the flexural strength of cementitious composites. However, it is important to know that replacing aggregates in a higher ratio than 30% may cause a significant decrease of this value even below the value determined for reference samples without granite powder [16].

However, this decrease in flexural strength can be observed with a smaller dosage of granite powder. For example, in Ghannam et al. [8] the increase in this strength was approximately 30% for a replacement ratio of 10% and for a replacement ratio of 15% the increase was not statistically significant.

Polished waste granite powder [18] in addition to being negative in compressive strength, it also negatively affects flexural strength with a slight decrease in this performance value.

2.3.4. Bond Strength

Investigating the bonding of the materials is a very difficult task because there are many ways to determine this strength. It can be evaluated using, for example, the pull-off method [5].

The addition of waste granite powder as a replacement for sand can increase the pull-off strength value of 20 and 25% with the replacement ratio of 30 and 40% respectively in 1:4 mortars; however, it is strongly affected by the w/c ratio of the mortar mixture. Because such replacement failed to improve this adhesive strength while the proportion of the mortar mixture is 1:6 (cement:water) [9].

Due to the lowering of the flexural strength of the cementitious composite with polished granite, the bonding strength is also observed to decrease event at 30% with replacement ratio of 40%. It may be affected due to the weak bond between the polished surface of granite and other particles in the concrete [18].

2.4 Chemical Properties of Cementitious Compounds Containing Granite Powder

2.4.1. Water Absorption

The absorption of water, while incorporating waste materials into the cementitious composite mixture, might be a key factor in some cases that increasing the replacement of the core materials is meaningless. It is due to the fact that during the hardening process of cementitious composites, water is needed in chemical reactions with cement.

It was observed in [16] that replacing the aggregate with the waste granite powder can cause a lower water absorption of the mixture. It is visible for the replacement ratio up to 30% where the water absorption ratio is decreased even by 50%. After that, increasing the replacement ratio to 40% results in an increase in the water absorption ratio up to 20% more than for reference sample.

2.4.2. Superplasticizer Consumption (Workability)

In order to maintain the properties of fresh cementitious composite mixtures, the superplasticizer is very often used for this purpose. Thanks to its appearance in the mixture, it is possible to increase the workability of it and even obtain self-compacting concrete, which is very often characterized by higher values of compression strength than ordinary concrete. It is due to the reduction of the air void ratio in hardened concrete.

Due to the usage of granite waste in a mixture, even as a replacement, it is important to investigate the required dosage of superplasticizer in a mixture. As presented in Kajdas et al. [11], a significant increase in the necessary dosage of superplasticizer has been observed to be up to 100% compared to the mixture without the waste granite powder. The workability of cementitious composites with the addition of waste granite powder generally decreases as stated in [9], due to the rough and angular texture of granite powder, which affects the higher need for water to be added to achieve the required flow value.

3 Conclusions

The addition of waste granite powder, especially in the form of fine aggregate (<63 μm) [19], to engineering and construction materials is a promising solution to address the problem of storage in heaps. It is also beneficial from an environmental point of view because, as it is in powder form, it may pollute air, water, and soil. Moreover, the use of waste aggregates, also granite waste, is cheaper compared to the ordinary way of obtaining mineral aggregates from quarrying [13].

Incorporating waste granite into cementitious composites has many advantages; mainly, it affects the mechanical properties in a positive way (increasing of the strength, e.g. compressive and flexural). However, the highest importance should be placed on the type of granite used and its morphology. Due to the fact that not all granites behave the same as it was presented at polished granite as an example. What is also important is that the replacement ratio should be chosen carefully and with paying attention to the effect that one would like to obtain. As stated above, the addition of a large amount of granite, treated as a substitute for cement, can be applied without general restrictions in terms of compressive strength. In contrast, it is not possible to freely select the replacement ratio in terms of other properties that are highly affected by the addition/replacement ratio of the granite powder (e.g. flexural strength, bonding strength).

Therefore, it is necessary to carefully investigate the potential use of waste granite powder in construction materials. In the opinion of the authors, there is the possibility of using it in industrial floors made of cementitious composite and epoxy resin. According to the literature survey, it is known how it affects the properties of cementitious composites, but it is not known how it affects the properties of epoxy resin. It might be a new possible material in which the waste granite powder may positively affect its properties, considering the fact that such successful attempts were made using the waste glass powder [4].

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Comparative Study on Fly Ash Based AAM Concrete with GGBS, Rice Husk Ash and Sugarcane Bagasse Ash

V. Poornima, K. Vasanth Kumar, and P. P. Hridhi Nandu

Abstract One of the main staples in the construction industry is Portland cement-based concrete, which currently contributes to 8% of global CO_2 emissions during cement production. In this respect, the geopolymer technology shows considerable promise for application in the concrete industry as an alternative binder to Portland cement. Still, there has not been a significant shift away from the use of Portland Cement due to the demand for additional necessary precautions and the requirement of high temperature to bring about rapid strength gain. The mechanical and durability properties of class F fly-ash (FA), based Alkali Activated Concrete (AAM) with varying percentages of Ground Granulated Blast Furnace Slag (GGBS), Rice Husk Ash (RHA), and Sugarcane Bagasse Ash (SCBA) cured at ambient weather conditions are discussed. The results of the tests further indicate the possibility of using ambient cured AAM Concretes for construction purposes.

Keywords Fly ash · Ground Granulated Blast Furnace Slag (GGBS) · Geopolymer Concrete (GPC) · Rice Husk Ash (RHA) · Sugarcane Bagasse Ash (SCBA) · Agricultural waste · Sustainable concrete · Concrete · Alternative construction materials

1 Introduction

1.1 General

In 2020–2021 CO_2 emissions due to cement production is reported to be 189.5 Million Tonnes, and this figure has been forecasted to exceed 221 Million Tonnes in the year 2021–2022 [1]. Reports by the IBEF show that cement production in India has reached 329 Million Tonnes as of 2020 and is expected to increase by 2022 at the rate of 13% [2]. In this regard, utilization of by-products from other

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industries as supplementary construction materials in concrete and cement has been well-apperceived for its enhanced properties and potential to truncate environmental impact [3]. The use of geopolymers as alternative binders and aggregates [4] in concrete has been well received as it eliminates the use of cement and can reduce the overall carbon footprint of the construction industry.

1.2 Geopolymer

Joseph Davidovits first coined the term geopolymer in 1994 when he observed that class F fly-ash, activated with alkaline solutions such as sodium hydroxide (NaOH), forms a silico-aluminate polymer that has a structure similar to zeolites [5]. For polymerization to take place, the pozzolanic material should be rich in both alumina and silica content.

Geopolymer binders utilize waste materials that contain a high volume of aluminum and silicon species. The chemistry of geopolymer binders has been widely investigated [5–8], and it has been shown that it is possible to use geopolymers as an alternative binder to Ordinary Portland Cement (OPC) in concrete production. However, due to several constraints concerning the production process, such as workability, the necessity of heat curing, and delay in setting time [9, 10] more widespread research of geopolymer concrete (GPC) is needed at both concrete manufacture and structural design levels.

1.3 Geopolymer Products and Advantages

The manufacturing of fly ash-based geopolymer concrete railway sleepers was reported by Palomo et al. [11]. They discovered that the geopolymer concrete structural members could be effectively manufactured using current technology with minimal adjustments. The engineering performances of the products were excellent, and the drying shrinkage was minute. Also, Recent studies show that geopolymers exhibit excellent fire resistance properties and Lahoti et al. [12], in their review, stated that geopolymers are chemically stable. Still, the compressive strength and sorptivity of geopolymers were determined to be affected on the one hand by microstructural changes such as the development of cracks, porosity changes, and densification [13].

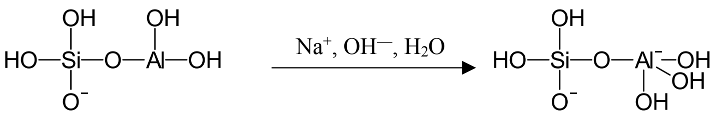
1.4 Coexistence of Geopolymers and Other Alkali Activated Materials

Binder matrices of geopolymers with additives rich in calcium are generally not considered true geopolymers because the resulting polymer compound is generally discrete and not a continuous network. However, the two systems can coexist, resulting in a binder matrix with properties that are advantageous to specific scenarios [14]. Li et al. [15] observed that the addition of GGBS in small quantities improved the overall strength of the concrete matrix significantly.

1.5 Mechanism Involved

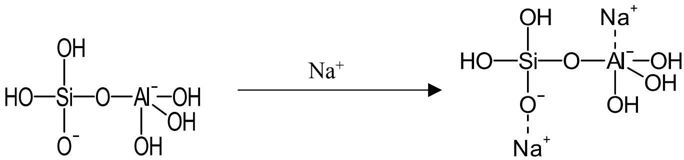
Geopolymerization is the process of transforming aluminosilicate raw material into a covalently bonded 3D network consisting of [—Si—O—Al—O—]$_n$ bonds. The two major components of a geopolymer binder are the pozzolanic material and the alkaline medium. The most commonly used alkaline medium for geopolymerization includes sodium hydroxide or potassium hydroxide in conjunction with sodium silicate. The generalized geopolymerization reaction is as follows:

Step 1: Alkalinization



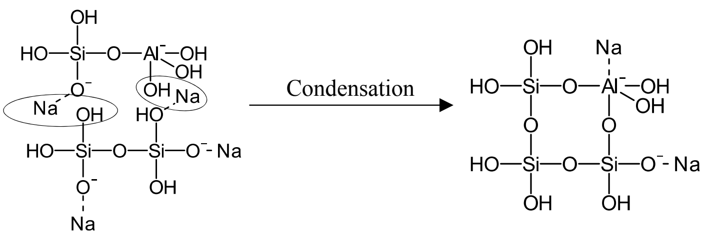
(1)

Step 2: Depolymerization



(2)

Step 3: Condensation



(3)

Alkalis involved in the chemical reaction are taken up by the amorphous pozzolanic components in the FA and are converted into cementitious binders and zeolite crystals. The unused alkalis attack the reactive aggregates initiating an alkali silicate reaction during which the material is still in the gel form. Under strong alkaline solution, the alumino-silicate reactive materials rapidly dissolve into solution resulting in the liberation of aluminate and silicate, most likely in their monomeric form [7]. Water plays no role in the chemical reaction but acts as a medium and imparts workability to the mixture [16].

1.6 Alkali Activation

Alkali activation is the general name for the reaction of a solid aluminosilicate (referred to as the "precursor") under alkaline conditions (caused by the "alkali activator") to form a hardened binder composed of a hydrous alkali-aluminosilicate composite. The presence of calcium in aluminosilicate material leads to the formation of phase-separated C—S—H and C—A—H gels, which technically is the normal pozzolanic reaction that occurs during the hydration portland pozzolanic cement (PPC).

$$Ca^{2+} + 2OH^{-} + SiO_2 \longrightarrow C - S - H \quad (4)$$

$$Ca^{2+} + 2OH^{-} + Al_2O_3 \longrightarrow C - A - H \quad (5)$$

Calcium interacts with Na_2SiO_3 solution in the presence of FA to generate C-S-H, which is amorphous or weakly crystalline, or Ca-Al-Si, causing a water deficiency in the alkaline medium increasing its alkalinity. This will allow for a more considerable degree of aluminosilicate dissolution and a faster pace of polycondensation—geopolymerization, resulting in an intricate structure with increased compressive strength. Furthermore, excessive lime will disturb the ideal geopolymer gel binder structure, inhibiting strength growth. However, this could be due to minor variations in the binder Si—Al ratio near the calcium silicate particles caused by Si and Al leaching, resulting in regions of less-than-optimal microstructure that act as matrix imperfections during mechanical strength testing [17].

1.7 Use of Additional Silicate in the Alkaline Solution

The type of solution used to activate the fly ash, according to Palomo et al. [6], is critical in the development of reactions. When soluble silicates (sodium or potassium silicate) are employed as activators in the alkali solution, the reactions proceed at a faster rate than when hydroxides are utilized. Again, the reaction phases overlap, and the solid evolves in such a way that chemical species dissolution, reaction product accumulation, and structural polycondensation all occur concurrently.

1.8 Significance and Objective of the Present Study

The objective is to study the mechanical properties and durability properties of FA based AAM concrete incorporated with industrial waste (GGBS) and agricultural waste (RHA & SCBA). From several studies, it has been reported that FA based GPC has a longer final setting time, i.e., around 2–3 days. Also, GPC requires heat curing for strength attainment. To overcome the issue of final setting time, FA was partially replaced with GGBS making the GPC matrix an AAM matrix. In addition to this, FA was also partially replaced with RHA or SCBA (in separate mixes) as both materials have high silica content and are abundantly available to check whether they are compatible. The mechanical and durability aspects of the resulting concrete mixes cured at ambient temperature were observed.

2 Literature Review

The current studies concerning geopolymer concrete and other alkali-activated materials have been reviewed. The background and requirements for the development of FA based AAM concrete have been further discussed.

2.1 Fly Ash

The precursors for geopolymers can be obtained by the dissolution of materials rich in silica and alumina through alkalinization. Fly Ash is rich in silica and alumina. It is abundant and readily available from coal power plants as waste material during the combustion of bituminous and sub-bituminous coal. The chemical composition of FA depends on the type of coal used [16]. According to ASTM C-618 [18], FA is classified into class F and class C based on the oxides of silicon (SiO_2), aluminium (Al_2O_3), and iron (Fe_2O_3), where class F contains a minimum of 70% and class C have a minimum 50% of these oxides. Due to the higher silica and alumina content in Class F FA is generally preferred over class C FA because any kind of hindrance towards geopolymerization reaction can be eliminated. Also, Rowles and O'Connor [19] stated that to reach sufficient mechanical strength, Si/Al ratio has to be around 2.

2.2 Selection of Alkali Activator

As discussed earlier, a strong alkali activator is required for the dissolution of alumina and silica from the parent pozzolanic material. The most commonly available ones are Sodium Hydroxide (NaOH) and Potassium Hydroxide (KOH). SEM analysis revealed fundamental changes in the morphologies of metakaolin-based geopolymer mortars depending on the alkaline activating solution utilized. Fast activation resulted in a heterogeneous morphology, porous and micro-cracks, in those made with alkaline sodium silicate, which led to high mechanical strength in the early ages and impeded matrix growth. The mortars made with potassium silicate have a consistent microstructure with few pores [20]. In addition, geopolymers containing potassium have better mechanical strength than those made with sodium, owing to the lower K^+ diffusion coefficient at high temperatures compared to Na^+, resulting in a greater melting temperature [21]. More notably, NaOH solution is projected to provide a greater degree of dissolution of Al–Si crystals with a five-membered rings structure, as well as a better initialization and faster gel formation, compared to other solutions [7]. It's also worth noting that KOH is more expensive than NaOH, and considering the difference in performance, it's uneconomical.

2.3 Molarity of Sodium Hydroxide Solution

The amount of material in a given volume of solution is measured in molarity (M). The moles of a solute per litre of a solution is known as molarity. The molar concentration of a solution is also known as molarity. Joshi et al. [22] investigated the variation of compressive strength as a function of the alkaline solution's molarity, finding a significant increase in compressive strength from 8 to 14M. Jaffery et al. [23] discovered a similar trend in split tensile strength and flexural strength. This connection diminishes as molarity rises, illustrating the unexpected behaviour at higher molarities due to shrinkage cracks and incomplete polymerization [24, 25].

Nagaraj et al. [26] observed that increasing the molarity showed a significant decrease in the workability of the concrete mix. Jaffery et al. [23] also observed as the molarity increased, there was a considerable loss in weight during the acid attack test.

2.4 Sodium Silicate to Sodium Hydroxide Mass Ratio

Increasing the Sodium silicate to Sodium Hydroxide mass ratio does not have any identifiable trend in the compressive strength parameter [22]. Furthermore, Habert et al. [27] suggested that the base material should be chosen with a suitable Si/Al molar ratio to reduce the use of Sodium Silicate solution when producing geopolymer concrete considering the environmental impact of Sodium Silicate production. Mustafa et al. [28] observed maximum compressive strength for Sodium Silicate to Sodium Hydroxide mass ratio of 2.5. Also, Kwon et al. [29] suggested that the Na_2O content should be at least 10% by mass of the Sodium Silicate solution for maximum strength attainment. Pradip et al. [30] observed that increasing the mass ratio increases the workability and the setting time.

2.5 Geopolymer Liquid to Binder Ratio

Sairam et al. [31] has observed that compressive strength increases with an increase in geopolymer liquid to binder ratio reaching its maximum strength at 0.5, after which it decreases, and Mustafa et al. [28] stated the optimum geopolymer liquid to binder ratio as 0.5. Nagaraj et al. [26] observed that with the increase in geopolymer liquid to binder ratio, there is a significant increase in workability.

2.6 Curing Conditions

Heat cured geopolymer has a substantially higher compressive strength than ambient cured geopolymer. The compressive strength of ambient cured specimens improves from 7 to 28 days, whereas the compressive strength of heat cured fly-ash based geopolymer concrete does not significantly increase after 7 days [10, 22, 29, 32, 33]. Kumudha et al. [10] also observed that the density of ambient cured specimens increases as the age of concrete increases from 7 to 28 days.

2.7 Replacement of FA with GGBS

The primary issue in using FA based geopolymer binder as an alternative to OPC binder is that the initial setting time of FA based binder exceeds 24 h. To work around this issue, researchers have tried replacing a part of FA with GGBS to use its calcium content to decrease the setting time. Mallikarjuna et al. [34], Pradip et al. [30], and Xie et al. [35] have observed that increasing the GGBS content in the mix design significantly decreases the initial and final setting time by more than 18 h. Also, the compressive strength of both GPC and geopolymer mortar is known to increase considerably with the addition of GGBS. The main drawback of adding GGBS is that the workability of the mix also decreases.

2.8 Replacement of FA with RHA

Ramani et al. [36] stated that the RHA could be used as source material in geopolymer concrete in addition to GGBS, and significant improvement in its corrosion resistance was observed. Mishra et al. [37] and Kishore et al. [38] observed that increasing the percentage of RHA in FA based GPC decreased its workability and compressive strength but increased its tensile strength. Kwon et al. [39] observed that GPC matrices with RHA had increased resistance to sulphate attack and acid attack. Raw RHA has high LOI and is unsuitable for chemical activity because of its microstructure. Salas et al. [40] observed that chemically treated RHA has a significant pozzolanic activity and can be easily used in GPC.

2.9 Replacement of FA with SCBA

The study conducted by Tashima et al. [41] demonstrated the feasibility of using SCBA in alkali-activated systems to form GPC, thereby reusing the ashes obtained in the sugarcane industry. Rehman et al. [25] and Tashima et al. [42] observed that increasing the replacement percent of FA with SCBA decreases the overall compressive strength, does not have a significant change in porosity of the GPC matrix, and increases the workability of the fresh GPC. SCBA collected from sugarcane boilers usually is combusted at 500–550 °C; therefore, the LOI of raw SCBA is very high. Cordeiro et al. [43] observed that controlled calcination of raw SCBA mitigated its negative effects by increasing the active silica and alumina.

3 Materials Adopted and Methodology

3.1 Materials Used in the Current Study

Class F fly-ash used in this study was obtained from Mettur thermal power plant, Tamil Nadu, having a specific gravity of 2.15. In this study Sodium based AAS is used. Sodium Silicate was obtained from Kuttuva Silicates, Madurai, Tamil Nadu, with chemical composition as mentioned in Table 1. Sodium Hydroxide flakes of

Table 1 Chemical composition of sodium silicate solution

Description	Value
SiO_2/Na_2O ratio	2.2
Na_2O %	15
SiO_2 %	30
H_2O %	55

Table 2 Chemical composition of GGBS

LOI %	CaO %	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	MnO %	Cl %	IR %	SO_3 %	Sulphide %
0.35	37.6	34.8	17.92	0.66	7.80	0.21	0.004	0.19	0.20	0.51

Table 3 Elemental composition of Flyash, RHA and SCBA

Element	Flyash	RHA	SCBA
	(Percentage weight)		
O	43.96	47.73	35.86
Al	17.09	0.91	0.99
Si	26.14	36.05	21.01
Ca	0.84	1.63	4.45
P	-	3.00	3.57
K	1.10	5.68	2.95
Na	-	0.43	0.45
Mg	0.37	0.55	3.52
Ti	1.5	-	-
Fe	5.97	1.92	4.29
S	-	-	1.16
C	4.00	2.11	21.1
Cl	-	-	0.67

Table 4 Physical composition of GGBS

Fineness (M^2/kg)	Specific gravity	Glass content (%)
386	2.9	96.85

Table 5 Aggregates properties

Properties	Coarse aggregate	Fine aggregate
Density (kg/m^3)	1610	1510
Specific gravity	2.65	2.59
Water absorption (%)	0.38	1.6
Fineness modulus	-	2.03
Zone	-	Zone II

90% purity were used in this study and were obtained from Tech Craft Scientific Chemicals, Coimbatore, Tamil Nadu. GGBS was obtained from the JSW Cement distributor, and the chemical and physical composition is mentioned in Tables 2 and 4, respectively. Calcined RHA and SCBA used in this study was obtained from Astraa Chemicals, Chennai, and Naturophilic Business, Gujarat, respectively. M Sand and 20 mm coarse aggregates were obtained from JFM Traders, Coimbatore. Their properties are mentioned in Table 5 (Table 3).

3.2 Methodology

Preliminary tests were conducted to fix the Sodium Silicate to Sodium Hydroxide ratio, GGBS content, and molarity. During the trials, it was evident that by increasing the GGBS content and molarity, there was a considerable decrease in workability. The workability of mixes with 8 and 10M NaOH solution was similar; thus, 10M was adopted. GGBS was primarily used for decreasing the setting time of the mix. Mixes with 20 and 30% GGBS content reached the final set within 24 h, whereas mixes with 10% exceeded the 24-h time limit. Therefore, 20% GGBS was adopted for the mix design. Then mechanical and durability tests were conducted.

3.3 Mix Design Details

The mix design used in this research was adopted from Asrani et al. [44], and the mix details are provided in Table 6.

3.4 Mix Proportion Details

The details of the mix used in the study are mentioned in Table 7. Cubes were cast with Fly Ash replaced with 10, 20, and 30% GGBS, which was allowed to set in ambient temperature resulted that after 24 h, both 20 and 30% GGBS moulds attained final setting time and were ready to demould whereas the cubes with 10% GGBS were not ready for demoulding. Also, from a literature study, it is said that FA replaced with RHA more than 20% in typical FA based GPC showed a decrease in compressive strength. Since both 20 and 30% GGBS had reached their final setting time, considering the addition of RHA, the GGBS proportion was fixed to 20%, which served as the control mix.

Table 6 Mix design details

FA (kg/m^3)	$Na_2O.mSiO_2$/NaOH	GL/B*	Molarity (M)	M. Sand (kg/m^3)	CA (kg/m^3)	Additional water (%)
414	2	0.5	10	515	956	10

*GL/B – Geopolymer Liquid to Binder Ratio

Table 7 Mix proportion

s	GGBS 20% (CM*)	RHA 5%	RHA 10%	SCBA 5%	SCBA 10%
$Na_2O.mSiO_2/NaOH$	2	2	2	2	2
GL/B	0.5	0.5	0.5	0.5	0.5
Molarity (M)	10	10	10	10	10
Fly ash (kg/m^3)	331.2	310.5	289.8	310.5	289.8
GGBS (kg/m^3)	82.8	82.8	82.8	82.8	82.8
RHA (kg/m^3)	0	20.7	41.4	20.7	41.4
M. Sand (kg/m^3)	515	515	515	515	515
CA (kg/m^3)	956	956	956	956	956
Additional water (kg/m^3)	41.4	41.4	41.4	41.4	41.4

*CM – Control Mix

4 Experimental Study

4.1 Preparation of Specimens

Preparation of specimens and procedure for the test was done as per IS 516 part 1 [45]. The quantities of cementitious material and water for each batch were determined by weight as per mix ratio adjusted for absorption by aggregates and accuracy of 0.1% of the total weight of the batch. While mixing with hand loaded machine mixer, all dry materials were first introduced into the pan mixer, water and solutions were added later. The mixing period was not less than 2 min; it was continued till uniform concrete was formed. All the mixes had very low workability (i.e., slump of less than 25 mm) and was somewhat viscous. Slump of control mix and mixes with SCBA were somewhat similar (in the range of 19 to 23 mm) whereas slump of mixes with RHA was in the range of 11 to 15 mm). Cube-shaped test specimens of 15 × 15 × 15 cm in dimension were used for testing compressive strength. Metal moulds were used to prevent distortion. All surfaces, including the base plate, were greased for easy removal of specimens after setting. Concrete was poured into the mould in layers of 5 cm each. Each layer received tamping 25 times using a tamping bar in a uniform pattern. Cylindrical test specimens with 15 cm dia. and 30 cm in length were used for split tensile strength. A similar procedure for compaction was used as per IS 516 [45]. Specimens used for the flexural test were 15 × 15 × 70 cm in dimension. The mould is constructed and filled with the longer side kept horizontal. The procedure for compaction remains similar. The specimens were made for each mixed group and marked with suitable identification. The test specimens were stored at a place free from vibration for 24 h. After 24 h, the specimens were de-moulded and stored in a clean area before the tests. All tests were carried out after 28 days of ambient curing.

4.2 Test Procedures

Compression Strength

The test was carried out following IS 516 Part 1 [45]. Cube specimens were compressed in a direction perpendicular to the casting direction. The load was applied without shock and gradually increased at a steady rate of 14 $N/mm^2/min$ until failure was reached. The indicated maximum load was recorded.

Split Tensile Strength

The test was carried out following IS 516 Part 1 [45]. The test specimen was carefully positioned in the centering jig with a packing strip and loading pieces at the top and bottom of the specimen's loading plane. The jig was installed in the machine with the specimen in the centre. The load was applied without shock and increased continuously at a nominal rate within the range of 1.2 to 2.4 $N/mm^2/min$. Maximum load at failure was recorded. The splitting tensile strength of the specimen was calculated using the formula fc $= 2P/\pi ld$.

Flexural Strength

The test was carried out following IS 516 Part 1 [45]. Two steel rollers, 38 mm in diameter, were put on the bed of the testing machine to support the specimen, and these rollers were mounted so that the distance from centre to centre is 40 cm for specimens with a cross-section of 10 $\times$ 10 cm. The load is applied axially through two comparable rollers installed at the third points of the supporting span, spaced at 20 cm centre to centre. As previously described, the load was applied perpendicular to the casting direction using two rollers at the top and bottom. The load was applied without shock and increased continuously at a rate of loading of 4 kN/min. The maximum load was noted. The flexural strength of the specimen was calculated using the formula given in IS 516 PART 1 [45].

Water Absorption Test

The test was conducted as per ASTM C642-06 [46]. Cube specimens of 10 $\times$ 10 $\times$ 10 cm were cast. A centimetre of the cube was shaved off on all sides to expose the core (ref. Fig. 1). The Specimens were placed inside a hot air oven for 24 h at 110° and were left to cool. The respective dry weight was noted down. The specimens were then immersed in water for 24 h, after which the surface water was removed from the cubes, and the weight was noted. Water absorption was found by dividing the difference in weight with the dry weight.

Fig. 1 **a** Exposed core **b** Cutting of specimen

5 Results and Discussion

The mechanical and durability tests, as mentioned in Sect. 4, were conducted, and the results are discussed. The tests were conducted after the specimens were ambient cured for 28 days, during which the specimens were exposed to a minimum temperature of 21.8 °C and a maximum temperature of 37.6 °C. The average temperature during this period 29.1 °C. For further details, refer Fig. 2.

5.1 Mechanical and Durability Properties

Compressive strength decreases with the addition of RHA but increases with the addition of SCBA, as seen in Fig. 3(a), which is consistent with prior research [25, 38, 47, 48]. It's also worth noting that specimens cast with SCBA had a 30% higher compressive strength than those cast with RHA. Split tensile strength improves with the addition of RHA and SCBA, which can be attributed to their fibrous nature, but there is a dip in the case of SCBA at 5% replacement (ref. Fig. 4), and RHA performs better than SCBA. Flexural strength seems to deteriorate when SCBA and

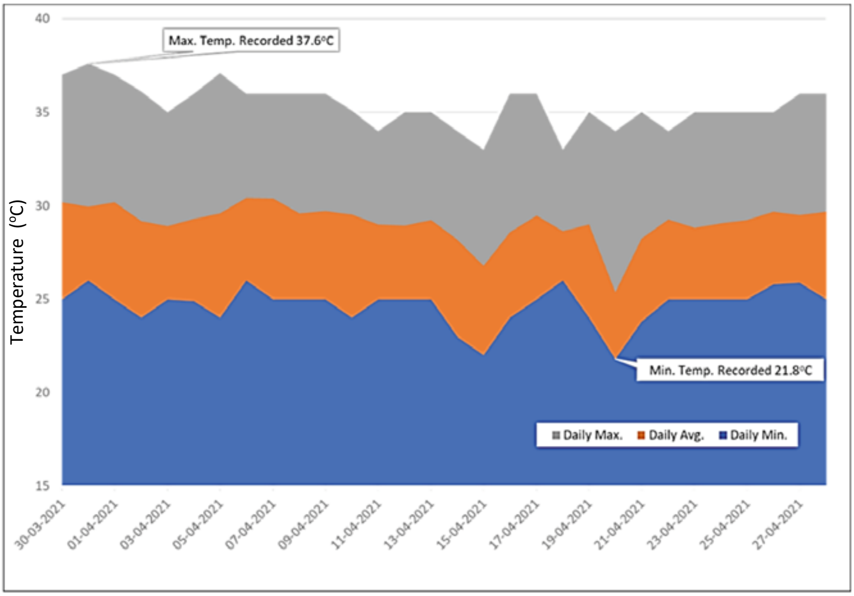


Fig. 2 Temperature data from 30 March to 28 April 2021

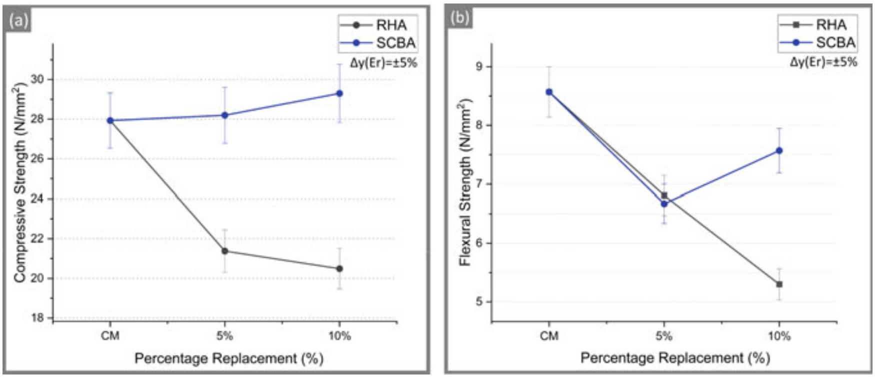
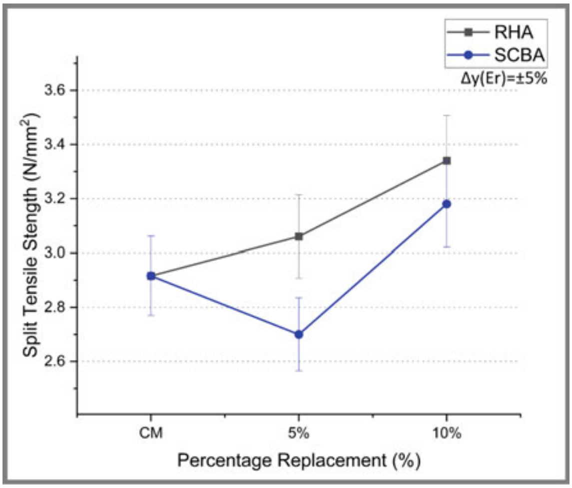


Fig. 3 **a** Compressive strength, **b** Flexural strength

RHA content rises. RHA's incorporation into the AAM concrete matrix tends to lower compressive and flexural strength by more than 10%, while SCBA performs better than RHA at greater replacements. Compared to traditional concrete of identical compressive strength, the flexural strength of all AAM mixes performs well [49].

Fig. 4 Split tensile strength



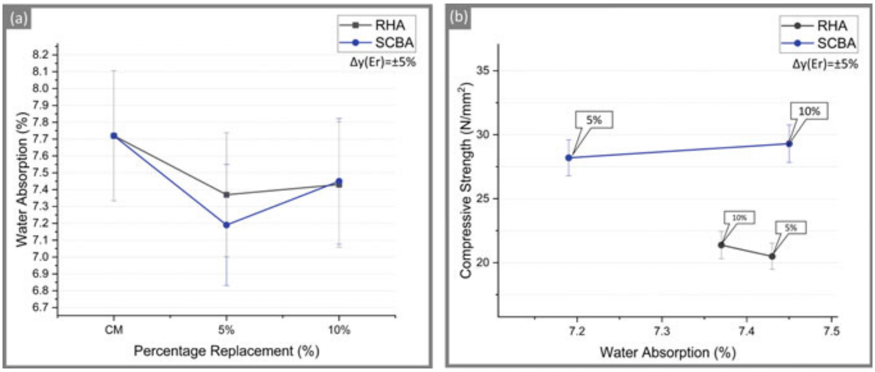


Fig. 5 **a** Water absorption, **b** Compressive strength vs. water absorption

5.2 Water Absorption

From the results obtained, it can be observed that with the addition of RHA and SCBA, water absorption has reduced (ref. Fig. 5(a)). Both the compressive strength and water absorption parameters follow a similar trend with addition to RHA, which was also observed by Kwon et al. [39]. Comparing 5 and 10% replacements of RHA, the water absorption decreases with an increase in compressive strength, contrary to that of SCBA (ref. Fig. 5(b)).

6 Conclusion

1. The addition of GGBS has reduced the final setting time from 2 to 3 days to 24 h, making it ideal for onsite use. After 28 days of ambient curing, the AAM concrete attained reasonable strength.
2. Vibratory compaction seems to be appropriate for the prepared mixes, which visually appeared to be less workable.
3. The adoption of RHA as a substitute for Fly Ash has considerable drawbacks. The use of RHA as a blended mix in AAM concrete can only be justified if there is a severe shortage of FA or improved durability characteristics in terms of acid, sulphate, and water absorption are required.
4. In the AAM concrete matrix, replacing SCBA with FA had a favourable effect, notably at 10% replacement
5. The water absorption characteristics of both RHA and SCBA mixes are similar.
6. The mechanical performance of the AAM concrete matrix with SCBA is better than the AAM concrete matrix with RHA in general. As a result, the use of SCBA as a fly ash alternative in small quantities can be advocated.
7. The use of ambient cured AAM concrete in construction sites should be planned ahead of time, taking local weather conditions into account to ensure warmer temperatures during curing.

6.1 Further Scope for Study

1. Microstructure analysis of AAM concrete with both GGBS and RHA content can be analysed.
2. The addition of RHA and SCBA has a positive effect on the durability of the concrete, so the durability aspects of AAM concrete with SCBA and RHA along with GGBS can be analysed.
3. Fire resisting properties of AAM concrete with RHA and SCBA along with GGBS can be analysed.
4. Probability studies need to be conducted and standardization of AAM concrete to increase the use of geopolymers in construction.

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Self-consolidating Concrete Produced with Fine CDW

Stéphanie Rocha, Joice Soares, Thâwanne Costa, and Lino Maia

Abstract Self-consolidating concrete is a concrete technology that seeks to simultaneously achieve fluidity, passing ability and segregation. In its manufacture there is the possibility of using alternative materials, such as ground ceramic, predominantly in construction and demolition waste. Therefore, this study aims to analyze the feasibility of this concrete regarding its properties in the fresh and hardened state when there is replacement of fine sand by ground ceramic aggregate. For this, the flowing tests, flow time, visual stability index, J ring, L box, V funnel and the molding of specimens in three different compositions were carried out, one being the reference compositions and the other two with replacements of 25 and 50% in the natural fine sand by the ceramic waste sand. The mixes in which the replacements were carried out presented good fluidity, without of segregation, however, the passing ability of the mix with 50% of replacement did not fit within the recommended range.

Keywords Workability · D-flow · Superplasticizer · Segregation

1 Introduction

Reinforced concrete is the most used structural construction technique in the world, it arose from the need to incorporate the high durability and compressive strength of concrete with the tensile strength of steel, being able to assume desired shapes

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easily and quickly [1]. Generally, the concrete used is the conventional, it has a dry consistency, characteristic compressive strength around 30 MPa and is used in most civil, industrial and precast factories [2]. However, the Conventional Concrete (CC) does not fit into projects with specific characteristics, such as the style of constructions adopted in Japan, where due to intense earthquakes, the structures have a high rate of steel and shapes complex, which makes it impossible to properly consolidate. Therefore, Hajime Okamura developed in 1983, at the University of Tokyo, the Self-consolidating Concrete (SCC) [3].

SCC is a concrete technology that seeks to simultaneously achieve fluidity, passing ability and strength to segregation. Thus, it is able to cohesively occupy the empty spaces within the form, without obstruction or segregation, when in contact or not with obstacles, only through gravity, without external interference [4].

Regardless of the types of concrete, the biggest challenge currently faced is the need to prepare concrete that in the course of obtaining it generates the least possible impact [2]. As population development and urbanization led to an increase in demand for goods and services, which consequently led to more consumption and waste. Thus, this is the sector that most generates environmental degradation, as it has a vast generation of waste and poor final disposal, as Construction and Demolition Waste (CDW) are often discarded in irregular areas and dumps [5].

Solid civil construction waste, recycling areas with guidelines for design, implementation and operation is cited in Brazilian regulations [6]. It was based on Resolution 307 of the National Environmental Council (CONAMA), on July 5, 2002, which aimed to create a plan for an efficient management of this type of waste, promoting an adequate destination. The incorrect management of these wastes negatively interferes in environment, because it causes siltation of water bodies, in addition to visually polluting cities and affecting the health of the population, since their disposal on vacant land allows for the release of other types of waste, which contributes to the appearance of vectors responsible for the transmission of diseases [7]. The use of waste resulting from civil construction is identified as the best alternative to reduce these impacts caused by the constant consumption of raw materials and the large volume of CDW [8].

In order to minimize the volume of wastes in landfills or inappropriate places, studies were carried out, where is possible using of CDW's as aggregate for the manufacture of CC [9]. However, when it comes to the SCC, there are few studies on this replacement. It is possibility of using alternative materials in the production of SCC. Pozzolanic materials such as fly ash, rice husk ash, silica fume, metakaolin and blast furnace slag; and non-pozzolanic ones, for example, ground ceramic, limestone filler and fine sand, those being used in the replacement of the binder and these in the fine aggregate [4].

A non-pozzolanic material found predominantly in CDW's aggregates are ceramics, as the largest portion of waste generally comes from the masonry [10]. In studies carried out in a landfill in Itatiba-SP, ceramic waste represents 63% of total CDW [11].

Studies carried out over time, to characterize the use of fine aggregate from CDW, show a reduction in workability, due to greater water absorption, and a decrease in strength when applied to concrete. However, it is observed that even with these particularities, if the problem is well dealt with, concrete with fine recycled aggregates (FRA) can be used with high performance. The academic and scientific community is conservative regarding the application of this material, such as the Brazilian standard, for example, which only allows the use of FRA for non-structural purposes. The regulations of countries such as Portugal, United Kingdom, Spain, Germany, China and Hong Kong, for example, are even stricter, as they do not allow the replacement of natural aggregate by FRA in concrete [12].

As previously mentioned in Refs. [9, 11], the positive impact that the use of CDWs has on the environment is indisputable. However, in addition to affecting workability due to water absorption by FRA, other factors can be discussed: the presence of new transition zones (ITZs) interferes with the mechanical properties and transport of new concrete [13]; the chemical attack caused by sulfates and chlorides influence the durability of concrete [14]; the variability of the aggregates, in a way that interferes with the physical and chemical properties and their quality control [15], which leads to many analyzes of concrete with agreggate CDW manufactured in the laboratory, however, with little practical application.

The application of different CDW materials to improve eco properties of SCC has being studied especially in the last decade. Among many others materials, research was carried out with ceramic waste [16], perlite [17], marble waste, fly ash and micro silica [18], glass powder [19], tire rubber [20]. Therefore, to propose an alternative for recycling ceramic CDW, due to the high percentage of this material that is generated during building demolitions, this study proposes the feasibility of partially replacing fine sand by crushed ceramic aggregate from CDW in SCC, evaluating its properties in the fresh and hardened state.

2 Materials and Methods

Three SCC compositions aimed for 30 MPa were performed. A reference mixture (T1), a composition with 25% replacement of fine aggregate by ceramic aggregate CDW (T2) and the latter with 50% replacement (T3). According to NBR 15,116 [21], recycled aggregates from civil construction waste can only be used for paving or in concrete without structural function (up to 15 MPa). Table 1 reports the aggregates properties.

Table 1 Aggregate characteristics

Material	Specific gravity (kg/dm^3)	Powder materials (%)	FM[a]	MCD[b] (mm)
Fine sand	2.60	1.60	2.07	1.2
CDW	2.17	28.20	2.54	1.2
Stone dust	2.66	19.4	4.34	4.8
Gravel 0	2.69	5.20	2.62	9.5
Gravel 1	–	–	0.66	19.0

[a]Fineness module. [b]Maximum characteristic dimension

As expected, analyzing Table 1, one observed that ceramic CDW sand has specific gravity smaller than fine natural sand. Moreover, ceramic CDW has a higher fineness modulus than fine natural sand.

The reference mix (T1) had 346.07 kg/m^3 of the Brazilian Cement CPV according NBR 16,697 [22], 673.33 kg/m^3 of natural fine sand, 286.67 kg/m^3 of stone dust, 666.67 kg/m^3 of Gravel 0, 166.67 kg/m^3 of Gravel 1, 185 L of water and 3.13 L of Additive MC-PowerFlow 1180. The natural fine sand in the mixes T2 and T3 was reduced for 504.80 and 336.40 kg/m^3, respectively. Additionally, the Ceramic CDW sand was of 140.40 and 280.80 kg/m^3 in the mixes T2 and T3, respectively. It was defined that the concretes should obtain slump of 3 cm through the slump test, before the addition of the superplasticizer additive, as it needs a minimum of humidity to disperse, so it was necessary to increase the w/c of the T2 and T3 mixes. According to [23], the particle size of waste influences the w/c factor, as the amount of water applied increases with addition of fines. This was effectively observed in T2 and T3, since the ceramic CDW has a higher fineness modulus than the sand, thus, it increased the water needed for mixes until reaching minimum slump of 3 cm.

It was noted that there was a reduction in the w/c when there was also a reduction in the replacement of fine sand by waste aggregate [23]. The increase in water in mixes was also due to that ceramic is a porous material, which allows for greater water absorption.

Even after T1, T2 and T3 mixes reached the 3 cm slump, it was necessary to add more additive, since the addition of initially intended 0.98%, as recommended, the mixes did not show a minimum spread of 550 mm [4]. Thus, spreading and flow time tests were repeated at each addition of additive until they reached the minimum spreading. The greater the replacement proportion of fine sand by ceramic CDW, the greater the w/c, to reach minimum abatement; and higher additive consumption to achieve minimum spread. After the addition, it was observed whether the mixes visually presented a fluidity characteristic of SCC, and subsequently, the mixes were submitted to tests in a fresh state to verify the characteristics. The final corrections of the mix compositions are shown in Table 2.

Table 2 Consumption of materials

Mix	Consumption							
	Cement CPV (kg/m^3)	Fine sand (kg/m^3)	Ceramic CDW (kg/m^3)	Stone dust (kg/m^3)	Gravel 0 (kg/m^3)	Gravel 1 (kg/m^3)	Water (L)	Additive *MC-PowerFlow* 1180 (L)
T1	346.07	673.33	0	286.67	666.67	166.67	185	3.42
T2	346.07	504.80	140.40	286.67	666.67	166.67	206	3.74
T3	346.07	336.40	280.80	286.67	666.67	166.67	248	4.44

2.1 Fresh State Tests

In the scattering test, the fluidity of SCC was determined by measuring two perpendicular measurements, of the diameter of circle formed by concrete, which was previously inside the Abrams cone (Fig. 1).

Concomitantly, the flow time was determined, as the result of this comes from the definition of the time it takes the SCC to reach the 500 mm mark, carried out on the base plate. For the IEV, the photographs obtained during the test were compared with Fig. 2.

The J ring test was determined using the method proposed in NBR 15,823-3 [25], so the Abrams cone and the J ring were positioned, both in the center of the base plate and the first of SCC; after removing the cone, the perpendicular diameters of the circle formed by the concrete were measured (Fig. 3).

Fig. 1 **a** Abrams cone filled; **b** Scattering measurements

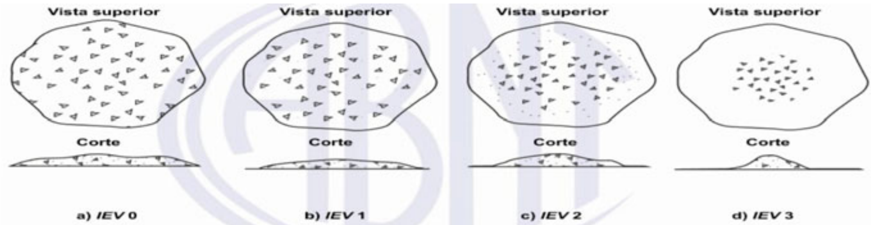

Fig. 2 Visual stability index classes (IEV) according to NBR 15,823-2 [24]

Fig. 3 **a** Positioning and filling the cone; **b** Suspension; **c** Measurement of diameters

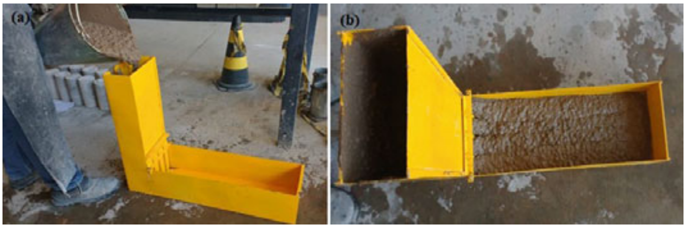

Fig. 4 **a** Filling the vertical chamber; **b** Opening the gate

Fig. 5 **a** Filling the funnel; **b** Opening the gate

The L box test follows the method proposed in NBR 15,823-4 [26]. Therefore, the vertical compartment was filled by SCC and later the gate present at the end of this compartment was opened and allowed the passage of concrete, through steel bars, to the horizontal compartment. At the end of the flow, depth of SCC was measured at the end of the horizontal chamber next to the vertical chamber and at the opposite end of the horizontal compartment of the box (Fig. 4).

In order to assess the quality of the SCC regarding its viscosity, the funnel V test was performed according to NBR 15,823-5 [27]. This property, according to NBR 15,823-1 [28], is related to the consistency of the mixture, which influences the concrete's strength to flow. In that test, the funnel was filled with concrete, and after its stabilization, the gate located at the bottom of the funnel was opened, allowing the passage of the concrete (Fig. 5). The time elapsed between the beginning and the end of the flow of all concrete through the funnel determines the viscosity of the SCC.

2.2 *Hardened State Test*

At the end of the fresh tests, the molding process of the specimens was started to carry out the compressive strength test, as proposed in NBR 5739 [29]. This test aims to analyze how the replacement of natural sand by CDW will change the mechanical strength of concrete. Twelve specimens were produced from each composition. Four specimens were tested at the age of 3 days, four at the age of 7 days and four at the age of 28 days.

The mold used was 100 mm in diameter and 200 mm in height and the specimens did not undergo densification. After 24 h these were demolded and taken to the immersion tank and remained in the curing process, completely submerged, until testing.

3 Results and Discussion

3.1 Tests in the Fresh State

Results from the D-flow test, flow time, visual stability index and funnel V are shown in Table 3. None showed bleeding or segregation. However, results from the flow time and the V-funnel indicate lower viscosity for the mixes with ceramic CDW sand. This was probably due to the extra water and additive added to the mix composition.

The difficulty of mix with ceramic CDW in flowing is due to the waste aggregate used, which presents finer particles than sand, thus reducing the number of voids and making it more cohesive. Figure 6 was used to classify the concrete in terms of visual stability index, as this demonstrates the appearance of the traces at the end of the flowing and flow time tests.

In Fig. 6 none of the mixes showed bleeding or segregation, even with the increase in the w/c and of additive. The concretes presented a surface mortar halo in

Table 3 Scatter test results, flow time, visual stability index and funnel V

Mix	D-flow (mm)	Flow time (s)	Visual stability index	Funnel V (s)	J Ring (mm)	L Box
T1	590.00	1.47	IEV 0	8.72	44.25	2.87
T2	602.50	1.23	IEV 0	4.68	49.25	1.08
T3	566.00	1.31	IEV 0	4.80	96.00	0.37

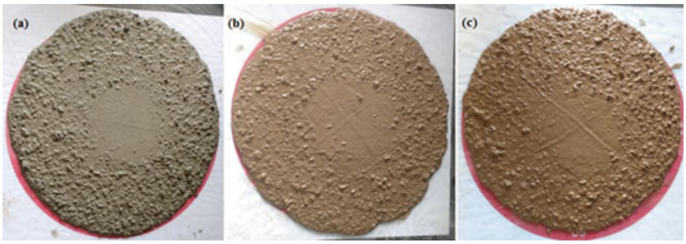

Fig. 6 D-flow: **a** Mix T1, **b** Mix T2, **c** Mix T3

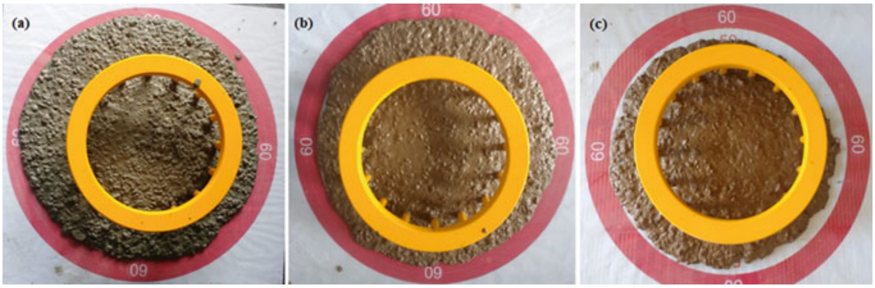

Fig. 7 J ring test: **a** Mix T1, **b** Mix T2, **c** Mix T3

the center; however, this comes from a thin layer of grout contained in the walls of Abrams cone, below this the concrete presented uniformly. Regarding to the passing ability for the J ring and L box it is observed in Table that T1 and T2 were the only ones to obtain passing ability, determined by J ring, since these were less than 50 mm. Therefore, it fits in class PJ 2, this presents ability pass through in reinforcement spacing between 80 to 100 mm; and by L box, since both had a ratio greater than 0.80, thus, it integrates the PL 2 class, that is the ability to pass between reinforcements with spacings from 60 to 80 mm, as the box used had three steel bars.

By adding the ceramic waste, they reduced their passing ability, which placed T2 close to the established maximum limit, and the higher concentration of CDW in T3 made it unfeasible, as it made the mixture extremely cohesive, what made it impossible to go through the armors. Figure 7 shows the characteristics of mixes at the end of the J ring. All mixtures did not show segregation at the end of the J ring test, including the T3 mix, which, despite not having the ability to flow through the steel bars, remained cohesive.

The results found diverge from the work carried out by Subaşi, Öztürk and Emiroğlu [16], who replace cement with ceramic waste in proportions of 5, 10, 15 and 20% (by mass), and found improvements in flow ability and viscosity of SCC. It is noteworthy that the residues used were similar in both works, however, one replaced fine aggregate and the other replaced the cementitious binder.

3.2 Hardened State Test

The data obtained in compressive strength test of mixes analysis are shown in Fig. 8. Although the increase in the w/c and the proportion of ceramic waste, the strengths at three days did not show a significant difference. When comparing T3, where there was the highest percentage of replacement of recycled material, with the reference mix, the variation between resistances was less than 0.3 MPa. This is

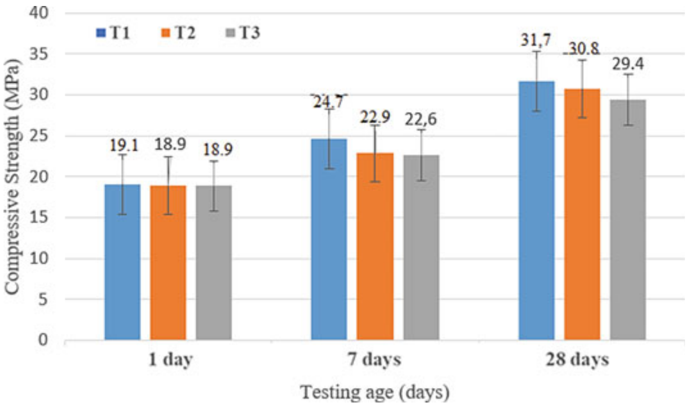

Fig. 8 Compressive strength

even smaller when comparing the two mixes in which there was replacing, even if the change in CDW between these mixes is 50%.

At seven days, the reference mix had a greater strength gain compared to those that had been replaced, but this was still moderate, with a variation of approximately 2 MPa when compared to T3. The fact that the strengths in the early ages have remained close can be explained by the presence of fine materials in the mixtures, which increase the strengths in the early ages [4]. At 28 days, the strengths presented were still close, but T2 and T3 had their strengths lower than the reference. It is noticed that T1 and T2 surpassed the strength proposed, however, T3 did not reach this, however, its value was approximated. It is observed that the mixes did not oscillate their position in the graph, at all ages analyzed they maintained their strength so that T1 was higher, followed by T2 and, finally, by T3.

When comparing with the research carried out by Subaşi, Öztürk and Emiroğlu [16], the results are similar: both showed a slight decrease in compressive strength, however, little significant in relation to the estimated characteristic strength.

4 Conclusions

This study presented results of the partial replacement of fine sand by ceramic CDW sand, regarding the properties in the fresh and hardened state of SCC. Although the present work lacks scientific rigor because water was added to the concrete compositions, from this exploratory work, the following remarks can be drawn:

– Mixes presented the similar classifications in regarding to fresh stage, since it did not impair the passing ability, and improved its characteristics in terms of fluidity and segregation resistance. In the hardened state, the mix wherein 25%

of the natural sand was replaced by ceramic waste sand showed difference compared to the reference mix, even with the increase in the w/c.

- The mix wherein 50% of the natural sand was replaced by ceramic waste sand would be impractical even if it had strength close to the reference mix and to the one with 25% replacement, as it presented high cohesion due to the proportion of waste material used in it, and the greater this, the greater the difficulty presented by the concrete in passing through obstacles, that is, he has no passing ability, which is an essential feature of SCC.
- The content of fines interferes with fresh and hardened properties. The higher the proportion of fine sand replacement by ground ceramic CDW, the higher cohesion, resistance to segregation, less possibility of exudation and less compressive strength.
- Mixes with substitutions higher than 50% are unfeasible, as the concrete becomes an extremely cohesive mixture, with reduce fluidity and passing ability. On the other hand, mixtures with substitution proportions below 25% look viable, as they have the fresh characteristics necessary for a SCC and maintain acceptable strength when compared to the reference mix. However, the economic factor of these substitutions was not analyzed, which would be a suggestion for future work.

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Fine Aggregates of CDW: Feasibility of Its Application in the Manufacture of Mortars for Laying

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Abstract One of the problems faced by the sector of civil construction currently is related to the difficulty to obtain environmental licenses for the extraction of natural aggregates, in due to the environmental impacts caused by such activity. The objective of this study is to propose the replacement of natural sand and gravel with aggregates of construction and demolition waste (CDW) in the production of mortar for laying. For the characterization of the mortars were determinate the consistency index, water retention, specific gravity, tensile strength in flexion and compressive strength. The CDW fine aggregates replaced the natural sand, in mixtures of mortar without to prejudice mortar properties.

Keywords Recycled aggregates · CDW · Concrete · Mortar

1 Introduction

Solid waste has been a topic of discussion for some decades around the world. Developed countries like Germany, Austria, South Korea and Wales recycle over 50% of all their waste produced. However, in underdeveloped countries, the lack of awareness of population in general, the reduced investment in new recycling plants and the lack of knowledge regarding the possibilities of using recycled material may justify the low recycling rates [1]. According to data collected by the Ministry

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of the Environment of the Brazil, through a report carried out by the Institute of Applied Economic Research [2], it is estimated that Brazil loses R$ 8 billion ($\sim$ 1.2 billion EUR) per year due to no recycling all waste with recyclable potential. According to the Secretary of State and Environment and Sustainable Development of the state of Minas Gerais, Brazil, the civil construction activity is a great waste generator, with waste arriving of civil construction to represent 40 to 70% of the total mass of waste generated in the Brazilian cities [3]. On the other hand, civil construction is the industry with the greatest potential to absorb its own waste produced.

CONAMA Resolution No. 307 of Brazil [4], which normalized the main issues related to CDW, defined as waste from construction, renovations, repairs and demolitions of construction works, as well as those resulting from the preparation and land excavation. The Article 10 of the aforementioned document indicates that the Class A CDW, after sorting, must be reused or recycled in the form of aggregates or sent to a landfill Class A waste from material reserve for future uses.

The use of recycled aggregates in the production of mixtures can provide advantages such as the use of all mineral components of the waste (bricks, mortars, ceramic materials, sand, stones etc.), without the need to separate any their; possibility of using a larger portion of the debris produced, such as of demolitions and small works that do not support the investment in equipment for grinding/crushing; and the possibility of improvements in the performance of concrete in relation to conventional aggregates, when using low-consumption cement. However, due to its variability and heterogeneity of the composition, generate unreliability in applications of greater economic value and responsibility [5].

Construction and demolition waste (CDW) valorization in a new production process has been widely studied in all the world. Many authors study the use of fine recycled aggregate and evaluate as a replacement of natural sand in coating mortars [6–10] Researches range from the analysis of the characteristics of recycled materials, potential of mineral processing to produce high quality recycled sand by comminuting mixed CDW [11], the behavior of cementitious renderings incorporating very fine recycled aggregates [12], separability studies for removing particles with a high content of cement paste from natural fine aggregate particles (quartz/feldspars) [13]. The goal is to increase the waste recycling rates and mitigate the sand scarcity in many world regions.

Despite being an ecologically correct initiative, in tune with the new environmental laws and normative codes, the use of recycled materials requires several precautions, mainly, in relation to the high percentage of recycled aggregates in the mixture. This fact which can lead to significantly increased water absorption, decreased cohesion and increased drying shrinkage of the units [5]. In another aspect, there are difficulties in releasing the environmental license for the extraction of natural aggregates due to the environmental impacts generated, the search for alternative technologies and studies related to the replacement of aggregates is intensified by CDW aggregates.

This is an exploratory work aimed to evaluate the physical and mechanical properties of mortar for laying produced with fine recycled aggregates from CDW.

The experimental procedures were carried out at the Soil and Technology Laboratory of Constructions of Faculty of Santo Agostinho, at Montes Claros-MG, Brazil. The study consisted of comparative analysis of mortar mixtures with total replacements of the natural aggregates by fine CDW aggregates, analyzing the influence on consistency, retention of water, specific gravity and mechanical strength.

2 Materials and Methods

2.1 CDW Aggregates

The recycled aggregates used for the production of mortar was originated from concrete, mortar, ceramic and asphalt waste. They are classified as Class A waste, which are reusable or recyclable as aggregate, according to Resolution CONAMA No. 307 [14]. According to NBR 10,004 [15], waste is classified as Class II B—Inert, which can be disposed of in landfills or recycled. According to NBR 15.116 [16] it is possible to classify the material as ARM (Mixed Recycled Aggregate), as it has less than 90% by mass, of concrete fragments.

The materials were supplied by a local recycling plant and went through four fundamental steps: screening, primary reduction, crushing and screening. The screening operation aimed to eliminate unwanted components (i.e., plaster, plastics, rubbers, woods, cardboard, paper, metals and organic matter), which harm the technical and environmental characteristics of the recycled product. Two particle sizes of recycled aggregates were obtained for analysis. The small plant is shown in Fig. 1 as well as the crushing process carried out from the mobile impact crusher. By the color of the fine aggregate, shown in Fig. 1a, b, it possible to observe if it is a recycled aggregate that contains a considerable amount of ceramic material. In Fig. 1c can be seen the coarse aggregate fragments of mortar and concrete and gravel surrounded by cementations material and fragments of ceramic and asphalt material.

Fig. 1 Recycled aggregates: **a** fine aggregate, **b** coarse aggregate being produced and **c** large aggregate

The incorporation of aggregates from CDW with a majority composition of concrete, presents better results and with less dispersion, compared to recycled aggregates consisting mainly of masonry [17]. For this reason, the use of the latter is usually limited to concrete applications. Thus, the fine aggregate obtained, being composed mostly of powder from ceramic waste was used for the mortar mixtures in this work.

2.2 Mortar Production

The production of mortar adopted standardized procedures in the standard NBR 16,541—Mortar for laying and coating walls and ceilings—Preparation of the mixture for carrying out trials [18]. It should be noted that this fine recycled aggregate was a by-product of the production of large aggregates with its properties being unknown. As the present work was exploratory in scope, progress was made without proceeding to any characterization and the mass mix was adopted 1: 5.871: 1.438, of Brazilian cement CP IV 32, fine aggregate and water. The reference mix used fine natural washed sand as aggregate for comparison with CDW sand illustrated in Fig. 1a.

With regard to mortars for laying masonry and wall cladding, Sousa and Bauer emphasizes that "workability is one of the most important properties of mortars, given its obligation, so that it can be conveniently used (with easy handling), showing its full potential during the coating execution process" [19]. Being aware that the w/c ratio has a crucial influence on the properties of any mortar (or concrete), in this work it was decided to adjust (slightly) the amount of water in the mix to ensure that all mortars had the same consistency index (flow table).

2.3 Mortar Tests

The test to determine consistency was performed according to NBR 1327—Mortar for settlement and coating of walls and ceilings—Determination of consistency index [20]. For the test was carried out (Fig. 2), a vibration densification table was used for consistency index, a metallic mold, and a socket, in addition to a metallic ruler and a measuring tape. After preparation of the mortar, it was used to fill the mold, placing it from centered on the table and filling in three successive layers of equal heights, applying to each of them, respectively, fifteen, ten and five strikes with the socket, evenly distributed.

The mortar was flattened with a metal ruler close to the edge of the mold, with short reciprocating movements along the entire surface, eliminating the particles around the mold with the aid of a dry and clean cloth. Then the mold was removed

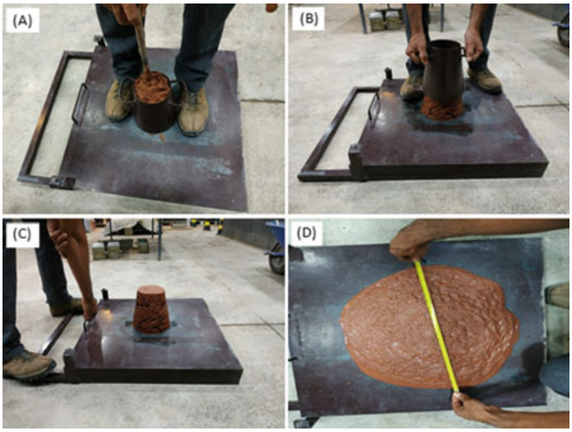


Fig. 2 Flow table test: **a** filling the conical mold with mortar; **b** removal of the conical mold vertically; **c** activation of the compaction by vibration; **d** measurement of mortar spread

vertically, and the table was activated for a consistency index with 30 drops in 30 s. Then, three measurements of the mortar spreading were performed, with the help of a measuring tape. These measurements performed on three diameters taken in pairs of uniformly distributed points along the perimeter of the three measurements and recorded. The consistency index mortar corresponded to the average of the three diameter measurements, being expressed in millimeters and rounded to the nearest whole number, recording the water/dry materials ratio used in the mortar mixture.

The water retention test was performed according to NBR 13,277—Mortar for laying and coating of walls and ceilings—Determination of water retention [21]. The main appliances used in the test were the mold with rigid plate and weight of 2 kg, filter paper discs, socket metal, beveled metal ruler, a scale with a resolution of 0.1 g and a stopwatch. To the execution of the test, the empty mold was weighed recording the weight, the dry filter papers were weighed and, after preparing the mortar, the mold was filled with 10 portions of mortar with assistance of the spatula. Afterwards, the mold edge was cleaned, and the mold was weighed with mortar. Subsequently, two gases, twelve discs of filter paper were placed on the mold surface, the rigid plate and the weight of 2 kg, and, after two minutes, the weight and plate were removed, and the mass was recorded of the wet filters—see Fig. 3. Then, the water retention and the water-to-fresh mortar factor were calculated.

The specific gravity test was performed according to NBR 13,278—Mortar for laying and coating of walls and ceilings—Determination of mass density and incorporated air content [22]. The main equipment used for the execution of the test were scales with resolution 0.1 g; a rigid, cylindrical container of non-absorbent material; and spatula. To run the test, the mortar to be used was prepared and, immediately after the mortar preparation, the empty container was weighed. Soon after, the container was filled with water and its volume.

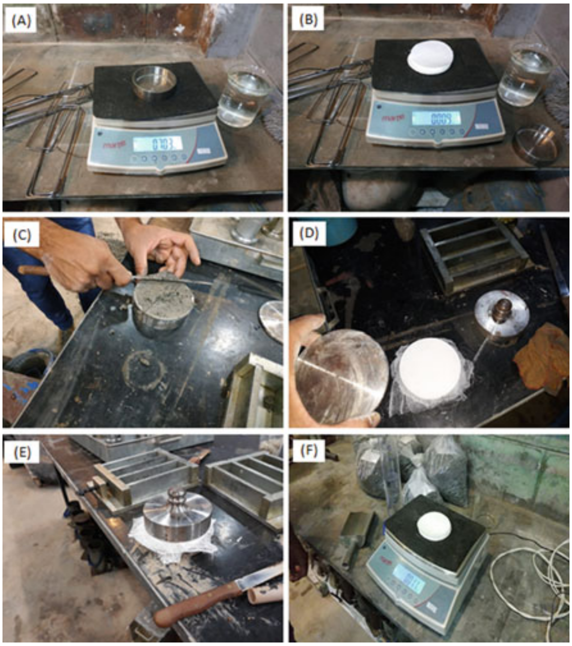


Fig. 3 Determination of water retention: **a** weighing of the empty mold; **b** weighing of dry filter papers; **c** filling the mold with mortar; **d** positioning gases and filter papers on the mold surface; **e** plate positioning rigidity and weight on the filter papers and mold surface; **f** weighing of wet filter papers

Then, with a spoon, portions of the mortar were gently introduced into the container, forming three layers of approximately equal heights, applying, in each layer, 20 blows along the perimeter of the mortar, each blow corresponding to the entrance and the out of the spatula in the vertical position and, after the last layer, 5 strokes were applied with the socket. The container was then leveled with the spatula, in two orthogonal passes to each other, making back-and-forth movements, with a 45° inclination in relation to the mortar surface. At particles adhered to the outer wall of the container were removed and the mold mass was weighed with the mortar, recording it—see Fig. 4. Then, the specific gravity of the mortar (in the fresh state) was calculated.

The mechanical strength tests were performed according to NBR 13,279—Mortar for laying and coating of walls and ceilings—Determination of tensile strength in bending and compression [23]. Two metallic prismatic molds were used, with three compartments of dimensions $4 \times 4 \times 6\ cm^3$ each for molding 6 specimens for each type of mortar, totaling 12 specimens. In addition to this equipment, a table for compaction by vibration, spatulas, metal ruler; hydraulic press. To carry out the test, the mortar was prepared. Then, three prismatic specimens, by age (7 and 28 days), were molded. With the help of the spatula, the mortar was spread in each compartment, forming a uniform layer. Then, the vibration densification table was activated with 30 falls in 30 s—see Fig. 5. Identical process occurred for the

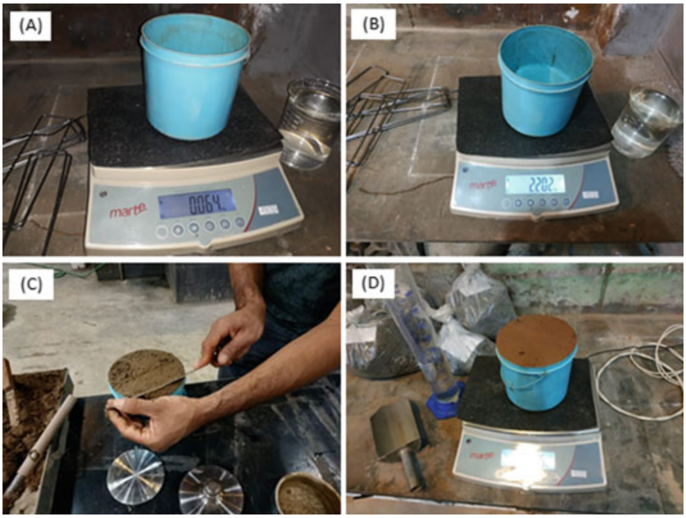
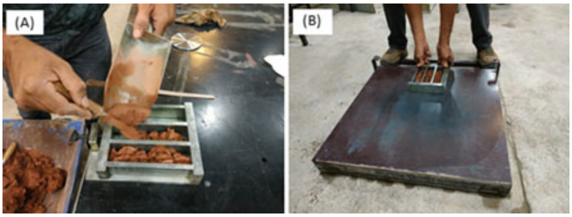


Fig. 4 Determination of density: **a** weighing of the empty container; **b** weighing m of the container with water; **c** filling the container with mortar; d weighing of container with mortar

Fig. 5 Molding of specimens: **a** filling of mold compartments of with mortar; **b** consolidation of the mortar with the aid of the consolidation table by vibration



second layer. Subsequently, the specimens were leveled with the aid of a metal ruler. At the age of 48 h, specimens were demolded.

The flexural tests of the specimens took place at the ages of 7 and 28 days. The specimens were positioned on the support devices of the test equipment so that the flat face does not stay in contact with the support devices or the charging device. The distance between the supports was 14 cm. The load was applied continuously until the specimen ruptured—Fig. 6a, b. To determine the compressive strength, according to NBR 13,279 [23], the halves of the three test specimens of the flexural tensile test, with the same care regarding the positioning of the faces and application of the load. Then the load was applied continuously until the specimen ruptures—see Fig. 6c, d.

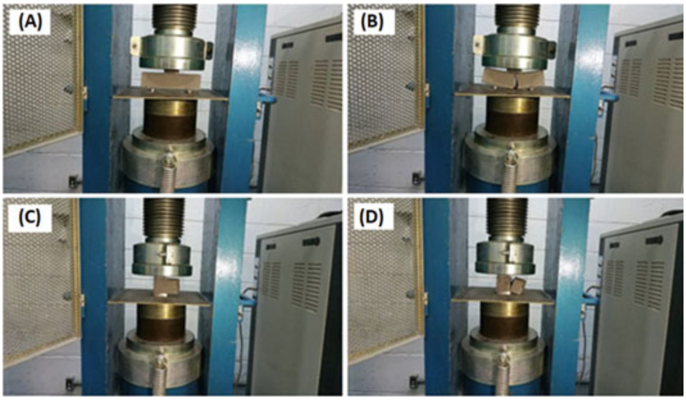


Fig. 6 Carrying out the flexion (**a, b**) and compressive (**c, d**) tests: **a** positioning of the specimen the support devices of the test equipment; **b** specimen after rupture; **c** positioning of the specimen in the support devices of the test equipment; **d** specimen after rupture

3 Results and Discussion

The flow table results found for the mortar specimens produced with CDW aggregates and for natural sand were 53 and 52 cm, respectively. To obtain close results, it was necessary to adjust the water content. The water added to the mortar with natural aggregates was +50 g. This addition has been added in a total of 2 kg of cement. These results allow one to verify that the mortar that reached the greatest spread was the produced with construction waste, even without the addition of extra water. In this sense, for the case of study, it is concluded that the mortar produced with this CDW aggregates is more workable when compared to the mortar with natural sand. Martinez et al. [9] analyzed three types of recycled fine aggregate with higher water absorption compared to natural sand, obtaining absorption values between 5 and 10% what are acceptable for recycled mortars [9]. As mentioned by Sabbatini [24], workability is associated essentially to consistency and expresses ease of handling. It is considered that a mortar it is workable when it is easily distributed after being seated, not sticking to the tool in the moment it is being applied, not segregating when transported, not hardening in contact with absorptive surfaces and remaining plastic long enough for handling.

The difference in the results was due to the fact that the CDW aggregate had a greater amount of fine in relation to natural sand mortar, a fact that interferes with cohesion, a property that it depends on the proportion of fine particles in the mixture and which is directly linked to consistency. As stated by Gomes [25], consistency results in effects of the actions of internal forces such as cohesion, friction angle and viscosity, which influence the change of shape of the mixture. Therefore, the water content, the shape and texture of the grains of the aggregates and the granulometry interfere in the consistency of mortars. The results found by Kruger et al. [7] showed that the RCD powdery material did not significantly interfere in the properties of consistency, water absorption and void index for additions of up to 12%. However, from the fraction of 20%, the higher the content of powdery material used, the greater the damage to the properties of the mortars. For the 30% content of powdery material, a 40% drop in compressive strength and 28% increase in absorption was observed in relation to the 20% addition content [7].

The results obtained in the water retention test of mortar samples presented very close values. It is noticed that the total replacement of natural sand by waste from construction does not considerably affect water retention. Approximate retention of water values, 97.10% for the mortar produced with construction waste and 97.28% for the mortar produced with natural sand can be considered efficient in this regard question. The property is fundamental for the development of mortar strength in the hardened state and directly influences cement hydration and adhesion phenomenon between the components of the mortar with the substrate.

In regarding to the specific gravity tests of the mortar specimens, specific gravities were recorded higher for natural sand (2060.4 kg/m^3) compared to mortar with CDW aggregate (1962.8 kg/m^3). Natural sand is mainly composed of quartz, which is a material that it has low porosity, which gives it greater density. Kruger et al. [7] concluded that, as the percentage of powdery material increases, there is a reduction in specific gravity. With 12% of powdery material (18.55% of incorporated air content) it reached a density of 1780 kg/m^3. After washing the material, they found 7.79% of incorporated air and 2019 kg/m^3 [7]. CDW aggregates are composed of lighter materials, such as ceramic material and cement paste. The Fig. 7a expresses the results obtained in the test for determining the tensile strength in flexion, at 7 and 28 days, with the respective standard deviations of the specimens. Comparing the results obtained from the mortars produced with the aggregates of CDW, the mortar produced with natural sand has reached flexural tensile strengths slightly higher than mortar produced with recycled aggregates. It was also observed that the mortar samples produced with construction waste, showed a decrease in strength of 24.3% from 7 to 28 days, as shown in Fig. 7a.

There is no justification for this decrease. It is believed that this observation is due to the variability associated with this property to which the variability of the aggregates used is added in mixtures. The LNEC Specification E 471 [17] emphasizes that fine recycled aggregates have a high percentage of grains with a dimension less than 0.063 mm, compromising the mechanical strength. Figure 7a

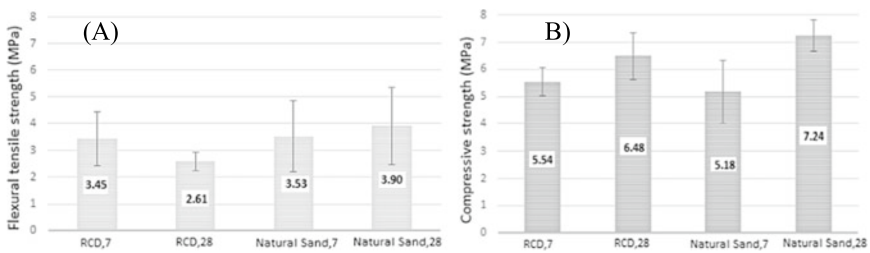


Fig. 7 **a** Flexural tensile strength; **b** Compressive strength

also allows verify that the mortars composed of natural sand presented a strength gain of almost 10% from 7 to 28 days, as expected. The mortar with CDW aggregates, even presenting a water-cement factor inferior to the natural sand mortar, it presented flexural strength at 28 days 10.4% less than natural sand mortar. The Manual on Solid Waste from Civil Construction [26] emphasizes, on the mixed recycled aggregate (ARM), that the possibility of the presence of polished faces in ceramic materials, such as floors and tiles, can negatively interfere in the compressive strength of concrete, similarly to mortars.

The Fig. 7b, illustrating the results obtained in tests determining the compressive strength at 7 and 28 days. The results show that there are no losses or gains of strength markedly when changing between natural sand and CDW sand. At 7 days to CDW sand mortar showed greater strength than natural sand mortar. However, at 28 days the opposite was observed. However, in both cases, considering the respective standard deviations, it appears that such variations are within the margin of error of the test.

Other studies have similar results. [6] concluded that the partial replacement of natural sand by the CDW presents potential for improvement of the main technological and environmental properties of mortars, contributing to a clean production mortar, with 25% of CDW composition being the most suitable for use in building construction [6]. [9] mention that, for mixes with 100% of recycled mortars, the mechanical strength is poorer compared to mixes made with natural sand, but both compressive and bond strength values of recycled mortar comply with established standards, allowing its use in construction using studied recycled aggregate in suggested proportions (1:3 or 1:4) [9].

In addition to the results found, the results showed by Carasek et al. [8] concluded that despite the distinct composition of the RCDs, when the same crushing process is used, very similar particle size distributions are obtained; however, other characteristics are different in these aggregates and these influence the behavior of the mortars and depend on the origin of the residue [8]. Then, it is important to mention that within the RCD segment, its composition is generally very diverse, ranging from organic substances, such as wood, or inorganic substances, such as metals, glass and minerals. This causes difficulty in its precise characterization, namely because each material has different specificities and environmental impacts [27]. Thus, thinking about increasing the quality of the product is thinking about the quality of its screening.

As one of the oldest records of encouraging the promotion of new products with greater durability, with the improvement of the quality of products made from RCD, the Dutch Research Center (CUR) is cited, which develops specifications for the use of recycled aggregates since 1984. The case of Germany is interesting because it is one of the EU countries that produces more CDW (214 million tons in 2002) and, even so, one of those with the highest recycling rate (85%). Among the existing guidelines in Germany, for example, the main one in the field of recycling and waste management comes from 1996, defining principles that go towards a closed cycle, establishing a hierarchy of treatments similar to the inverted pyramid existing in Portuguese legislation, which prioritizes waste prevention [27].

4 Conclusions

This research contributed to demonstrate the technical feasibility of replacing fine aggregates by fine recycled aggregates, contributing to a reduction in the mass of landfilled waste and conservation of natural resources. From the tests carried out for the characterization of mortars for laying with fine waste aggregates from CDW it is concluded that the mortar with fine CDW sand presented performances satisfactory in the properties analyzed: consistency, water retention, specific gravity and strength.

The total replacement of natural sand by fine recycled aggregate in mortars for laying is technically viable regarding the physical and mechanical properties analyzed. If introduced in the construction processes in replacement to natural fine aggregate, may provide a minimization of impacts environmental issues arising from industrial processes, release of industrial yards, in addition to add value to solid wastes.

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Evaluation of Barrier for Promoting Green Building Technologies in Coimbatore as Smart City

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Abstract Developing and promoting smart cities in India is the dream project of Government of India. Coimbatore is one among the city identified as smart city project for improving the existing infrastructure and constructing green building in order to improve the habitation and energy efficiency through utilization of natural resources. Implementing the green building and energy efficient building concepts in construction industry are the major focus with the aid of technological development. The transformation from conventional to the futuristic approach is the major task in the construction sector. This sector alone requires 40% of natural raw materials, 25% of water and 35% energy resources, as well as emitting 40% of wastes and 35% of greenhouse gases. Considering these parameters, the paper was intended to furnish the detailed investigation to identify the various barriers and suggest the measures to be taken to promote the green building technologies for a sustainable development in smart city mission.

Keywords Green building · Smart city · Barriers in construction sector · Sustainable development

1 Introduction

Green building technology has gained its prominence in the building sector recently, adding to the benefits it may offer through energy efficiency, modern trends, economy and the sustainability aspects. By tradition, India has been found to adopt nature friendly buildings that illustrate the application of natural materials

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like bamboo, agricultural residues, clay etc., since ancient period. But, the present trending concept of green buildings began to grow only in late 1990's. With the inception of Green Rating for Integrated Habitat Assessment (GRIHA) by The Energy resources institute (TERI) and MNRE and Indian Green Building Council (IGBC) by Confederation of Indian Industry (CII), India has started its green building movement progressively with its own green rating systems.

But, existence of substandard construction materials and techniques has hindered the growth of sustainable construction practices in India. It has been reported that buildings in India account for 40% of its total energy consumption and more than 60% of its share is taken by residential projects alone. 'Green building' is the possible solution for sustainable construction sector, since it promotes sustainability without disturbing natural ecosystem, and can cut down energy consumption, save money and renders a major positive impact on environment. There is a huge demand and market potential for green and eco-friendly buildings in India.

According to US Green Building Council (USGBC) report, Green building industry will rise by 20% in India in a couple of years, may be due to the new environmental laws and demand and the green building market is estimated to double by 2022 at 10 billion sq. ft. At present India has 752 LEED certified projects and 7.17 billion sq. ft (5900 projects) of green buildings certified under IGBC. Reports add that, the existence of green buildings in India is only 5% of the total buildings in our country. This proves the possibility of massive green building market demand in the country, and the same is driven by increasing environmental awareness, its assured benefits and legal support. Moreover, initiatives like Smart city mission, increasing concern towards energy efficiency further advances the growth of market potential of green buildings in India. This paper will describe the recognition of greening the buildings in India and the prevalent opportunities for its improvement based on refining resource efficiency.

Foremost, Green buildings are often recognized for its operational cost savings, wherein new green buildings are expected to yield 14% savings in operational costs and green retrofit buildings yield 13% savings in operational costs over a five years average period [1]. Though, construction of green buildings adds to 7% higher costs than average. India has emerged as one of the leading countries in terms of green projects; with more than 5400 projects of about 6.3 billion sq. ft of built-up area. This is only about 5% of the total buildings in India, and hence forth, there is a huge potential for further penetration of green building technology in the future.

2 Need of Investigation

Increasing urbanisation and rising standards of living has catalysed the growth of built infrastructure [2] in the country. In addition to that, governmental policies and initiatives towards improving infrastructure, expansion of highways, railways and housing schemes has led to the requirement of construction materials in large quantities. The world is already facing a scarcity of these resources and the problems created due to their negative impacts to the surroundings [3]. An analysis of the material flow of each resource pertaining to the construction sector is discussed here, in detail, from their extraction to final disposal, to give a better understanding for the management of these resources. The Indian building industry holds a major share in consumption of natural resources and is also the key role players in harmful emissions. The construction sector alone consumes forty percent of natural raw materials, more than twenty five percent of water and energy resources, and emits thirty five percent of greenhouse gases along with forty percent of waste disposal. Hence, it is highly advisable that sustainable and green building technologies should be incorporated by the building sector to reduce its negative impacts.

The analysis of material requirement in buildings is predicted from the report on 'Material Consumption Patterns in India' [4], taking into account of the construction materials namely cement, sand, stones, soil and limestone. India is the second largest producer of cement in the world, producing 210 million tonnes in 2010 (which is 6.3% of global production), though, per capita consumption of cement (200 kg/person) is comparatively lower than developed countries. The cement production in the country is expected to increase by 4–7 times in 2050. It is also evident that the Indian construction industry will face material supply problems triggered with fluctuations in prices and construction schedules in some parts of the country. This factor should be seriously addressed, since material costs account for roughly 2/3 times of the total cost of a typical building.

Next to cement, the highly demanded resources in the construction sector is Sand. River sand has already turned to be a scarce resource in South India, while most of the other rivers are exploited due to rampant mining. Replacement of sand by manufactured sand (m-sand), prepared from natural sources will be a very good alternative to solve these issues. Clay brick is another building material which consumes natural resources. About 12% of total fly ash generated in India is presently used for the production of bricks and tiles [5] as per the recommendations of the government. Coarse aggregates also occupy its share in demand, as an ingredient of concrete, which is the major component of construction. The construction industry is expected to have a demand of more than 2 billion tonnes of coarse aggregates by 2020 [6]. Apart from concrete, the demand for coarse aggregate required as a base material will also increase in view of the recent commitment of the Indian government to build 30 km of roads per day.

A mineral mostly extracted for construction activities in the country is Limestone, which is used mainly in cement manufacture. Currently, India utilises about 226 million tonnes of limestone [7] in cement industry, steel, chemical and others, but the major utilisation is about 93% for the cement industry alone. Thus, an appropriate solution for the problems on conservation and management of our natural resources would be focussing on suitable alternatives for the construction materials. The total quantity of construction debris (C&D) generated in India is 716 million tonnes per year, which simply ends up in landfills. Several research and experimental studies have proved that recycled aggregates produced from C&D waste satisfies the properties as a construction material. Due to the lack of appropriate standards and marketing, the preference of such recycled aggregates denies by local builders and contractors. To be noteworthy, Bureau of Indian Standards (BIS) have formulated standards for the use of C&D waste as coarse aggregates in concrete. Bricks can be recovered from old buildings and reused, as another option to conserve natural resources.

The construction industry uses steel as reinforcement in all its reinforced cement concrete (RCC) structures. Steel has a very high recyclability potential and the steel industry is well regulated in utilising the iron/steel scrap from the C&D sector. Reuse of C&D waste in construction will ensure savings of virgin natural resources and thereby, help in mitigating CO_2 emissions, which would arise from the processing of those natural resources [8]. The rate of CO_2 which is emitted during the processing of recycled aggregate (C&D waste) is very much lesser compared to that which is emitted during the processing of natural aggregates by 8 kg of CO_2 per tonne of aggregate. Therefore, if the natural aggregates are replaced by recycled aggregates, we can save a substantial percentage of carbon dioxide emissions. Thus, material use in buildings account for 28% of the annual CO_2 emissions in total. Many countries have initiated activities to address the direct emissions, those are emitted due to the combustion of fuels and other relevant indirect emissions to reduce embodied carbon in buildings. The relative importance of carbon footprint of the buildings and construction is therefore increasing.

3 Research Methods

The extent of awareness of professionals in the construction industry towards reducing the negative impacts from buildings, their attitudes and perceptions on green practices is an essential tool to strengthen the green building technology. A perception survey was conducted through a descriptive questionnaire among a set of professionals in the construction industry in Coimbatore, South India. The questionnaire was framed with closed ended questions using the Likert Scale. Interview with some of the respondents was also carried out. Out of a total of 100 questionnaires, 81 responses were received (response rate of 81%). The objective of the survey was to gather information about the barriers and prospects of Green Buildings in the industrial city of Coimbatore. Table 1 summarizes the category of professional who were involved in the survey.

Table 1 Basic information of the respondents

Category	Number of responses	Average experience in years
Architects	6	5
Building Owners	20	4
Building/Real Estate Valuers	4	8
Design Engineers	7	7
Engineers	20	8
Non-professionals	7	4
Planning Engineers	5	5
Project Directors/Managers	16	4
Structural Consultants	8	8

4 Results and Discussions

The survey focused on identifying the attitudes of professionals in the construction industry towards green building concepts, the extent of awareness about green concepts and practices, and their perception regarding the barriers and other obstacles that may prevent the growth of green developments in the city. A mixed response was received that reflected the gaps in the green buildings awareness levels among the professionals, which is represented in the Table 2.

Table 2 Summary of Questionnaire responses received

Parameter/Responses	Strongly agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly disagree (%)
Perceived Barriers for Green Construction					
High Investment Costs	14	31	23	9	23
Public Awareness	23	31	11	17	17
Lack of green building codes and regulation	23	14	20	29	14
Lack of Professional Knowledge	26	23	14	17	20
Lack of incentives and government support	26	20	26	9	20
Excessive documentation for certification	9	40	20	11	20
Perceived Benefits of Green Building					
Economy over long run	8	15	7	1	4
Energy savings and Low maintenance	13	10	7	3	2
Sustainability	12	8	9	1	4
Better comfort and indoor health	13	9	7	2	4
Pride in owning a green certified project	11	11	7	1	5

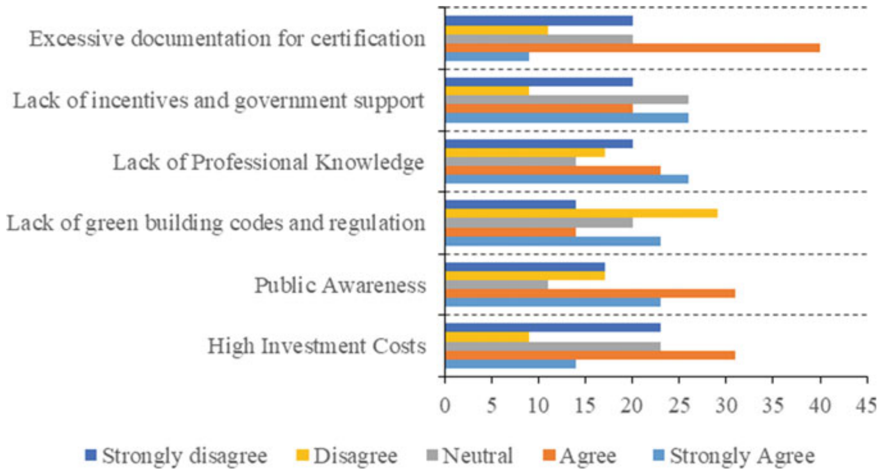


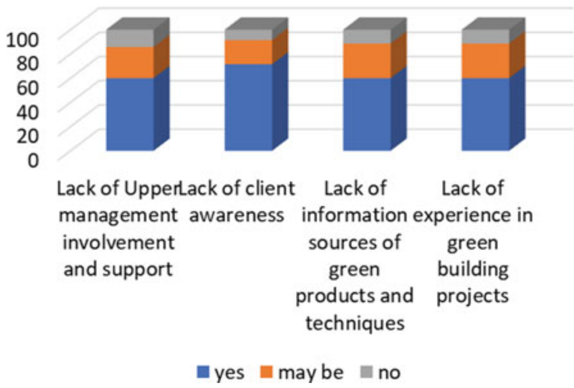
Fig. 1 Barriers for green certification

The responders who were already involved in green projects or undergone any training related to green practices were able to depict correct reflections in the survey whereas, remaining fraternity were not able to give appropriate responses. The trained professionals are also having knowledge about the usage of alternate materials and its need for sustainability in construction. Among the responders, more than five years experienced professionals are accepting the parameters included in the questionnaire regarding the benefits of green building and its implementations. However, the existence of the inherent barriers are identified from the experience responders which are reflecting the delay in transition from conventional to green building concepts. The perceived barriers for green building construction were identified and shown in Fig. 1. The important barriers are high investment costs, lack of public awareness, lack of incentives from government, lack of professional knowledge, lack of green building codes and principles and excessive documentation for green certification.

A set of questions were framed for gathering the information on the major perceived hindrance towards the growth of green building construction and the observed results are depicted in Fig. 2. The survey reflected the existence of obstacles for green construction activities due to lack of upper management involvement and support (60%), client awareness (71%), lack of sufficient information about green products and techniques available (60%) and lack of technical knowledge in such projects (60%). Almost all the respondents agreed that green buildings have positive benefits, namely, its economy over long run, savings in energy consumption, improved comfort and indoor health aspects and overall sustainability as shown in Fig. 3.

Moreover, the respondents have agreed that owning a green certified project is a sense of pride and satisfaction. It was clearly evident from the survey that the respondents could not clearly understand the principles and technologies of

Fig. 2 Hindrance towards green building construction



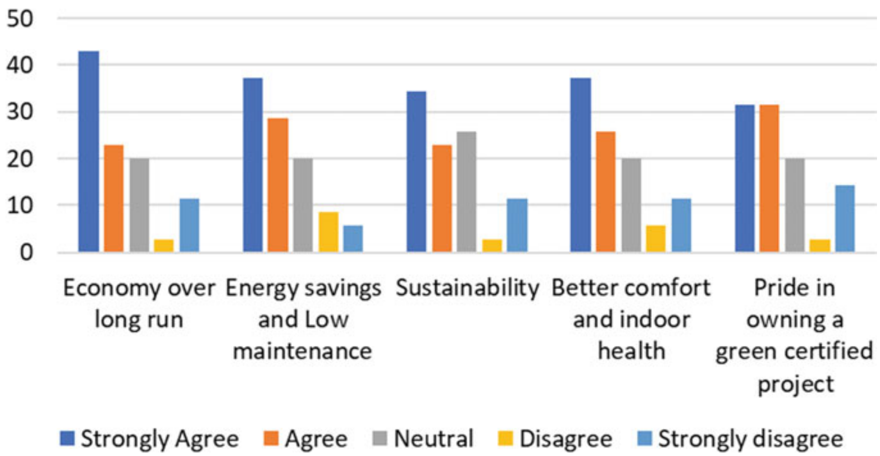


Fig. 3 Benefits of green buildings

green building construction, all of them agree that green techniques are beneficial and are sustainable.

4.1 Resource Conservation Through Green Rating Systems

GRIHA (Green Rating for Integrated Habitat Assessment), is one of the important national rating systems for green buildings in India. In the Abridged manual of GRIHA, there are two important criteria under sustainable building materials, emphasizing the importance of resource management in buildings. The first criterion, encourages use of alternative materials, which minimize the detrimental impact of construction on environment by conserving natural resources, further minimizing the use of virgin materials and converting suitable wastes from the landfills to the construction industry (as per BIS standards).

Credit points (maximum 5 points) are allotted based on percentage of replacement of OPC with BIS recommended waste materials (such as fly ash, slag, etc.) by weight of cement used in structural concrete as per the recommended standards. A minimum of 5% replacement of natural aggregate with recycled concrete aggregates (RCA)/recycled aggregates (RA) by weight of that category of aggregate in structural concrete is given 1 Point.

All the walls (internal and external) in the building is encouraged to adopt any one of these alternative materials light weight aggregate blocks (hollow, solid or AAC) with minimum 40% fly ash content by weight, Adobe bricks/Rammed earthen blocks, Bamboo/any other rapidly renewable material (not including bamboo cladding), monolithic concrete wall with minimum 30% replacement of OPC with BIS recommended waste material by weight of cement and C&D waste blocks containing minimum 30% C&D waste material by weight [11].

It further adds a minimum 30% replacement of OPC with BIS-recommended waste by weight of cement used in masonry mortar and plaster. IS 269-2015 recommends to incorporate a minimum of 5% fly ash in OPC manufacturing as performance improver of cement which gives durable concrete [12]. The second criterion suggests substituting conventional materials to be used for external site development with alternative materials, in order to reduce pressure on both mining for virgin materials and landfills required for the disposal of waste material.

Another prominent rating system adopted in India is IGBC which is formed in the year 2001. The rating system also encourages the usage of building materials which will reduce or nullify the associated negative environmental impacts. It recommends that salvaged or reused or refurbished materials may contribute at least 2.5% of the total material cost of the building. Salvaged or reused materials correspond to those materials that are mostly recovered from old or demolished buildings. Usage of materials with recycled content in the building is encouraged and the building materials are preferred to be manufactured locally within a distance of 400 km. This is encouraged to avoid other negative impacts to the environment that would have been caused by the processing and transportation of the resources/raw materials for a long distance [13].

4.2 Challenges and Barriers

India has started constructing green buildings, though, there exist few challenges and barriers. A majority of stake holders are not aware of benefits of green buildings and refrain green technology as an expensive or unfeasible option. Also, there is lack of green building norms and standards to enforce large-scale implementation of such buildings in the country. In India, people in the construction sector ranging from policymakers to architects, engineers, contractors and workers don’t possess adequate skills and the knowledge required for green buildings construction.

Many environmental-friendly design and practices are accepted, yet designers and constructors often fail to recommend them or building owners fail to adopt such practices. Reasons for these failures may include following traditional approaches, lack of expertise or short-term financial considerations. Meanwhile, thrust of environmental problems has now created an emerging shift towards green building practices that believe to include buildings which are assumed healthy.

5 Conclusions

- Green buildings would definitely help our country in overall resource conservation, minimization of construction waste and recycling in addition to other benefits.
- Green buildings can be promoted through legal provisions and encouraged by creating awareness among all stakeholders.
- The technology and the materials used for infrastructure development should adopt the usage of local resources and waste materials.
- Processing of waste must be taken up at a large scale and occur locally in each segment of the country.
- Green building construction will be the solution for improving the present situation in our country. This will not only generate jobs but also generate energy and resources which can be usefully utilized further.
- It endorses that the salvaged materials during construction may contribute at least 2.5% of the total material cost of the building.
- It is possible to replace of cement up to 30% by adding fly ash as per BIS recommendations and 5% replacement is now practising in OPC manufacturing as performance improver which leads to improve the durability of building elements and makes as green building.
- The major barrier for implementing the green construction technologies and activities are primarily due to lack of upper management involvement and support (60%), absence of client awareness (71%), lack of sufficient information about green products and techniques available (60%) and improper technical knowledge in such projects (60%).

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Cement After Expiry Date: Effect in the Concrete Properties

Stéphanie Rocha, Cássio Gonçalves, and Lino Maia

Abstract Portland cement has been widely used around the world to produce concrete. When Portland cement is not used correctly, following the normative prescriptions, its use can compromise the aesthetics and the safety of structures. The present research consisted of analyzing the workability of concrete in fresh state and compressive strength in its hardened state when using Portland cement with expired date higher than 90 days defined by the Brazilian standard NBR. For the tests, three cements were selected with different manufacturing dates: November 2018, July 2019 and August 2020. The workability was assessed through the slump test and the compressive strength test at the ages of ages 1, 7, 14 and 28 days. The mix used was for a compressive strength of 25 MPa at the age of 28 days. The slump tests showed divergent values regarding to the expired cements, leading to inconclusive findings, because even with the w/c change, the slump achieved for the 2019 cement-based concrete was lower than that recommended for common concrete. It was concluded that the compressive strength decreased for concretes produced with expired cement.

Keywords Cement · Compressive strength · Concrete · Expired date · Workability

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1 Introduction

The production capacity of the cement industries in Brazil in 2018 was 102 million tonnes. Sales in the sector peaked in 2014 with 70.9 million tonnes, in 2019 with the crisis in the civil construction sector, sales reached 54.3 million tonnes [1]. The retail trade distributes approximately 2/3 of this production, generally selling the cement in 50 kg bags, with the cement “ant” consumer (the one who purchases cement with hired or own labor for small repairs, renovations, or small constructions size) one of the final destinations [1, 2].

Irregular constructions occur outside inspections, monitoring by civil engineers and with current regulations, without proper technological control of the concrete used. One of the basic requirements to be observed is the expiration date and the storage period. The storage of cement is recommended for 30 days, which may increase this period by up to 60 days depending on weather conditions [3], as the expiration date is 90 days according to NBR 16,697 [4].

To minimize the energy crisis and the impacts caused on the environment due to the cement manufacturing, several researches were carried out about recycling expired cement and about the closed packaging method in which active silica and aged props were added [5]. Besides, the use of waste in concrete research is widespread: silica, rice husk, glass, plastics, construction and demolition waste are some of the various materials used in recycled concrete [6–9]. However, these studies carried out with concrete using cement after expiration date stipulated by the manufacturer and standards are still recent.

The present work aimed to understand and quantify the loss of quality of concrete in its fresh state regarding its workability and compressive strength in a hardened state when Portland cement is used after the expiration date determined by the NBR 16,697 [4].

2 Materials and Methods

For the tests, the composite cement with the addition of Filler (CP-II) with a strength class of 32 MPa was chosen. To make the concrete, cements with three different manufacturing dates were used, namely: 2018 sample, manufactured on November 29, 2018; 2019 sample manufactured on July 1, 2019; and sample from 2020, with manufacturing dated August 4, 2020. The other materials used to carry out the tests were: washed sand, coarse gravel, fine gravel and water.

Concrete composition followed ABCP method, an empirical method that uses basic information for the characterization of the component materials [10]. The mix 1:2.6:2.8:0.53 was used (cement, sand, gravel and water-cement), which should reach a characteristic compressive strength of 25 MPa at 28 days. After homogenization, the slump test was performed according to the Brazilian NBR NM 67 [11].

For the test, a slump of 70 mm was used, considering a concrete for an ordinary structure with plastic consistency [3].

Cements with the manufacturing date in November 2018, July 2019 and August 2020 were used. For the compressive strength, the specimens were tested at the ages of 1, 7, 14 and 28 days. Three specimens per cement per testing age (totaling 36 specimens) were tested.

After the 24-h period of molding, the specimens were demolded, the specimens aged 1 day were submitted to the compressive strength test. Those scheduled to be tested at other ages were stored in a saturated solution of calcium hydroxide for the curing period and awaited the compressive strength test date provided for in the schedule. The compressive strength tests were carried out in a hydraulic press with manual activation, the results are displayed on a side panel to the equipment in tonne force, in compliance with the NBR 5739-Concrete-Compression test of cylindrical specimens [12]. The cylindrical mold used has dimensions of 10 cm in diameter and 20 cm in height.

3 Results and Discussion

3.1 Analysis of the Properties of Fresh Concrete

Workability is the most important property of concrete in fresh state [SOBRAL 8]. Slump between 60 and 80 mm is recommended for structural concrete of common use without the use of vibrators for consolidation [3]. The slump test was 80 mm for the 2018 sample, 20 mm for the 2019 sample and 70 mm for the 2020 sample.

To carry out the mix, a water-cement factor of 0.53 was initially established, but only the cement manufactured in 2018 was used. The concrete with cement manufactured in 2019 had to be corrected to 0.58 water-to-cement ratio (w/c) because the aggregates do not present cohesion with the cement paste during the homogenization process. Despite the small slump, it presented a homogeneous aspect among the constituent materials of the concrete and an adequate consistency. For the 2020 sample, the 0.58 ratio in the w/c factor was maintained, producing a concrete with the expected slump.

There are five factors that can modify the slump test: water content in relation dry mix; cement type and fineness; granulometry and grain shapes of aggregates; combined action of factors; time, temperature, and relative humidity. Bringing these parameters to the experiment, it was possible to preliminarily discard only one of them, granulometry and forms of the grains of the aggregates because aggregates of the same origin were used [13].

The water content in relation to the mixture was changed so that the concrete presented a homogeneous appearance after the mixture. The 2019 and 2020 samples used the same w/c factor, but presented divergent results, which leads to considering other parameters to understand the results.

Even with the use of a cement of the same brand, type and strength class, the fineness of the cement cannot be guaranteed due to the cement pre-hydration process that occurred due to its exposure in the environment over time. It can be inferred that the 2018 cement was the most affected, the 2020 sample can be disregarded as this factor as the cause of divergent results due to the short period of exposure and absence of rain and low relative humidity in the opening period packaging and carrying out the tests.

3.2 Analysis of the Concrete Compressive Strength

The cement manufactured in 2018 was cobbled due to the long storage period, with different sizes amidst the characteristic powdery material, according to Fig. 1(a), being necessary to carry out the sieving of the cement before mixing the materials, as shown in the Fig. 1(b). The particles retained by the sieve were discarded to carry out the trace. It is noteworthy that the cement was sheltered in the concrete laboratory, protected from the most severe weather such as sun and rain, but still exposed to moisture since it was in direct contact with the floor and with the open package. When removed from the molds, the samples showed edge breakage, as shown in Fig. 1(c).

The cement manufactured in 2019 was in the concrete laboratory stored in contact with the concrete floor and protected from the sun and rain. The poor storage associated with the long period was possibly responsible for the cementitious material clogging, as can be seen in Fig. 2(a), in the same way as the 2018 cement, it was necessary to carry out the preliminary sieving of the cement, the material retained in the sieve has been discarded. When removed from the molds, the samples presented good apparent quality similar to that expected for a concrete within the validity period, as can be seen in Fig. 2(b).

When removed the molds, the specimens from the cement from 2020 presented an appearance of good quality. The 2020 cement-based concrete presented satisfactory performance for all ages tested, reaching the expected strength at 28 days.

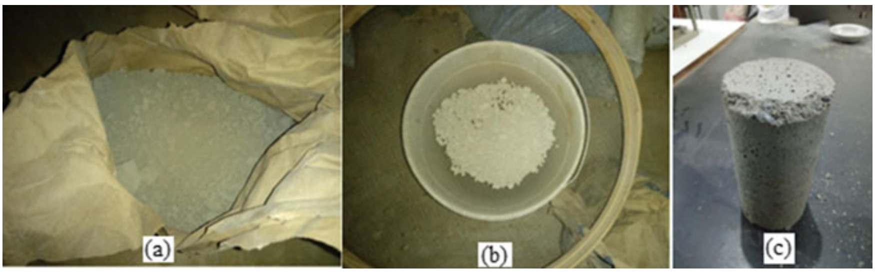

Fig. 1 Visualization of the cement produced in 2018

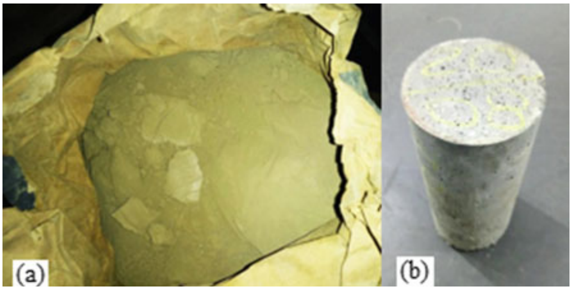

Fig. 2 **a** Cement manufactured in 2019, **b** concrete specimen with cement manufactured in 2019

After an individual analysis of the concrete, it is important to observe the behavior of the specimens in comparison with the concrete produced with cement manufactured in 2020. Figure 3 allows us to observe the trend line of each concrete for all ages until the 28th, notice the behavior analogous to a logarithmic function with a tendency to decrease the strength gain after 28 days. Concrete with cement out of date had a low value for the first ages, later showed a very gain in strength, with emphasis on cement from 2019, with values approaching that of cement from 2020.

As a guide, NBR 6118 [14] presents the values of 78 and 90% for the ages of 7 and 14 days of the estimated value for the age of 28 days. Analyzing this parameter, the 2018 concrete had much lower values for these ages, 30 and 40%. Concrete with cement from 2019 and 2020 had similar values and very close to those recommended by the standard.

The storage and storage of cementitious material in an inappropriate place and for a long period caused the pre-hydration of the cement, a fact that may have contributed to the low results of expired cements. The pre-hydration causes changes

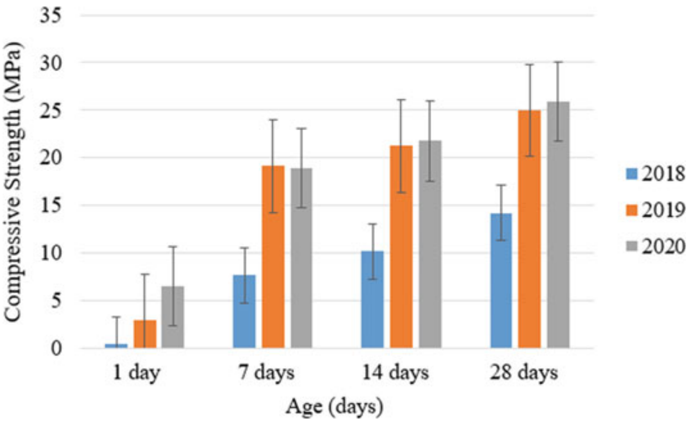

Fig. 3 Average compressive strength trendline

in the chemical composition and increases the surface area of the binder, forming a barrier that prevents chemical reactions when the cement meets water [15].

4 Conclusions

The present work investigated the loss of slump and of compressive strength of concrete when a cement with more than 90 days of manufacture. From the results, the following remarks are taken:

- The slump test to verify the workability was inconclusive when using cements beyond the expiration date, since even with the increase in the w/c factor for concrete with cement from 2019, it showed a lower reduction in relation to the concrete with cement from 2018.
- In regarding to the compressive strength, the cement manufactured in 2018 presented a low performance for all ages. The cement-based concrete manufactured in 2019 had a low compressive strength for the age of 1 day, approximately 45% of the value recorded for the cement-based concrete manufactured in 2020. However, for the other ages, the concrete showed satisfactory results for the test averages to compressive strength.

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Problems and Prospects of Heritage Based City Development in India

Shipra Goswami and Ashwani Kumar

Abstract India has been widely recognized for its rich and diverse heritage. Because of the same the country has been a destination spot for many international tourists as well. The heterogeneity of urban fabric especially in heritage zones is a magnificent paradigm to analyse it on all parameters based on pedagogy of imperial practice. The concept of heritage in Indian Cities is challenged because of several factors such as rapid urbanization, increase in the demand for a household in the cities, cultural changes, climatic changes, and various other factors that emphasize pressure on the cities.

India's GDP include 7.3% of the tourism industry that accounts for 6.5% of total export. This sector also generates 2.7% of the total employment in the economy. Since tourism is directly linked with the heritage can help in generating more economy and employment for the people living in the city. However, heritage relies on the tourism directly or indirectly for its livelihood. But the city historic places are unable to balance the development between the old and new, that is harnessing the interest of tourists. The magnanimous manifestation can only be practiced by the people living in the core area. The solution to such challenge for generating more and more economy and employment can be generated by integrating tourism with heritage and making city responsive to development.

This paper thus intends to understand the pressure of newer infrastructural developments on the existing heritage fabric by identifying the issues and challenges that has been faced by the heritage precincts. However, the objective of the paper is to study the best practices implemented in various heritage sites and identify the missing link between the best practices and the current practices in the case of Indian heritage sites. The paper further intends to recommend plausible strategies that can be implemented through efficient governance and management to achieve a sustainable heritage-based development in Indian cities.

Keywords Heritage · Core areas · Indian cities

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1 Introduction

The influx of population growth, economic development and lack of institutional and legal framework in several cases is the prime reason for destruction of urban fabric of heritage cities. Historic towns are a combination of social, cultural, architectural and historical heritage values. In order to satisfy the needs of the stakeholders, streetscapes and urban fabric and buildings are evolving but the importance of urbanization in preserving the heritage character is often neglected. Heritage is now being encouraged as a subject for achieving a stronger economy, still it is constantly challenged worldwide due to several pressures, including increased urbanization, increasing demand for housing, deteriorating infrastructure and social and cultural changes.

By the year 2050, 69% of the population would be concentrated in urban regions as per United Nations report of 2017. While growth and expansion are beneficial for agglomerated development, there is a potential for loss of historical areas that serve a heritage value to the city and its citizens. Urbanization tends to bring rapid transitions which often leads to alterations to the historical areas. Factors like population growth and increasing pressure for newer developments plays a vital role in influencing the needs of the population residing in the precincts of such historical areas. Hence there is a need of upgraded guidelines for planning, development and implementation that holistically approach the heritage-based development of such areas.

Urban Conservation Planning in Southeast Asia (2017) of the Getty Conservation Institute, showcases a great example of progressive urban planning and focus on the issues and challenges in countries such as India, China and other regions in South-east Asia that are currently facing the model of urbanisation.

Today's urban regions confront significant problems and they are at the forefront of inclusive city development. However, there has been a shift in how cities are built with tangible and intangible heritage being recognised as critical assets in constructing more resilient, inclusive and sustainable communities.

In developing countries like India, urbanization is happening at a rapid pace threatening the identity of heritage towns with unique historical significance. Urban planning of historic towns should incorporate identification, conservation and management of historic areas that primarily builds upon physical characteristics as well as socio cultural and economic values. It is often seen that rapid urbanization mostly results in deteriorating conditions of the urban fabric of the rich heritage areas. Most Asian nations must contend with the pressures of urbanisation in order to preserve their cultural identity and continuity.

It is reported that India's urban residents will reach to 857 million in 2050 which shall double as present in 2014. The urban fabric of heritage cities is under constant threat due to housing shortage and increasing rural to urban migration. The uniqueness of a country like India lies in the fact that it is a popular tourist destinations which makes it more vulnerable to the challenges offered to preserve its rich heritage.

Fig. 1 Images showing the changing character of historic structures in walled city area of Jaipur adding pressure on infrastructure facilities

India comprises of a number of heritage cities along with significant number of heritage structures with many inscribed in world heritage list as well. However, these heritage cities are facing major problems due to development pressures and demolitions.

Although there are many initiatives taken by the government in terms of restoration in order to safeguard the essence of the heritage cities but still new developments replacing old heritage structures is happening significantly at a rapid pace.

However, this rich heritage is facing major threats in urban areas from urban pressures, neglect, vandalism and, demolition. Restoration efforts to safeguard valuable heritage assets are visible at only a few places deemed to be of historic significance, which are in most cases designated UNESCO World Heritage monuments (Fig. 1).

The replacement of ancient structures with modern infrastructure and commercial constructions is frequently based on standardised solutions that are designed to produce quick revenue. However, they are frequently unconcerned with cultural heritage's authenticity and integrity. In addition, the diversity of traditional social practices and activities has often been affected by growing urban development and pressures, resulting in a continuous loss of sense of place, belonging and identity.

2 Recent Missions and Schmes Floated by Government of India

The improvement in urban infrastructure clubbed with the desired levels of service and effective governance is critical for promoting cities as the economic engines for any nation's overall growth. In order to achieve this goal, a number of schemes, mission and policies are been actively enforced in Indian cities, especially in the cities having heritage identity. There are six flagship missions that the Government of India has currently employed in the country viz., Smart Cities Mission, AMRUT, HRIDAY, Swachh Bharat, Pradhan Mantri Awas Yojana-Housing for All (Urban) and National Urban Livelihoods Mission. Of these six flagship missions, HRIDAY (Heritage City Development and Augmentation Yojana) was specifically employed in order to augment the holistic development of cities having a heritage value. The scheme was implemented in 12 cities and the whole programme is centrally funded. On 21 January 2015, the Ministry of Housing and Urban Affairs of the Indian Government started the National Heritage City Development and Augmentation Yojana (HRIDAY) programme. This design intends to conserve and revitalise the soul of the historic city to represent the distinctive character of the city by fostering an aesthetically attractive, accessible, instructive and safe environment.

Six flagship missions

Smart Cities Mission	AMRUT	HRIDAY
Swachh Bharat	Pradhan Mantri Awas Yojana- Housing for All (Urban)	JNNURM

Revitalization of infrastructure in the precincts of heritage assets is the major node on which the HRIDAY mission is focused. The revitalisation includes the various development programs like improving the water-supply, sanitation, drainage, waste management, approach roads, footpaths, street lights, tourist facilities, electrical wiring, and landscaping related citizen services. Even the Smart Cities Mission has been implemented to work parallelly with the heritage sites that haven't been recognised in the HRIDAY mission. The focal point of the Smart Cities Mission is in cognizance to other schemes that is to achieve comprehensive development in Indian cities by the integration of physical, social, economic and institutional infrastructure.

3 Methodology

Research methods are the procedures for gathering, interpreting, organising, and analysing data in order to answer a research issue. The information gathered for the study is divided into two categories: primary and secondary. The main data are the firsthand data that the researcher collects personally. On the other hand, Secondary data is the second hand data that has been obtained or retrieved from sources where the data has already been published. Primary data collection is not feasible for the proposed study due to time and financial constraints. Furthermore, contacting individuals in charge of urban development projects, ministries, or inhabitants of urban regions is difficult. As a result, secondary data is collected. Secondary data can be collected in a variety of ways, including literature surveys, case studies, and so on.

The case study approach is used in this investigation. In order to perform the current case study, secondary materials such as news articles, media sources, and reports were used. The present case study technique is a type of qualitative analysis that includes a comprehensive and systematic observation of a key region of a city in India. It's a method of exploration that focuses on depth rather than broad. In this case study, the complete examination of a small number of occurrences or circumstances, as well as their interrelationships, is given a much important. The methods and their linkages are the focus of the case study. As a result, a case study is successfully employed as an in-depth investigation of the individual unit in question. The goal of the case study approach is to discover the factors that contribute to the attitudes and behaviours of a particular unit as an embedded whole.

To begin the case study, the first step was to properly analyse and read the case in question. The most important issues were identified, significant information were evaluated, underlined, and notes were taken. To get the general framework of the case, the interrelationships between the facts were discovered. The causes and consequences, as well as the concerns, were emphasised and investigated. The data was then organised and analysed in relation to the study topic (Fig. 2).

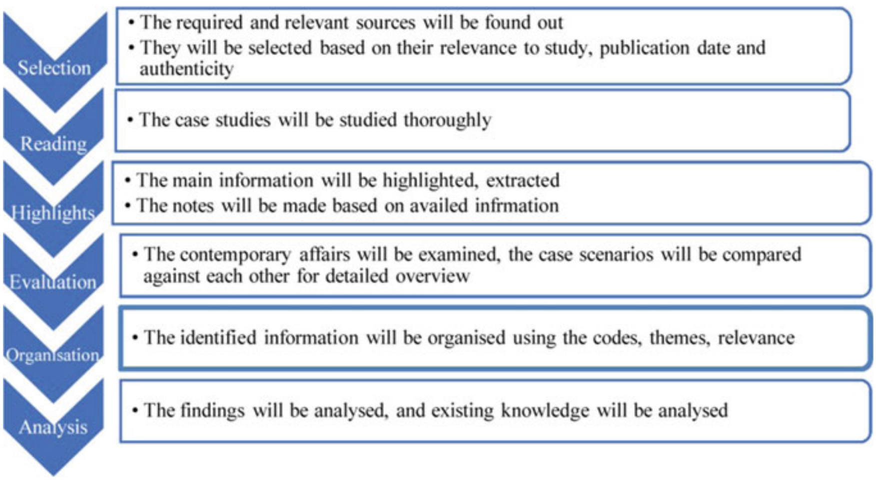

Fig. 2 Methodology chart

4 Problems Faced by Core Areas of Indian Cities

With more than 5000 years old documented history and the largest density of cultural and heritage assets, India and its cities are bestowed with 30 heritage sites and thousands of historical monuments throughout the vastness of its natural and built landscape. The heritage of Indian cities are majorly garlanded with monumental buildings, traditional neighborhoods, streetscapes, ghats, parks rooted within various traditions and practices. Thus it is possible for Indian cities to use heritage as a channel to achieve sustainable development. The schemes like Jawaharlal Nehru National Urban Renewal Mission (JnNURM) and Heritage City Development and Augmentation Yojana (HRIDAY) are the premier examples in India that have set the tread stone of heritage-based development in India.

With certain schemes and policies in place, the role of appropriate stakeholders comes in to picture whose responsibility is to take care and safeguard the quality of historic environment for the generations to come (Fig. 3).

The complexity of issues relating to planning interventions for old areas includes structure and infrastructure that falls into the domain of 'housing planning,' rather than a slew of issues related to market factors, redevelopment interests, rent control, and so on, which fall under the domain of 'urban planning'.

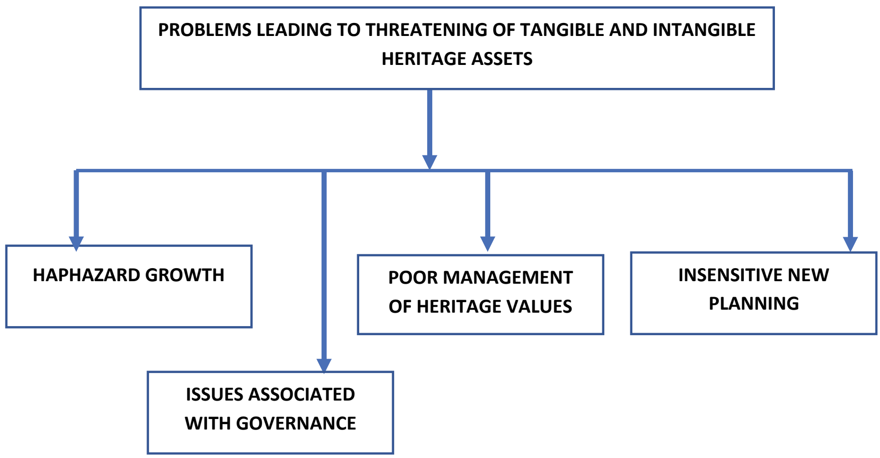

Fig. 3 Factors involved in Heritage City Development

In the countries such as India, Inner city renewal interventions are focused toward the ‘housing planning’ rather than the ‘urban planning’ side of the inner city problem. Upgrade solutions for squatter settlements or poor peripheral projects are used to solve these issues. On the other hand, such interventions in inner-city regions must integrate conventional components in not so conventional ways.

These inner cores for years has been identified with various political and socio-cultural developments that has undergone significant modifications to show typical features. The ageing inner cores are typically structurally weak owing to numerous causes including age, insufficient maintenance and overuse stresses. The occupancy rates are however higher than the usual and overcrowding and small units are typical. Physical infrastructure does exist, whereas a few designed in core area are used by many, leaving the patterns of growth overburdened and crowded, sometimes organic, and unable to accept additions. In addition, the majority of inner city districts are important economic hubs with intensive mixed land use characteristic.. Residentials are often low-income and frequently engage in informal sector activities, which are typically home-based and have strong horizontal interconnections. However, there may be severe environmental issues as a result of traffic congestion, pollution, and conflicting land uses. In addition, inner city regions have a terrible reputation for communal politics, rioting, and high crime rates.

Several cities have designated their inner cities as special zones, with particular development limits and urban rejuvenation initiatives in place.

Special agencies have been established in several situations. However, no major renovation plan has been executed in any of the cities (Figs. 4 and 5).

Fig. 4 Images showing the acute congestion, bottlenecks at the local streets of walled city area

Fig. 5 Images showing the infrastructure facilities being placed haphazardly without considering the heritage character

The paradigm of city development has shifted its course towards human dimensions in the cities. In order to achieve this shift, urban heritage can play a pivotal role in reinforcing city's identities through heritage based development approach which facilitates the integration of planning strategies into local development processes. This kind of strategy allows to broaden the horizon of urban areas in accordance with heritage and its physical form, spatial organizations, and values.

The major issues that is faced at the time of making urban development in the core areas of Indian cities can be summarized under the following heads:-

- There is a lack of proper governance in urban areas
- They do not have an adequate amount of financial resources for the development
- There is no proper planning in urban areas which leads to a rise in the price of the house and office space in the urban areas and;
- Absence of infrastructure and shortage of services such as water and electric supply
- There is lack of appropriate Development Regulations
- There is lack of heritage Conservation & Preservation
- There is a severe problem of encroachments
- Lack of Maintenance and cleanliness
- Unplanned and unregulated urban extensions
- Conservation works carried on adhoc basis with no prioritization

- Absence of heritage essence with new developments coming up in the interiors of the walled city area.

Small towns do not attract migrants to settle over there because of the absence of proper infrastructure and employment opportunities. When it comes to the core region, they face the issues of traffic and amalgamation of small scale industries and residential settlements. All this has led to urban crime, prostitution, and the amount of Juvenile crime is also increasing on an everyday basis. The problem of land acquisition is also faced by the municipal bodies when they need land for the development of public purposes. Even the government is lacking behind as the plans for the development are not structured in a proper way. ULB's allot 50% of their revenue on expenses such as salary, pension, office maintenance, and other things.

5 Factors Affecting the Urban Development in the Core Areas of Indian Cities

These are the factors which often play a vital role in core areas of Indian cities. The core areas of Indian cities are usually the areas having highest density of population now due to rapid urbanization the increasing density represents an extra burden for historical facilities and services in the area affecting overall quality of life. The character of the traditional houses of the core areas are endangered due to housing demand as well as increase in the commercial activity in core areas (Fig. 6).

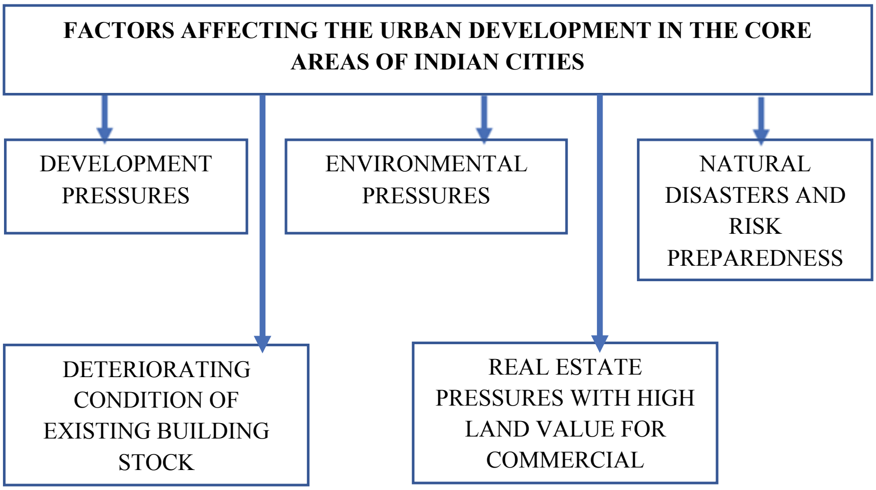

Fig. 6 Factors responsible for urban development in core areas of cities

Now with modernisation these core areas are experiencing real estate pressures for new infrastructures and commercial developments that can accommodate more people and add increased value to add.

Rapid Urbanization is also the root cause for incorporating new infrastructure and commercial developments which are planned in a standardized manner which can generate immediate returns which are usually very insensitive towards the heritage fabric of the areas.

6 Role of Heritage-Based City Development

Heritage as a concept is difficult to define, its meaning and its presentation, representation, its development, set against a back-drop of the demands, motivations has been multidimensional over the period of time.

Due of its richness and diversity, living representations and practices of legacy are frequently misinterpreted and viewed as ambiguous. Heritage is defined as aspects of the past that are inherited, recorded, conserved, and passed on to future generations by literature, which defines heritage as components of the past for present society to inherit, record, conserve, and pass on to future generations.

Heritage is related to the continuity and maintenance of the cultural and natural traditions with time. Therefore, heritage is the concept of acceptability and unique sensibility in a particular culture (Singh). Heritage is the representation of our past and transferring its root to the next generation. The concept of heritage can also be described as the meaning that we conclude and perceive within a culture and their impacts on the real and practical life and exchange of these meanings thus produced. It is also related to the things we use in our daily life and how we represent these things and what meaning we derive from their use. As a language is the source of expression, in the same way, heritage is also a mechanism of transferring the cultural and inherent values with time [3]. However, different spaces and times have interpreted the different meanings of heritage but the basic mechanism of maintenance and continuity of the culture is the same. Therefore, it sets the norms and rules to conserve and maintain our traditional activities and customs. Thus, cultural heritage is now considered an economic commodity and its marketing has been in practice for a long time. Heritage tourism is an important example of the marketing of cultural heritage. Heritage can be given different meanings in one culture at the same time. It can also be given different meanings in different cultures at different times. It can also give the common acceptability as well as the opposing uses concerning heredity. It can be a source of conflicting meanings within a particular culture. That is why, heritage is determined by its meaning within a specific culture [1].

Heritage relates to the identity of the culture when it is viewed from the individual and pluralism within a culture. It is also closer to the religious practices especially in the old cultures where the customs and practices were maintained and conserved. With time, the process of layering of the different cultures showed their marks and symbols, which became the source of conflicting reviews among different cultures about the meaning of heritage. Therefore, the differences in rituals, control, power, and issues of representation emerged among different cultures. According to the latest UNESCO-based description of heritage, heritage is not an aggregation of the individual social destinations. But it is a unique platform having its social integrity and is constantly evolving day by day [2].

7 Need for Heritage Based City Development

In the traditions of India, heritage is described by the word "dharohara". This word is derived from the meaning "the mother earth" and "struggle for identity with time". That is why heritage is described in the words of root and identity in the Indian culture. Hence, it is a framework of the possibility of interconnectedness within a particular culture. Therefore, heritage is a shadow of the memories as well as glories and their relation with the historical places [4].

In the representation of both heritage and history, there is selective use of the past time. The heritage uses the heritage resource for its manifestation in the form of symbolic and visual representation and converts it to commodities for contemporary satisfaction. The progress of heritage tourism is based upon the process of commodification and marketing of heritage. However, the conservation of heritage is determined by the type of heritage planning in a particular region. This can lead to the "place-making" process where human beings live and transform commodities and places. This place-making process has led to the creation of historic buildings that have a high value and character. These have value in three aesthetic contexts, community, and economic value. Time, city, and planning are three components that have laid the foundation of heritage planning that has led to the place-making process [2].

The process of urbanization is inevitable and is a continuous process. Though it is a beneficial process for many businesses as the population expulsion can lead to the popularity of many products for them. At the same time, it is harmful and disadvantageous for the maintenance and survival of the historic heritage buildings [5]. These historic buildings have an enormous value that is being populated by the urbanization process (Fig. 7).

Fig. 7 Images showing new developments happening in walled city area without paying attention to the authenticity to cultural heritage

8 Recommendations

8.1 Vision of Urban Planner for a Core Areas of Indian Cities Having Heritage Importance

The city that has the heritage site should be planned accordingly. The city is the site of attraction for the tourists and thus it is advised to the urban planner to focus on environmental planning to conserve the beauty of the city. The environmental factors affecting the heritage site should be the point of concern for the planner and thus to be precisely worked upon [8]. Another part on which the focus is needed is the transportation facility in the city. The tourism spots should be well-connected to all the parts of the city, and thus facilities should be provided in the urban city plan. An urban planner is crucial in identifying and protecting the buildings of major importance. The information about heritage sites and other important buildings must be stored and should be looked upon on a special basis. The work of the urban planner is not only limited to the structures and transportation of the city, they are responsible to look after the economic development of the city. They are responsible for the encouragement of the investment in the city through the planning model [9]. Proper infrastructure planning is also part of the urban planner, and while looking at the city with a heritage site, it is crucial to connect the heritage site with the facilities of the necessary use like hospitals and restaurants.

Fig. 8 Images showing developers replacing the old heritage structure with new commercial complexes

8.2 *Interventions Important at the Governance Level*

During the preparation of the local development plan (LDP), it is crucial to consider the heritage built in certain cities of India and also their impacts on the social, economic, and cultural levels of the country. This assessment can help to considerably survive the characteristics of heritage as much as possible [6]. The regression model recognized the huge impact of different variables and factors in the physical contest, socioeconomic context, and sociocultural context. These factors have impacted the heritage of these historic buildings and their characteristics. The physical factors include the architectural structure, building materials, height of the buildings, and others like these. In the case of these factors, there is a need of deciding by municipal administration on the conservation of the heritage buildings. Moreover, the local development plan should also include the instructions that make sustainable development of urban areas and maintenance of the heritage places. The use of these buildings is included in the commercial factors. This also shows the great contribution in mitigating the survival of heritage culture and loss of heritage characteristics as well as increasing the process of urbanization (Fig. 8).

The socioeconomic factors have consisted of the number of residing inhabitants, variations in the value of land, and type of ownership. These factors are also significantly important during the preparation of local development plans and making the new developments without destroying the heritage characteristics within certain regions. The stakeholder's input is also contributing and significantly important in this process. The research has shown that these stakeholders keep an eye on all the factors during the decision-making process, and thus, they considerably take part in the effects and factors that change the heritage characteristics of a city [7].

Historicity has its own significance which explicitly or inexplicitly related to our future growth of the city. There are quantum of issues that we need to take under consideration while reframing or rediscovering our own heritage that reflects our identity. These issues are being addressed at various platform and are being viewed at various scales, but now it's high time to consider it extravagantly. This whole system is a web that needs to be redesign to protect the antiquity at greater scale.

- Firstly to consider it by creating a transparent web of the governing body who is going to cross-check the approach towards designing, rethinking and reframing the ideology of historic significance.
- A robust vision that could be the foundation of this whole process.
- A collaborative working between all the institutions with more to enhance and to add public participation to understand the requirements and usability of the space with the human psychology.
- Then to develop a master plan with possibilities to encourage the future growth of the society and to make them financially more lucrative. To ponder upon the merits and demerits of restructuring the past and to create a strong balance between the present and how to proceed further.
- These all aspects need to be compile under one system which sub branches to look it up and build a paradigm for posterity to learn, aspire and reconnect with the past and its incidences.
- The regulation should have some resistance, which should be taken under consideration as we cannot change the history or we can redesign it, we can just conserve it, as it's our spine at every stage of life. So, a new set of rules to be made for such zones, which should be more socially, culturally, historically and monumentally inclined towards such precincts and it should always admire the psychology and philosophy of the elements of life and design. Such overarching visions could be a task that need to be tackle at every stage of conservation.
- Rules and regulations should also focus on the inappropriate way of public practices, which is destroying the legacy of heritage and dividing the core essence with respect to the upgrading market forces (for example, to reframe the sewage system, channelize the electrical system, to work on pedestrianization and to develop the walkability concept as the stitching element in the historic precincts.

9 Conclusion

At last as a concluded recommendation, the whole process is a hand in hand way of achieving the goals by giving resistance to the tangible aspects of heritage, due to its limitations and not to degrade the aesthetics, ostentatious attractions which allure the global market and also without deviating the human ethics and its pedagogy.

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An Overview of Technique Used in Traffic Monitoring System

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Abstract In the recent past, the term traffic congestion has emerged as one of the most brutal challenges to face for the engineers, governments, planners and policy makers in almost every country. With ongoing advancements in social and economic structures, fabricated by vehicles-oriented urban development, they have established congestion as an inevitable reality of urban life. Predominantly there are various factors which play a humongous role towards aggravating this problem some of them are listed as: (Speed, Travel time, Delay, Volume) etc. Subsequently, every research demands exhaustive data collection and based upon that, reaching upon suitable methods to overcome the widely spread problem. Speed has emerged as the most important traffic measurement to identify congestion. This phenomenon has been widely classified into two types (i) Recurring and (ii) Nonrecurring. According to the United States Department of Transportation Federal Highway Administration-alone, nonrecurring congestion is responsible for more than 50% of the total traffic congestion, whereas, recurring congestion contributes for about 40%. Extensive collection of data is aimed to be done at several locations in order to measure the maximum number of traffic characteristics. The main emphasis of this paper is aimed towards understanding the techniques used in recurring urban congestion, its types and methods to curtail it with least available manpower. Literature reviews regarding this problem reveals some interesting insights.

Keywords Congestion · Speed · Travel time · Recurring · Non-recurring

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1 Introduction

In the transportation realm, congestion is a phenomenon resulting in speeds that are slower and sometimes much slower—than the conventional/normal or required free flow speed. The after effects of the congestion are quite often serious and involves issues including unexpected travel times for the drivers, pedestrians, passengers etc., increased fuel consumption, emission of harmful and toxic greenhouse gases and higher susceptibility to accidents are some its brutal effects. According to the 2011 census, India's urban population has substantially grown from 290 million in 2001, to 377 million in 2011, and this figure is equivalent of about 30% of India's overall population. Speedy urbanization along with many advantages has also come with several problems, including increased congestion. With about 1.21 billion in population in 2011, India emerged as the second largest country after China in terms of the density of population [1]. Although the present share of the urban population in India is relatively small, in the year 2020, urban population of India was estimated/accounted for about 34.9% of total population. Urban population of India progressively increased from 20% in 1971 to 34.9% in 2020. Now even though the percentage density of urban population in India is much more trivial in nature yet, the major contribution of the traffic congestion hails from the urbanized areas only. The causes are in abundance including:

- Large number of vehicles on the roadways due to scant in major transit options or due to some other unusual reasons.
- Asynchronous switching of traffic signals many times on a road intersection, when apparently the computers are suffering from breakdown.
- Overdeveloped areas wherein the major transition system itself is already overflowing and the provided road system results in inadequacy and so on and so forth.

According to a report published by The Financial Express (April 26th 2018) —"The traffic in Delhi costs $9.6 billion, which is about 12% of the GDP, while the peak-hour congestion is 129%. In Mumbai, the following cost is $4.48 billion and the rate of congestion is 135%, in Bangalore, the estimated cost is $5.92 billion and congestion is 162%. The highest level of peak-hour congestion is in Kolkata accounting for 171%, even as the cost is lowest at $1.97 billion." To add more to this grave situation, it was found out that traffic congestion in above mentioned four major cities costed the nation a massive sum of Rs 1.5 lacs crore, which itself was greater than the entire Railway transport budget of that year in many folds. Hence the nation's traffic management system seems to be highly adulterated and the ongoing scenarios of traffic congestion appear to be perpetual. However, TMS schemes have been formulated in many nations alongside India but the implementation of the policies and methods show vivid divergence from nation to nation [2]. TMS aims at making the commuters much more informed about traffic and road status hereby, reducing the negative impact of congestion, even though it can't be permanently solved but it can be permanently handled. Effective data acquisition alone will not be sufficed to deal with this heterogeneity of vehicles on roadways, it requires comprehensive R&D efforts. Applications which are required in order to assess and manage the existing and forthcoming scenarios need transportation engineering background. Hence, the TMS terminologies must be comprehensible to all the domains working on it. In order to comprehensively utilize the potential of TMS following objectives must be fulfilled:

- Prioritize traffic scenarios according to real-time changes in traffic conditions.
- Accident Prevention and Safety.
- Management of Emergency vehicles.
- Route Optimization and Divergence information.
- Minimum involvement of manpower.
- Environmental Sustainability.

The typical Smart TMS not only helps in monitoring the vehicular traffic but is also a major source of imparting variety of related jobs to it. One can visualize this system as a costlier one; as it involves abundant amount of resources, but it has a much wider scope and even though it requires a good initial investment yet, it contributes towards the Sustainable Development of our existing fragile system. Developed countries like America, U.K. and Japan, have already implemented the TMS on their roads and still many researches are being conducted on to make the traffic systems more advanced and reliable for other developing countries as well.

2 Literature Review

Bertini and El-Geneidy [3]. In the given study, the researchers conclude that a complete ITS system requires collaboration in time, funding, and institutional arrangements. ITS components that are integrated can result in synergistic effects when considered as an entire system. It is shown that in some cases it is possible to build upon national level statistics describing ITS benefits by using data collected from the systems themselves [3]. In addition, there is no guarantee that travel time reduction due to the installation of ramp metering in one city will result in similar benefits in another city particularly if the nature of system integration and institutional cooperation is widely different.

Allström et al. [4]. In this study, the researchers have found that the large amount of data from these sensors does not by itself improve information to the road users (e.g. travel time information) or provide means for traffic control to the road authorities [4]. It is through the use of filtering techniques and models that this data enables new possibilities for online estimation and prediction of the traffic state, and for wide-area control in urban areas.

Aycard et al. [5]. In this study, A complete solution for the safety problem including the tasks of perception and risk assessment using on-board lidar and stereo-vision sensors will be presented. An approach for the safety of vehicles at the intersection developed on the Volkswagen demonstrator is introduced. A complete solution to this safety problem including the tasks of environment perception and risk as-assessment are presented along with interesting results which could open potential applications for the automotive industry [5].

Cafiso et al. [6]. In present learning a case study was done with in field experiment, to show practical applicability of the system in bus-pedestrian conflicts, but potential use can be extended to different traffic conflicts in the field of vision of the system (e.g., rear end collision) and road users (e.g., vehicle, motorcycle, bikes) [6]. Indeed, the system is able to identify any spatial information of objects in the video frame with the added value, when compared to traditional radar equipment, to turn out in real-time a depth-map where spatial data are provided together with shape and color attributes of the object.

Al-Sakran [7]. The proposed traffic system based on the IoT consists of a large number of RFIDs and sensors that transmit data wirelessly. This calls for improved security to protect such massive amounts of data and privacy of users. IoT requires modification of network connectivity models and readiness for massive increase in amount of real-time information. To achieve that, interaction communication models must be redesigned to include machine to machine and people to machine communications.

3 Methodologies: (Proposed Prototype of TMS)

As mentioned above the paper deals with the congestion by adopting various measurability standards and comparing the data obtained so as to have a bird's eye view on the conditions and henceforth, proposing the most suitable method. In order to rationalize the proposed system, a comprehensive traffic solution is needed to be performed. The paper extensively imparts insights to the two working principles of TMS, namely, V2V (vehicle to vehicle) and V2I (vehicle to infrastructure) technologies.

V2V. Vehicle-to-vehicle (V2V) communication's competency is to cordlessly interchange particulars regarding the speed and coordinates of neighboring vehicles which shows great impact in helping to avoid several crashes/accidents to clear traffic congestion, and to contribute towards improving the environment. However, it must be kept in scrutiny that the greatest advantages can only be achieved when all the vehicles can interact with each other. Vehicles that could potentially use V2V communication technology on a wider scale range from two wheelers to 8 wheelers. Pedestrians may also avail advantage from V2V communication technology so that they can enhance their visibility to motorists and the others.

V2I. Vehicle-to-Infrastructure (V2I) communication is defined as a cordless barter of data existing between the automobiles and the route infrastructures (Command and Control Centre, traffic lights, lane markings etc.) [8]. With large data being clutched and exchanged, copious and well-timed information can be optimized so as to enable a wide range of safety, accuracy, transportability, flexibility and environmental prosperity.

3.1 Sensors

The role of sensors is to prioritize the traffic intensity based on real-time data and real time scenarios. A sensor is a device which converts a physical phenomenon into a quantifiable analog voltage (or seldom a digital signal) which is fatherly converted into a human-readable display or is transmitted for reading and further processing. It is classified on the basis of power or energy supply requirement as:

Infrared Sensor

The TMS is comprised of Command & Control Centre which is responsible for monitoring and predicting several aspects and their related effect on the pre-existing traffic state. If management, for an instance is equipped with an infrared sensor, it is then embedded into various traffic gauging and maintenance tools at a road intersection for ex. traffic lights, CCTV, electric poles, crossways, electric meters etc. The principle on which it works is- "Active infrared sensors emit and detect infrared radiations, shown in Fig. 1. These sensors have two parts: a light emitting diode (LED) and a receiver. Whenever an object comes close to the sensor, the infrared light emitted from the LED reflects off of the object and thus, it is detected by the receiver" [9].

Acoustic Detectors

Like the infrared sensors the main purpose of these detectors is to accumulate the real time data and based on it gauge the ongoing situations. The major principle on which these detectors work is-"Acoustic wave sensor works on an oscillating electric field which in turn generate a mechanical wave, further propagating through the substrate and converting into an electrical field for measurement" [10]. The algorithms thus, established are used for the investigation and categorization of

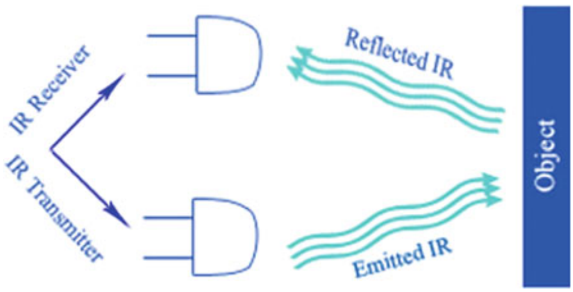

Fig. 1 Working of an infrared sensor

different acoustic signals, and also play a key role in detecting different types of impetuous sounds, which proportionately results in increasing traffic immunity.

Piezoelectric Sensors

These are one of the most widely used sensors which are required for the agglomeration of traffic-oriented data. The most common example of piezoelectric sensor is accelerometer. The main purpose of the sensor is to adjudge the object's position and coordinates in space and monitors its movement. They currently are being used in variety of sectors such as medical, aerospace, and nuclear instrumentation and consumer electronics. Similar to the acoustic detectors they also are squeezed by the pneumatic pressure of the vehicles and in turn generate an electric potential which is converted into a digital signal and get transmitted to the infrastructure.

Inductive Loop Detectors

These are one of the most frequently used detectors and are suitable and favorable to work in V2V and V2I information communication technologies. Their working principle is based on an inductive looping system that behaves as a tuned in EC (electrical circuit) in which, it comprises a loop wire and a fabricated lead-in cable and thus, these serve as the constituent inductive elements. When a vehicle is passed over the given loop or is halted within the loop, then instantaneously it induces eddy currents in the given wire loops, and causes reduction in their inductance. This decrease results in change in the magnetic field which causes a pulse and is installed as a vehicle registration in database [11].

Thus, sensors in future can play a pivotal role for TMS. Their incorporation enables the advancement of a diverse variety of implementations for the traffic safety, congestion control and many more. Sensors render the required mechanism for data accumulation pertaining to the vehicular circumstances (like-route conditions, congestion conditions and vehicular conditions) which can be unified with the existing transportation systems so that it can lessen many of the problems that our transportation systems are facing from a long time.

3.2 Global Positioning System (GPS)

In last few years, TMS are potentially acquiring propensity towards ever more automatic, creditable, interrelated, disseminated operations. The latest development of dynamic transmission gadgets and conveying automation has stimulated an expanding curiosity in the Geographic Information System & Global Positioning System-built position-informed structures and assistance [12]. Everyone is well acquainted as up to what extent GPS has been unified in their daily lives, particularly in the mobile phones. The mentioned system is advanced as a fully automatic, ceaseless and a concurrent invigilate structure that engages GPS detectors as well as coaxial cable sequent port inter-transmission methods which further are utilized to exchange information between receivers and a data processing unit.

The infrastructure of TMS is dormant of various devices located in a given juxtaposition of a road intersection and based upon their workings the data is conjunct and transmitted to the Command & Control Centre where-about it is further handled and monitored. GPS can serve as a guiding tool. Hereby, GPS works on Route Optimization and Divergence information. At this juncture, transportation/hauling system has a very crucial role in practically everyone's life however, when the time comes to lay hold of the public transportation, specifically the bus transport and its related networks, time and perseverance are of prime importance. To put it into another way, large number of people which currently are using the facility of bus transport have encountered loss in their time because of long duration waiting at the bus stops, due to which the spirit to prefer public transportation in time of urgency exponentially deteriorates, and also it escalates the congestion. In order to curb down this problem, the Malaysia Public Bus Monitoring System came forward to track the current locations of the buses and other public transports in the form of coordinates of latitude and longitude via GPS and GSM [13]. It thus, focuses on reducing waiting time of the bus users and to make the current bus service system robust, flexible and dynamic.

3.3 Radio Frequency Identification (RFID)

It is a system, which works on the emission and reception of radio waves so as to transmit the data of the vehicles passing through it from one place to another. In this study, a RFID Identification System is planted for checking the details of the vehicles at the traffic monitoring centers which are located at various locations. The main concern of implanting RFID in the study is to provide flexibility to the emergency vehicles. Emergency situations are always unpredictable and demand immediate attention and thus it becomes utterly necessary to provide anytime access to the emergency vehicles like Ambulance, Fire extinguishing vehicles [14]. Here RFID can extend a big role in allowing uniform access to such kind of vehicles. The vehicles are equipped with RFID tags analogous to a QR code. If the intersection on which they are transiting is overcrowded with congestion, then the drivers of the vehicles need to activate the tags which emit radio frequencies in a given proximity and these frequencies are detected by the receivers which alert the traffic administrators regarding their arrival and thus, they can take necessary actions to maintain the homogeneity in flow of these vehicles. RFID system works on a variety of frequencies such as, Ultra-high frequency, Low frequency and High frequency [15]. The working of various frequencies shown in Table 1 for various countries is as follows.

Low frequency tags are cheaper in nature and feed on less power when compared to different varieties of RFID tags. High and ultra-high frequency tags can

Table 1 Working frequencies of RFIDs

S. no.	Various range of frequencies	Countries
1	125 to 134 kHz	U.S.A, Japan, Canada
2	13.5 MHz	U.S.A, Japan, Europe
3	433 kHz to 434 MHz	Japan, Europe
4	864 kHz to 869 MHz	India
5	865 to 868 kHz & 920 to 970 MHz	South Korea
6	900 kHz to 930 MHz	U.S.A
7	2400 kHz to 2500 & 572 to 587 MHz	U.S.A, Canada, Europe

transfer data faster, are expensive and provide better ranges as compared to low frequency labels. Generally, two types of RFID tags are used, namely:

Passive Tags: Such tags receive power through the reading transmitting aerial antenna, which generates an electromagnetic wave to produce a current in the antenna situated within the RFID tags. Structural passive RFID tags and active RFID are shown in Fig. 2 and 3 [16].

Active Tags: In such RFID tag a battery is provided, which acts as its power source.

RFID possesses the following components namely (a) a scanning antenna, (b) transponder and (c) receiver. RFID reader is a combination of a scanning antenna and a transceiver.

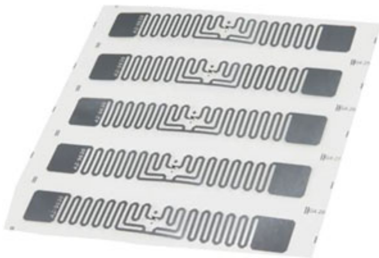

Fig. 2 Structural passive RFID tag

Fig. 3 Structural active RFID

3.4 Smart Traffic Lights

Smart traffic light or intelligent traffic light is a contingency traffic curbing system for a road convergence particularly defined for the event of collision/crashing and accident, with congestion recovery, live lock interception, and dispute resolution. These ingenious traffic lights reduce slacks such as congestion or automobiles standing by at vacant convergences. A grid of these lights can recognize paradigms in traffic states and then refurbish their signals in actual duration. These ingenious traffic lights utilize data procured from devices like sensors, cameras, GPS, vehicles, cell phones and other devices to detect patterns of traffic and the density of vehicles, pedestrians and bicyclists close to an intersection.

"A Modified Approach: Smart Traffic Congestion Control System" incorporates RFID technology to recognize the frequency of traffic jams. The entire light cycle is dynamic and is synchronized, based on density of traffic so as to reduce congestion with prior help of numerous sensors. On every vehicle a passive RFID tag is instated, and the detectors are responsible for recording total number of automobiles passing through the upcoming sensors located in given vicinity [16].

Smart Traffic Lights for Stolen Vehicles

For "Intelligent Traffic Control System and its Implementation for Congestion Control and Stolen Vehicle Detection," extensively, the emphasis is laid on the collaborative working of smart traffic lights and RFID tags in order to trace vehicles which are stolen. The working of the system is as follows-"If the given vehicle crosses a convergence, it is detected/ identified and a text message is thus, sent to the police Centre". As mentioned earlier emergency vehicles are differentiated based on the frequency of their RFID tags, and the idea of providing a green light is used for better precision [17].

Smart Traffic Lights for Pedestrians

Study on "Smart Pedestrian Crossing Management at Traffic Light Junctions through a Fuzzy-Based Approach," utilizes a bleary-based approach by introducing in three mode functions i.e. (low, medium and high). The number of pedestrians on the road serves as input and the stages of the traffic lights as output [18]. Working of smart traffic light for pedestrian is shown in Fig. 4.

Fig. 4 Infrastructural working of smart traffic light

4 Conclusions

- Traffic Monitoring System can be created by utilizing different parts of Internet of Things. Traffic enhancement is accomplished by utilizing those devices which work on the basis of some scientific principle. Two basic highlights for this system have been mentioned namely V2V and V2I for proficient functioning of the system.
- The transmission of information from one technique to another facilitates least density, more accuracy and more flexibility on the road. Various services like collision prevention, path optimization, procurement of real time data, systematic monitoring and so on, overshadow the very few shortcomings that this initiative initially has.
- This paper tries to present a viable answer for quicker development of traffic reducing stream especially in enormous urban communities which are invariably expanding step by step.
- However, this proposed structure which is based on IOT devices carries with it a permanent threat of data breaching of the commuters. Equipped with devices, that carries data without a physical medium. This by default arises the need for enhanced security measures to secure this colossal amount of data of the users.
- The decentralized methodologies make the flow of information streamlined and thus, this framework works flawlessly regardless of whether a neighborhood's road intersection is heavily congested or not.

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An Overview of Highway Failure and Its Maintenance on Old NH-2

Parveen Berwal, Maneesh Pal, Ishtiaque Ali, Shilpa Singla, and Rajesh Goyal

Abstract Full-grown transportation infrastructure is very important for social, industrial, cultural, and economic development. The main focus of this paper shows an examination to track down the adaptable asphalt distress and rigid pavement failure types and recognize the causes and select the best maintenance for the disappointment of flexible asphalt along the 10 km distance of old NH-2 (current NH-19) in Fatehpur district in Uttar Pradesh. It includes 8 km flexible pavement and 2 km rigid pavement. There are numerous kinds of distresses that occur in the road like various kinds of breaks, potholes raveling water dying, layering and pushing, misery and rutting. The fundamental driver of flexible asphalt is poor mixing of bituminous, heavy loads, poor drainage conditions, and heavy rainfall. The failures are removed by adequate planning, inspection, and treatment. These failures create problems for motorists, passengers and also increase cost maintenance. National highway authority of India suggests that to try maintenance regularly with the needs of critical support and accessibility of assets. Which is found during this examination. The present study identifies the different types and classifications of faults in flexible pavements and the sources of these faults and how to correct them also the current pavement flaws and associated maintenance procedures.

Keywords Pot hole · Raveling · Maintenance · Transportation

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1 Introduction

Developed in transportation infrastructure is important for social, cultural development, industrial, and economics of a country. Because of this need, generally three methods of transport is created, i.e., via earth, water body and airway [1–3]. The main focus of this paper to study and shows an examination to process the adaptable asphalt disappointment and rigid pavement disappointment types, to characterize and recognize the causes, and select the best upkeep for that disappointments of adaptable asphalt inside the 10 km distance of old NH-2 (currently NH-19) in Fatehpur district in Uttar Pradesh [4]. Which have include 8 km flexible pavement and 2 km rigid pavement. Different forms of cracks, potholes, raveling, water bleeding, corrugation and pushing, depression, and rutting are all examples of road failures. The main reasons of flexible pavement are as follows: is to poor mixing of bituminous heavy loads, poor drainage conditions and heavy rainfall. The objective of present study is.

- To identify the different types and classifications of faults in flexible pavements.
- To determine the sources of these flaws and how to correct them.
- To identify current pavement flaws and associated maintenance procedures.
- To investigate and identify flaws in the traffic flow so that it can flow smoothly and easily.

Based on structure and shape pavements on the road are mostly Flexible and stiff pavements are the two types of pavement. In India mostly the flexible pavement is built. Because it have more advantage than rigid pavement [2]. This old NH-2 is the major highway in India it is also part of AH-1 (Asian Highway). This study was conducted to determine the types and reasons of maintenance failures, as well as the procedures used by the various authorities. The term “pavement” refers to a single layer’s covering. In highway design, the entire thickness of the road is considered. Which have include the surface, base and sub-base.

Zulufqar Bin Rashid1, Dr. Rakesh Gupta [5] emphasized on the parameters influencing the performance of pavements and to identify them. For efficient maintenance of road pavements, the deficiencies in our existing highway system need to be clearly understood. Proper design, regular inspection and maintenance of pavement is of utmost importance and in preserving the investment made on highway system and in providing comfort and safety to the road user. Aaron Steinfield, BenedicteBougler, Dan Empey emphasize [6] on snow removal and how it is critical for winter highway maintenance operations. However, it is subject to significant risk due to adverse operating environmental conditions such as total visual whiteout, low tire/road traction, difficulty for detecting roadway boundaries and obstacles buried in or obscured by snow. Parveen at el. [7] emphasis the road side features cannot be neglected because the things like hidden signs, damaged edges, bearing course having potholes, improper design of vertical and horizontal curves, boulders at edges etc. sometimes results in road accidents.

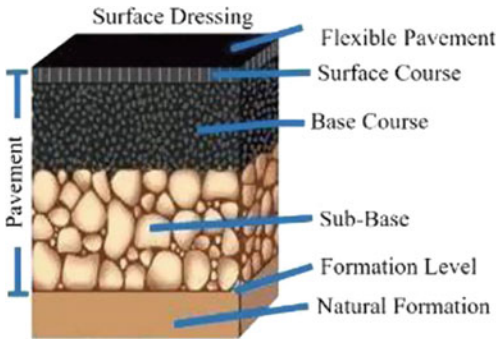


Fig. 1 Layers of flexible pavements

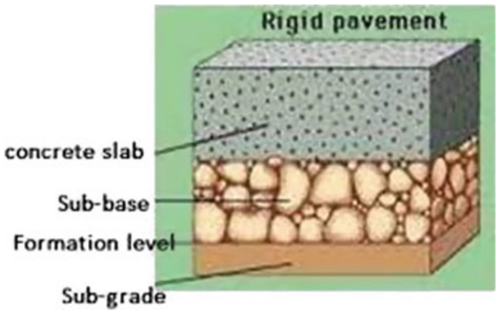


Fig. 2 Layers of rigid pavements

The literature on flexible and stiff pavement deterioration is examined in order to get insight into the various forms of failures and the necessary maintenance management. To fix the failures, the following procedures are carried out: cutting, cleaning, filling, and sealing. Periodic, regular, and emergency maintenance are required to keep the failing road in good working order and under budget. Flexible pavements are ones with low flexural firmness and a flexible configuration response when loaded. The distortion of the final layers on the surface of the flexible pavement layers may be seen. Figure 1 shows the four components of flexible pavement. Figure 2 depicts the rigid pavement component.

2 Study Area

Old NH-2 is the major highway in India which connect the Delhi to Kolkata. Our study area is located in fatehpur district of Uttar Pradesh. Distance of our study of 10 km which connect the two town Kalyanpur and Chaudagra. I have choose this because it is most busy highway in country. Figure 3 depicts a map of the area.

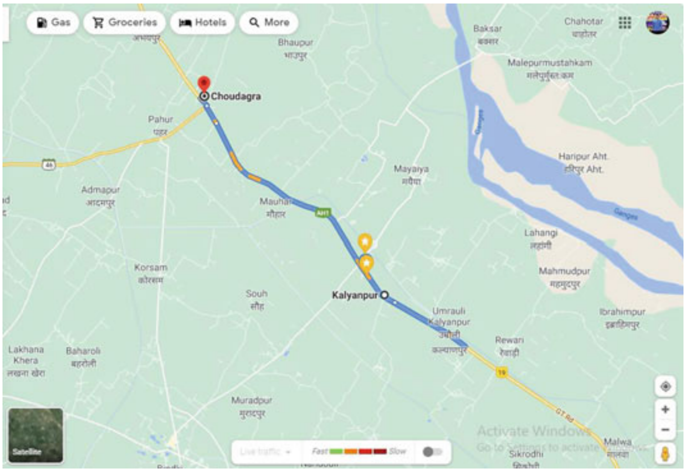


Fig. 3 Map of study area

3 Methodology

Within a 10-km radius of the former NH-2, many forms of road failures have been found. Potholes, raveling, water bleeding, corrugation and pushing, depression and rutting block cracking, slippage cracking, longitudinal cracking, and transverse cracking are examples of these types of cracking. Field investigations are used to learn about the reasons of failures and how to maintain them. Field investigation was wiped out October 2020 where at each location, failures were closely watched in order to detect them and determine their reasons. Here we have collected opinion from the peoples to know the cause of failures. The maintenance of highway is carried out by the routine, periodic as well as essential maintenance. Maintenance should be done on a regular basis have high frequency. The activity includes grass cutting, cleaning of ditches which are filled with ditches and cleaning of culverts, and patching. Periodic maintenance which have includes activities to Preventive maintenance, resurfacing, overlaying, and pavement rebuilding are all options [8].

Block Cracking

Block cracking has been discovered in old NH-2. Moisture obtrusion and roughness are allowed via block cracking. This is due to the highway's poor construction and shaky foundation. Seal coat is placed after carpeting to restore the block fractured surface (Fig. 4).

Transverse Cracking

Transverse cracking found in Mauhar village. Transverse cracking enables moisture to enter obtrusion and harshness. It is the result of the moving of a lot of traffic of vehicles as well as poor mix design this crack is maintained using a surface treatment such as carpeting (Fig. 5).

Fig. 4 Block cracking in old NH-2

Fig. 5 Transverse cracking in old NH-2

Potholes

It's the most frequent failure, and it happens everywhere, Muradipur, Chauraha, Baxur mod, Gugauli mod. It cause due to structural failures and roughness in road. It is brought about by the movement of a heavily loaded truck and the accumulation of rain water. When the depth of the pothole is sufficient, cutting, filling, and rolling operations are considered. When the depth of the pothole is insufficient and the number of potholes is greater, only premix material filling is performed to prevent failure (Fig. 6).

Corrugation and Shoving

There is corrugation and pushing in Gopalganj and Kalyanpur area. Corrugation and showing create rough as well as an elevated percentage. It happens as a result of a bad combination of bituminous, high volume of traffic, and an inappropriate binder bad material quality. The approaches are applied once the failed section has been removed used to repair, premix filling, rolling, and sealing are carried out and maintenance of corrugation and shoving, as shown in Fig. 7.

Fig. 6 Pothole in old NH-2

Fig. 7 Corrugation and shoving

Raveling

Raveling is located at Chaudagra, Kalyanpur and Mauhar. It causes loose rubbles in the surface roughness of the pavement and a loss of dip resistance. It occurs due to the shortcoming of binder for asphalt inadequate compaction and an outdated asphalt binder to keep aggregate in place to solve raveling us used surface treatment (Fig. 8).

Fig. 8 Raveling at old NH-2

Fig. 9 Depression in old NH-2

Depression

Depression is found in muradipur and chaudagra. It causes bumps on the road. Heavy rainfall and a clogged drainage system are to blame. It is fixed by removing the damaged area and replacing it with a premixed filler as shown in Fig. 9.

Slippage Cracking

Kalyanpur and Gopalganj have slippage cracks. It provides a glistening effect on the road. It's caused by a slick wearing surface and a lack of drainage. For the maintenance job, the surface used as carpeting is treated and sealed (Fig. 10).

Rutting

Rutting occurs at Bindki in Muradipur Chauraha. Ruts Vehicles that are flooded with water might cause damage. Aquaplaning. Heavy truck loads and inadequate building methods are the major causes. Remove the rutting section and replace it with premix. Finally, for rutting repair, they were combined and put to premix, as shown in Fig. 11.

Fig. 10 Slippage cracking in old NH-2

Fig. 11 Rutting at old NH-2

4 Analysis and Findings

For the data obtained from various sorts of failures, all maintenance processes are taken into account under particular maintenance categories. All maintenance data was obtained from the appropriate authorities and is given in the Table 1, shown below.

Table 1 illustrates the types of maintenance and the frequency of failures by location. The pie chart below (Fig. 12) illustrates the percentage of each failure category, with cracks and potholes having the largest number of failures. The pie chart in Fig. 13 depicts the percentage of used maintenance kinds, and it can be observed that urgent maintenance is the most popular. Both charts are based on the data shown in Table 1.

Table 1 Shows the many sorts of failures, how they occur, and how they are maintained

No	Failure	Failure presence (locations)	Maintenance
1	Potholes	10	Urgent
2	Cracks	12	Routine
3	Raveling	4	Periodic
4	Corrugation and shoving	6	Urgent
5	Rutting	6	Periodic
6	Depression	5	Urgent

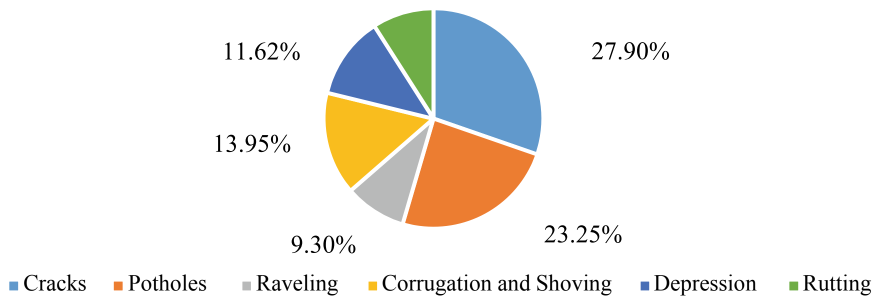
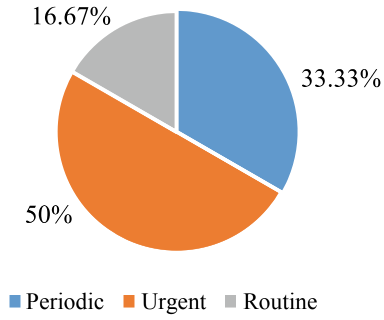


Fig. 12 Presence of failures (according to locations)

Fig. 13 Used maintenance types



5 Conclusions

- The case study was undertaken to investigate the road failures on particular stretch from Kalyanpur to Chaudagra in old NH-2. The purpose of this research is to analyze and evolution of pavement failures.
- The technique is based on the past experience by keeping on the mind of previously published research. I have talked to the respective authorities about the presence of failure in the national highway.
- Authorities have also confirmed the presence of failure and they also tell the cause of failures.
- The main cause of bituminous failure in occur in old NH-2 is use of mediocre quality materials, weather conditions A high volume of traffic, and dampness in the air in the subgrade.
- This study shows that urgent maintenance is mostly used when compared to the regular and periodic. Use of quality and standards are not controlled properly which required early and repeated road maintenance in the country.

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Effects of Soil Type on Contaminant Transport in the Aquifer System: A Numerical Investigation Using 2D Mobile-Immobile Model

Abhay Guleria and Sumedha Chakma

Abstract A 2-D nonpoint source contaminant transport behaviour in the aquifer system (100 × 50 m) using a mobile-immobile (MIM) model with variable dispersion function for various soil-type (sand, silt, clayey loam, and sandy loam) was investigated. A Finite-difference method-based Crank-Nicolson scheme was used to obtain the concentration by solving governing equations of MIM model for contaminant transport in groundwater system in the 2-D spatial domain. The temporal evolution of concentration profiles and breakthrough curves were compared for conservative and reactive cases due to pulse-type and continuous source boundary conditions. Zeroth and first temporal moments (ZTM and FTM) were computed by implementing numerical integration to investigate the effect of soil type on plume evolution dynamics. A significant variation in the magnitude and spatio-temporal distribution of contaminant plume was observed between low (silt, clayey loam, sandy loam) and high (sand) hydraulic conductivity soil-type. The spreading of a contaminant plume in the transverse direction was dominant in the clayey loam and sandy loam compared to sand soil-type. The maximum value of mass recovery for the reactive contaminant was found to be much lower (2–8 order less) than the conservative case and followed the order as sand > silt > clayey loam soil-type, showing the influence of hydraulic conductivity on plume evolution dynamics. On the basis of maximum value, the FTM of reactive contaminant for all soil-type was found to be 0.5% to 2% higher than the conservative case; whereas, for locations near to contaminant source region, the FTM of reactive contaminant was found to be ∼9–11% higher than conservative case. The dual-porosity model-based approach implemented in this study can be used for scenarios where fluctuations in the water table and non-Fickian mass transfer occur.

Keywords Soil type · Stagnant region · Reactive contaminant · Dual-porosity model · Contaminant mass recovery

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1 Introduction

The hydraulic conductivity and, subsequently, soil type govern the transport of contaminant and spatio-temporal plume evolution dynamics [1]. The spreading and mixing of contaminants are majorly dependent upon the dispersion, sorption, and mass-transfer processes and then on the heterogeneity of the porous media [2]. The dispersive processes in the transverse direction are observed as critical for the plume evolution and smoothing of concentration fluctuations in the groundwater at steady-state flow [3]. The contaminant transport behaviour was studied for the homogenous and heterogeneous porous media; however, emphasized the spatio-temporal variation in the longitudinal dispersion only and ignored the effect of transverse dispersion in several studies [4, 5]. Contaminant transport behaviour through stratified porous media and rock fracture-matrix system was studied using higher mathematical models; however, limited to 1-D systems [6–8].

The efficiency of simulating contaminant transport in the heterogeneous porous media via double porosity model such as mobile-immobile model (MIM) was highlighted by Gao et al. [9, 10]. In several field- and laboratory-based studies, the scale and/or time-dependent nature of dispersion parameter was observed [11–14]. The distance and/or time-dependent dispersion function was integrated into higher mathematical models such as MIM for several column and tank experiment studies [15–21]. However, it can be seen from literature that these models were limited to the 1-D domain and ignored the impact of transverse dispersion on plume evolution. It can be inferred from literature that MIM model in 2-D with variable dispersion function will capture the plume evolution and ever-changing contaminant behavior effectively.

Therefore, in the present study, MIM model with an asymptotic time-dependent dispersion function was used for numerical investigation. The objectives were to investigate the impact of soil-type on the transport dynamics assuming a 2-D mathematical model. Firstly, the temporal evolution of conservative and reactive, decaying contaminant plume was studied for pulse-type, and continuous source scenarios and breakthrough curves were simulated at environmentally sensitive locations. Secondly, temporal moments (mass recovery and average residence time) of contaminant concentrations were computed to understand the time-averaged response in various soil-type.

2 Governing Equations and Mathematical Model

The mobile-immobile model (MIM) is based on the partitioning of porous media into a mobile (flowing) region or immobile (stagnant) region [22]. The mobile region comprises of well-connected pore space where advection, diffusion, spreading take place, whereas the immobile region represents the constricted pore space, where only diffusion dominates the mass transport. In the time-dependent contamination source scenarios, immobile regions behave as sink and source components during loading and source removal/isolation, respectively. The governing equations of MIM model considering linear sorption isotherm with time-dependent dispersion function are written as [22]:

$$\begin{aligned}(\theta_m + f\rho_b K_{d_m}) \times \left(\tfrac{\partial C_m}{\partial t}\right) = -v_m\theta_m\left(\tfrac{\partial C_m}{\partial x}\right) + \theta_m D_L(t)\left(\tfrac{\partial^2 C_m}{\partial x^2}\right) + \theta_m D_T(t)\left(\tfrac{\partial^2 C_m}{\partial z^2}\right) \\ -\omega \times (C_m - C_{im}) - (\theta_m\mu_{lm} + f\rho_b K_{d_m}\mu_{sm}) \times C_m\end{aligned} \quad (1)$$

$$\begin{aligned}(\theta_{im} + (1-f)\rho_b K_{d_{im}}) \times \left(\frac{\partial C_{im}}{\partial t}\right) = \omega \times (C_m - C_{im}) \\ - (\theta_{im}\mu_{\mathrm{lim}} + (1-f)\rho_b K_{d_{im}}\mu_{sim}) \times C_{im}\end{aligned} \quad (2)$$

$$D_L(t) = \left\{\alpha_L v_m \times \left(\frac{t}{t + K_{asy}}\right)\right\} + \{\theta_m D_m\} \quad (3)$$

$$D_T(t) = \left\{\alpha_T v_m \times \left(\frac{t}{t + K_{asy}}\right)\right\} + \{\theta_m D_m\} \quad (4)$$

Where C_m and C_{im} are the solute concentrations in the mobile and immobile regions [M/L^3] at any time (t); x and z are spatial coordinate [L] taken in the longitudinal and transverse direction to the fluid flow, respectively; $D_L(t)$ and $D_T(t)$ are longitudinal and transverse hydrodynamic dispersion coefficient [L^2/T]; θ_m and θ_{im} are volumetric water contents of the mobile and immobile regions respectively, and $\theta = \theta_m + \theta_{im}$; θ is the total volumetric water content; v_m is the mobile pore water velocity [L/T]; $q = v_m\theta_m$ is the flow rate [L/T]; ω is the first-order mass transfer coefficient [T^{-1}]; f and (1-f) represent the fractions of adsorption sites that equilibrate instantly with the mobile and immobile regions, respectively; $\mu_{lm}, \mu_{\mathrm{lim}}, \mu_{sm}, \mu_{sim}$ are the first-order decay coefficient in the liquid-phase mobile, liquid-phase immobile, sorbed-phase mobile and sorbed-phase immobile region, respectively [T^{-1}]. K_{d_m} and $K_{d_{im}}$ are the sorption distribution coefficient in the mobile and immobile region, respectively [L^3/M]; ρ_b is the bulk density of the porous medium [M/L^3]; α_L and α_T are the longitudinal and transverse dispersivity of the porous system respectively [L]; D_m is the molecular diffusion coefficient of contaminant [L^2/T]; K_{asy} is the asymptotic time-dependent dispersion coefficient which is equivalent to mean travel time [T].

2.1 Initial and Boundary Conditions

The initial condition assumes that the aquifer is free from any contamination initially and are given as follows:

$$C_m(x, z, t = 0) = C_{im}(x, z, t = 0) = 0 \quad (5)$$

Dirichlet type boundary condition (BC) was implemented at the source zone. Two scenarios namely continuous and pulse-type were considered as:

$$C_m(x, z, t)_{sourcezone} = C_0 \quad (6)$$

$$C_m(x, z, t)_{sourcezone} = \begin{cases} C_0, & 0 < t \le t_p \\ 0, & t > t_p \end{cases} \quad (7)$$

Dirichlet type BC with zero concentration was assumed at the top and left side of the numerical domain (Fig. 1). Further, at the right and bottom side of numerical domain, Neumann type boundary condition (BC) were considered as:

$$\left(\frac{\partial C_m}{\partial x}\right)_{(x,z,t)} = \left(\frac{\partial C_m}{\partial z}\right)_{(x,z,t)} = 0 \quad (8)$$

Where C_0 = injected contaminant source concentration [M/L^3].

A two-dimensional (2-D) saturated aquifer system of size 100 × 50 m was considered for analysis. The governing equations were solved using Finite-difference method adopting Crank-Nicolson scheme. The advective term was discretized using the first-order upwind scheme, and dispersive term in the mobile transport equation was discretized using a central difference scheme [23]. The temporal term was discretized using a first-order forward difference scheme. The in-house code of the model using Gauss–Seidel method was developed to solve the set of simultaneous algebraic equations. Figure 1 shows the schematic of spatial domain, including boundary conditions used. Input parameters used in this study are presented in Tables 1 and 2.

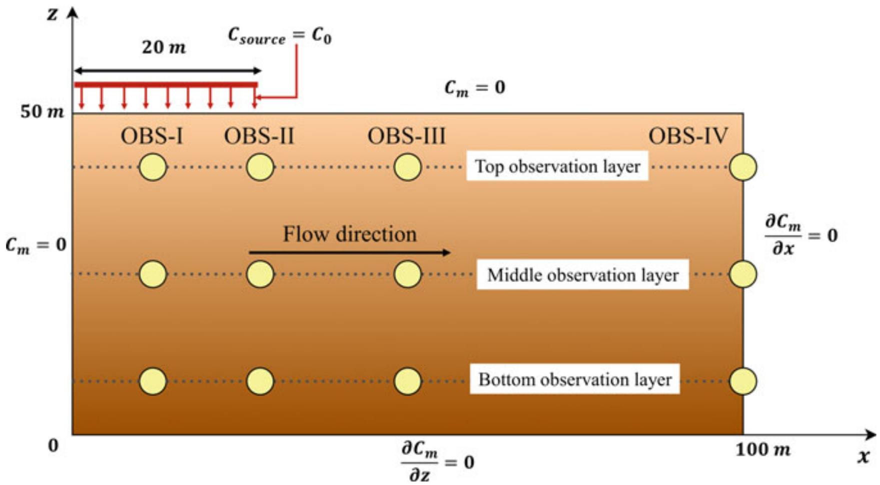

Fig. 1 Schematic diagram of the numerical domain

Table 1 Input parameters used in the modelling

Parameter	Value	Parameter	Value
Length (L)	100 m	α_T	1 m
Depth (H)	50 m	D_m	1E−05 m^2/day
Δx	1 m	K_{asy}	50 days
Δz	0.50 m	Source concentration	10 mg/L
$t_{simulation}$	1825 days	K_{d_m}	0.267 mL/gm
t_p	180 days	$K_{d_{im}}$	0.267 mL/gm
Δt	1 day	μ_{lm}	0.01/day
Gradient (i)	0.001	μ_{lim}	0.01/day
Mass transfer coefficient	0.01/day	μ_{sm}	0.01/day
α_L	10 m	μ_{sim}	0.01/day

Table 2 Physical parameters of different soil-types

Parameter	Soil-type			
	Sand	Silt	Clay loam	Sandy loam
Hydraulic conductivity (m/day)	45[a]	3.0[a]	0.88[b]	0.17[b]
Porosity	0.32[c]	0.40[c]	0.366[d]	0.481[d]
Fraction of mobile region	85%	85%	85%	85%
θ_m	0.272	0.34	0.311	0.409
θ_{im}	0.048	0.06	0.055	0.072
Bulk density (gm/cm^3)	1.82[c]	1.63[c]	1.60[d]	1.25[d]

a—[24]; b—[25]; c—[7]; d—[26]

3 Results and Discussions

In this study, the effect of soil type on the contaminant plume evolution was investigated using a dual porosity-based model. Firstly, numerical simulations were conducted to investigate the plume evolution using spatial profiles and breakthrough curves. Further, zeroth and first temporal moments of contaminant concentrations were computed to analyze the time-averaged response of the contaminant.

3.1 Influence of Soil-Type on Concentration Profiles and Breakthrough Curves at Environmentally Sensitive Locations

The temporal evolution of conservative contaminant plume is presented for different soil-type (Fig. 2). The plume front of conservative contaminant was observed at 45 m longitudinally and 9 m in the transverse direction from the source zone after 180 days for sand soil-type (Fig. 2a). However, for the silt layer, movement of the plume front was limited to 25 m in x-direction and 2.5 m in z-direction (Fig. 2d). In a similar way, plume front advected to 1.5 m and $\sim$1 m in the transverse direction below source zone for clayey loam and sandy loam soil-type, respectively, after 180 days (Fig. 2g and j). The spatial distribution of contaminant concentration at a 1-year time level was found to be significantly different after the source removal for sand soil-type (Fig. 2b). The center of mass of plume with concentration was found to be 4-order less than source concentration, located at 100 m longitudinal and 15 m transverse distance from the source zone after 5-years for the sand soil-type (Fig. 2c). It is observed that the center of mass of contaminant plume in the silt soil-type traversed 28 m longitudinally and 4 m in the transverse direction from source zone after 5-years. A significant difference in the magnitude and spatial distribution of contaminant was observed between sand and silt soil type after 5-years. It can be seen that the spatio-temporal variation and magnitude of a contaminant in the high hydraulic conductivity soil-type (sand) vary significantly as compared to the low hydraulic conductivity soil-type (silt, clayey loam, sandy loam). The influence of diffusion and transverse dispersion on the contaminant distribution was predominant in the low hydraulic conductivity soil-type (clayey loam and sandy loam) as compared to the high hydraulic conductivity soil-type (sand), as the plume stretched in the transverse direction dominantly.

Figure 3 shows the simulated BTC at the OBS-III (top layer, $x = 50$ m, $z = 10$ m from the source) of domain for contaminant transport through sand, silt, clayey loam soil-type. The peak value for conservative and reactive contaminant transport in the sand was observed after 750 days for a continuous source scenario, depicting the dilution of a plume. The peak value of 0.31 mg/L was observed for conservative contaminant–pulse-type source at 300th day for sand soil-type. However, the peak value for reactive and decaying contamination scenario was observed to be 2-order less than conservative contaminant transport, indicating the impact of sorption and degradation on transport behaviour (Fig. 3a). The concentration value of conservative contaminant in the silt soil-type was found to be in the range 10^{-1} mg/L, which is 1-order less than that of sand soil-type case (Fig. 3b). Further, the concentration value of reactive contaminant through silt soil-layer was found to be in the range 10^{-9} mg/L, which is much lower than conservative case. Also, a delay in the breakthrough point was observed for silt and clayey loam soil-type compared to sand soil-type, indicating the effect of diffusion and sorption processes in the low hydraulic conductivity soil type. In the case of clayey loam soil-type, it was found that the peak value of concentration has not reached after 5-years; however, the magnitude of concentration was found in the range 10^{-13}–10^{-5} mg/L.

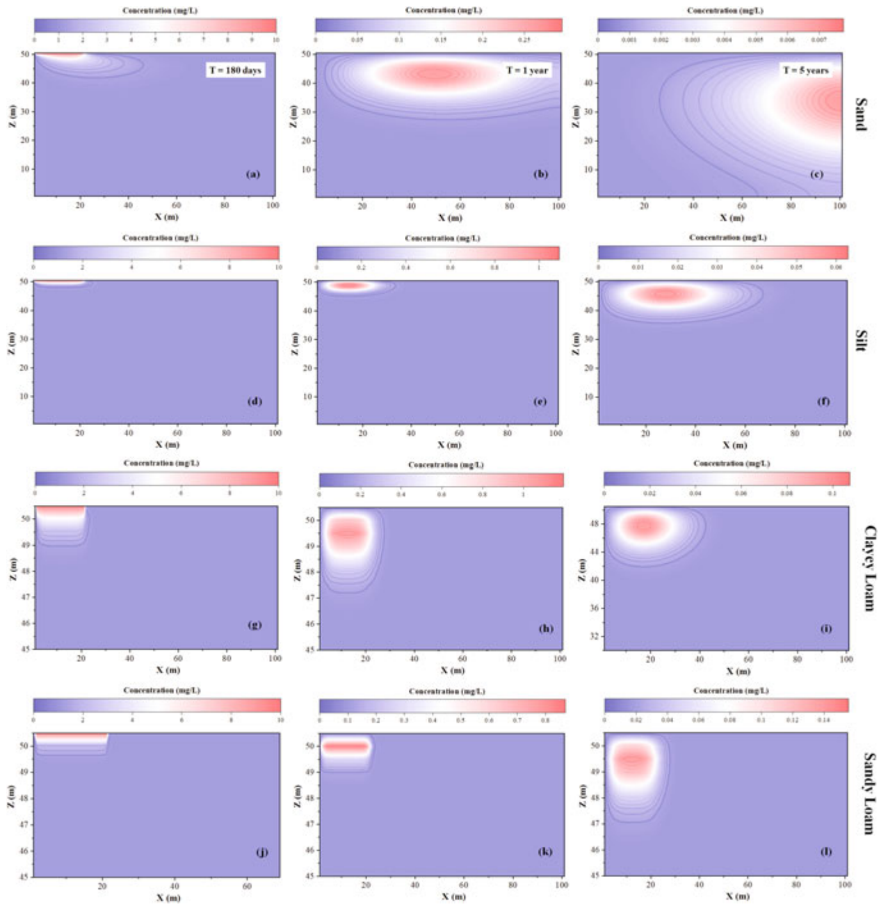

Fig. 2 Temporal evolution of conservative contaminant plume in various soil-types for pulse-type. *Source* condition

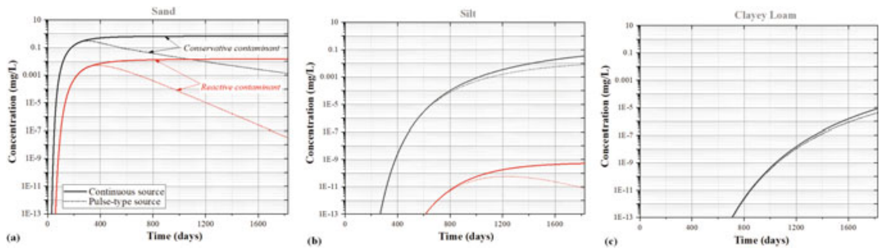

Fig. 3 Breakthrough curves predicted at the OBS-III (top layer) of the domain for four scenarios of contaminant transport in the **a** sand, **b** silt, and **c** clayey loam soil-type

3.2 Spatial Distribution of Temporal Moments

Zeroth Temporal Moment (ZTM)

In this study, zeroth temporal moments (ZTMs) were calculated for both the conservative and reactive contaminant transport through different soil-type following procedure adopted in previous studies [16, 27]. The highest value of 107.5 mg/L * day of a zeroth moment at $z = -10$ m and $x = 50$ m was observed for conservative contaminant transport in the sand soil-type among all the scenarios (Fig. 4). For the reactive contaminant transport in the sand soil-type, the ZTM was found to be ranged from 4.67E−07 to 4.88 mg/L * day. It is observed the ZTM value of conservative contaminant was higher than reactive for specific soil-type. It is observed that with decreasing hydraulic conductivity value, the contaminant mass recovery (or ZTM) decreased. The maximum value of ZTM for conservative contaminant was found to be 107.09, 19.33, and 0.26 mg/L * day for sand, silt, and clayey loam soil-types, respectively (Fig. 4a to c). Whereas, for the reactive and decay contaminant case, the maximum value of ZTM was found to be much lower (2–8 order less) than the conservative contaminant. Thus, it can be hypothesized that the contaminant mass was sorbed to the soil grains and undergo degradation, which lead to significantly lower values of ZTM for the reactive contaminant transport scenario. Overall, it is observed that most of the contaminant mass recovery was limited to 1–10 m below and up to 5–50 m longitudinally from the source zone.

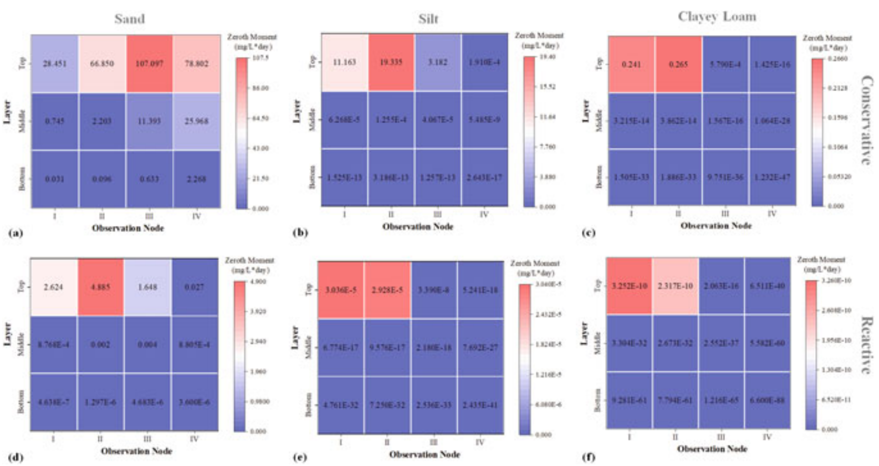

Fig. 4 Spatial distribution of zeroth temporal moment for conservative and reactive contaminant transport through sand, silt, and clayey loam soil-type

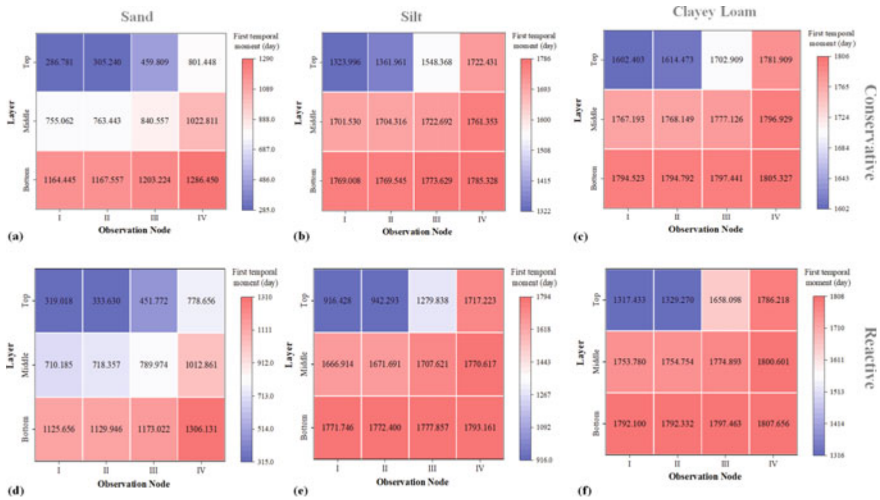

Fig. 5 Spatial distribution of first temporal moment of conservative and reactive contaminant concentration for various soil types

First Temporal Moment (FTM)
The spatial distribution of first temporal moment, also known as average residence time of contaminant for various soil-type (Fig. 5). It is observed that the average residence time varied inversely with hydraulic conductivity value, as overall FTM value was found in the order as sand < silt < clayey loam soil-type. The FTM value for a conservative contaminant in the sand soil-type varied from 285 to 1290 days; however, for the reactive contaminant, the FTM value was found to be ranged between 315–1310 days. A similar pattern of FTM was observed for silt and clayey loam soil-type. An enhancement of average residence time was observed for a reactive contaminant as compared to conservative, which might be due to a decrease in the pore water velocity by retardation factor ($v_{m(reactive)} = v_m/R$) and subsequently, an increase in the advection and dispersion time-scale. For most of the cases, higher values of FTM were observed near the bottom layer of an aquifer, away from the source zone, which might be due to dominance of diffusion. It can be hypothesized that at locations away from the source zone, the transport of contaminant was governed by diffusion, due to which contaminant remains in the aquifer for a longer duration which ultimately caused an enhancement of FTM.

4 Conclusion

A 2-D nonpoint source contaminant transport in the aquifer system (100 × 50 m) using MIM model with variable dispersion function for various soil-type was investigated. A substantial variation in the magnitude and spatio-temporal distribution of contaminant plume was observed between low (silt, clayey loam, sandy loam) and high (sand) hydraulic conductivity soil-type. The spreading of a contaminant plume in the transverse direction was dominant in the clayey loam, and sandy loam as compared to sand soil-type indicated the effect of diffusion and transverse dispersion. The maximum value of mass recovery for the reactive contaminant was found to be much lower (2–8 order less) than the conservative case and followed the order as sand > silt > clayey loam soil-type, showing the influence of hydraulic conductivity on plume evolution dynamics. On the basis of maximum value, the FTM of reactive contaminant for all soil-type was found to be 0.5 to 2% higher than the conservative case; whereas, for locations near to contaminant source region, the FTM of reactive contaminant was found to be $\sim$9–11% higher than conservative case. Thus, results from the present study highlighted the impact of diffusion and transverse dispersion on the plume evolution in low hydraulic conductivity soil-type and revealed the complex interplay between these processes. The modelling approach implemented in this study can be used for a scenario where continuous pumping and recharge operations take place and non-Fickian mass transfer occurs. The implementation of a dual-porosity model with a variable dispersion function can be helpful in mimicking realistic scenarios in a better way.

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A Novel Plan for Gujarat to Mitigate the Effect of Flood, Drought and Salinity Using Interlinking of Canal and Rivers

Anant Patel, Upasana Panchal, and Neha Keriwala

Abstract The rivers play a very important role within the lives of the people, because the Rivers are very much helpful in water supply, irrigation, water transportation, generation of electricity, and tourism. Most of the major cities are situated on the shores of holy rivers or near the coastal area. Depleting the status of water resources could also be one among the foremost critical resource problems with the twenty-first century. The country's rivers must be interconnected to provide water to the drought-prone areas. The method is designed to preserve river water that flows into the ocean every year during the monsoon season. The study focuses on interlinking key rivers in Gujarat to meet the requirements of regions with severe water shortage such as North Gujarat, Saurashtra, and Kutch. This article proposes a sustainable resilient strategy for river water interlinking, which helps manage surface water storage and salty water intrusion into coastal groundwater. The planned unlined canal is intended for low silting and scouring. The canal's bottom width is 152 m and its depth is 5.4 m. This canal will act as a multifunctional strategy to solve different water problems while also affecting the environment.

Keywords River interlinking · Saline water intrusion · Canal network · Drought & Flood · Water resources management

1 Introduction

Water is the most important asset on the earth for the survival of life. The importance of the water increases because of population growth in water scarce regions. In spite of the fact that freshwater is the most far reaching thing to be found in the environment, it isn't consistently disseminated all around the world [1]. Water requirement is crucial for daily life activities such as: cooking, sanitation,

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cleaning, bathing, drinking, agriculture, industry and many more endless other purposes. As opposed to reducing assets, worldwide interest for water is increasing [2]. Since the last five year the water demand is calculated six to seven times more than twofold the rate of populace development [3].

The environmental conditions of mouth items, as well as the economy of such regions, are severely harmed by seawater intrusion [4]. Seawater infiltration into river mouths causes salinization of surface water, groundwater, and soils, as well as affecting the freshwater biota and disrupting the natural environments of plants and wildlife that are not accustomed to salt or brackish water [5]. Seawater infiltration at river mouths results in the inflow of salt water onto water courses and bodies of water [6]. A saltwater wedge in the river mouth's bottom layer can obstruct sediment transport, resulting in silting of navigation canals, harbour ponds, and docks, as well as the accumulation of contaminants in bottom sediments [7]. River mouths (deltas, estuaries, lagoons, and limans) are currently among the most endangered geological features on the planet due to flooding, sea waves, and seawater penetration, which is becoming exponentially stronger and threatening [8]. When it comes to addressing hydraulic engineering, land reclamation, and environmental conservation issues in mouth zones, preventing these negative impacts is a top priority [9].

The rapid expansion of the economy and population in coastal areas has depleted freshwater supplies, resulting in a rise in seawater penetration [10]. As a result, groundwater supplies can be protected from saltwater contamination by employing appropriate steps. Since groundwater must be handled before it can be used, salinization is a restriction. Treatment of salt ground water can be costly and time-consuming depending on the source [11]. Different steps have been established to regulate Sea Water Infiltration in coastal aquifers. Todd discussed various methods for preventing salty water from contaminating freshwater supplies, including the relocation of pumping wells, the elimination of pumping prices, the usage of underwater walls, natural recycling, and saline water abstraction, artificial recharging, and hybrid strategies [12]. The Coastal aquifer is under severe hydrological stress as a result of overuse of the shallow groundwater table. The major cause of sea water infiltration into groundwater tables is a consistent drop in ground water levels over the last few years as a result of massive ground water use across the world [13].

Large-scale study has been undertaken to explore Sea Water Infiltration in coastal aquifers. However, only a small amount of research has been done on the control of SWI. To monitor SWI, existing control methods depend on the above-mentioned steps [12]. The aim of lowering the abstraction rate is to save money by using other water supplies and lowering pumping rates [14]. Seawater cannot drain through the basin because of subsurface barriers. The aim of natural recharge is to bring more surface water to rivers [15]. Artificial recharge can help raise groundwater levels by using surface dispersal for unconfined aquifers and recharge wells for restricted aquifers. Water for injection may come from surface water, treated wastewater, groundwater, or desalinated water [16]. Fresh water injection and salt water withdrawal together decrease salt water levels while increasing fresh water levels [15, 17].

The Gujarat Water Resource Development Corporation, Gujarat has identified the limits of ground water salinity in terms of Total Dissolved Solids (TDS) in the coastal region of Kutch and Saurashtra. Ground water with TDS more than 6000 ppm is considered highly saline, 4000–6000 ppm as medium saline, 2000–4000 ppm as low saline and below 2000 ppm as fresh water.

Fluctuation in the salinity of groundwater in these coastal regions is a complex phenomenon. On the whole, it fluctuates with the geological formations and their disposition along the coast. There are various factors such as infiltration of sea water, inherent salinity and the structural properties of the formations deposited underneath marine conditions which will affect the groundwater [18]. To solve this problem it is essential to interlink all the rivers within the whole country to supply water to the deficit area. The approach is made to store river water which discharges an ample amount of water every year during monsoon season into the ocean. The main priority is given for interlinking of the Gujarat state major rivers to fulfill the needs of the areas which are facing the severe water scarcity In this paper a sustainable resilient plan is suggested for river water interlinking, which is helpful in control of surface water storage and saline water intrusion into the ground water along the coastal area.

2 Study Area

Different researchers have observed and described the worst effect of saline water intrusion in coastal zones of various parts of the globe like the Coast of USA, Japan, Italy, Greek Island, Oman, Atlanta, Netherlands, Turkey, Nigeria, and coastal areas of India. India has a long coastline of 5700 km [19–21]. Gujarat has the longest coastline in India having 1600 km length, having the Gulf of Cambay and Gulf of Kutch situated in the southern and western part of Gujarat. For this research study area has been taken as the Gulf of Cambay (Khambhat) and rivers which are draining their water into the Gulf of Cambay. A quadruplet coastal sector of western coastline furnished with an engrossing variety of geological features is formed at the entrance of the Arabian Sea. The Gulf frames a funnel-like shape at the entrance of the Arabian Sea and is positioned in continental shelf which is the widest portion of the western coast. The river sediments carried by the currents from the mainland contaminate the water of the Gulf of Cambay to an extraordinary degree, and the water is continuously churned up by the tidal currents. The Gulf of Cambay shoreline is attributed by variety of deltas, salt marshes, islands, cliffs, mangrove forest and mud flats [22]. The perceptible deltas are the Tapi, Narmada, Mahi, Sabarmati, Bhogavo, Shetrunji, Bhadar, Sukhbhadar, Sani and Saraswati. There has been considerable infilling in the estuarine and rivers which diverge around the islands. Aside from the islands, there are numerous shores found in the Gulf, especially at the opening of estuaries (Fig. 1).

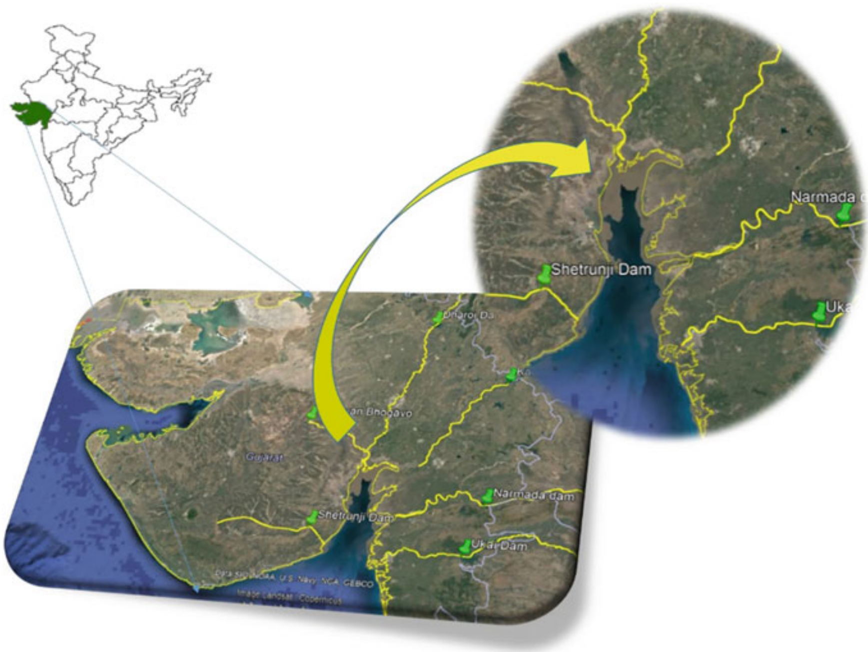

Fig. 1 Location map of rivers of Gujarat

3 Methodology

The maximum emphasized water sources of the world are Coastal aquifers. 70% of the world’s general population is inhabited in coastal areas. Rise in population in the coastal area clearly results in over exploitation of groundwater resources. The herbal equilibrium inside the coastal aquifer reverses because of immoderate depletion of groundwater and outcomes in salinity ingress [23]. On the other hand, flood frequency for the various rivers is consistently increasing year by year. Rivers and reservoirs are getting filled up by sediment load which tends to increase flood frequency. For this study past flood & drought history and effect of salinity in Gulf of Cambay location have been amassed and analyze for better planning and control of water resources available on the earth surface. Rainfall data has been accumulated from the State Water Data Center, SWDC, Gandhinagar, Gujarat. Rainfall facts of the last 30 year have been collected for major river basins like Tapi, Narmada, Mahi, Sabarmati, Bhogavo and Shetrunji River. Every basin having a different number of rain gauge stations and annual average rainfall of each major region of Gujarat state have been calculated through thiessen polygon method and based on that average annual rainfall was carried out (Figs. 2 and 3).

Many damaging floods were seen in the history of Gujarat. In the state all major rivers pass through a wide stretch of very flat terrain (frequently in the way of fifty

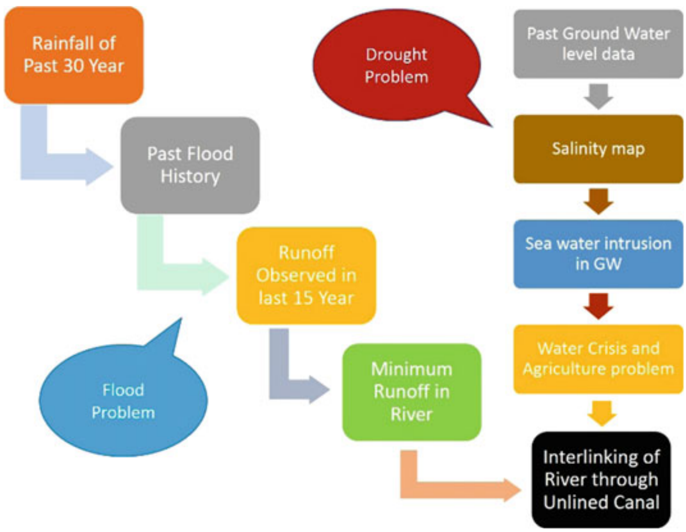

Fig. 2 Methodology plan to mitigate risk of flood & drought

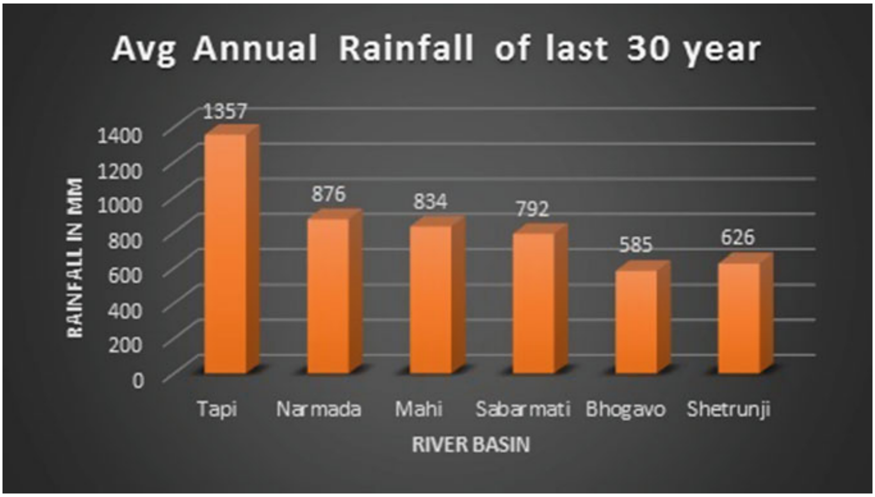

Fig. 3 Average annual rainfall of last 30 year for Gujarat state

km) before reaching the sea. Flooding may occur rapidly in these flat lowlands of lower river basins [24]. Periodical cyclones and depressions additionally cause serious downfall in large parts of Saurashtra, Kutch, central and northern parts of Gujarat. The urban cities like Ahmedabad, Surat, Vadodara and Bharuch are also placed on the flat alluvial plains of enormous rivers and are susceptible to flooding. Table 1 shows past flood history in Gujarat state (Fig. 4).

Table 1 Past flood history in Gujarat State

Sr. No.	Month and Year	Flood region	Sr. No.	Month and Year	Flood region
1	June, 2018	Surat and Saurashtra	10	2004	Narmada, Tapi
2	July, 2017	Banaskantha	11	1998	Surat, Tapi
3	Aug, 2016	Surat and Valsad	12	1994	Surat, Tapi
4	June, 2015	Amreli, Bhavnagar	13	1983	Shetrunji river
5	Sept, 2014	Vadodara	14	1979	Surat, Tapi
6	Aug, 2013	Bharuch, Narmada	15	1977	Mahi river
7	Sept, 2007	Mahi river	16	1973	Sabarmati river
8	Aug, 2006	Surat, Tapi	17	1970	Narmada river
9	July, 2005	Surat, Tapi	18	1968	Tapi river

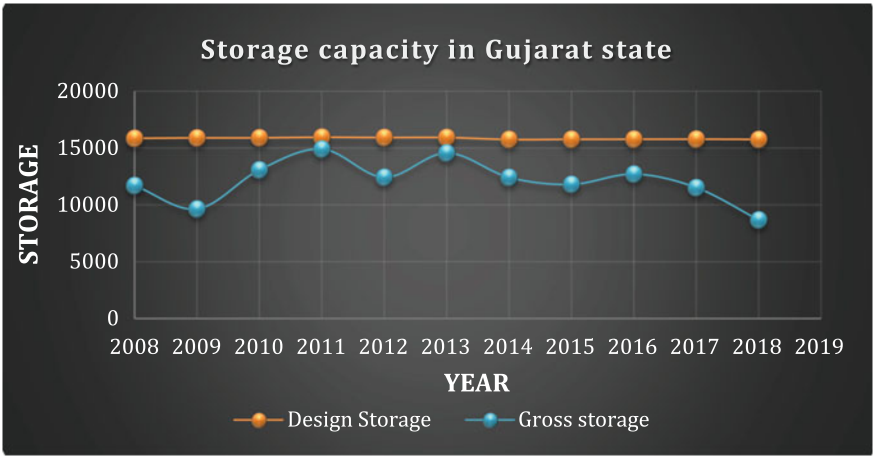

Fig. 4 Surface water storage in Gujarat State

Flood and drought both are unpredictable as it is a natural disaster [25]. Table 2 shows that in Gujarat state in the last 10 year there are both situations were reported i.e., Flood & Drought in some of the locations. Runoff collected at the estuaries of the river needs to be measured through discharge at a particular section. For this research, discharge data at the estuaries of rivers was collected and an average daily discharge was identified for each river.

3.1 Effect of Salinity in Coastal Region of Gujarat state

Ground water is not equally distributed throughout the globe relying upon various climatic conditions such as moderate zones with enormous rainfall providing an

Table 2 Discharge of major river of Gujarat

River	Maximum discharge reported	Daily average discharge	% Weightage assigned
Tapi	42,475 cumec	470 cumec	21.8
Narmada	69,400 cumec	1200 cumec	35.7
Mahi	33,000 cumec	250 cumec	17.0
Sabarmati	14,150 cumec	186 cumec	7.3
Bhogavo	1886 cumec	80 cumec	1.1
Shetrunji	7,080 cumec	150 cumec	3.6
Sukh Bhadar	10,700 cumec	180 cumec	5.5
Bhadar	5,667 cumec	110 cumec	2.9
Sani	7,019 cumec	130 cumec	3.6
Sarasati	3354 cumec	90 cumec	1.7

essential renewable recharge to the aquifers which act as a vital role together with surface water, guaranteeing a good year to year management in case of drought [26]. Infiltration or intrusion of surface water and rainfall through permeable layers gives great quality of groundwater; which results in easy access to groundwater in numerous regions of the world, clarifies the extensive utilization of ground water for human water sources covering greater than 58% of human needs. Ground water is frequently over-utilized particularly in arid zones bringing down the water table level [27]. The areas which are densely populated across the world are coastal areas. In this area, the consumption of water is amplified due to an increase in population. As a result, the aquifers in coastal zones are being over exploited. Sea water intrusion in aquifers can be caused due to over exploitation of groundwater [28]. The water level increase due to global warming and other occurrences are increasing rapidly as a result the intrusion factor of salty water in coastal aquifers also increases. The groundwater discharges into the sea and a natural gradient exists towards the coast, at the junction of groundwater aquifers with the coastline. Fresh water is 1.025 times lighter than sea water; it meddles in coastal area groundwater aquifers forming a wedge between saline and freshwater [29] (Fig. 5).

According to the Ghyben-Herzberg connection seen in Fig. 6, the interfacing layer resides at a depth lower than sea level, h2, which is 40 times the height of freshwater above sea level, h1. As sediment from a well in a coastal aquifer is expelled. Due to heavy groundwater injection, the normal hydraulic gradient reverses, and the aquifer can become saline. Bore-wells are evacuated when the saline content exceeds a certain tolerance level. A seaward hydraulic gradient should be maintained to regulate seawater penetration, and a portion of the natural freshwater recharge should be permitted to flow into the shore.

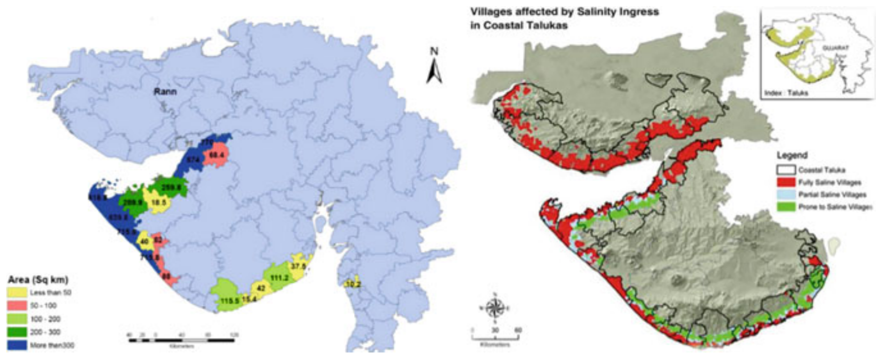

Fig. 5 Salinity affected region of Gujarat state

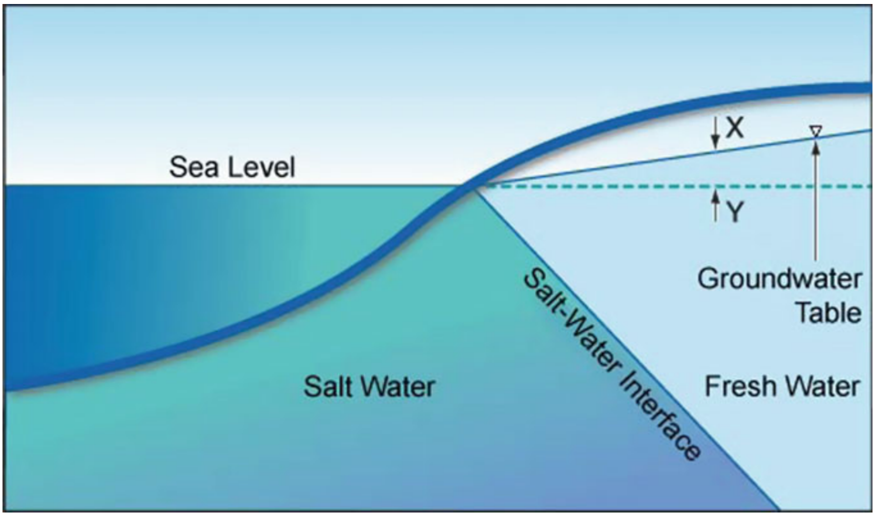

Fig. 6 Sea water interface with fresh water in coastal area

4 Results and Discussions

After analysis of past flood history, drought history, rainfall and average daily discharge in rivers for the study area, a sustainable plan is proposed to mitigate risk of flood and drought. Fresh river water barrier in terms of an unlined canal has been proposed as a mitigation structure which will help in reduction of salinity and also recharge the groundwater table.

Design of Alluvial Canal

Those canals which are excavated in alluvial soil, such as silt, and carry a lot of silt along with water. The boundary or perimeter of such a canal is therefore made of

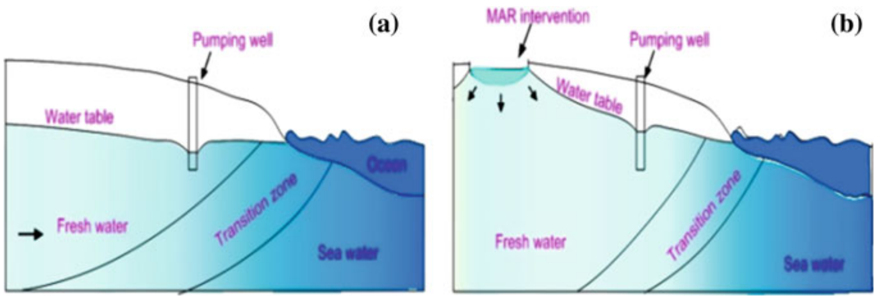

Fig. 7 Conceptual cross section showing **a** seawater intrusion due to over pumping and **b** Fresh water barrier for mitigation

silt, commonly known as "Alluvium". Design of the canal is done based on "Non Silting & Non-Scouring Velocity". The main benefit of this canal is that water can easily percolate inside the ground and thus ground water recharge becomes easy. Also this canal is more cost effective compared to lined canal (Fig. 7).

The designed canal has to draw a fair share of silt flowing in the river. This silt is carried along the bed of the canal or in suspension. Silt load carried by the canal is a challenging problem in canal design in alluvial soil. According to Lacey Regime Theory "Silt is kept in suspension by the vertical component of eddies generated at all points of forces normal to the wetted perimeter".

For canal design an average daily discharge is taken as 1200 cumecs.

Step-1 Assume the silt factor:- f = 1.0

Step-2 Calculate the velocity of Flow:- $V = \left[\frac{Qf^2}{140}\right]^{1/6}$, $V = 1.43$ m/s

Step-3 Calculate cross sectional area (A):- Q = A × V, A = 840 m^2

Step-4 Calculate perimeter:- P = 4.75 × $Q^{1/2}$, P = 165 m

Step-5 Assuming the side slopes of the channel 0.5:1 (H:V)

- $A = BD + D^2/2$ & $P = B + D\sqrt{5}D$
- $D = \frac{P - \sqrt{P^2 - 6.944A}}{3.472}$,
- D = 5.41 m
- $B = P - 2.236D$, B = 152 m
- $R = A/P = 4.45$, $R = \frac{5V^2}{2f} = 5.11$ R = 5.11

Step-6 Calculate bed slope:- $S = \frac{f^{5/3}}{3340Q^{1/6}}$, S = 1 in 10,888

Number of barrages and weirs are required to construct for the proposed plan of interlink major rivers to mitigate risk of drought and flood in the Gujarat state. This interlinking canal will connect important rivers of Gujarat. Distance between Barrage Mugdhalla on Tapi river and Bhadbhut Barrage on Narmada river is 60 km. Distance between Bamangam Barrage on Mahi river and Bhadbhut Barrage on Narmada river is 67 km. Distance between Barrage Bamangam on Mahi river

Fig. 8 Proposed route of Unlined Canal for river interlinking

and Vataman Barrage on Sabarmati river is 69 km. Distance between Pipali weir on Bhogavo river and Talaja weir on Shetrunji river is 140 km. Huge volume of water can be stored through this canal which can helpful in drought as well as flood situation also (Fig. 8).

Advantages of Proposed Canal: (i) Sea water intrusion decreases, Runoff will reduce [5] (ii) Water will be easily available for irrigation [30] (iii) Saline land will be converted into cultivable land [9, 31] (iv) Water will be equally distributed to nearby areas. (v) Connectivity will be increased between villages and cities [32] (vi) It will create employment and help in socio economic development of people [19].

Disadvantages of Proposed Canal: (i) the available elevation is not feasible for flow of rivers hence pumping is required [19, 33] (ii) Land acquisition is required and it will take longer time [24] (iii) Rehabilitation of some villages is required where canal is aligned [26, 27] (iv) Political support is also necessary for inter-linking as it needs concordance among districts of state for land acquisition [26].

5 Conclusion

In the southern part of Gujarat, the coastal area of Gulf of Cambay and western part the coastal area of Saurashtra and Gulf of Kutch, is extremely set out by the sea water intrusion into the fresh water aquifers due to overuse of groundwater for numerous human uses like farming, civil application and commercial application. Heavy drawdown of water table is observed in the regions surrounded by Tapi, Narmada, Sabarmati, Mahi, Bhadar, Machhu and Bhogavo River during summer season which results in drastic scarcity of fresh groundwater, as a result the boundary of saline water steadily move towards inland direction. A resilient proposal for water resources management has been proposed through an unlined canal which connects different rivers to mitigate the risk of drought and flood in Gujarat state. The main agenda is to recharge the aquifer with fresh water, improving the quality of groundwater and repress saline water ingression threat. This plan is productive when restriction of withdrawals from coastal aquifers and groundwater regulation act has been maintained. This research proposed an unlined canal having a minimum average discharge of 1200 cumecs. This canal is designed based on the non silting and non scouring velocity concept. Designed velocity for the canal is 1.43 m/s, perimeter is 165 m, cross sectional area of canal is 840 m^2, hydraulic mean depth is 5.11, bottom width of canal is 152 m, canal bed slope is 1 in 10,888 and depth of canal is 5.4 m. This canal will be solution for the many of the problems faced by the Gujarat state and it having many advantages of this proposed interlinking canal plan.

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Ground Water Potential Zone Mapping Using Remote Sensing and GIS in Saurashtra Region of Gujarat, India

Anant Patel, Kinjal Zala, and Krupali Solanki

Abstract Ground water is the water contained in the soil pores under the earth's crust. The challenges of ground water shortages and contamination have become worse in recent decades as a result of population development. Traditional approaches for groundwater conservation, such as groundwater based surveys, exploratory exploration, and geophysical techniques, are not only inefficient yet often time consuming. As a result, an advanced Remote Sensing and Geographic Information System (GIS) approach is used. Ground water management may be divided into distinct Potential Zones based on the amount of ground water accessible in a given region. Using Remote Sensing and GIS, any area's ground water potential zone can be calculated by combining tiff maps and assigning ranks and weightages to each parameter. Slope, drainage density, geomorphology, Lineament Density, Soil, Lithology, and LULC (Land Use Land Cover) are the parameters used to determine the possible zone of ground water in any given region. This paper describes the work that went into determining the GW potential zone in Gujarat's Saurashtra region. The area from which ground water can be readily accessed can be determined using the Ground Water Potential Zone chart, and this information can be used to dig wells and create hydrological structures.

Keywords Ground water · Potential zone mapping · GIS · Water level · LULC

1 Introduction

Ground water is the water that lies under the earth's crust, and ground water fluctuation is the continuous variation of the water depth. The form of aquifer, rainfall in the state, aquifer recharge, and regional ground water circulation all influence ground water level fluctuations [7]. The ability of the ground to hold water in the aquifer is known as ground water potential. Any region's ground water capacity is categorized into various potential areas, such as extremely good, high,

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moderate, low, and very poor potential zones, depending on the ground water ability [4]. The various geographical characteristics of that region are used to classify the ground water potential. Natural and human activity may also have an effect on groundwater potential [13]. Geological features, drought levels, and the amount of perennial and non-perennial rivers are all impacting environmental features, while human activities are the demand for water and, in order to meet that need, overexploitation of ground water is causing depletion and contamination of water [16]. Ground water is the world's greatest accessible reservoir of fresh water, located under the earth's crust and used for a variety of purposes including domestic uses, industry supply, and irrigation, among others [34, 36], Day by day, as the population grows, so does the need for fresh water. This results in water shortages in several parts of the world. Water is drained from the field to meet the rising demand, causing the ground water level to drop. Many factors pollute ground water, including on-site sewage facilities, landfills, effluent from wastewater treatment plants, overflowing sewers, gas filling stations, and agricultural fertilizer overuse [8]. In addition, in marine areas, seawater infiltration induces salinity in groundwater, which has recently resulted in soil salinization [6]. The amount and consistency of ground water have been impacted by rising population and poor groundwater management. It is important to determine the amount and condition of ground water in order to maintain it [20, 33]. Also, the ground water capacity zone of any location must be identified before drilling wells or constructing any hydrological system. As a result, evaluating the possible zone of ground water is critical for ground water quality safety and management, and the results may also be used for further evaluation and construction [2, 24, 32]. To conduct this research, we must first comprehend the principle of ground water level mapping as well as the applications used in remote sensing and geographic information systems (GIS), and then prepare different maps for ground water fluctuation analysis using Remote Sensing and GIS [3, 18]. Analysis is performed using numerous maps developed by Remote Sensing and GIS to carry out impact evaluation of Ground Water Fluctuation.

The current analysis is for the Saurashtra area of Gujarat, which encompasses around one-third of the state's territory and includes 11 districts: Rajkot, Jamnagar, Bhavnaga, Morbi, Junagadh, Porbandar, Veraval, Surendranagar, Gir Somnath, Devbhoomi Dwarka, and Amreli. Geophysical approaches, ground water dependent surveys, and exploratory sampling are examples of ground water potential investigative techniques [15, 24]. However, these approaches are costly and time intensive, and they necessitate massive data sets. To address this, the use of remote sensing and geographic information systems (GIS) has opened up new avenues for groundwater research [1, 10, 22]. Remote sensing is the act of gathering data, and GIS analyses and visualizes the data obtained by Remote Sensing. Because of the synoptic coverage and revisit capabilities provided by the EO constellation of satellites, remote sensing aids in better water quality evaluation and management

[38]. Water resource management is critical for the region, and there are numerous problems related to water supplies that can be effectively solved with space inputs. The parameters that should be tracked are divided into two categories: surface water and ground water [19]. If surface water takes the form of lakes, reservoirs, river systems, snow cover, and so on, ground water is found in various aquifers underground [5, 9]. Remote sensing is a technique for gathering information from a distance. Data are used to determine the spread of surface water for reservoir and other construction preparation, for reassessment of basin-wise capacity in the region, for assessing the status of irrigation infrastructure growth for estimating the irrigation capacity created, and for forecasting short-term and seasonal snow-melt runoff using space data and the Bhuvan network [12, 14]. An optimized method of Remote Sensing and GIS is used in this study to establish an effective forum for the analysis of vast data sets [17, 28]. In a limited amount of time, remote sensing may provide knowledge on vast regions as well as inaccessible areas. GIS converts and analyses spatial data before displaying it in a pictorial format for a variety of uses, including determining the viability of recharge sites, locating polluted sites, and determining the best location for hydraulic structures [29]. Using Remote Sensing and GIS, every area's ground water potential zone can be calculated by combining tiff maps according to the ranks and weightages allocated to each portion [34]. Slope, drainage density, geomorphology, Lineament Density, Soil, Lithology, and LULC (Land Use Land Cover) are the parameters used to determine the ground water potential zone of any given region [23, 35]. Using Remote Sensing and GIS, knowledge about these parameters is provided in the form of maps.

2 Study Area

On the Arabian Sea Coast, Saurashtra is a peninsular district of Gujarat. It takes up almost a portion of the state of Gujarat. It is bordered on the north by the Little Rann of Kutch, on the east by the Gulf of Khambhat, on the southwest by the Arabian Sea, and on the northwest by the Gulf of Kachchh. Saurashtra is located between the latitudes of 21 to 21.78° North and the longitudes of 70.83 to 72.17° East. Jamnagar, Morbi, Rajkot, Porbandar, Junagadh, Gir Somnath, Devbhoomi Dwarka, Amreli, Bhavnagar, Botad, and Surendranagar are among the 11 districts of Gujarat's Saurashtra region as shown in Fig. 1.

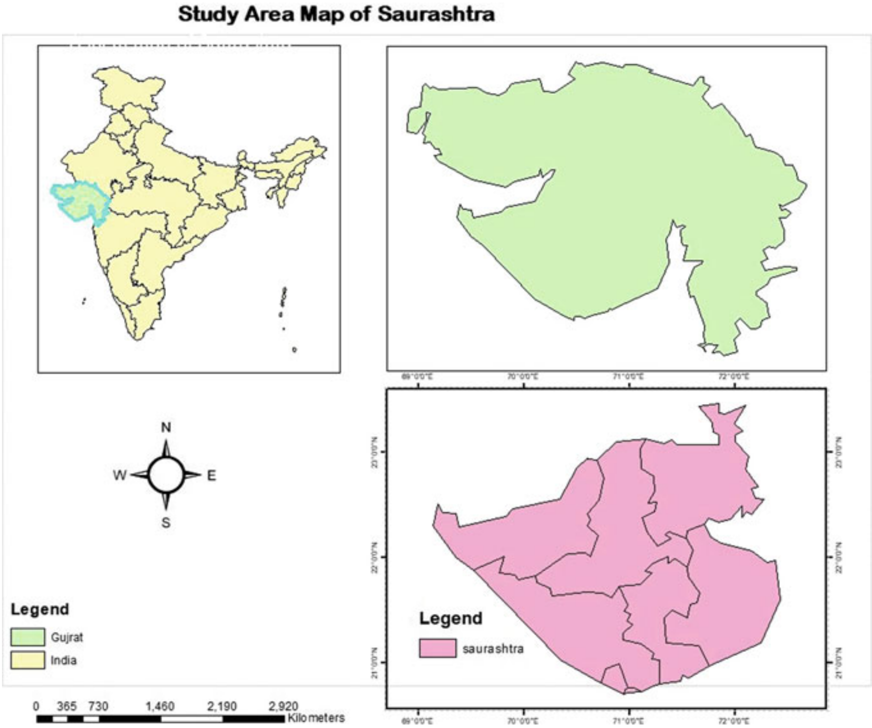

Fig. 1 Location map of study area

3 Methodology

The steps followed in the work done for the mapping of ground water level of Saurashtra region is shown below in the form of Flowchart Fig. 2.

a) Selection of Study Area:

The Saurashtra region of Gujarat is selected as the study area as it is located near the Gulf of Cambay (Gulf of Khambhat), so here the ground water level variation is more and also the pollution of ground water can be analyzed.

b) Data Collection:

The Data collected were satellite data and data from literature through different journal papers and websites. DEM Image of Saurashtra region was downloaded from BHUVAN, ISRO and Shapefile of India was downloaded from USGS. Rainfall data and other topographical data of Saurashtra region was collected from different literatures and documents from Central Ground Water Board for Saurashtra region.

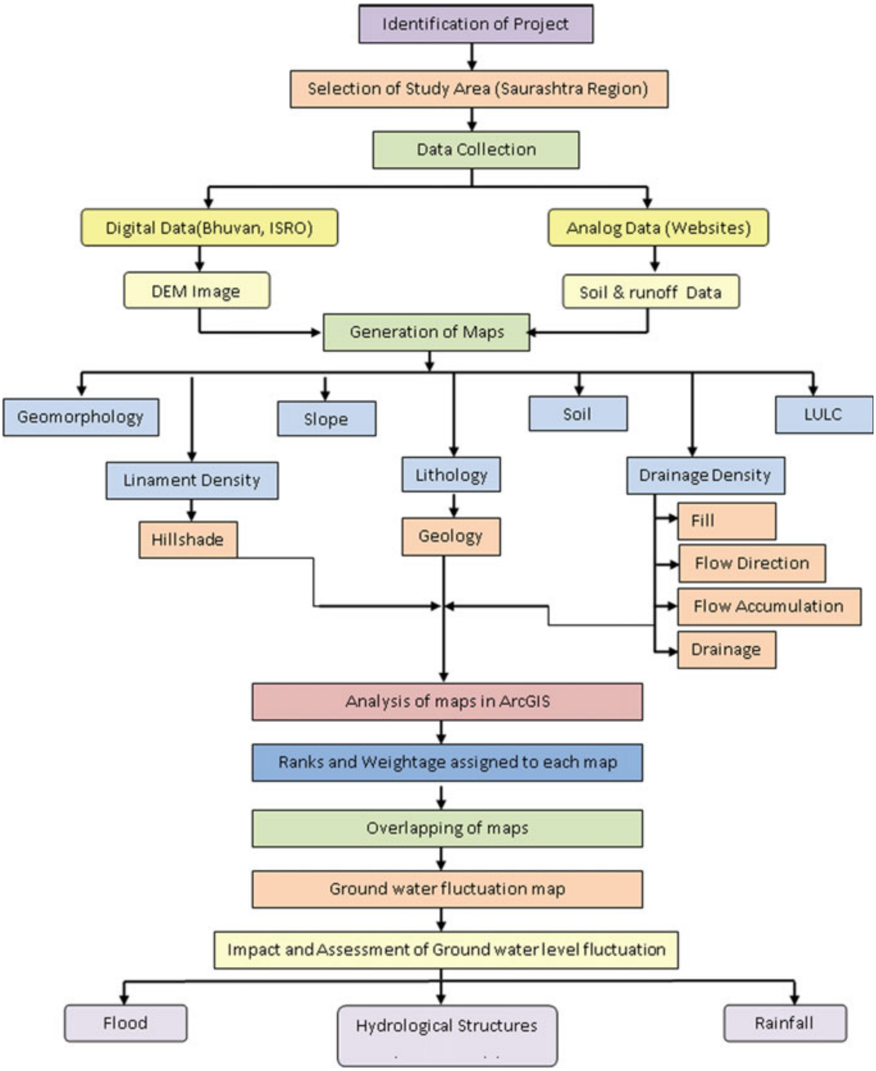

Fig. 2 Methodology flowchart for ground water potential zone mapping

c) Analysis of collected data:

The data collected from satellite images of Saurashtra were analyzed in and Arc GIS.

d) Generation of Maps:

Firstly, the study area map of Saurashtra is prepared and then the data was analyzed in GIS and different Maps of Saurashtra such as Slope map, Hillshade map, Geology map, Geomorphology map, Lithology map, LULC map, Drainage density map, Lineament Density Map, Fill Map, Flow Direction Map, Flow Accumulation Map and Soil map are generated in Arc GIS.

e) Overlapping of Maps:

The different maps generated are overlapped after assigning ranks and weightage to each maps and the map of Ground Water level of Saurashtra is generated.

f) Impact and assessment of Ground water level fluctuation:

Based on the ground water level maps generated, impacts of fluctuation of ground water level and its assessment is done for Saurashtra region.

Generation of maps: ground water potential zone mapping is prepared using 7 layers:

(i) Drainage Density Map (ii) Lineament Density Map (iii) Slope Map Soil Map (iv) Lithology Map (v) Land Use and Land Cover Map (vi) Geomorphology.

1) Drainage Density Map:
The maps required to generate the Drainage Density Map are:

a) Elevation Map: DEM Map of Saurashtra as given in Fig. 3.
b) Fill Map: Fill Map is the map generated after filling all the sinks on a surface raster to remove all the imperfections.
c) Flow Direction Map: Flow direction maps shows how surface runoff contributes to flooding. The direction in which water travels can be found out using the slope of the area.
d) Flow Accumulation Map: The accumulated flow is calculated using the aggregate weight of all cells in the output raster by the flow accumulation tool. A cell with a large concentration of flow is a localised flow region that can be used to classify stream networks. Local topographic highs with flow concentration 0 may be used to distinguish ridges. This can calculate how much rain has dropped within a specified watershed using this map.
e) Drainage Map: Drainage Map shows the path followed by the tributaries and the streams to meet the river and then ultimately to the ocean.

After preparing the above maps shown in Fig. 4, the drainage density map is generated using the line density tool in ArcGIS and then classified into 5 classes from very low to very high.

Drainage Density Map: The cumulative length of all streams and rivers in a drainage basin separated by the drainage basin's overall region is known as drainage density as shown in Fig. 5. It depicts how stream channels empty a watershed . The temperature and physical features of the drainage basin influence drainage density.

2) Lineament Density:

Lineament Density Map is generated through Hillshade Map and then classified into 5 classes from very low to very high as shown in Fig. 6.

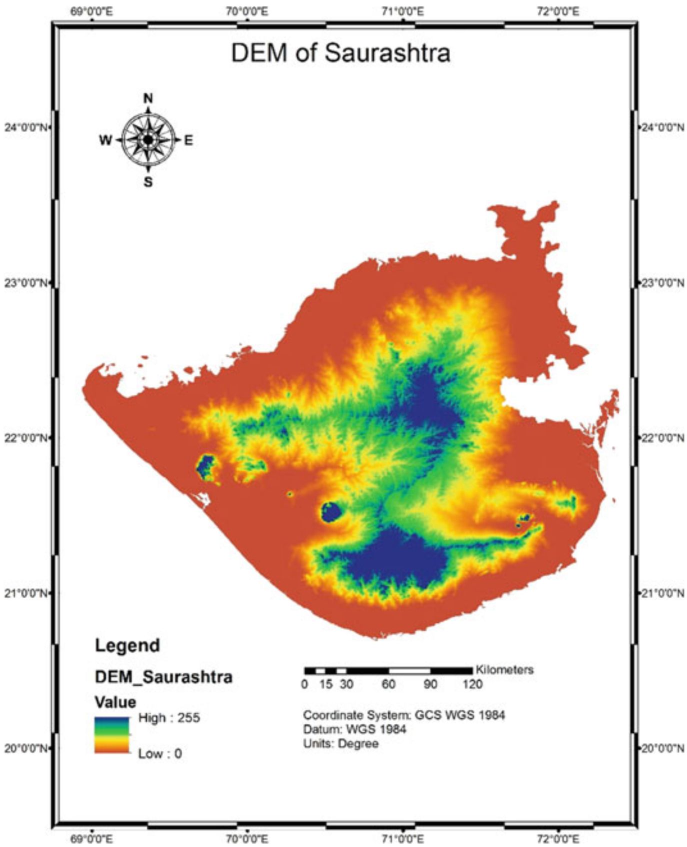

Fig. 3 DEM image of Saurashtra region

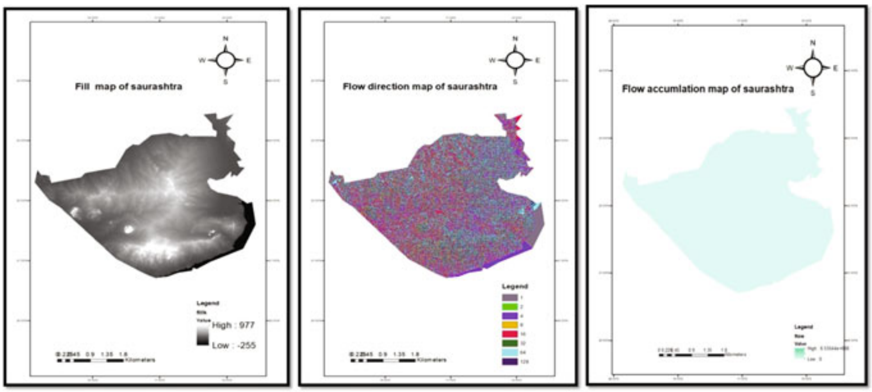

Fig. 4 Fill map, flow direction map and flow accuulation map

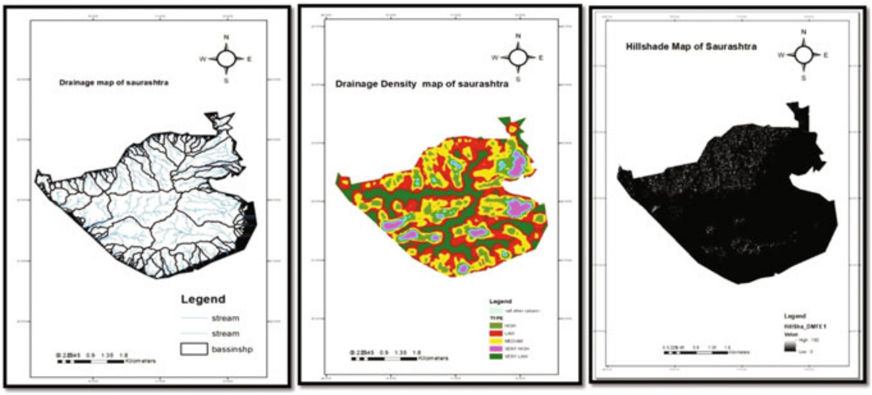

Fig. 5 Drainage map, drainage density map and Hillshade map

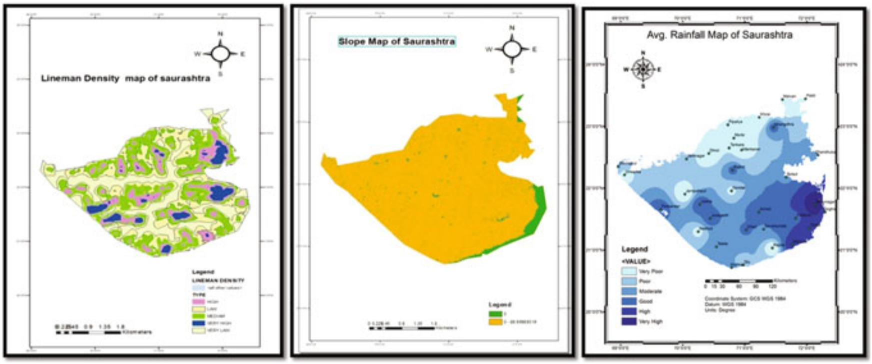

Fig. 6 Linament density map, slope map and rainfall map

Hillshade map: Hill shading is a map-making method that uses the topographical outline of hills and mountains to reveal relative slopes and mountain ridges. Hill shading is a technique for providing a convincing image of landscape by converting a two-dimensional display into a three-dimensional field. Hill shading provides a fictitious illumination of a surface by placing a light source in a certain location and measuring an illumination value for each cell depending on the cell's relative inclination to the light, or the cell's slope and aspect.

3) Slope map:

It is created using elevation data. The topography of a region is depicted on a slope chart, along with an overview of topographic characteristics. The area's slope is a very efficient and valuable metric for determining groundwater recharge ability. Because of the elevated slope and therefore higher drainage and reduced infiltration, steep slopes are thought to have slow groundwater regeneration. Because of the nearly flat landscape, a gentle slope is known to be really beneficial for groundwater recharge because it allows for slower surface runoff and better infiltration.

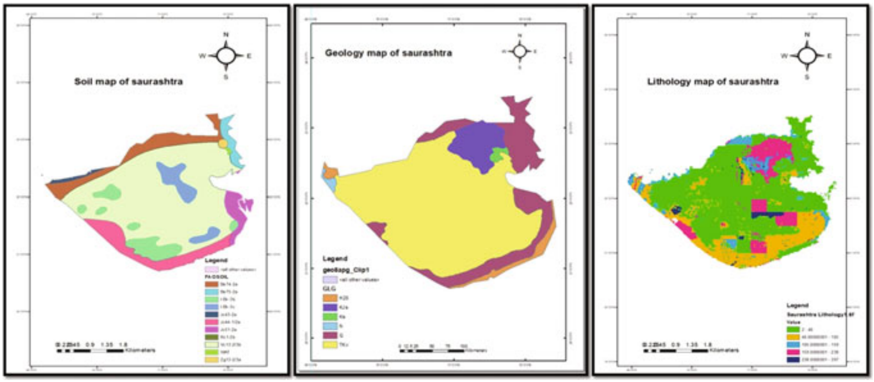

Fig. 7 Soil map, geology map and lithology map

4) Soil Map: A soil map is a geographical representation that depicts the variety of soil types and properties such as pH, textures, organic matter, and horizon depths in a defined region. Soil maps are used in a variety of programmes, including land assessment, urban design, agricultural extension, environmental conservation, among others. Soil data were gathered from the National Bureau of Soil Survey and Land Use Planning Data in order to create a soil chart as shown in Fig. 7.
5) Lithology Map: Lithology Map is prepared after the Geology Map.

Geology map: Geology map gives the information about various geological features such as cliff, valleys, river basin, etc. It also indicates the folds and faults in the rocks. The data for Geology Map is taken from Geological Survey of India as shown in Fig. 7.

6) Land Use Land Cover Map:

LULC map is prepared using the landset imaginary data. LULC Map of an area provides the information of the landscape of that area. LULC Map shows the land which is used or has concrete surface and the land which is green covered. Within a given region, LULC involves the form of soil deposits, residential area distribution, waterbody, and vegetation cover. It is a significant determinant of groundwater recharge, occurrence, and supply. Landsat 8 (OLI) satellite image of 2021 with 30-m spatial resolution was used for supervised image classification to characterise and describe the kind of LULC. Agricultural region, shrubs cover area, grassland, forest/woodland, bare soil/rock, settlement area, and waterbody are the seven forms of LULC included in the research area as shown in Fig. 8.

7) Geomorphology Map:

The data for Geomorphology Map is taken from National Remote Sensing Centre of India as shown in Fig. 8. Geomorphological units, or geographic

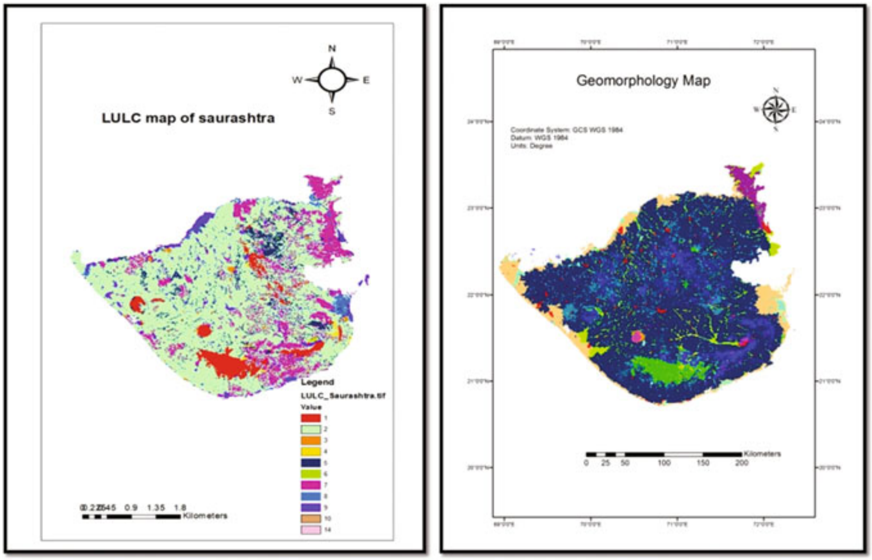

Fig. 8 LULC map and geoorphology map

characteristics of the earth's surface and near-surface underground, play an important role in hydrogeological investigations, topography assessment, and groundwater resource delineation. Previous research has used geomorphology features as a major parameter for defining GWPZ. The current study's geomorphic features were geo-referenced and digitized from photographs.

4 Results and Discussions

The groundwater potential map was created by including the weight values of each thematic layer in a weighted index overlay study. A groundwater prospective region was described as an area score with a high weighted value. As a result of the rating system of equal intervals, the groundwater potential map has been classified into five groups, with groundwater potentiality ranging from very good to very bad (Fig. 9).

Assigning Rank and Weightage to Each Maps
The rank is given according to the importance of the factor for Ground Water Potential Zone Mapping. The order of giving rank in ascending order (i.e. Lowest to highest weight) is: Geomorphology, Lineament Density, Lithology, Slope, Soil, LULC and Drainage Density. The value of Rank is provided 7 to geomorphology map and horizontally the value decreases by 1 and vertically divided by increasing order. The Weightage assigned to each map is shown in the below Table 1.

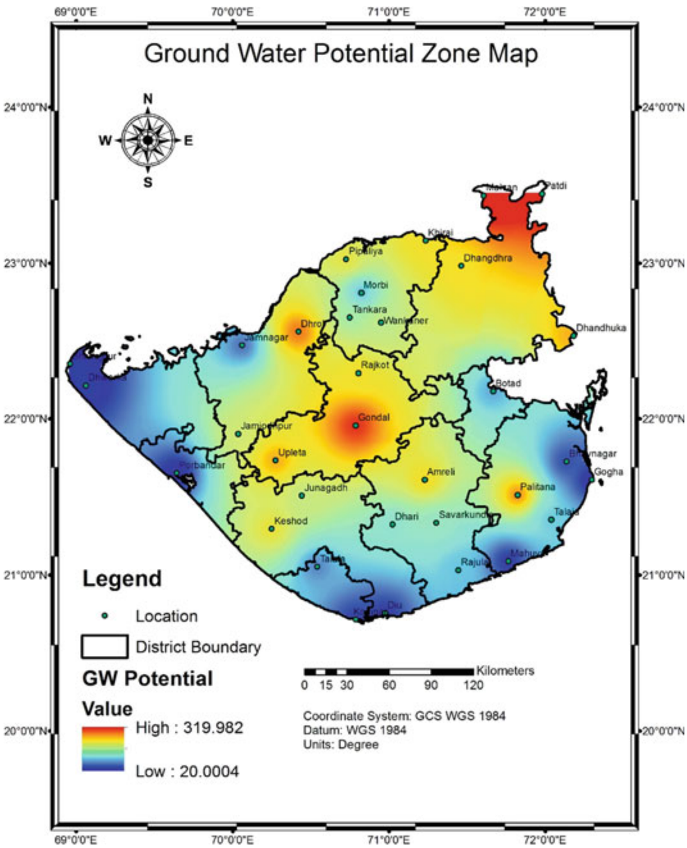

Fig. 9 Ground water potential zone map of Saurashtra region

The Ranks are assigned to each component of all layers according to its importance in the Ground Water Potential Zone Mapping. Then the Weightage and Rank are multiplied to get the overall value of the given factor shown in Table 1.

The value of each factor us added to the data in ArcGIS and then using the analysis tool all the 7 layers are overlapped which gives the Ground Water Potential Zone Map of Saurashtra Region.

In ArcGIS, all thematic layers were transformed to grid (raster) format and then overlaid using the weighted overlay technique using the spatial analysis tool to delineate the research area's ground water potential zone. It uses a method in which each of the primary thematic layer's thirteen classes is qualitatively classified into one of three categories: "low," "moderate," or "high," as appropriate. A rating from 1 to 4 is assigned to each parameter of each thematic map based on its importance in relation to site selection and weight is assigned for the impact of various parameters on the installation of groundwater potential zone areas. This ranking is used in weighted overlay analysis. Ranking methods provide a higher number value

Table 1 Calculation of weightage of all maps

Factors	Geomorphology	LD	Lithology	Slope	Soil	LULC	DD	Weightage
Geomorphology	7	6	5	4	3	2	1	7/18.5 = 0.38
Lineament density	7/2	6/2	5/2	4/2	3/2	2/2	1/2	3/15.56 = 0.19
Lithology	7/3	6/3	5/3	4/3	3/3	2/3	1/3	1.67/ 12.9 = 0.12
Slope	7/4	6/4	5/4	4/4	3/4	2/4	1/4	1/10.37 = 0.10
Soil	7/5	6/5	5/5	4/5	3/5	2/5	1/5	0.6/ 7.78 = 0.08
LULC	7/6	6/6	5/6	4/6	3/6	2/6	1/6	0.33/ 5.18 = 0.06
Drainage density	7/7	6/7	5/7	4/7	3/7	2/7	1/7	0.14/ 2.59 = 0.06
Total	18.15	15.5	12.9	10.3	7.78	5.18	2.59	1

to features with the greatest groundwater potential, while assigning a lower number value to those with the least. The sum of a theme's rank and weightage determines its ultimate score. Slope maps, for example, give a higher rating for a moderate slope and a lower rank for a steep one.

After assigning the overall weightage to all the 7 layers of map, the maps are overlapped on each other and the final Ground Water Potential Zone Map of Saurashtra region is generated which is shown in Fig. 9:

As shows in Fig. 9 that very good and strong groundwater potential areas are clustered in the region. These deposits are distinguished by high primary and secondary porosity, respectively, and, as a result, have a high propensity for groundwater retention due to maximum percolation. Furthermore, high lineament density was shown as one of the primary factors for groundwater possible zonation. The low to very poor potential zones are often seen in places of strong drainage density. As a result, the freshwater capacity in these areas could be insufficient for agriculture and other subsistence needs. As a result, groundwater development practises were preferentially carried out in strong groundwater prospective areas.

5 Conclusion

The realistic production of groundwater supplies would have a significant impact on the community's socioeconomic change. Indeed, creating a groundwater potential map has a major impact on improving the long-term management of groundwater supplies in the research region and throughout the world. As a result, a thorough investigation was conducted to locate possible groundwater resource areas for increased utility. In order to provide adequate administration, maintenance, and safe usage of groundwater supplies in the sub-basin, this paper contributes by having delineated groundwater potential zones by the use of remote sensing techniques and GIS instruments. The research took into account seven determinant factors: lithology, slope, LULC, runoff, lineaments, and drainage density. The fundamental definition of ground water level fluctuation is explored in this article. The weighted overlay analysis tool, which integrates Remote Sensing and GIS techniques, is used to find the ground water level map of any area. To obtain a map of Ground Water level, different maps such as Slope, Hillshade, Geology, Flow Accumulation, Flow Direction, Fill, Drainage, LULC, Drainage Density Map, and Lineament Density Map are overlapped in this process. The ground water level chart for Gujarat's Saurashtra area is generated by overlapping maps with ArcGIS software. The area from which ground water is readily accessible can be determined using ground water level charts, and the difference in water level can be measured by analyzing maps from various years. These maps of ground water levels may be used to dig wells and build some kind of hydrological system. Mapping groundwater capacity using remote sensing data and GIS techniques is becoming more common due to its applicability in inaccessible areas, which saves time and resources. In this research, qualitative analysis was used to determine groundwater potential zones in the Saurashtra area utilizing GIS and remote sensing techniques. The investigation of groundwater capacity in specific areas is critical, but further research is needed to ensure its dependability. Furthermore, research on the efficiency and suitability for various factors such as drinking, agricultural, and manufacturing practices may be conducted. Groundwater regeneration has a significant impact on the resource's capacity. As a result, a comprehensive investigation of groundwater recharge is proposed for future research because it would help in providing analytical proof of an area's groundwater capacity.

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Analysis of Spatial and Temporal Variability of Rainfall Using GIS in Rasipuram Taluk, Tamil Nadu, India

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Abstract In this paper, the variation in spatial and temporal scales of rainfall in and around Rasipuram Taluk, Tamil Nadu, India is presented in which agriculture is a major land use category. Daily rainfall data are collected for seven rain gauge stations namely, Kullampatti, Salem Junction, Sankagiri, Rasipuram, Senthamangalam, Thiruchengode and Gangavalli. The rainfall data are sorted into monthly, seasonal and average annual categories for assessment. The spatial distribution of rainfall during all the major seasons and average annual rainfall are plotted for better understanding of the spatial variability. Monthly rainfall analysis demonstrates that October month receives highest rainfall whereas lowest rainfall would usually be registered during January at all seven rain gauge stations considered. Annually, the highest rainfall is received in 2015, and least amount of rainfall is received in 2006. Northeast monsoon has the highest average rainfall of 374 mm when compared with all the other seasons during the study period from 2006 to 2015. Spatial analysis reveals that the major portion of the Rasipuram Taluk belongs to moderate rainfall category except in north east monsoon season. The regional level long term analysis of rainfall variation can depict exact trend which can be used for agricultural development plans in semiarid regions.

Keywords Rainfall variation · Spatial and temporal analysis · Rasipuram taluk · GIS

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1 Introduction

Fresh water is used by the people for all their day to day needs as it is one of the essential factors of living organisms. The sources of fresh water includes dams, lakes, river and underground aquifers. Rain in freshwater ecosystem assistant in restoring of natural resources [1]. The mean rainfall in a freshwater ecosystem receives depends upon the geographical location. The storage of clean and fresh water is crucial in order to meet the demands. The increasing requirement for fresh water is due to urbanization and industrialization. The quantity and quality of water is utmost important because of its extensive usage for manifold purposes [2]. The groundwater availability is predominantly influenced by precipitation and runoff. The drinking water and agricultural planning are critically dependent on the variability of rainfall in spatial and temporal scales. The rainfall trend has been analyzed by many researchers throughout the world [2, 3]. The climate change also has a serious role in the rainfall pattern and their variations [4, 5]. The climatic disasters like cyclones are most crucial factors which plays a noticeable impact on the rainfall variability and distribution [6]. Agriculture is the predominant source of income for the majority of people in India including the Rasipuram Taluk. These agricultural activities are dependent on rain water sources for irrigation. So, the rainfall pattern and its quantity are becoming economically important factors in the fields of hydrology and agriculture [7].

Rising fresh water consumption is putting pressure on water resources and nearly half the world's population will faces high water stress by 2030. Water scarcity in the southern Plateau and southeastern coastal regions in India around 2025 are predicted by Anuraga et al. 2006 using modeling techniques [8]. The other techniques such as palaeo-environmental techniques, anomaly index, precipitation concentration index and threshold determination of rainfall have also been emphasized for proper planning and management of water resources [9, 10]. The rainfall variation analysis has manifold applications and uses. Elena et al. (2017) reported the effects of variation in rainfall pattern and trend on the hydrological processes in urban environment [11]. Rajendran et al. (2016) have estimated the number of rainy days in a year through frequency analysis in Dharmapuri District of South India [12]. The water scarcity is one of the important factors to be considered in contemporary environment and it can be addressed and properly planned by software models [13].The spatial analysis can be well organized and displayed in Geographical Information System (GIS). Spatial comparison studies are carried out on regional scale using GIS [14, 15]. Agriculture is the predominant source of income for the residents in Rasipuram Taluk. People residing in the study area are mainly relied on the groundwater for their domestic and irrigation needs. Nearly 176 Sago factories are located in the Rasipuram Taluk and they are constantly exploiting the groundwater resources for their industrial uses. All the four administrative blocks in Rasipuram Taluk namely, Rasipuram, Namagiripet, Vennandur and Pudhuchathram are declared as overexploited regions of groundwater [16]. So, importance needs to be given for the water resources and their potential sources of the study area. With this back ground, an investigation is carried out on the rainfall variation in Rasipuram Taluk.

2 Study Area

The present study is conducted in Rasipuram Taluk, Namakkal District, Tamil Nadu, India. The Rasipuram Taluk comes under the geographic coordinates on the north by latitude 11°18′23.69″N to 11°34′58.33″N and on the east by longitude 78° 2′0.69″E to 78°28′33.08″E as shown in Fig. 1. It has a population of 3,39,790 as per 2011 Census with a spatial coverage about 815.53 km^2. During the periods of February to July, dry climate occurs in the study area and the sub-tropical climate occurs during the period from November to January [17]. The study area receives little rainfall in the period from March to May and major contribution from both southwest as well as northeast monsoons. Relative humidity is high during the period from September to December. The temperature is observed to be varied between 25 to 40 °C in Rasipuram Taluk [18]. Almost an elevated topography is observed in the study area with some undulations and hills. A maximum altitude of 1410 m above MSL is observed in Kolli hills and the lowest altitude is about 194 m above MSL [19].

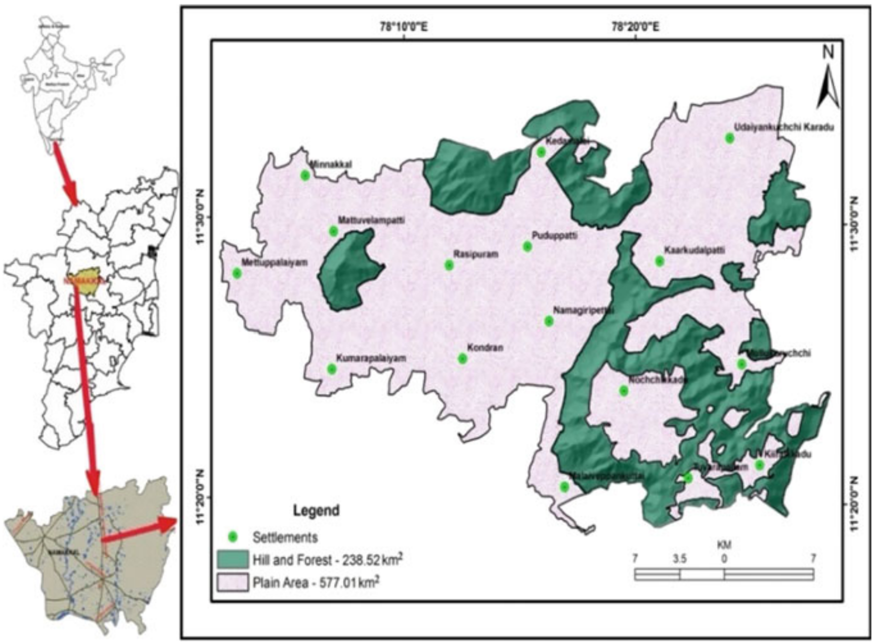


Fig. 1 Base map of the study area

3 Methodology

The monthly rainfall data for a decade long period from 2006 to 2015 are obtained from State Ground and Surface Water Resources Data Centre (SG&SWRDC), Chennai, Tamil Nadu. The data collected are categorized for monthly, seasonal and annual variation analysis. The data is organized into four seasons: (1) Post-monsoon from January to February, (2) Pre-monsoon from March to May, (3) the South-West monsoon from June to September and (4) the North-East monsoon from October to December. The locations of the rain gauge stations considered for the study are Kullampatti, Salem Junction, Sankagiri, Rasipuram, Senthamangalam, Thiruchengode and Gangavalli. The spatial distribution of the rainfall is studied using GIS by considering all the above monitoring stations in and around the study area. The rain gauge station locations are digitized by giving ground coordinates and the calculated rainfall values of various seasons are given as attributes. This data are used for the preparation of maps through interpolation techniques. The rainfall is classified as low, moderate and high for each season and annual data based on Quantile method [20] and their spatial distribution is presented using GIS. The location of rain gauge stations is presented in Fig. 2.

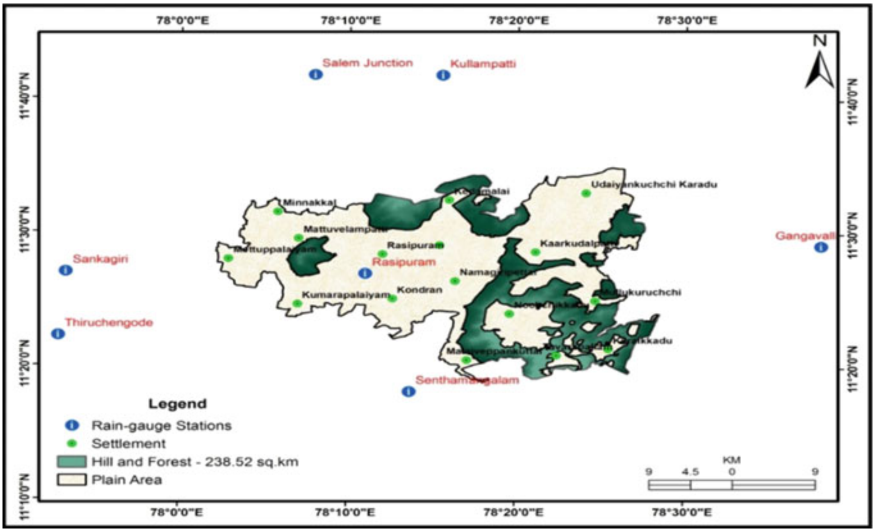


Fig. 2 Rain gauge stations spatial reference map

4 Results and Discussion

4.1 Monthly Variation of Rainfall

Monthly precipitation in Rasipuram Taluk shows a uniform pattern at all the seven monitoring stations. The average monthly rainfall for ten years from 2006 to 2015 is computed for the seven stations and employed for preparing variations in rainfall as represented in Fig. 3. The increasing pattern in the precipitation throughout January to May, and furthermore declining pattern during June are recognized. Then the precipitation trend has slow and steady increase from July and reaches the peak value during October, but decreases to reach a minimum in the month of January. Monthly rainfall analysis demonstrates that October month receives highest rainfall whereas lowest rainfall would usually be registered during January at all seven stations considered.

4.2 Seasonal Variation of Rainfall

The average southwest monsoon rainfall is found to be 324 mm and the average northeast monsoon rainfall is to be 374 mm. During pre-monsoon season, the rainfall is noticed as 177 mm and just 4 mm is received in the post-monsoon season on average during the study period. The average seasonal rainfall data of seven rain gauge stations are displayed in Table 1 and shown in Fig. 4. Figure 4 reveals that the most of the precipitation is recorded during north-east monsoon except two, Senthamangalam and Gangavalli, rain gauge locations. Insufficient precipitation is noticed in the post-monsoon throughout the study period from 2006 to 2015.

4.3 Annual Variation of Rainfall

The rainfall data of past ten years from 2006 to 2015 are interpreted in Figs. 5 and 6. The years 2009, 2010 and 2015 received annual rainfall of more than 1000 mm during the study period and the least amount of annual rainfall was recorded in 2006. Linear trend line in Fig. 5 reveals that the increasing trend in the rainfall is observed from 2006 to 2015. Figure 6 reveal that out of seven rain gauge stations considered, four stations, i.e., Kullampatti, Salem Junction, Gangavalli and Rasipuram received average annual rainfall similar to Tamil Nadu state average (987 mm). Three rain gauge stations, namely Sankagiri, Senthamangalam and Thiruchengode received low rainfall during the study period. Kullampatti, Salem

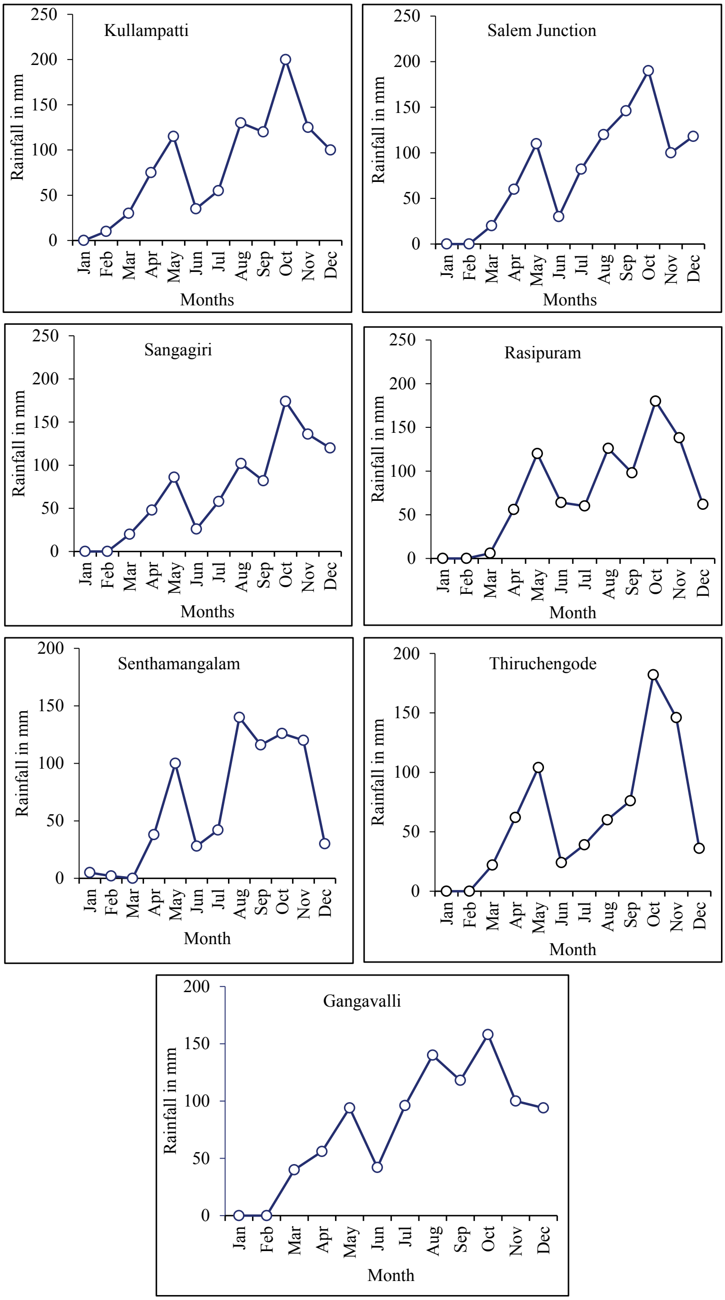


Fig. 3 Monthly rainfall variations at various rain gauge stations considered

Table 1 Average seasonal rainfall at various rain gauge stations during the study period

Rain gauge stations	Post-monsoon	Pre-monsoon	Southwest monsoon	Northeast monsoon
Kullampatti	9	203	324	410
Salem Junction	1	181	387	407
Sankagiri	2	156	273	422
Rasipuram	3	186	348	366
Senthamangalam	8	133	328	290
Thiruchengode	5	190	221	369
Gangavalli	1	193	387	354
Average	4	177	324	374

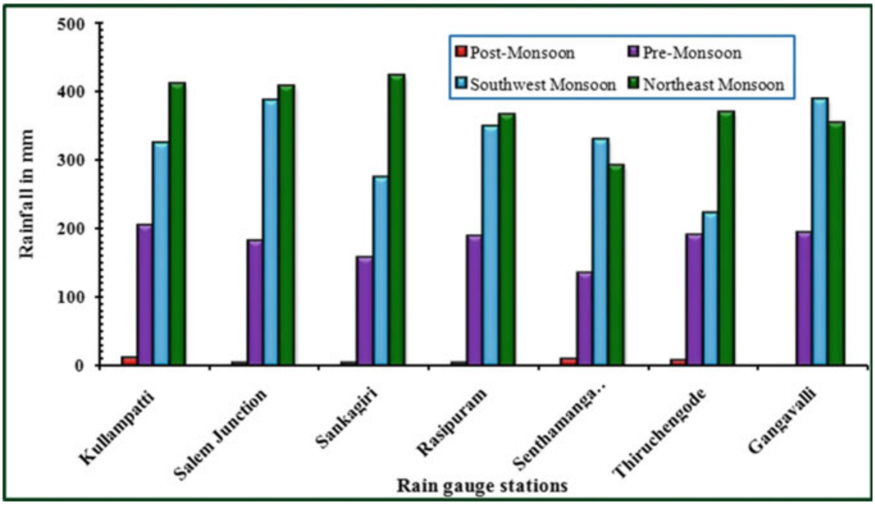


Fig. 4 Average seasonal variation of rainfall at seven rain gauge stations during the study period

Junction, Sankagiri and Gangavalli stations are situated in Salem district. The rest of the rain gauge stations namely, Rasipuram, Senthamangalam and Thiruchengode fall in Namakkal district. Kullampatti and Salem Junction have received the highest precipitation, located nearby Shervorayan hill and the other highest precipitation rain gauge locations are Rasipuram and Gangavalli located nearby Kolli hills.

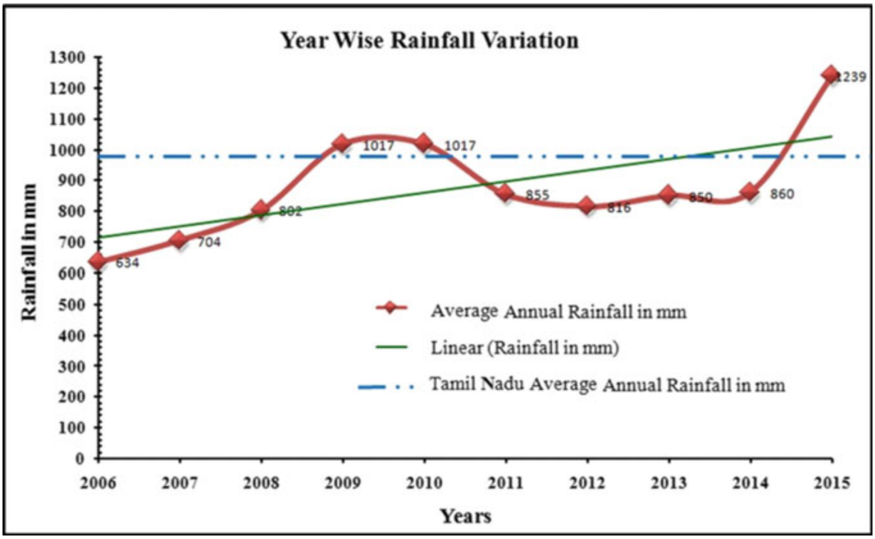


Fig. 5 Total average annual rainfall variation

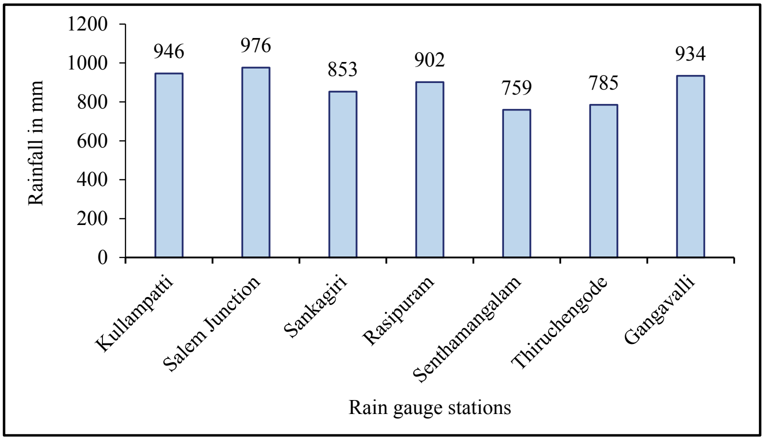


Fig. 6 Average annual rainfall variations at seven rain gauge stations

4.4 Spatial Distribution of Rainfall

The spatial distribution of seasonal rainfall is prepared using GIS and presented in Fig. 7. The rainfall in each season is classified as high, moderate and low with respect to the amount of rain fall received during that particular season based on Quantile method [20]. The rainfall data pertaining to southwest monsoon, post-monsoon, pre-monsoon, and northeast monsoon seasons and the average annual precipitation data for the study period are used for producing the isohyetal maps. In pre-monsoon season, moderate rainfall of 177 mm is recorded during the study period from 2006 to 2015. The spatial distribution of rainfall during the pre-monsoon season is presented in Fig. 7a reveals that the southern part of the Rasipuram Taluk has the least precipitation of less than 170 mm whereas other regions received moderate rainfall of 171 to 190 mm. The isohyetal map for the post-monsoon season as given in Fig. 7b reveals that the eastern portion of the study area has received more rainfall than the western parts. High precipitation is recorded in and around the Kolli hills. The post-monsoon season received the lowest average rainfall of 4 mm when compared with the other seasons during the study period from 2006 to 2015. A major part of the study area (560.71 km^2) received moderate rainfall of 321 to 360 mm in southwest monsoon as presented in Fig. 7c. The isohyets map of the northeast monsoon indicates that moderate rainfall of 370 to 410 mm is recorded in the northern region of the Rasipuram Taluk as in Fig. 7d. Northeast monsoon has the highest average rainfall of 374 mm when compared with all the other seasons during the study period from 2006 to 2015. The isohyetal map pertaining to average annual rainfall as given in Fig. 7e reveals that spatially northern part of the Rasipuram Taluk experiences moderate precipitation of 870 to 940 mm and southern part receives low rainfall of less than 870 mm. The precipitation study in and around the study area implies that the precipitation was insufficient in Rasipuram Taluk while the average annual rainfall of 987 mm in Tamil Nadu during the study period from 2006 to 2015. The spatial distribution results of average rainfall during the study period are presented in Table 2.

Table 2 Spatial distribution of average rainfall during the study period

Rainfall seasons	Category	Area in km^2	Area in %
Post-monsoon	High	1.43	0.24
	medium	329.62	56.15
	Low	245.96	43.60
Pre-monsoon	Low medium	80.66 496.35	13.74 84.56
Southwest monsoon	Low medium	16.30 560.71	2.78 95.52
Northeast monsoon	Low medium	432.50 144.52	73.68 24.62
Average annual	Low medium	118.15 458.87	20.13 78.17

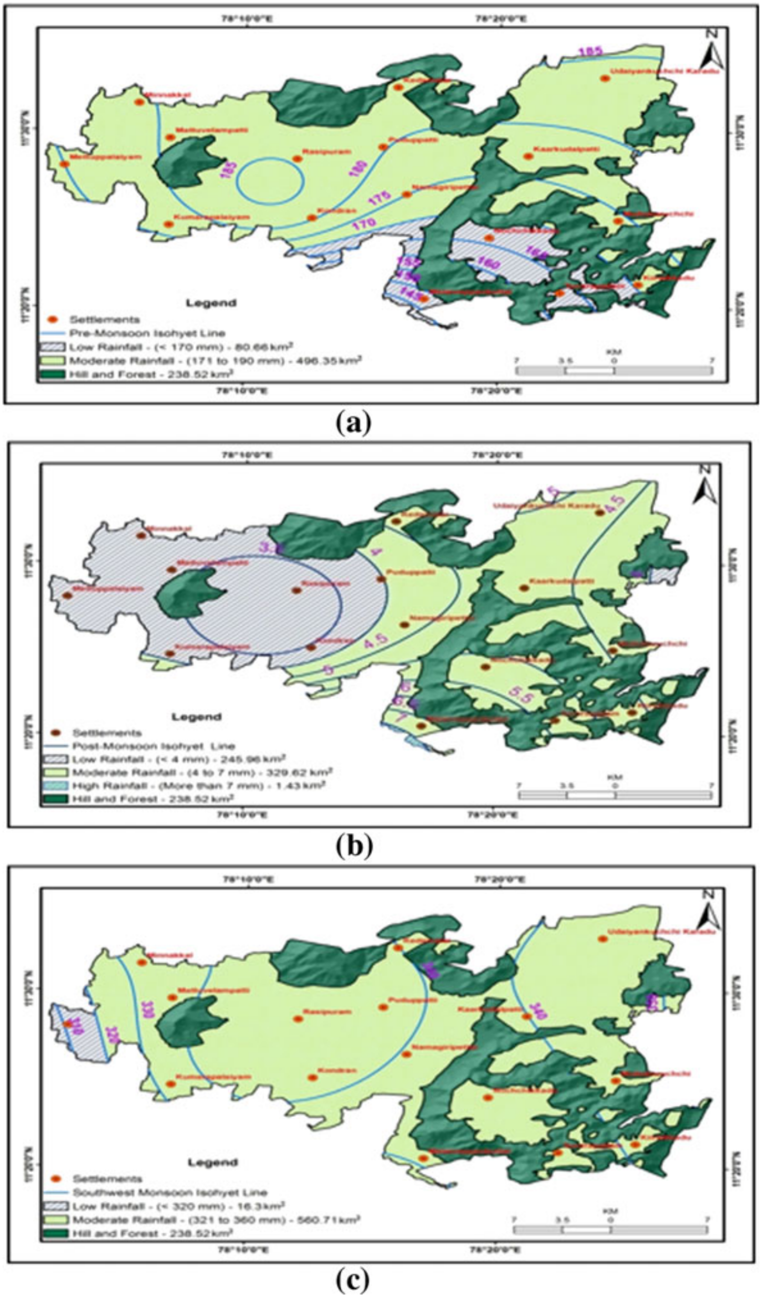
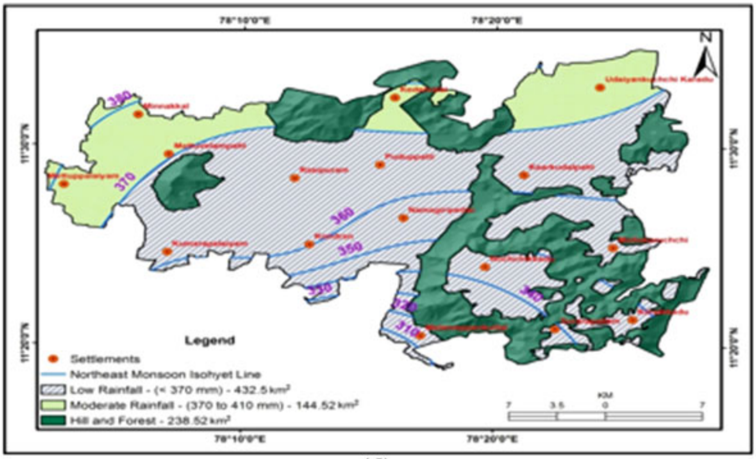
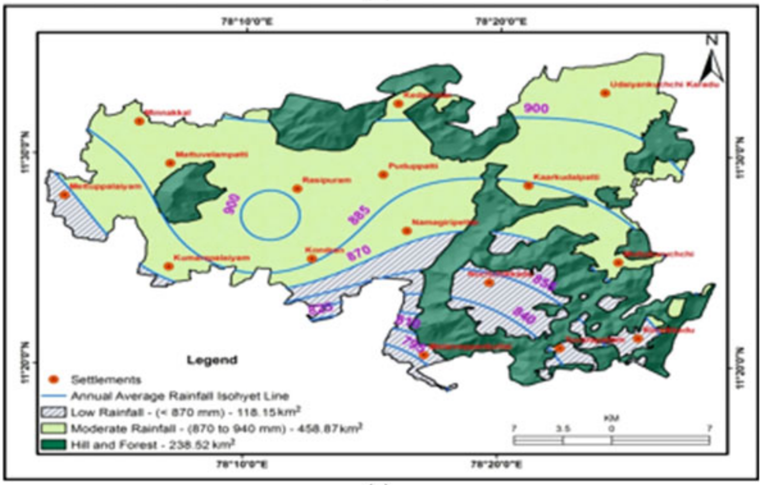


Fig. 7 **a** Pre monsoon rainfall, **b** Post monsoon rainfall, **c** Southwest monsoon rainfall, **d** Northwest monsoon rainfall, **e** Average annual monsoon rainfall



(d)



(e)

Fig. 7 (continued)

5 Conclusion

This study was undertaken to analyze the variability of rainfall on spatial and temporal scales in Rasipuram Taluk, Tamil Nadu, India. Rainfall data of seven rain gauge stations are collected for interpretation. The rainfall data of the study area is calculated by interpolation technique in GIS. Salem Junction rain gauge station is noticed as high rainfall zone because this location is situated nearby Yercaud hills. Overall, the study area during the study period shows the high rainfall in 2015 and low rainfall in 2006. Season wise precipitation reveals that north east monsoon is a high rainfall season. It is observed from the spatial variation of average annual rainfall that the northern part of the Rasipuram Taluk experiences moderate rainfall and the remaining parts belong to low rainfall category. When compared to the average annual rainfall of Tamil Nadu state of 987 mm, all the rain gauge stations considered experience deficient precipitation. This study could provide insight into the spatial and temporal pattern of rainfall in the study area and can be used for further planning and implementation of water resources related projects.

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Land Degradation in the Western Ghats: The Case of the Kavalappara Landslide in Kerala, India

Nirmala Vasudevan, Kaushik Ramanathan, and T. S. Syali

Abstract Landslides are a menacing problem in India. Each year, there are several landslides in various parts of the country. With extreme weather events occurring more frequently and human activity negatively impacting slope stability, the number of fatal landslides has been increasing over the years. One such event was the 2019 Kavalappara landslide in the Western Ghats of Kerala State, India, which resulted in the loss of 59 lives and considerable damage to property. Our observations show that human activity exacerbated slope instability—the conversion of natural vegetation to plantations, step cutting of slopes, construction of soak pits causing water to infiltrate into the slope, construction of homes on natural drainage channels, and improper methods of drainage such as directly releasing water from homes into the slope, have all contributed to slope instability. Extremely heavy and continuous rainfall on the days preceding the slide and toe incision of the slope by an inundated tributary of the Chaliyar River proved to be fatal, resulting in a huge debris flow. We recommend some immediate remedial measures and also discuss possible long-term solutions to the problem of slope instability in this region.

Keywords Landslide · Kavalappara · Western Ghats · Malappuram · Kerala · India

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1 Introduction

Landslides are one of the major geohazards in the world. With extremes of weather and climate change, the loss due to landslides is on the rise. Human activity has played a significant role in making slopes more vulnerable to landslides and other mass wasting processes. Some of the most detrimental human activities responsible for slope instability include deforestation, excessive mining, blocking natural drainage paths, and non-adherence to engineering principles in construction [1–3].

In India, the Himalayas and the Western Ghats witness several landslides each year [4, 5], and are among the global landslide hotspots. In recent times, there has been a spate of floods and landslides in the Western Ghats of Kerala [1, 6]. For instance, there were 80 landslides during the 3-day period from 8–11 August 2019 [7, 8]. Of these, the most devastating landslides occurred on 8 August at Kavalappara locality, Malappuram District (59 deaths) and Puthumala locality, Wayanad District (17 deaths). Landslides on 8 August included those at Valamkolli, Athiruveeti, and Malamkundu hills in and around Pathar locality[1], approximately 4 km away from Kavalappara [9–11]. On 9 August, there were two landslides at Kottakunnu locality, Malappuram District, one of them resulting in 3 deaths [12].

We visited the Kavalappara landslide on 3 September 2019. Locals informed us that there had been prior indications of slope instability, such as cracks on the hill, but this was the first recorded landslide at this site. In this paper, we report our findings on the landslide, its possible causes, and potential remediation.

2 Study Area

Muthappankunnu (Muthappan Hill) lies in Kavalappara locality of Pothukal Panchayat, Malappuram District, Kerala State, India[2] (Figs. 1 and 2). The hill witnessed three landslides on 8 August 2019 [11], with one of the smaller landslides in a forested area and the other in a rubber plantation (Fig. 2). The main slide (11° 24′26″–11°24′51″N, 76°13′56″–76°14′19″E) started at about 250 m above mean sea level and spanned an area of over 0.2 km^2 (Fig. 3).

Muthappankunnu lies in the Western Ghats mountain range, which stretches for about 1,600 km along the western coast of India. The 169 km-long Chaliyar River flows close by, approximately 1 km away from the base of the hill (Fig. 2). Unlike most rivers that flow through Malappuram District, the Chaliyar is a perennial river [14]. A tributary of the Chaliyar, Kavalapparathodu, flows at the base of the hill.

[1] Pathar and Kavalappara are both located in Pothukal Panchayat. A Panchayat is an administrative unit consisting of either a large village or a cluster of small villages.

[2] Muthappankunnu lies in Kavalappara, Pothukal (also spelt Pothukallu) Village, Pothukal Panchayat, Nilambur Taluk, Malappuram District (https://malappuram.nic.in/administrative-setup/). Taluk is a higher administrative unit than Panchayat.

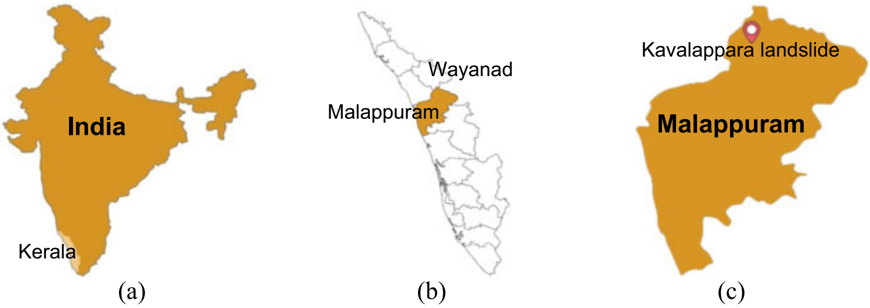

Fig. 1 **a** Kerala State, India, **b** Malappuram District, **c** Kavalappara landslide

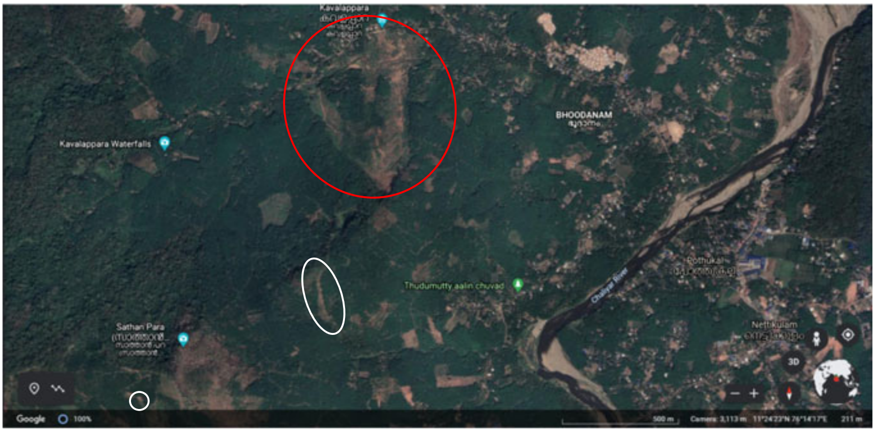

Fig. 2 Google Earth [13] image of the Kavalappara site captured on 23 February 2021. The main Kavalappara slide is circled in red, while the smaller slides, at distances of approximately 0.5 km and 1.5 km from the main slide initiation point, are circled in white

The predominant rock types in Pothukal Panchayat are hornblende-biotite gneisses of the Peninsular Gneissic Complex and charnockites of the Charnockite Group, both of the Archaean Eon [15–17]. Highly weathered biotite granite gneiss and charnockite were observed at the landslide site, along with brownish-red laterite soil.

Malappuram District receives approximately 3,000 mm of annual rainfall, of which more than 2,000 mm falls during the main monsoon season from June to September. During this season, moisture-laden winds from the southwest are intercepted by the Western Ghats, bringing rain to the region. The southwest monsoon is followed almost immediately by the northeast monsoon from October to December. Approximately 500 mm of rain falls during the northeast monsoon, very little falls during January and February, and some pre-monsoon showers occur during the summer months from March to May [14, 18].

3 Causes and Trigger of the 2019 Kavalappara Landslide

3.1 Alteration of Natural Drainage

Rubber and coconut plantations covered a large part of the hill prior to the slide; the rubber plantations were first cultivated around 1961 (conversations with locals). Studies report that the cultivation of rubber plantations in the Western Ghats of Kerala may lead to a greater vulnerability to landslides [19–21]. At Muthappankunnu, the slope was modified to create terraces for the rubber plantations (Fig. 4). Further, $1.5 \times 1.5 \times 0.5$ m^3 pits were dug at different locations on the terraces to collect and store rainwater. These practices led to increased waterlogging and infiltration [17], thereby increasing pore water pressures, especially during the rains.

During heavy rains, water would flow down the slope through seasonal rivulets that would drain into Kavalapparathodu at the base of the hill; a few houses and roads were in the way of these rivulets and blocked the natural flow.

3.2 Excavation of the Slope

There are reports of excavations for the cultivation of rubber plantations [11, 22, 23]; these excavations may have made the hill more susceptible to landslides.

3.3 Rainfall and Flooding

The landslide was triggered by exceptionally heavy downpour. Typically, the southwest monsoon winds arrive in Kerala by 1 June; the 2019 monsoons were delayed and began on 8 June. There was significantly lesser rainfall than normal during the months of June and July, as seen in Tables 1, 2, and 3.

However, during the first week of August, Malappuram District received 189.4 mm of rain, 66% more than normal (Table 1). In fact, for the month of August, the closest meteorological observatory to Kavalappara (located in Nilambur at an aerial distance of approximately 10 km), recorded 1,151.9 mm of rainfall as versus the long-term normal 391.8 mm of rainfall [8].

Kavalappara Village was flooded by 12 p.m. on 8 August, all bridges were submerged, and the water level rose to 5 m in some places (conversations with locals).

Table 1 2019 Malappuram District rainfall (*Source*: India Meteorological Department, IMD [24])

	Jan	Feb	Mar	Apr	May	Jun	Jul	1–7 Aug
Actual rainfall (mm)	0	0.4	2.8	71.3	52.1	337.8	580.8	189.4
Normal rainfall (mm)	1.7	5.7	21.5	88.0	200.4	625.6	754.3	114.3
Departure from normal	−100%	−93%	−87%	−19%	−74%	−46%	−23%	66%

Table 2 Malappuram District rainfall—June 2019 (*Source*: India Meteorological Department)

	30 May–5 June	6–12 June	13–19 June	20–26 June
Actual rainfall (mm)	34.4	98.8	86.2	124.3
Normal rainfall (mm)	73.2	139.5	188.1	144.9
Departure from normal	−53%	−29%	−54%	−14%
Comments[a]	Deficit	Deficit	Deficit	Normal

[a]As per India Meteorological Department, Large excess: +60% and above, Excess: +20% to +59%, Normal: +19% to −19%, Deficit: −20% to −59%, Large deficit: −60% or less, No rain: −100%.

Table 3 Malappuram District rainfall—July 2019 (*Source*: India Meteorological Department)

	4–10 July	11–17 July	18–24 July	25–31 July
Actual rainfall (mm)	170.7	51.0	281.5	30.6
Normal rainfall (mm)	169.8	195.8	144.4	161.2
Departure from normal	1%	−74%	95%	−81%
Comments	Normal	Large deficit	Large excess	Large deficit

4 The August 2019 Kavalappara Landslide

The main slide initiated at around 7:30 p.m. at approximately 11°24′27″N, 76°14′13″E, 250 m above mean sea level, on the north-facing Muthappankunnu slope at Kavalappara (Figs. 2 and 3). The locals reported that it was raining heavily at the time of the slide, and they heard an ominous sound like that of a helicopter.

Based on observations and conversations with the locals, we conjecture that the landslide began as a planar failure at the overburden-rock interface; it transformed into a debris flow with three runout paths. The flow was extremely rapid, with the entire event lasting less than 10 minutes. Huge boulders were dislodged; one of them came down the hill, destroying a house in its wake.

Fig. 3 The Kavalappara landslide photographed on 3 September 2019. Inset: landslide dimensions obtained from Google Earth [13]

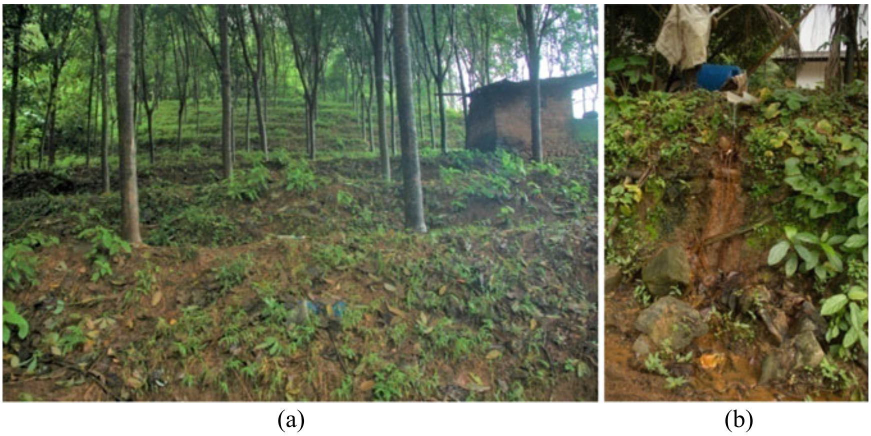

Fig. 4 Practices negatively impacting slope stability: **a** Terracing of the hill for rubber plantations **b** Releasing water into the slope

The landslide resulted in 59 fatalities. Even a year later, 11 of the 59 bodies had not been recovered. 81 houses were partially or wholly destroyed [9], vegetation was up-rooted, electrical poles were broken, and the communication network was damaged. Lot of material was mobilized and another landslide could be triggered in future.

5 Remedial Measures

Some of the immediate measures to be carried out at Kavalappara are the demolition of structures in the path of natural drainage and afforestation with endemic vegetation. Since drainage plays a vital role in slope stability, all obstacles on natural drainage channels must be cleared and the water channelized to drain into the adjacent river. We believe that even these simple measures would go a long way in improving the stability of the hill. The measures adopted should be monitored for their efficacy and performance.

6 Discussion

The Western Ghats of Kerala have witnessed sporadic landslide activity for several decades [25, 26]. However, since the mega floods of 2018, there has been a spurt in landsliding activity following extreme rains and floods each year. This has led to the assumption that rains have caused the landslides. While rainfall is often the trigger, in most cases, it is the proverbial last straw that broke the camel's back and not the main cause. In 2018, though Nilambur received torrential rainfall of 398 mm on 8 August [27], there were no landslides at Muthappankunnu. Thus, attributing landslides to rainfall alone is erroneous.

Various studies and our own observations at Kavalappara and other sites have shown that human activity plays a major role in aggravating slope instability and causing landslides in these parts [1, 2, 4, 26, 28, 29]. In addition to the rubber and coconut plantations which we saw, reports suggest that there was deforestation and quarrying in Kavalappara and surrounding areas [30]. When the slope is excavated, it leads to a sudden release of the overburden pressure, which causes heaving. This weakens the underlying layers and also exposes them to weathering. Therefore, quarrying and mining must be carried out very carefully and in line with sound engineering judgment.

Human violence against Nature has been going on for a very long time in the Western Ghats [26, 31]. Realizing the seriousness of the matter, various committees were constituted to balance environmental conservation and development. These experts had warned that the hilly regions of Kerala were prone to landslides, and the rampant modification of slopes through deforestation and excessive quarrying and mining should be discontinued [29]. However, the warnings weren't heeded, and the results are evident. Since 2018, the state has reeled under the onslaught of multiple landslides in the hilly districts of Idukki, Wayanad, Malappuram, and Kozhikode [6, 8, 32].

There are some similarities in the landslides which have occurred in these places. There has been widespread deforestation, slope modification through excessive quarrying and mining, and disruption of natural drainage. Such activities create conducive conditions for waterlogging as well as more weathering and slope erosion, accelerating slope degradation and paving the way for landslides.

7 Conclusion

Landslides can be remediated. Instead of responding after a landslide, it would help if we identify precursors through detailed site investigations and preempt the event. Certain landslides are known to recur periodically during the monsoons. By identifying the landslide shear boundaries and causative factors, we would be able to remediate landslides. This would not only save lives, but also the livelihoods of people.

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Study of Sustainability Aspects of Chambal River Linking System Using Reservoir Simulation Techniques

Rajesh Kumar Jain, Rajesh Goyal, and Dulal Goldar

Abstract In the present analysis, computer based multi reservoir simulation model of four reservoirs viz. Gandhi Sagar, Rana Pratap Sagar, Mohanpura and Kundaliya in Chambal basin has been done while they are in isolation or iner connected with success rate of 75% for irrigation, 100% for drinking water and 90% for Hydro power in term of volume and time reliability. Three scenarios **Case I**: When these reservoirs are operated in isolation with their performance and efficiency and reliability in term of time and volume as well as targeted hydro power generation. The analysis established availability of water for diversion with the success rate needed and spills at Mohanpura and Kundaliya are available for interlinking. **Case II** when water is diverted from Mohanpura to Kundaliya and then Gandhi Sagar **CaseIII** Kundaliya to Rana Pratap Sagar These further done for three sub cases. 1st when designed parameters of all 4 reservoirs kept intact. 2nd only water use targets modified and 3rd optimization of reservoir capacities.

The case II established either increase in target diversion II(1 &2) or reduction in reservoir capacity II(3) and the success rate of Mohanpura and Kundaliya reservoirs more than in case I and also improves irrigation and power for Gandhi Sagar The case III established that either diversion can be increased or hydro power can be increased, the success rate for Mohanpura and Kundaliya remains same as in case II, No change in success rate of Gandhi Sagar over case I and increase in power generation in case III(1,2&3) up to 94%.Thus the simulation studies confirm the sustainability of Chambal river system by River Linking System using multi reservoir simulation technique.

Keywords Reservoir · Sustainability · Mohanpura · Kundaliya · Gandhi Sagar · Rana Pratap Sagar

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1 Introduction

A simulation model for operation of reservoir can be used for deciding capacity of a reservoir or outflow from a reservoir for given capacity, performance of a reservoir, decide its efficiency for various uses in volumetric and time scale. Before taking up simulation analysis, it is necessary to decide purpose. In the present analysis, multi reservoir simulation of four reservoirs viz. Gandhi Sagar, Rana Pratap Sagar, Mohanpura and Kundaliya in Chambal basin has been done while they are in isolation or connected. The objective of research is to device and establish Chambal River interlinking system.

The Chambal catchment has a geographical area of 132,508 km^2. with river Chambal as a main river. In the Chambal river in its total run of 960 km, in its run from 328 to 440 km the river passes through a deep gorge, which is ideally suitable for storage Dams. The storage exists in the Gandhi Sagar Dam (MP) and Rana Pratap Sagar dam, Jawahar Sagar/Kota Barrage in Rajasthan. In addition to above, there are Mohanpura Dam on Newaj river a tributary of Chambal and Kundaliya Dam on Kalisindh river a tributary of Chambal. These rivers also joins Chambal but in plain area. The Table 1 gives the brief salient features of 4 reservoirs:

Table 1 Salient features of dams/reservoirs

S. No.	Parameter	Gandhisagar dam	Rana Pratap Sagar Dam	Kundaliya dam	Mohanpura Dam
1	Minimum water level (Meter)	381	344.06	355.63	385
2	Tail water level (Meter)	344.4	296.4	335	375.84
3	Bed level (Meter)	341.38	341.38	335	375.84
4	Gross storage capacity (millions of cubic meter)	8326	3237.89	379	107.05
5	Dead storage capacity (millions of cubic meter)	7743.79	1332.16	130	29
6	**Hydropower generation:**				
(i)	Installed capacity (Mega Watt)	5 unit of 23 MW each	4 unit of 43 MW each	-	-
(ii)	Firm power potential (Mega Watt) at 60% load factor	80	90	-	-

2 Literature Surveys

Before taking up present study, over view of various studies have been carried out based on advanced theories and methods in the field of optimization of Water Resources System. A brief review of earlier works which helped to further proceed are given below:

i. Simulation programme has been developed by Srivastava, D. K etc. which continues screening on the basis of the information obtained from linear programming model. The study has been carried out in which alternative combinations for capacities of six major dams Bargi, Tava, Narmada Sagar, Harinphal, Jalsindhi and Navagam in Narmada basin can be best optimized (1).
ii. Simulation programme has also been developed and applied to the Narmada River Reservoir system in India by Geeta S. Joshi, Kapil Gupta to meet industrial, domestic, irrigation and hydropower generation water requirements. Five reliability performance indicator indices formation for evaluating the performance (2).
iii. Hydrological model study using SWAT – a case study of Tapi river basin in India (Ninavika and ChoudhariPreetam) 24th Hydro 2019, International conference, Osmania University, Hydrabad (3).
iv. Simulation and its importance in reservoir planning – a case study,2021 has been done by Prof. Srivastava D.K., etc. which deals with application simulation technique in reservoir planning in context of existing Krishna Raj Sagar reservoir in Karnataka State. The study reveals that a storage capacity of the reservoir of 1200 Million Meter3 may be enough as compared to the existing capacity of 1240 Million Meter 3 to satisfy the demand of 1850 Million Meter3without much irrigation deficit and spill from the reservoir (4).
v. Simulation programme has also been developed and applied to Par-Tapi-Narmada Link by NWDA, www.nwda.gov.in pp-2017. Multi reservoir simulation studies of 6 Dams proposed for Par-Tapi-Narmada Link to meet the water requirement within basin and establish quantum of water which can be transferred though link canal at desired success rate and establish hydropower generation (5).
vi. Simulation programme has also been developed and applied to NWDA Reports of Kalisidh-Chambal www.nwda.gov.in pp-2005 (6).

3 Methodology and Approach

The reservoir simulation study under present problem is confined to Chambal catchment. The reservoirs considered in the study are four existing reservoirs namely; Mohanpura on river Newaj, Kundaliya on river Kalisindh, Gandhi Sagar and Rana Pratap Sagar on river Chambal. Simulation of individual reservoir has been attempted and their performance for maximize the benefits namely irrigation, drinking water supply and hydro power has been done. Thereafter, multi reservoir operation has been done. Simulation can be defined as the process of designing a computerised model of a system and conducting experiments with this model for the purpose of either understanding the behavior of the system or evaluating various strategies for operation of the system.

In present case use of search technique for simulation is made so as to maximize the benefits and minimize the cost. The various aspects considered in simulation are:

1. Determine a combination of reservoirs, power plants an irrigation - diversion and distribution facilities.
2. Target level of irrigation 75% and energy outputs (90%), M&I (100%).
3. Allocations of reservoir capacity for active, dead and flood storage so as to get maximum present value of net benefit for a given data of monthly runoff values and operation procedure.
4. In the analysis the reservoirs are simulated for 16 years at monthly time interval and inflow at start of month and storage at the end of month are duly considered in three scenarios as graphically depicted in Figs. 1, 2 and 3.

The simulation model has been prepared and tested in 4 stages:

I. Individual Reservoir Run for all four reservoirs.
II. Downstream return flow and spill in case of series reservoirs of Gandhi Sagar and Rana Pratap Sagar.
III. Diversion i.e. water from one reservoir to another reservoir
   a) Mohanpura to Kundaliya, combined balance of Kundaliya to Gandhi Sagar.
   b) Mohanpura to Kundaliya, combined balanceof Kudaliya to Rana Pratap Sagar (Rana Pratap Sagar will get spill of Gandhi Sagar and its own free catchment water).
IV. Hydropower generation

Table 2 .

Case	Scenario details/ Parameter	Mohanpura (1)	Kundaliya (2)	Gandhi Sagar (3)	Rana Pratap Sagar (4)
Case I When these reservoirs are operated in isolation	No diversion				
	Gross capacity	✓	✓	✓	✓
	u/s M&I	✓	✓	---	---
	u/s Irrigation	✓	✓	✓	---
	d/s Irrigation	✓	✓	✓	---
	d/s Hydropower	---	---	✓	✓
Case II Diversion to Gandhi Sagar	With diversion				
	Gross capacity	✓	✓	✓	✓
	u/s M&I	✓	✓	---	---
	u/s Irrigation	✓	✓	---	---
	d/s Irrigation	✓	✓	---	---
	Division	1-2	2-3	---	---
	d/s Hydropower	---	---	✓	✓
Case III Diversion to Rana Pratap Sagar	With diversion				
	Gross capacity	✓	✓	✓	✓
	u/s M&I	✓	✓	---	---
	u/s Irrigation	✓	✓	---	---
	d/s Irrigation	✓	✓	---	---
	Division	1-2	2-3	---	---
	d/s Hydropower	---	---	✓	✓

Table 3 .

Case	Parameters considered
1. Case I	No linking Reservoir capacities and annual water use targets as per Project parameters 1, 2, 3, 4 run
2. CaseII	Diversion to Gandhi Sagar
5. Case II (1)	Reservoir capacities and annual water use targets asper Project parameters 1, 1-2, 2, 2-3, 4 run
4. Case II (2)	Reservoir capacities no change,annual water use targets modified by simulation 1, 1-2, 2, 2-3, 4 run
5. Case II (3)	Optimise Reservoir capacities, no change in water use targets 1, 1-2, 2, -3, 4 run
6. CaseIII	Diversion to Rana Pratap Sagar
7. Case III (1)	Reservoir capacities and annual water use targets as per Project parameters 1, 1-2, 2, 3, 2-4, 4 run
8. Case III (2)	Reservoir capacities no change, annual water use targets modified by simulation 1, 1-2, 2, 3 , 2-4, 4 run
0. Case III (3)	Optimise Reservoir capacities, no change in water use targets

A table showing various uses and scenarios used in study furnished below:

First individual reservoir simulation has been done for Mohanpura, Kundaliya, Gandhi Sagar and Rana Pratap Sagar reservoir. Thereafter multi reservoir simulation has been done in three scenarios as depicted in Figs. 1, 2 and 3(a) i.e linking Mohanpura to Kundaliya, Kundaliya to Gandhi Sagar reservoir, Gandhi Sagar to Rana Pratap Sagar reservoir (b) Mohanpura to Kundaliya reservoir, Kundaliya to Rana Pratap Sagar reservoir. In order to estimate model parameters viz. inflow of four reservoirs rainfall to reservoirs, evaporation and evapotranspiration, irrigation, water requirement, diversion/transfer and hydro power need and their monthly distribution, reservoir elevation curve and water spread area on various capacity has been prepared. Data available from Metrological Department Observatory at Rana Pratap Sagar and at Ujjain has been used to assess evaporation values. The municipal, industrial and hydro power demand has been considered uniformly distributed throughout the year and irrigation demand has been considered based on climatological water demand. The diversion in case of linking various reservoirs has been computed on the basis of surface water available on the dam site. Computer program by least square method and block print for area capacity and elevation curve are attempted to fit multi leaner regression format.

$Y = a_o + a_1x + a^2_{2x} + a^3_{3x} + a^3_{3x} + \ldots\ldots a_{n-1}x^{n-1}$, fitted curve for reservoir content are given at Table 2:

Table 4 Fitted curve of elevation vs reservoir content for four reservoirs

Site	Relationship	Coff. of correlation
1	ELEVAT = (379.391d3) + (C.2756923*(x))−(0.1240241 * 10.** ((−2) * (x**2)) + (0.1817969 * 10.**(−5)*(x**3))	0.999
2	ELEVAT = (344.8298) + (0.9812164 * 10.**(−1)*(x)) −(0.1098583 * 10.**((−3)* (x**2)) + (0.4022513*10.**((−1) * (x**3))	0.999
3	ELEVAT = (356.5933) + (0.296533 * 10.**((−1)*(x)) −(0.7289138 * 10.**((−5)*(x**2)) + (0.5532964 * 10.**(−9) * (x**3))	0.990
4	ELEVAT = (321.7425) + (0.3002614*10.**(−1) * (x)) −(0.1258786*10.**((−) * (x**2)) + (0.300264 * 10.**(−8) * (x**3))	0.994

The rule curve used is simulation study of Chambal basin are described below:

(1) The volume of water released during any period cannot exceed the contents of the reservoir at the beginning plus the flow into the reservoir during the period i.e.:

$$O_{nt} < S_{t-1} + I_{lt} + P_t + I_{lt} - O_{nt} - EI_{lt} - Ymin_t \quad \text{for all } t \tag{1}$$

(2) The continuity equation for reservoir is defined as

$$S_t = S_{t-1} + I_{lt} + P_t + I_{lt} - O_{nt} - EI_{lt} - O_{nt1} \quad \text{for all t} \tag{2}$$

(3) The content of the reservoir at any period cannot exceed the capacity of the reservoir as well as the dead storage of the reservoir puts a lower limit on the reservoir storage such as

$$Yd = Ymin_t < S_{t-1} < Y \quad \text{for all t} \tag{3}$$

(4) Hydropower generation E = c.e. $Ha_tO_{nt,}$ Wherein.
EI_{lt} = Reservoir evaporation in time t
I_{lt} = River inflow to reservoir in time t
I_{lt} = Local inflow to reservoir from surrounding areas in time t
O_{nt} = total water release from reservoir in time t
O_{nt1} = release to natural channel (downstream riparian rights) from reservoir in time t
P_t = Precipitation directly upon reservoir in time t
t = Any time
Y = total capacity of reservoir at maximum pool level
Y_d = Dead storage of reservoir
$Ymin_t$ = variable capacity up to minimum pool level of reservoir in time t
E = Monthly energy generation
c = conversion factor
e = Turbine and Energy efficiency.
Ha_t = Average - storage head for time t
O_{nt} = Release from reservoir in period t (MM3).
$Q_t \leq$ Q Max where Q_{MAX} = Maximum turbine discharge

3.1 Model Parameter Estimation

Inflow to Gandhi Sagar Reservoir

No records of flow of the Chambal River over maintained anywhere prior to 1946. It was only in 1916 when a G & D site about 16 km upstream of Chambal gorge were maintained till same get vitiated in 1959 due to backing of the stored water in Gandhisagar reservoir. Since then the inflow into the reservoir have been computed from the changes of reservoir level and out flows releases. The 75 and 50% dependable yield works out to be 3817 Million Meter 3 and 6333 Million Meter 3 as per Master Plan of Govt. of M.P.

Inflow to Rana Pratap Sagar Reservoir
The Catchment area of Chambal river at the Gandhisagar Dam is 22748 and 2275 Sq. Km. between Gandhisagar and Rana Pratap Sagar hence the inflow to this reservoir through the free catchment between Gandhisagar and Rana Pratap Sagar has been estimated to be about 10% of inflow at Gandhisagar. The Rana Pratap Sagar lies at downstream of Gandhisagar & downstream return flow and spill at Gandhisagar is considered to join historical inflow at Rana Pratap Sagar.

Inflow at Mohanpura Reservoir
The discharge data at Sangod site intercepting a catchment area of 9337 Sq. Km against the catchment of 3594 Sq. Km upto Mohanpura Dam has been utilised. The site is operative since 1970–71.

Inflow at Kundaliya Reservoir
The discharge data at Saranpur G&D site intercepting a catchment of 2600 Sq.Km. against 5953 Sq. Km. upto kundaliya dam has been utilized. The site is operative since 1975–76. The 75 and 50% depend yield works out to be 1694 Million Meter3 and 1254 Million Meter3.

Evaporation
At Chambal reservoir with the help of Meteorological Department, an observatory was set up at Rana Pratap Sagar Dam in the year 1956 which maintain the daily record of rainfall, wind velocity, Temperature and evaporation losses. At Mohanpura and Kundaliya reservoirs in the absence of Meteorological observatory at these sites the evaporation loss data has been taken from Meteorological observatory at Ujjain.

3.2 Monthly Demand Pattern

The Municipal and industrial demands has been considered uniformly distributed throughout the year while the irrigation demands have been considered on the basis of average flow available at reservoir sites. The hydropower demands have been considered uniformly distributed throughout the year, i.e., giving constant firm supply. The diversion demands have been considered on the basis of working table of surplus water available at Dam sites.

4 Flow Diagram

Case I No diversion

When these reservoirs are operated in isolation

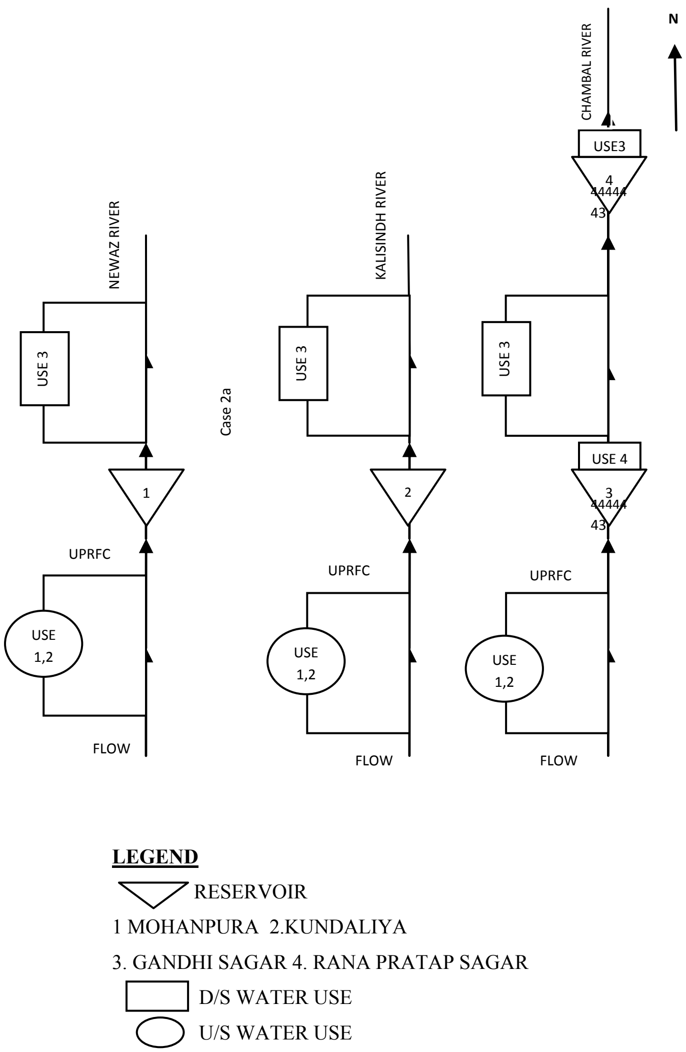
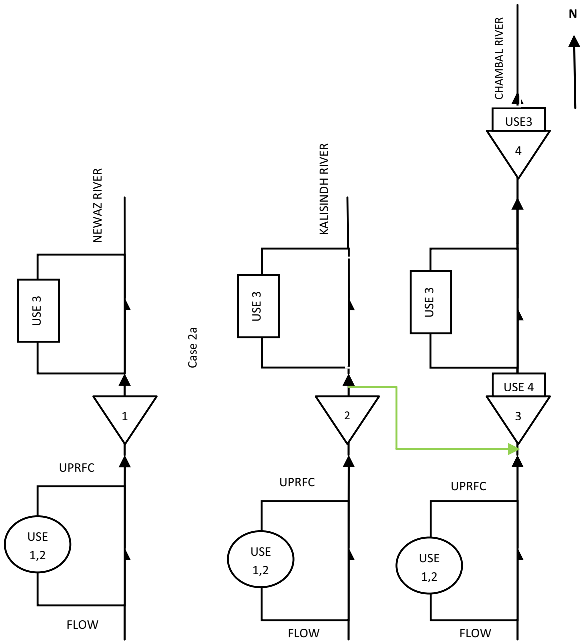


Fig. 1 Simulation without any diversion no interlinking

Case II Linking with Gandhi Sagar 1, 2, 2–3, 4

Case II Linking with Gandhi Sagar 1, 2, 2-3, 4 (Figure 2)

When water is diverted after accounting their in-basin use from one reservoir viz. Mohanpura to Kundaliya and then combined flows from Kundaliya to Gandhi Sagar



LEGEND

RESERVOIR

1 MOHANPURA 2.KUNDALIYA

3. GANDHI SAGAR 4. RANA PRATAP SAGAR

D/S WATER USE

U/S WATER USE

Case II1,2,2-3, 3,4 simulation Kundaliya to Gandhi Sagar in three scenarios (I) Original Parameters (II), Increase in output (III) Reduction in reservoir capacities

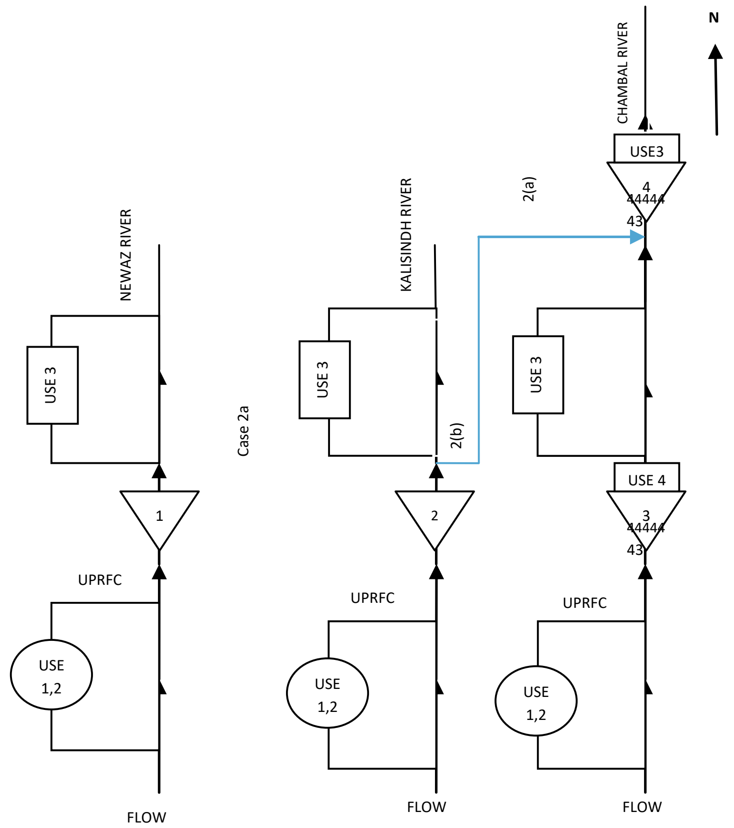
Fig. 2 Reservoir configuration case linking with Gandhi Sagar (1, 2, 2–3, 4) CaseII

Case III Linking with Rana Pratap Sagar

When water is diverted after accounting their in-basin use from Mohanpura to Kundaliya reservoir and then to Rana Pratap Sagar thus having no addition of water in U/s Gandhi Sagar.

Case III Linking with Rana Pratap Sagar

When water is diverted after accounting their in-basin use from Mohanpura to Kundaliya reservoir and then to Rana Pratap Sagar thus having no addition of water in U/s Gandhi Sagar



LEGEND

RESERVOIR

1 MOHANPURA 2.KUNDALIYA

3. GANDHI SAGAR 4. RANA PRATAP SAGAR

D/S WATER USE

U/S WATER USE

Case III 1,2,2-4,3,4 simultionKundaliya to Rana Pratap Sagar

NOTE: Case II (b) done in three scenarios

(I) Original Parameters (II), Increase in output (III) Reduction in reservoir capacities

Fig. 3 Reservoir configuration case linking with Rana Pratap Sagar (1, 2, 3, 2–4) CaseIII

5 Analysis and Results

Case I—No diversion

Mohanpura reservoir andKundaliya reservoir have sufficient water to divert to other reservoirs. The project dependability criteria assessed for D/S irrigation uses are more than 75%. The average Hydropower generated in case of Gandhi Sagar reservoir 200 thousand MW hr which is 35% of annual requirement at 90% project dependability assessed. The average hydropower generated in case of Rana Pratap Sagar 48 thousand MW hr which is 7% of annual requirement at 90% project dependability.The simulation analysis yielded the required output for cases considered above. The typical summary of output is presented in Table 5.

Table 5 CASE 1: Simulation without any diversion no interlinking (Millions of Cubic Meter)

Sl. no.	Reservoir	Water use/ reservoir capacity	Target		Modified target by simulation			
			Design parameters		Simulated parameters			
			Annual value/ reservoir capacity	Project dependability criteria (%)	Annual value/ reservoir capacity	Average annual deficit	No. of deficits out of 16 years	Project dependability criteria assessed (%)
1	Mohanpura	Gross Capacity	107.05	100	-	-	-	-
		U/S M&I	92.00	100	50.00	0.0	0	100.0
		U/S Irrigation	199.00	75	17.00	0.2	4	75.0
		D/S Irrigation	62.00	75	62.00	1.8	2	90.0
		Diversion	337.00	75	337.00	1.6	1	93.0
2	Kundaliya	Gross Capacity	579.10	100	579.00		-	-
		U/S M&I	160.00	100	160.00	0.0	0	100.0
		U/S Irrigation	879.00	75	879.00	14.26	4	75.0
		D/S Irrigation	53.40	75	53.40	0.0	0	100.0
		Diversion	642.40	75	642.40	0.0	0	100.0
3	Gandhi Sagar	Gross Capacity	7743.79	100	-	-	-	-
		D/S Irrigation	3363.00	75	3363.00	29.07	2	90.0
		D/S Hydropower	700.80	90	633.90	21.16	1	94.0
4	Rana Pratap Sagar	Gross Capacity	3237.89		-	-	-	-
		D/S Hydropower	788.40	90	50.00	0.52	1	94.0

Case II when water is diverted after accounting their in-basin use from one reservoir viz. Mohanpura to Kundaliya and then combined flows from Kundaliya to Gandhi Sagar.

Csse II(1) Reservoir Capacities and Annual Water Use Targets as per Project Provisions
The proposed diversion from Mohanpura and Kundaliya reservoirs are 337 Million Meter 3 and 642 Million Meter 3 transfer water at 93 and 100% project dependability respectively. The average hydropower generated in case of Gandhi Sager reservoir is 633 thousand MW hr which is about 3.17 times of average hydropower generated in case of without diversion (Case I) at same project dependability criteria.

Case II(2): Change in Proposed Project Annual Water Use Target
The diversion from Mohanpura and Kundaliya reservoirs is increased from 337 Million Meter 3 to 400 Million Meter 3 and 642 Million Meter 3 to 750 Million Meter 3 as compared to previous Case II2(a). Theaverage hydropower generated in case of Gandhi Sagar reservoir is 650 thousand MW hr which is about 3.25 times of average hydropower generated in case of without diversion at same project dependability criteria. The average hydropower in case of Rana Pratap Sagar reservoir is 50 thousand MW hr no significant increase.

Case II(3): Change in Proposed Project Reservoir Capacities; No Change In Project Annual Water Use Targets
Due to diversion the capacities of Mohanpura reservoir and Kundaliya reservoirs can be reduced upto 95 Million Meter 3 and 475 Million Meter 3 respectively with D/S irrigation and diversion successful at project dependability criteria of 75%. The average hydropower generated Gandhi Sagar reservoir and Rana Pratap Sagar reservoirs remains identical with Case 2(a)I. The typical summary of output is presented in Table 4.

Thus, the analysis with diversion to Gandhi Sagar Case II established either increase in target diver sion or reduction in reservoir capacity. the success rate of Mohanpura reservoir is 75% or more for irrigation, 100% for municipal and industrial uses and 100% for diversion in case II(1), 100% in case II(2) & 75% in case II(3) the success rate of Kundaliya reservoir is 75% or more for irrigation, 100% for municipal and industrial uses and 90% for 75% for diversion in case II(1), 75% in case II(2) & 75% in case II(3). The success rate of Gandhi Sagar in term of irrigation also increases to 90% and hydropower 94% in case II(1), no significant increase. The typical summary of output is presented in Tables 6, 7 and 8.

Table 6 CASE II(1)Reservoir capacities and annual water use targets as per project provisions (Millions of Cubic Meter)

Sl. no.	Reservoir	Water use/ reservoir capacity	Target		Modified target by simulation			
			Design parameters		Simulated parameters			
			Annual value/ reservoir capacity	Project dependability criteria (%)	Annual value/ reservoir capacity	Average annual deficit	No. of deficits out of 16 years	Project dependa- bility criteria assessed (%)
1	Mohanpura	Gross Capacity	107.05	100	-	-	-	-
		U/S M&I	92.00	100	50.00	0.0	0	100.0
		U/S Irrigation	199.00	75	17.00	0.2	4	75.0
		D/S Irrigation	62.00	75	62.00	1.8	2	90.0
		Diversion	337.00	75	337.00	1.6	1	93.0
2	Kundaliya	Gross Capacity	579.10	100	579.00		-	-
		U/S M&I	160.00	100	160.00	0.0	0	100.0
		U/S Irrigation	879.00	75	879.00	14.26	4	75.0
		D/S Irrigation	53.40	75	53.40	0.0	0	100.0
		Diversion	642.40	75	642.40	0.0	0	100.0
3	Gandhi Sagar	Gross Capacity	7743.79	100	-	-	-	-
		D/S Irrigation	3363.00	75	3363.00	29.07	2	90.0
		D/S Hydropower	700.80	90	633.90	21.16	1	94.0
4	Rana Pratap Sagar	Gross Capacity	3237.89		-	-	-	-
		D/S Hydropower	788.40	90	50.00	0.52	1	94.0

Table 7 CASEII(2): Change in proposed projects water use targets (Millions of Cubic Meter).

1	Mohanpura	Gross Capacity	107.05	100	-	-	-	-
		U/S M&I	92.00	100	50.00	0.0	0	100.0
		U/S Irrigation	199.00	75	17.00	0.21	4	75.0
		D/S Irrigation	62.00	75	62.00	2.8	4	75.0
		Diversion	337.00	75	400.00	5.5	2	90.0
2	Kundaliya	Gross Capacity	579.10	100	-	-	-	-
		U/S M&I	160.00	100	160.00	0.0	0	100.0
		U/S Irrigation	879.00	75	879.00	14.3	4	75.0
		D/S Irrigation	54.40	75	54.40	0.0	0	100.0
		Diversion	642.40	75	775.00	8.6	4	75.0
3	Gandhi Sagar	Gross Capacity	7743.79	100	-	-	-	-
		D/S Irrigation	3363.00	75	3363.00	259.3	4	75
		D/S Hydropower	700.80	90	650.00	19.8	2	90.0
4	Rana Pratap Sagar	Gross Capacity	3237.89	100	-	-	-	-
		D/S Hydropower	788.40	75	50.00	0.5	2	90.0

Table 8 CASE II(3): Change in proposed reservoir capacities; no change in proposed projects water use targets (Millions of Cubic Meter)

1	Mohanpura	Gross Capacity	107.05	100	95.00	-	-	-
		U/S M&I	92.00	100	50.00	0.0	0	100.0
		U/S Irrigation	199.00	75	17.00	0.21	4	75.0
		D/S Irrigation	62.00	75	62.00	2.72	4	75.0
		Diversion	337.00	75	337.00	1.13	2	75.0

(continued)

Table 8 (continued)

2	Kundaliya	Gross Capacity	579.10	100	475.00		-	-
		U/S M&I	160.00	100	160.00	0.0	0	100.0
		U/S Irrigation	879.00	75	879.00	14.30	4	75.0
		D/S Irrigation	879.00	75	53.40	0.21	3	80.0
		Diversion	642.40	75	642.40	16.12	4	75.0
3	Gandhi Sagar	Gross Capacity	7743.79	100	-	-	-	_
		D/S Irrigation	3363.00	75	3363.00	8.51	1	75.0
		D/S Hydropower	700.80	90	633.87	24.42	2	90.0
4	Rana Pratap Sagar	Gross Capacity	3237.89	100	-	-	-	_
		D/S Hydropower	788.40	75	50.00	0.52	1	90.0

Note: All Hydropower values are in mega watt hours

Case III when water is diverted after accounting their in-basin use from one reservoir viz. Mohanpura to Kundaliya and then combined flows from Kundaliya to Rana Pratap Sagar.

Case III(1) Reservoir Capacities And Annual Water Targets As Per Project Provisions

The Mohanpura reservoir can transfer water 337 Million Meter 3 at 94% project dependability assessed while Kundaliya reservoir can transfer water 570 Million Meter 3 at 75% project dependability assessed, with D/S irrigation at all the projects successful at project dependability criteria of 75%. The average Hydropower does not increase in case of Gandhi Sagar reservoir as compared to without diversion case. The average hydropower generated in case of Rana Pratap Sagar reservoir 175 thousand MW hr is 22% of annual requirement which is about 3 times of the hydropower generated in case of without diversion.

Case III(2) Change in Proposed Project Annual Water Use Target
The proposed Mohanpura reservoir can transfer 400 Million Meter 3 (larger as compared with 2(b)I case) while there is no change in diversion from Kundaliya reservoir at 75% project dependability assessed, with D/S irrigation at all the projects successful at project dependability criteria of 75%. The average hydropower generated does not increase in case of Gandhi Sagar reservoir as compared without diversion case. The average hydropower generated does not increase in case of Rana Pratap Sagar reservoir case 2(b)I.

Case III(3) Change in Proposed Project Reservoir Capacities; to Change In Project Annual Water Use Target
Capacities of Mohanpura reservoir and Kundaliya reservoir can be reduced upto 95 Million Meter 3 and 475 Million Meter 3 respectively with D/S irrigation and diversions successful at project dependability criteria of 75%. The average hydropower generated at Gandhi Ssagar reservoir does not increase as compared to the case of no diversion. The average hydropower generated in case of Rana Pratap Sagar is about 24% of annual requirement which is about 3.2 times of hydropower generated in case of no diversion.

The analysis with diversion to Rana Pratap Sagar Case III it is found that either diversion can be increased or hydro power can be increased, the success rate for Mohanpura and Kundaliya remains same as in case II, No change in success rate of Gandhi Sagar over case I and increase in power generation in case III(1),(2) & (3) up to 94%.

The typical summary of output is presented in Tables 9, 10, 11.

Table 9 CASE III(1): Reservoir capacities and annual water use targets as per project provisions (1,1–2, 2, 3, 2–4, 4 run) (Millions of Cubic Meter)

Sl. no.	Reservoir	Water use/ reservoir capacity	Target		Modified target by simulation			
			Design parameters		Simulated parameters			
			Annual value/ reservoir capacity	Project dependa-bility criteria(%)	Annual value/ reservoir capacity	Average annual deficit	No. of deficits out of 16 years	Project dependa-bility criteria assessed (%)
1	Mohanpura	Gross Capacity	107.05	100	-	-	-	-
		U/S M&I	92.00	100	50.00	0.0	0	100.0
		U/S Irrigation	199.00	75	17.00	0.21	4	75.0
		D/S Irrigation	62.00	75	62.00	0.0	0	100.0
		Diversion	337.00	75	337.00	0.61	1	94.0

(continued)

Table 9 (continued)

Sl. no.	Reservoir	Water use/ reservoir capacity	Target		Modified target by simulation			
			Design parameters		Simulated parameters			
			Annual value/ reservoir capacity	Project dependa-bility criteria(%)	Annual value/ reservoir capacity	Average annual deficit	No. of deficits out of 16 years	Project dependa-bility criteria assessed (%)
2	Kundaliya	Gross Capacity	307.05	100			-	-
		U/S M&I	160.00	100	140.00	0.00	0	100.0
		U/S Irrigation	62.00	75	604.31	10.44	3	81.3
		D/S Irrigation	53.40	75	53.40	0.00	0	100
		Diversion	644.60	75	570.00	28.57	4	75.0
3	Gandhi Sagar	Gross Capacity	7743.79	100	-	-	-	-
		D/S Irrigation	3363.00	75	3363.00	168.50	4	75.0
		D/S Hydropower	700.80	90	200.00	23.83	2	90.0
4	Rana Pratap Sagar	Gross Capacity	3237.89	100	-	-	-	-
		D/S Hydropower	788.40	75	175.00	0.15	2	94.0

Table 10 CASEIII (2): Change in proposed projects annual water use targets (1,1–2, 2, 3, 2–4, 4) (Millions of Cubic Meter)

1	Mohanpura	Gross Capacity	107.05	100	-	-	-	-
		U/S M&I	92.00	100	50.00	0.0	0	100.0
		U/S Irrigation	199.00	75	17.00	0.21	4	75.0
		D/S Irrigation	62.00	75	62.00	0.0	0	100.0
		Diversion	337.00	75	400.00	5.46	1	90.0
2	Kundaliya	Gross Capacity	307.05	100			-	-
		U/S M&I	162.00	100	140.00	0.00	0	100.0
		U/S Irrigation	879.00	75	604.31	10.44	3	81.3
		D/S Irrigation	53.40	75	53.40	0.00	0	81.0
		Diversion	644.60	75	570.00	28.57	4	75.0

(continued)

Table 10 (continued)

3	Gandhi Sagar	Gross Capacity	7743.79	100	-	-	-	-
		D/S Irrigation	3363.00	75	3363.00	168.50	4	75.0
		D/S Hydropower	700.80	90	200.00	23.83	2	90.0
4	Rana Pratap Sagar	Gross Capacity	3237.89	100	-	-	-	-
		D/S Hydropower	788.40	75	175.00	0.15	2	94.0

Note: All Hydropower values are in thousand Mega Watt Hours.

Table 11 CASE III(3): Change in proposed projects reservoir capacities: no change in proposed projects water use targets (Millions of Cubic Meter)

1	Mohanpura	Gross capacity	107.05	100	95.00	**-**	**-**	**-**
		U/S M&I	92.00	100	50.00	0.0	0	100.0
		U/S Irrigation	199.00	75	17.00	0.21	4	75.0
		D/S Irrigation	62.00	75	62.00	2.72	4	75.0
		Diversion	337.00	75	337.00	1.13	2	75.0
2	Kundaliya	Gross capacity	307.01	100	475.00	-	-	-
		U/S M&I	162.00	100	160.00	0.00	0	100.0
		U/S Irrigation	879.00	75	879.00	14.30	4	75.0
		D/S Irrigation	879.00	75	53.40	0.21	3	82.0
		Diversion	644.60	75	644.60	16.12	4	75.0
3	Gandhi Sagar	Gross capacity	7743.79	100	-	-	-	-
		D/S Irrigation	3363.00	75	3363.00	3.51	1	94.0
		D/S Hydropower	700.80	90	633.87	24.42	2	90.0
4	Rana Pratap Sagar	Gross capacity	3237.89	100	-	-	-	-
		D/S Hydropower	788.40	75	50.00	0.52	1	94.0

Note: All Hydropower values are in thousand Mega Watt Hours.

6 Concluding Remarks and References

From the detailed analysis of present study following conclusions are made:

(1) The study without diversion shows that water can be transferred from proposed Mohanpura and Kundaliya reservoirs.
(2) The sustainability of diversion, in cases II is better than in Case III
(3) The analysis of Case II diversion to Gandhi Sagar shows that the requisite proposed diversions from Mohanpura reservoir to Kundaliya reservoir and from Kundaliya reservoir to Gandhi Sagar reservoir can be increased with same reservoir parameters or alternatively reservoir capacities of Mohanpura and Kundaliya reservoirs can be reduced.
(4) In Case II increase in hydropower generation at Gandhi Sagar reservoir is established.
(5) In case III, diversion to Rana Pratap Sagar can be increased for same reservoir parameters.
(6) The analysis of case 3 also shows that the existing diversions proposed can increase the hydropower generation at Rana Pratap Sagar reservoir.

From above it is concluded that four reservoir if interlinked are more sustainable than in isolation.

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Assessment of Environmental Flow Requirements Through Rainfall-Runoff Modelling for Hydropower Project

C. Prakasam, R. Saravanan, and M. K. Sharma

Abstract Catchment modeling using computer-based models has been identified as an effective tool in water resources planning and management. However, physically-based distributed computer models require either high-resolution data for a shorter period or large amounts of past data which are not readily available for some basins. Environmental flow is termed as the minimum required flow that has to be released on the downstream side of the hydropower project to maintain the health of the ecosystem. The NGT order defines 15% of the average lean season flow as the environmental flow. In the Himalayan belt, there are many major and minor hydropower projects. Assessing the environmental flow requirements for the hydropower projects has many hiccups. One major disadvantage is the absence of the flow data or the reliability of the data. To overcome this, the research work attempts at evaluating the inflow data through rainfall-runoff modeling. This methodology will be useful for all the major and minor hydropower projects with data discrepancies. The planning and management of the river basin are principally relying on the accurate assessment and prediction of runoff. The rainfall, Soil, Evaporation data sets have been used in designing the model. The MIKE 11 NAM approach, a conceptual hydrological has been used in this research work for developing a runoff from the rainfall data. It has been evaluated to result in the inflow of any river basin and hydropower project. The inflow data of the river basin has been used to calculate the environmental flow. The flow duration curve method has been chosen to do the same. The required environmental flow is 150 m^3/s in the Pandoh hydropower project downstream side for a healthy ecosystem.

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1 Introduction

A key challenge to environmental flow assessment is to measure the amount of water that ought to be held in the river so as to keep up the health and esteemed highlights of riverine biological systems. Due to the discharge data deficiency, many indirect methods have been used for deriving the inflow that indirectly assesses the environmental flow. Appropriate investigation of precipitation data brings forth educated measurable data which is the spine for legitimate planning of hydrological hazards. One of the primary analyses, while investigating landforms and estimating the surface discharge, is drainage analysis; since it has a specific pertinence to geomorphology. For a drainage basin, the hydrological response is defined by the generation of a runoff against a given rainfall, which in turn depends on various parameters, like morphometric properties of the basin, soil quality, and land use design. The drainage system is an example shaped by rivers, streams, and lakes in a drainage basin. The drainage system, due to its indivisibility, is a vital element in terrain analysis and geographical information systems (GIS). In a drainage system, rivers or streams dependably interface organized to shape systems. The environmental flow is the minimum flow that has to be maintained on the downstream side of the river to maintain the health of the ecosystem. To assess the required environmental flow, there are many challenges. The lack of data is one of the key issues in environmental flow evaluation. To overcome that, this method is employed in assessing the flow data from the rainfall data and in turn evaluating the environmental flow from the simulated runoff data. By maintaining the evaluated environmental flow, the health of the ecosystem will be sustained.

[1] the rainfall-runoff modeling process is highly nonlinear and time-varying. To select the suitable hydrological model, hydro metrological data, accuracy criteria, and hydrological problem plays the criteria. The parameters are finalized by calibrating the model as the parameters cannot be collected from the source [2]. Simulated the rainfall-runoff modelling in Vinayakpur, Chhattisgarh state using MIKE 11 NAM model. The gauge flow data (2001 to 2004) was used to calibrate and validate for a period of 3 years (2005 to 2007). The Nash–Sutcliffe coefficient helps us in determining the reliability of the MIKE 11 NAM model, root mean square error (RMSE), and correlation coefficient (r^2). The advantage of the NAM model is that the large basin can be divided into small sub-basins in a network form and each basin contribution can be calculated. [3]. The rainfall-runoff models are the simplified characterization of the real-world system into models. MIKE 11 NAM model is one of the most accurate rainfall-runoff models being used the world over [4]. The NAM model describes the land cover behaviours against the hydrological cycle via a set of linked mathematical statements in a simplified way [5]. Utilized the RS techniques to generate the land use/cover maps, Thiessen polygon for evapotranspiration, rainfall, soil map, and Topography map were prepared using ArcMap. The model has been

calibrated and validated for 4 and 2 years respectively, considering different efficiency criteria between observed and simulated discharge [6]. The simulated flow will be compared with the gauged flow data followed by the auto-calibration procedure of NAM model parameters. The calculated set of NAM model parameters is used for this purpose. The resultant NAM parameters are obtained by calibrating the hydrological observational time series data either automatically or manually [7]. To minimize the water balance error and overall RMSE between the simulated and observed runoff, the auto-calibration will be carried out. It's also done to optimize the hydrograph shape [8]. Carried out the rainfall-runoff modeling for the Shaya catchment, Ethiopia using MIKE 11 NAM model. The correlation between the observed and computed runoff was in good agreement, in particular, the low runoff compared to the high runoff. High flow phenomena are often not caught by hydrological models but the low and average flows do.

[9] studied the drainage pattern for the environmental planning of the Suketi river basin using a 1:50,000 scale survey of India (SOI) toposheets to prepare the base map to analyze the Strahler stream and also various thematic maps were prepared to delineate the Suketi river basin tributaries. [10] modeled geoinformatics-based for Muya watershed for its drainage qualities in the drainage of Upper Niger in Nigeria. Stream pattern was generated using the Landsat images and topographic map, whereas initially DEM was created using the topography map. The process assessed the fundamental drainage parameters such as flow accumulation, direction, length, density, bifurcation ratio, etc., were estimated to give a brief idea about the drainage model in the study area. [11] introduced a technique dependent on quantitative indicators of geometry to perceive drainage designs in a river arrange spontaneously. The author gave an overview of different types of drainage patterns and their characteristics. [12] an endeavor has been made using GIS to examine morphometric parameters of Karadya small-scale watershed. The investigation uncovers that the terrain shows a dendritic sort drainage design with the most noteworthy stream request being the 3rd order [13]. Utilized the hydrological sensitivity method for the Hwacheon dam upper basin to point out the discharge variations and the outcomes from this examination can be utilized successfully to build up the transboundary river basin between South and North Korea. [14] used the Hydraulic Engineering Center-Hydrologic Modeling System (HEC-HMS) to generate the rainfall-runoff model for the Cahora Bassa and GIS techniques to evaluate both the ungauged and gauged runoff involvement in the water balance. [15] used the HEC-HMS which transforms precipitation excess into runoff and overland flow [16]. The assumptions regarding the extreme rainfall-runoff relationships are less valid in most cases. Studying the extreme runoff event will be useful in designing and managing the basin infrastructure and water management [17]. Regression analysis and land use classification techniques identified environmental indicators of inflow at ungagged locations. [18] studied the effects of land-use change impact on inflow and sediment yield were found to be positive [19]. In the process of evaluating the environmental flow the fundamental thing is to monitor the authenticity of the input data by checking and improving the certainty of the data, yet in addition to assess whether assigned environmental flow norms attain the required outcome of a healthy ecosystem [20].

The dam/weir controls optimize the flow of the river impacting the socioeconomics and the environment [21]. The storage of flow, Abstraction, and diversion modify the river's nature. To mitigate environmental flows are applied and to defend affected rivers from ecological weakening. Ecologically sustainable environmental flows must be function- and process-oriented [22]. Stated that hydropower development and climate change are two major stressors that affect the riverine ecosystems. Both the stressors are facilitating the invasions by non-native species in the river. Native fish shifted further to tributary and higher in elevation than non-native [23, 24]. The assessment of the minimum flow requirement is needed to preserve ecosystem functionality at its balance. The timing, quantity, and quality of required river flow for the sustenance of the human livelihoods and the freshwater ecosystems are termed as the environmental flow [25]. The environmental flow is the minimum flow required for maintaining the health of the ecosystem [26]. The impact due to the hydropower project on the downstream side has been highlighted through the GIS application for the Pandoh Hydropower project. Table 1 shows the comparison of various models.

Table 1 Comparison of models

Model	Inferences	Reference
Hydrologic Engineering Centre's Hydrologic Modelling System (HEC-HMS)	This model of dendritic pattern helps the watershed to divide and rule the process for each and every component such as sources, sinks, junctions, reservoirs, reaches, diversions, and sub-basins	[27]
Distributed Hydrology-Soil-Vegetation Model (DHSVM)	The model development was done especially for the cases of complex natural terrains The model processes the effects of roads on the paths of forest and snow melts	[28]
Water Flow and Balance Simulation Model (WaSiMETH)	The WaSiMETH model accounts for various sizes of watersheds in the regions of pre-alpine and alpine respectively	[29]
MIKE SHE	The model of empirical equations and illustration of physically-based methods. It is a clubbed framework of a fully distributed and physically-based hydrological model	[30]
WATFLOOD	This model mainly preserves the computational efficiency by forming subgrid-scales in the hydrological variability. As there are various HRU's complied under Grouped Response Unit (GRU) for processing the parameters	[31]
Variable Infiltration Capacity (VIC)	For the consideration of spatial heterogeneity, the VIC model is in macro-scale approaches for the varied hydrological characteristics in the watershed	[32]

(continued)

Table 1 (continued)

Model	Inferences	Reference
Soil Conservation Service Curve Number (SCS-CN) Method	This method is a combined form of the physically conceptual and spatially lumped process which is strictly adhered to empirical formulae along with simple mass balance equations	[33]
Soil and Water Assessment Tool (SWAT) and TOPMODEL	The SWAT model is an alternative or semi-distributed model while TOPMODEL for the physically-based one. Both the model comes under lumped type with the Hydrologic Response Unit (HRU) characterization for the analysis of parameters like elevation, climate, soil, slope, and aspect	[34]

The flow data maintained by the dam administration is costly and not much reliable. The lack of data disables the environmental flow assessment paving the way to non-maintenance of the environmental flow. As the authenticity of the flow data is questionable. The present research attempts at simulating the inflow data i.e., runoff data from the rainfall data collected from IMD. The Mike Hydro Basin model has been used for the rainfall-runoff modelling of the basin to simulate the flow data. The estimated flow will be used for calculating the environmental flow required using the Flow Duration Curve. The estimated environmental flow has been suggested as the required minimal flow that has to be maintained downstream of the river to maintain the health of the ecosystem.

2 Study Area

Pandoh dam is located in Mandi district, Himachal Pradesh, India. It is an embankment dam on the Beas River. It is 2134 m in length, 457 m in width is situated in Mandi district of 134 hectares catchment area encompassed by Shivalik mountains at 899 m altitudes. Bhakra Beas Management Board (BBMB) operates and manages the dam since 1977. The Pandoh dam is located downstream of the Larji hydropower project. The monthly average of the maximum and minimum daily air temperature was recorded to be 40 and −3’C in May and December month. The increase is quite gradual in beginning but fairly rapid from June onwards with the highest flow occurring in July and August. Towards the end of September or early October, the flow begins to recede sharply. The lowest flow generally occurs in January and February. The conversion of snowmelt to the river occurs in winter and vice versa during the summer. Since Pandoh Lake is situated in the tropical belt of the Indian subcontinent therefore climatologic data is very explicit and objective. The snow cover in the region is 45%. The maximum temperature is found in the July month of the monsoon but the general trend indicates that daily temperature is greater

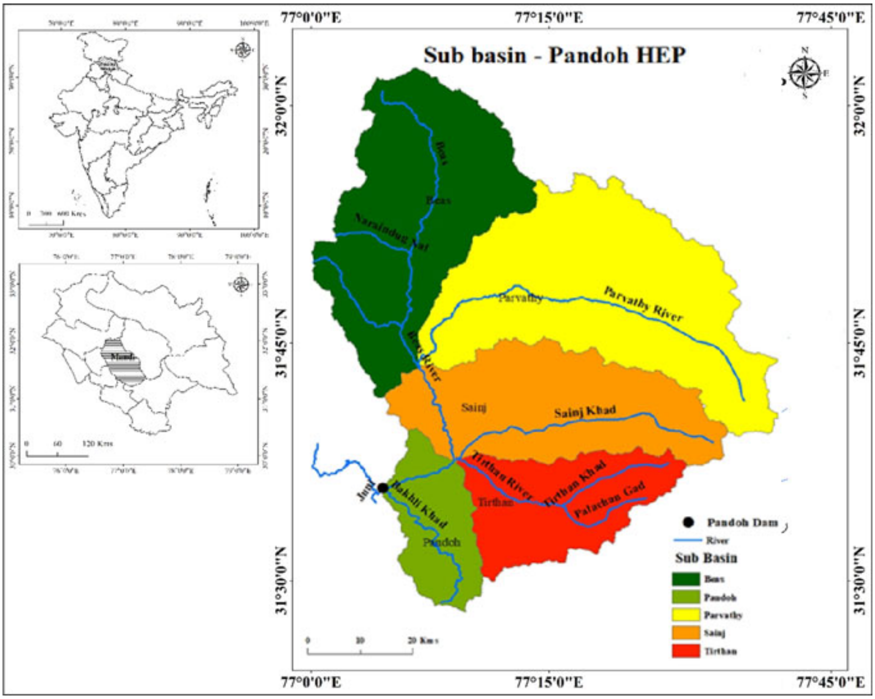

Fig. 1 Study area map. *Source* SOI Toposheets and ASTERDEM

in the summer season. The unexpected high temperature in the monsoon season may be due to global warming and the high-altitude effect. The monsoon season also experiences high relative humidity than winter and summer. The slope in the basin is of the moderate slope of 28% area coverage. The study area is in the hilly region. The plain region is along the riverside of 14.43% area. The soils such as gray micaceous sandstones, sandstones, and shales of sub-Himalayan are found in this region. The sources for the Pandoh dam are Beas River, Sainj, Tirthan river, Parvathy River. Based on the river, the basin has been divided into sub-basins as shown in Fig. 1.

3 Materials and Methods

3.1 NAM Model

Rainfall-Runoff (RR) modeling has been carried out for the selected river basin using the NAM model in the MIKE Basin software. NAM (Nedborg Afstromnings Model) is a conceptual, lumped, and deterministic RR model that operates between the baseflow, overland flow, and interflow storages. These are mutually interrelated storages in which continuous account for the moisture content is modelled. NAM is based on important nine parameters, representing the surface zone, root zone, and groundwater storage. NAM model is set up with the input information such as rainfall and climate data for each sub-basin and it is simulated for the period from 1980–2018 (Table 2). The number of rain gauges and climate stations contributed to each sub-basin is shown as Theisen polygon analysis of rain gauge and climate station for each sub-basin in Figs. 2 and 3. The river run-off consists of two parts, one which is derivative of snow ice/glacier melting around the catchment and directly derived from the rainfall. The snowmelt is a dominating factor in the production of run-off. The primary use of the NAM model is to simulate the runoff and also for forecasting the droughts/floods. There are two types of model Lumped conceptual models (NAM type) and Distributed physically-based models (MIKE SHE type). In the NAM type, the following analysis can be performed as the simulation of spatial patterns within a catchment, Water quality (non-point), Soil erosion, Effects of land-use change, Surface water/groundwater interaction, Climate change studies/coupling with atmospheric models (Table 3).

Table 2 Rain gauge station and observed data availability details. *Source* IMD

S.No	Station	District	Latitude	Longitude	From	To
1	Bajura	Kullu	29.62	81.60	2011	2018
2	Dhundhi	Kullu	32.35	77.13	2008	2016
3	Manali	Kullu	32.24	77.19	1979	2018
4	Solangnala	Kullu	32.31	77.15	2008	2013
5	Bhuntar	Kullu	31.86	77.15	1980	2018
6	Keylong	Lahul And Spiti	32.57	77.03	1979	2018
7	Kokhsar	Lahul And Spiti	32.41	77.23	1979	2009
8	Kothi	Lahul And Spiti	32.31	77.19	1979	2009
9	Baldwara	Mandi	31.56	76.76	2007	2018
10	Bhang	Mandi	31.00	77.00	2008	2016
11	Bharol	Mandi	31.93	76.71	2001	2016
12	Bijahi	Mandi	31.55	77.10	1991	2018
13	Gohar	Mandi	31.58	77.05	1990	2018
14	Jhungi	Mandi	31.39	77.11	1979	2013
15	Mandi	Mandi	31.59	76.92	1981	2018
16	Sundernagar	Mandi	31.54	76.9	1980	2018

Table 3 Average ET value. *Source* IWMI data portal

Month	Average ET	Month	Average ET
January	1.09	July	3.56
February	1.46	August	3.21
March	2.33	September	3
April	3.39	October	2.36
May	3.98	November	1.61
June	4.17	December	1.21

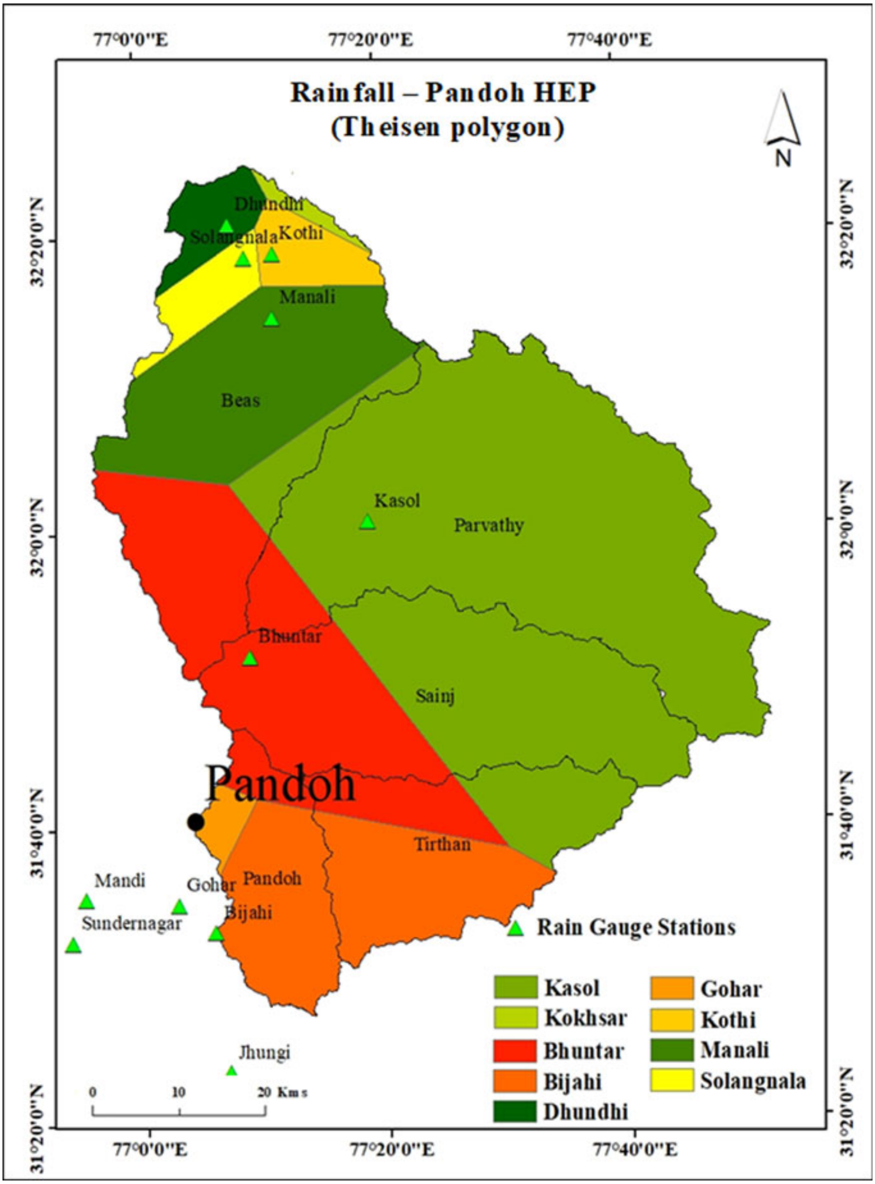

Fig. 2 Rainfall–Pandoh hydropower project (Theisen polygon)

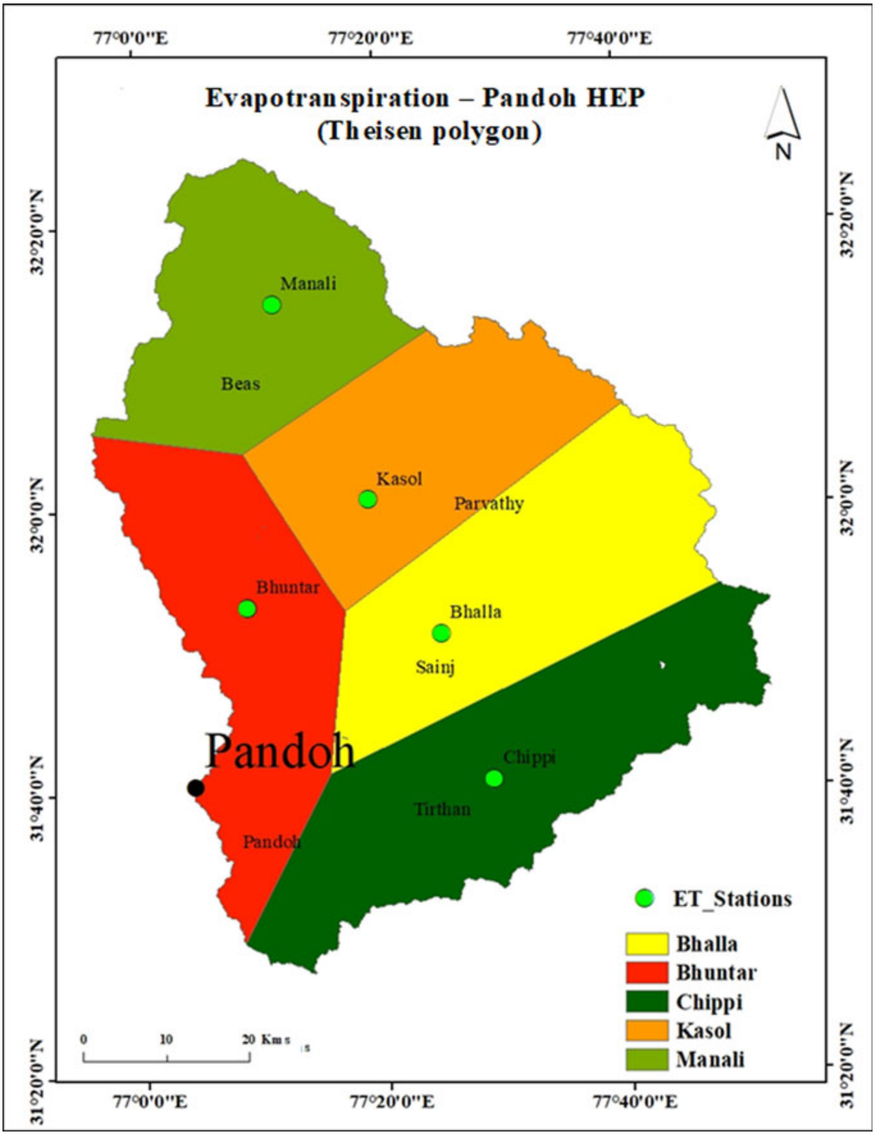

Fig. 3 Evapotranspiration–Pandoh hydropower project (Theisen polygon). *Source* IWMI

3.2 Rainfall-Runoff Modeling

In the process of estimating the catchment runoff, we can determine the temporal and spatial variation in water availability, calculate deficits (lack of water) and understand the impact of changes in water usage or climate. There are 15 NAM parameters of which 5 parameters are usually changed to mimic the ground condition and 10 parameters are used for calibration. The parameters such as L_{max}, U_{max}, and CQOF are used for water balance modelling while the others are used for adjusting the peaks and for routing. The input data for simulating the rainfall-runoff modelling in the NAM model are the rainfall data, Evapotranspiration Monthly mean and for calibrating the model the inflow data is used. Table 4 shows the parameter definition, values, and characteristics. Figure 4 shows the Model window.

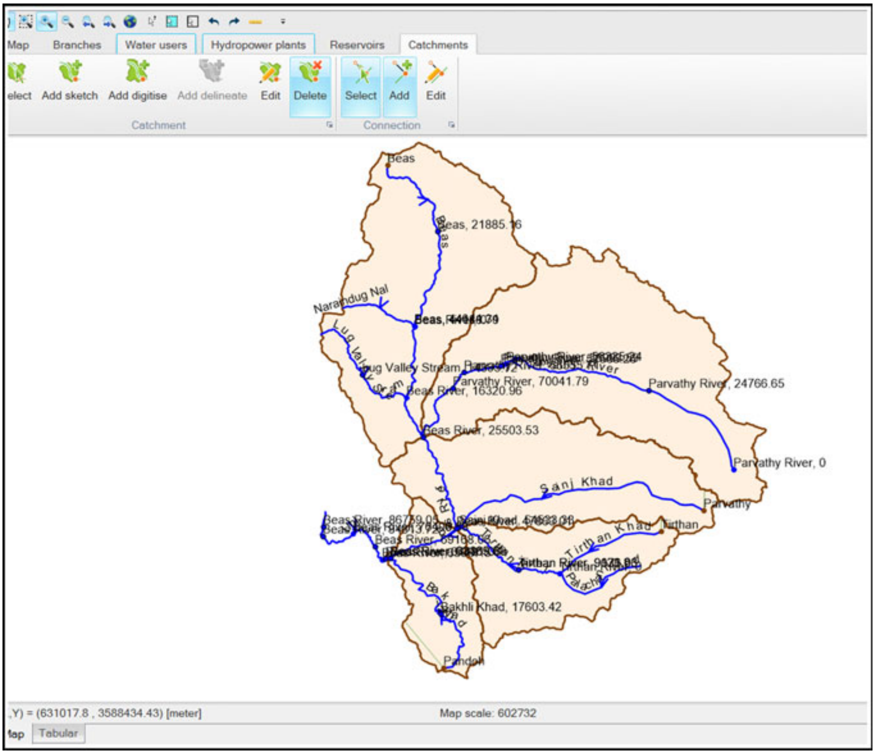

Fig. 4 MIKE HYDRO Basin–NAM model

Each basin has its runoff response to rainfall and will respond differently to various rainstorm events. Land use, topography, and soil moisture are the key factors of runoff. Basins with steep slopes tend to shed more water and infiltrate less. Due to rapid runoff, less infiltration, and antecedent soil moisture condition, basin areas will have a high runoff. Spatial distribution of rainfall data is essential in rainfall-runoff and water balance analysis to capture the real ground condition. The NAM model requires setup parameters such as topography, catchment area, and soil properties. Model parameters such as threshold values and time constants for routing of overland, inter, and baseflow. The hydro-meteorological data such as evaporation, streamflow, and precipitation. The basin is divided into 10 equal elevation zones delineated from the DEM. The area for each elevation has been calculated and entered correspondingly. The amount of precipitation for each elevation zone is corrected based on the following equation.

$$R = 100\left(\exp[0.0003(E_i - E_{ave})]\right) \quad (1)$$

Where Ri = Correction ratio (%), $E_{i\,=}$ average elevation of each elevation zone (m), E_{ave} = average elevation of catchment (m). (Source: Step-by-step Guideline for MIKE 11-RR (NAM) Model).

Table 4 NAM parameters and characteristics. *Source* DHI

Parameter	Symbol	Characteristics	Value range
Maximum water content in surface storage	Umax	✓ Maximum contents of surface storage ✓ Evaporation; small peaks	10–25 mm
Maximum water content in root zone storage	Lmax	✓ Maximum contents of rootzone storage ✓ Evaporation; water balance	50–250 mm
Overland flow runoff coefficient	CQOF	✓ Overland flow coefficient ✓ Divides excess rainfall in runoff and infiltration	0.01–0.99
Root zone threshold value for overland flow	TOF	✓ The rootzone threshold value for overland flow ✓ Delays overland flow at the beginning of a wet season	0.0–0.7
Root zone threshold value for groundwater recharge	TG	✓ Root zone threshold value for recharge ✓ Delay's groundwater recharge at the beginning of a wet season	0.0–0.7
The time constant for routing base flow	CKBF	✓ The time constant for routing baseflow ✓ Determines the shape of the baseflow hydrograph	500–5000 h
Time constants for routing overland flow	CK1, CK2	✓ The time constant for routing overland flow ✓ Determines the shape of peaks	3–48 h

Table 5 Theisen weightage for rainfall data

Sub-Basin	Area	Station	Subbasin area coverage	Weightage
Beas	1416.763	Bhuntar	332.61	0.235
		Kothi	117.03	0.083
		Kokhsar	26.92	0.019
		Solangnala	103.85	0.073
		Manali	611.68	0.432
		Bharol	8.00	0.006
		Kasol	104.68	0.074
		Dhundhi	111.96	0.079
Pandoh	420.1266	Jhungi	13.51	0.032
		Bhuntar	60.93	0.145
		Gohar	46.94	0.112
		Bijahi	297.75	0.709
Parvathy	1765.268	Nichar	237.48	0.135
		Bhuntar	78.64	0.045
		Kasol	1448.22	0.820
Sainj	1093.351	Nichar	141.58	0.129
		Bhuntar	396.73	0.363
		Kasol	555.04	0.508
Tirthan	679.6776	Nichar	111.31	0.164
		Bhuntar	138.05	0.203
		Bijahi	337.32	0.496
		Kasol	92.99	0.137

Table 6 Theisen weightage for evapotranspiration data

Basin name	Area	Station	Sub basin area	Weightage
Beas	1416.763	Kasol	89.98379	0.06
		Bhuntar	383.3006	0.27
		Manali	943.4366	0.67
Pandoh	420.1266	Chippi	148.478	0.35
		Bhuntar	270.6487	0.65
Parvathy	1765.268	Bhuntar	89.09122	0.05
		Chippi	188.9004	0.11
		Bhalla	662.9201	0.38
		Kasol	823.4353	0.47
Sainj	1093.351	Kasol	24.09961	0.02
		Bhuntar	256.3643	0.23
		Chippi	311.4886	0.28
		Bhalla	501.3934	0.46
Tirthan	679.6776	Bhalla	16.13114	0.02
		Bhuntar	16.96946	0.02
		Chippi	646.5718	0.95

The Parbati River, Tirthan, Sainj Rivers, Sabari Nala, Bakhli khad joins as the major tributaries in the upriver at Bhuntar, Larji, Kulu, and Pandoh Dam respectively. Based on the DEM data, the Pandoh basin has been subdivided into 5 sub-basins and named Beas, Pandoh, Parvathy, Sainj, and Tirthan with respect to the river. The total number of rain gauge stations in and around the basin is 26 rain gauge stations. The data has been downloaded for the period of (1979–2018) from the IMD, Pune. Based on the rain gauge stations, the Theisen polygon analysis was carried out to work out the extent of rain gauge influence for each sub-basin. The influence is given in terms of weightage. The monthly average evapotranspiration

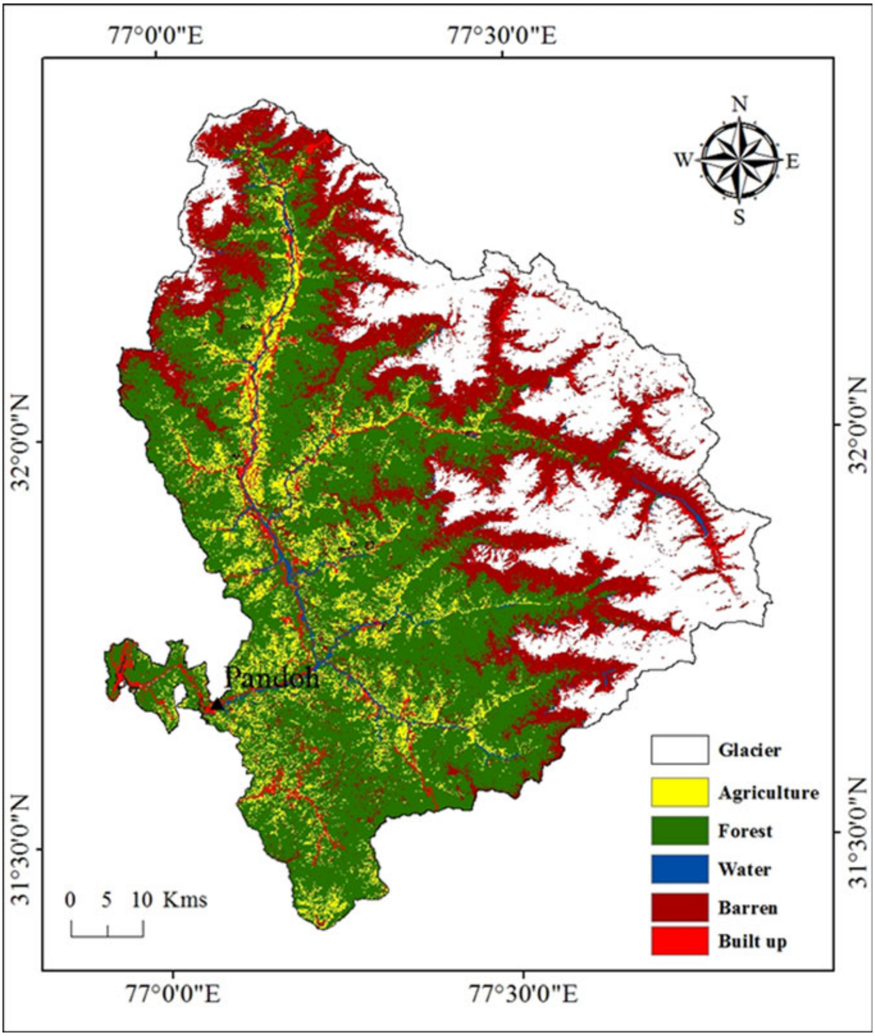

Fig. 5 Land use land cover–Pandoh basin. *Source* Landsat 8

(1961–2018) data has been downloaded from the IWMI website. The weightage for each sub-basin is calculated using the Theisen polygon analysis for rainfall (Table 5) and evapotranspiration (Table 6).

The Pandoh Dam is on the downstream side of the Larji dam accumulates the same water with the addition of 447.5 sq. km land use as part of its watershed. Figure 5 represents the land use land cover. The basin consists of agriculture (7.9%), barren (30.7%), built-up (1.1%), forest (30.1%), glacier (29.3%), Water (1%). The land cover supports the runoff to take place rapidly in the study area. The Glacier melting contribution for the runoff is major, as about 30% of the study area is covered with the glacier.

3.3 Environmental Flow Assessment

The flow Duration Curve method (FDC) will be used when there is an insufficiency in the flow data pertains. This method helps in identifying the environmental flow by plotting the graph between the discharge and the percentile of exceedance.

The Percentage of Exceedance (Pp) or the exceedance likelihood of the occasion P was determined by the Weibull plotting equation (Eq. 1).

$$P_p = (m/N + 1) * 100 \tag{2}$$

where N = no. of flow events; m = ranking of the flow events

The FDC method was chosen because of its advantage of producing the result for data deficient flows. Hydrological techniques, which depend on recorded data methods, are condemned for being frail as far as environmental information and are deficient to clarify the ecological hydrological relationship. It has an abnormal state of result exactness in the examination with the other three strategies.

4 Results and Discussions

The NAM model is a lumped conceptual model, hence the flow data derived from the model will be calibrated using the measured flow data. Since the flow data obtained from the authorities were questionable, the model hasn't been calibrated using the flow data. Instead, the NAM parameters were given based on the LULC, topographical properties of the study area. For example, the CQOF values for an urban area are 0.7, forest varies from 0.5–0.6, agriculture is 0.35–0.4, and for the hilly terrain 0.7–0.8. The U_{max} will be 8 to 10% of the L_{max}. The CK1,2 value for the steeper slope can be 10, agriculture can be 70, etc., These values were conceptualized based on various literature and study area understanding (Table 7). The snow is also modeled as a contributor to the runoff. The constant degree of snow (Csnow) and base temperature were set by the default as 2 and 0. The flow data

Table 7 NAM parameters simulated for each sub-basin

Sub-basin	Umax	Lmax	CQOF	CKIF	TOF
Unit	mm	mm	Fraction	Hours	Fraction
Description	Maximum water content in surface	Maximum water content in the root storage	Overland flow coefficient	Interflow drainage constant	Overland flow threshold
Beas	10	80	0.6	600	0.5
Pandoh	10	100	0.5	250	0.625
Parvathy	10	80	0.6	600	0.5
Sainj	8	80	0.6	250	0.625
Tirthan	10	100	0.5	250	0.625
Sub-basin	TIF	TG	CK1	CKBF	Carea
Unit	Fraction	Fraction	Hours	Hours	Ratio
Description	Interflow threshold	Groundwater recharge threshold	Timing constant for overland	Timing constant for base flow	The ratio of the GW area to the catchment area
Beas	0.5	0.3	25	1200	1
Pandoh	0.45	0.5	10	1000	0.9
Parvathy	0.5	0.3	25	1000	1
Sainj	0.5	0.45	25	1750	0.9
Tirthan	0.45	0.45	30	1200	0.9

derived from this model is the base for all the analysis of the environmental flow. The minimum and maximum storage in the zone, maximum water retained in the snow, dry, and wet temperature corrections are some of the data entered associated with the elevation. Based on the assessed parameter values the NAM model simulated the inflow value. Figure 6 shows the simulated value from the rainfall value.

The estimated inflow value has been used for the environmental flow estimation. The Fig. 7 and 8 show the flow duration curve for the (1979–1999) and (2000–2018). The shape of the FDC curve can tell the anomaly in the flow data. Here the curve progresses gradually showing the river flow is natural and without any hindrance. The flow data corresponding to 95% of the flow duration curve for the year (1979–2018) has been noted down. The environmental flow value corresponding to 95% of the FDC ranges from (144–153) m^3/s for the inflow values in the (1979–2018) year. The average environmental flow value required for the maintenance of a healthy ecosystem is 150 m^3/s.

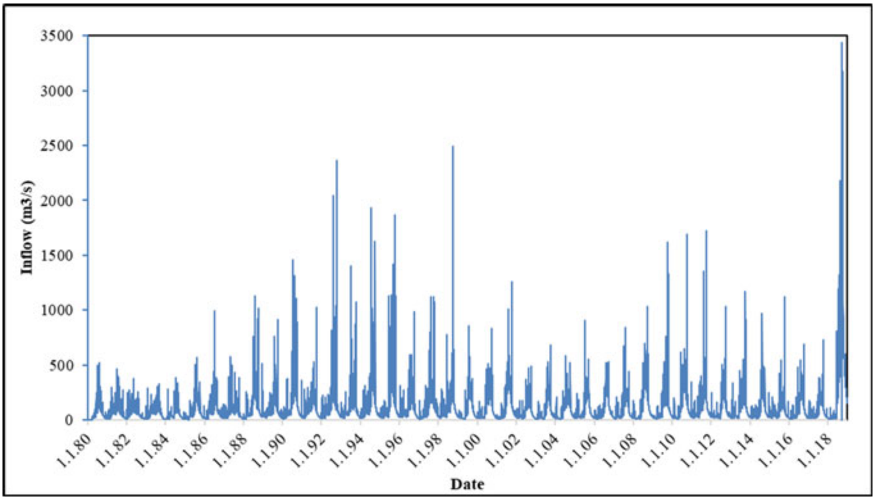

Fig. 6 Estimated flow data for the Pandoh basin

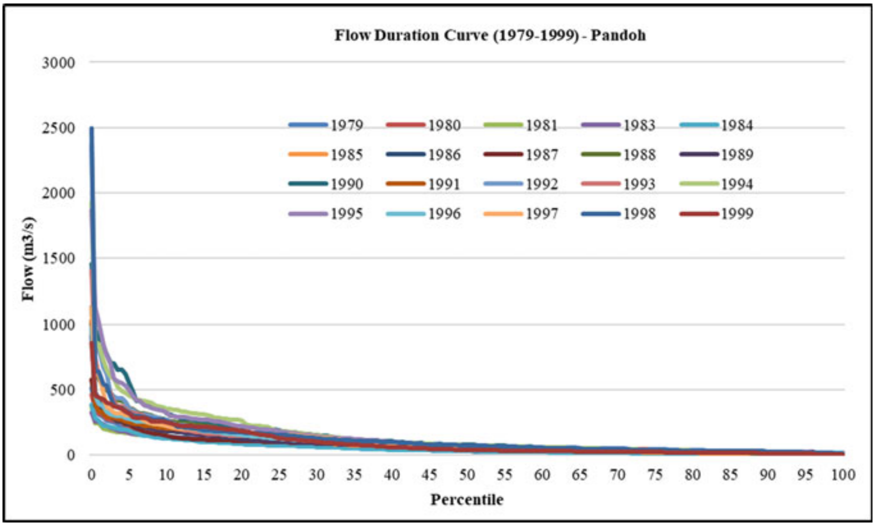

Fig. 7 Graphical representation of FDC (1979–1999)–Pandoh basin

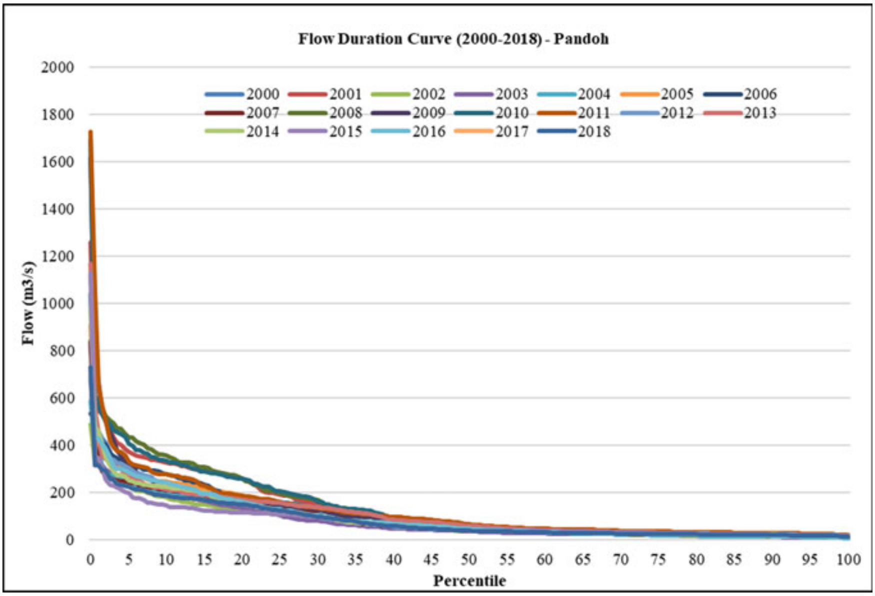

Fig. 8 Graphical representation of FDC (2000–2018)–Pandoh basin

5 Conclusion

The inflow data is one of the prominent input data in assessing the environmental flow. Since the inflow value availability and the reliability becomes a question mark, the rainfall-runoff modelling can be used in that instance. The rainfall, soil map, LULC, and DEM data are interrelated to finally assess the inflow. The analysis of basin drainage parameters is observed to be exceptionally valuable in the drainage basin assessment, water preservation, and characteristic management of resources at a small-scale level. For better and sustainable watershed management practices in this study area, this research will be helpful. Dependable evaluations of runoff from a catchment are needed to assist policymakers with illuminating choices on water management and planning. There is a scope of strategies accessible to appraise streamflow from catchments, utilizing noticed information at every possible opportunity, or utilizing experimental and measurable methods to gauge waterway release, all the more normally known as precipitation spill over models. Runoff models help to picture the reaction of water frameworks because of changes in land use and meteorological occasions. The physical processes that convert precipitation to overflow are conceptualized with a bunch of conditions by utilizing different boundaries that depict the catchment. Demonstrating surface overflow is trying as the computation includes intricacies with many interconnected factors. Anyway, general model parts incorporate data sources, administering conditions, limit conditions or boundaries, model cycles, and yields. Based on the inflow, the flow duration curve is derived to obtain the Q95 percentile for the minimal flow to be discharged downstream. Although this method has various uncertainties, in terms of data deficiency this can be used.

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Assessment and Suitability Analysis of Water Quality of River Ganga in Patna, Bihar

Reena Singh and Saurabh Kumar

Abstract The river Ganga is the largest river in India. It is the number one resource for ingesting water for humans in villages, towns, and cities. Its water is used for many purposes like drinking, agriculture, cattle bathing, etc. People's regular use of Ganga water for all different works increases the possibility of human fitness dangers. This paper deals with the identity of the water quality status of selected fourteen Ghats in Patna. The physicochemical parameters namely Temperature, Electrical conductivity (EC), pH, Total Dissolved Solids (TDS), Alkalinity, Hardness, Conductivity, Chloride, Turbidity, Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD), etc. are found. The samples were collected from Feb 2019 to February 2020 just before complete lockdown. It was found in the study that the WQI of all the Ghats was categorized as unsafe for drinking purposes and suggested that water should be supplied after proper treatment.

Keywords River Ganga · Water quality index · Water quality parameters · Unsafe for drinking

1 Introduction

The river Ganga is classified among the pious rivers of India. It is also a large resource of potable water for residents in villages, cities, and towns [1]. It starts from Gangotri glacier at Gomukh (30°36′ N; 79°04′ E) in Uttarakhand state at a height of about 3800 m above MSL. The length is about 2550 km. It's far a

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reality that potable water is a useful resource on which lifestyles rely upon. All the notable civilizations around the world advanced at the bank of the rivers. The water is also utilized for industrial, agricultural, and other purposes like cattle bathing along with drinking purposes and they even discharge their wastewater in the river Ganga. Many people utilized river water for their daily needs which increases their risk of health hazards due to these water pollutants. The quality of drinking water is the reason for about 80% of all diseases in mankind [3]. Also, the suitability of water and its utility is assessed by the water quality index (WQI) [4, 5]. Along the banks of rivers, the quality and quantity of water are deteriorating [1]. More than 1.3 billion liters per day of wastewater directly enters the river, along with thousands of animal bodies, mainly cattle. About 80% by volume of the total waste which is disposed into Ganga is by municipal waste and industries contribute about 15%. Organic waste, plastics, domestic waste, carcasses, etc. contribute to major portions of Ganga pollution [7]. Many studies have observed that the pollution level in Ganga water is exceeding the allowable limits and the water is considered to be unfit for domestic use [9]. Different approaches and tools have been developed to assess the contaminants in water. These approaches include the study of different specifications like pH, conductivity, TDS, and heavy metals. They may affect the quality of water if their concentration exceeds the IS10500:2012 limits. Therefore, it is recommended to timely assess the water quality by researchers and governmental departments.

The objectives of the present study are**:**

- To know the physicochemical properties of water samples from selected 14 Ghats i.e., Collectorate Ghat (S1), Anta Ghat (S2), Adalat Ghat (S3), Kali Ghat (S4), Krishna Ghat (S5), Gandhi Ghat (S6), Gulbi Ghat (S7), Roushan Ghat (S8), Choudhary Tola Ghat (S9), Pathri Ghat (S10), Alamganj Ghat (S11), Raja Ghat (S12), Kadam Ghat (S13), Gai Ghat (S14).
- To estimate the water quality index of the above ghats.
- To assess the suitability and health of Ganga River water for various purposes.

1.1 Study Area

The study areas under consideration are given in Fig. 1.

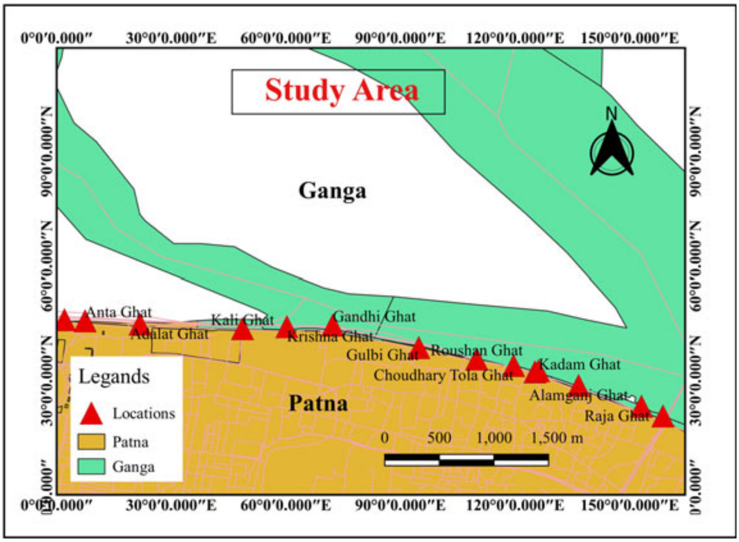

Fig. 1 Different Ghats of River Ganga under study

Table 1 Specifications, units, and techniques adopted for the study

Parameters	Unit	Methods
pH		pH meter
EC	µS/cm	Conductivity meter
Alkalinity	mg/l	Titration method
TH	mg/l	EDTA titration method
Chloride	mg/l	Argentometric method
TDS	mg/l	Oven-dried method
Temperature	ºC	Thermometer
Turbidity	NTU	Turbidity meter
DO	mg/l	Winkler azide method
BOD	mg/l	Titrimetric method

2 Methodology

In this study, the water quality of river Ganga at different sites is checked. The physicochemical parameters containing DO, BOD, Temperature, pH, alkalinity, Hardness, Conductivity, TDS, chloride, Turbidity, etc. are calculated. The water samples were collected for one year from Feb 2019 to February 2020 just before complete lockdown.

The sample was collected in pre-cleaned; autoclaved plastic cans and was immediately taken for testing in the laboratory of the Civil Engineering Department, NIT Patna. The water samples were assayed according to fashionable

Table 2 Water quality rating according to weighted arithmetic mean method [11]

Range	Category of water quality	Ranking
0–25	Superior quality	A
26–50	Excellent quality	B
51–75	Bad quality	C
76–100	Worst quality	D
>100	Not safe for drinking	E

techniques for the Examination of Water and Wastewater [12]. Table 1 gives the parameters tested, units, and methods used in testing. The WQI is calculated in terms of the suitability of pond water for human consumption. The results are then compared with indices given by [6, 11]. Table 2 represents the Water Quality Rating Based on the weighted arithmetic mean method.

2.1 Calculation of Water Quality Index

The selection of WQ parameters is very important. As it is well known that if too many parameters are selected, the WQI may widen. So, the importance depends upon the utility of water. Here, nine physicochemical parameters (except temperature), were taken to analyze the WQI. The method adopted is the weighted arithmetic mean method, for the observation of WQI which is calculated as follows [6, 11]. Also, it has been seconded by another method Oregon Water Quality Index (OWQI).

Step 1. Calculation of Quality Rating (Qn):
The Qn is estimated given in the following equation.

$$\mathrm{Qn} = 100[(\mathrm{Un}-\mathrm{Ui}) / (\mathrm{Gn}-\mathrm{Ui})] \tag{1}$$

where,
Qn = Quality rating of the nth water quality parameters.
Un = Tested value of the nth parameter of given sapling location.
Gn = Standard permissible value of nth parameter.
Ui = Ideal value of ith parameter in pure water.

Step 2. Estimating of Unit Weight (Wn):
The unit weight (Wn) is estimated as the given equation.

$$\mathrm{Wn} = \mathrm{T} / \mathrm{Gn} \tag{2}$$

Where,
Wn = unit weight for nth parameter.
Gn = standard value for nth parameters.
T = proportionality constant and is given as [8].

Table 3 Water quality rating according to OWQI method

Range	Category of water quality
90–100	Superior
85–89	Super
80–84	Fair
60–79	Bad
0–59	Very bad

$$T = 1 / [1/G1 + G2 + \ldots\ldots\ldots\ldots + 1/Gn]$$

Step 3. Calculation of WQI:

$$WQI = \Sigma QnWn/\Sigma Wn \tag{3}$$

2.2 Oregon Water Quality Index (OWQI) Method

This is also a good method to know the status of the water quality. The index is free from the arbitration in weighting the parameters and employs the concept of harmonic averaging. It is calculated as [10] and the water quality rating according to OWQI is given in Table 3.

$$WQI = \sqrt{\frac{n}{\sum \frac{1}{Sli^2}}}$$

Where n = number of subindices.
Sl = subindex of ith parameters.

3 Results and Discussions

The observed average values of various physical and chemical parameters are mention in Table 4. The result of the Water Quality Index (by Weighted Arithmetic Mean method and Oregon Water Quality Index method) for selected ghats and quality of water are mention in Table 5. Comparison of WQI with Superior water quality (A ranking water) is mention in Fig. 2.

Dissolved oxygen is required to sustain aquatic life in a water body. 4 mg/l is the minimum value of DO to survive aquatic life. Here all the Ghats have to be found the greater value of minimum DO for the survival of aquatic life. BOD gives the amount of oxygen consumed by the microorganisms to decay this waste. All the samples were having BOD levels not within the permissible limit mainly in drinking water BOD levels should be negligible. pH value gives the acidic or alkaline nature of

Table 4 Average values of various physicochemical parameters of the study area

Location	DO	BOD	pH	Temperature	Alkalinity	TDS	Cl	TH	Turbidity	Conductivity
S1	7.9	2.3	7.31	24.3	141	310	67.3	241	13.5	480
S2	7.6	3.4	7.49	24	146	325	61.3	247	17.2	490
S3	7.6	3.6	7.25	25.1	151	331	75.2	262	16.5	525
S4	6.9	6.1	8.4	25	148	390	82.36	301	18.2	740
S5	6.4	5.2	8.1	25	154	330	71	350	18.4	550
S6	7.7	4.6	8.2	24.4	162	365	68.16	340	20.5	510
S7	7.2	6	8.3	25.2	171.2	381	81.2	340	21	742
S8	7.9	2.2	7.29	25	148.2	316	61.2	265	20.2	486
S9	7.2	2.6	7.8	24.3	151.3	325	65.3	280	17.5	476
S10	7.4	2.6	7.1	24.1	159	363	72.3	405	18.5	560
S11	6.6	6	8.2	25	178	410	89.2	386	13.5	760
S12	6.4	5.4	7.8	25.2	162.2	416	87.3	362	16.2	758
S13	8.1	3.3	7.7	24.2	152.3	323	69	280	18.2	491
S14	7.1	4.2	8.1	25.1	172	401	86.3	310	16.3	701

Table 5 Water quality index for selected Ghats and quality of water

Location	WQI by weighted arithmetic mean method	WQI by Oregon water quality index method	Quality of water
S1	110.33584	0.3163	Unsafe for drinking
S2	139.192493	0.3062	Unsafe for drinking
S3	134.078617	0.346	Unsafe for drinking
S4	171.577205	0.389	Unsafe for drinking
S5	165.839291	0.3373	Unsafe for drinking
S6	171.332312	0.342	Unsafe for drinking
S7	184.543359	0.387	Unsafe for drinking
S8	146.039117	0.303	Unsafe for drinking
S9	141.024461	0.318	Unsafe for drinking
S10	139.055792	0.354	Unsafe for drinking
S11	144.689041	0.42	Unsafe for drinking
S12	152.269248	0.416	Unsafe for drinking
S13	145.051458	0.328	Unsafe for drinking
S14	147.257589	0.407	Unsafe for drinking

water. The variation of pH in Ganga water depends upon the dissolved gases such as carbon dioxide, hydrogen sulphide, ammonia, etc. CO_2 is produced due to the productivity of algal blooms [13]. The supply of sewage and industrial waste is also the main factor for variation of pH. Microorganisms decompose the organic matter and produce hydrogen sulphide, ammonia, etc. Measurement of pH is one of the most important parameters as every phase of the water supply is pH-dependent. The pH of all investigated samples is within the limit [7].

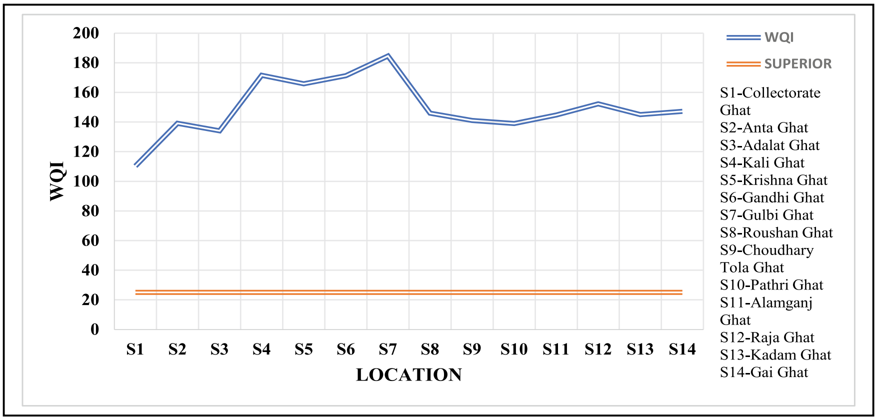

Fig. 2 Indicates variations of WQI (weighted arithmetic mean method) with comparison to superior water quality (a ranking)

Chloride ions in excess impart a salty taste to water. The allowable limit in drinking water is 250 mg/l [7]. The highest value of chloride was observed in Kali ghat while its minimum value was observed in Collectorate ghat. Electrical Conductivity is more indicates the presence of high ionic concentrations in water. In drinking water concerning [7], the maximum allowable limit is 1400 µS/cm. All samples were found to be not within the permissible limit. Alkalinity measures the amounts of bicarbonates, carbonates, and hydroxides present in water. Low alkalinity causes deterioration of plumbing and increases the chances for many heavy metals in water present in pipe or plumbing fixtures. In drinking water concerning BIS, all samples were found within the permissible limit. In drinking water acceptable limit of alkalinity is 200 mg/l–600 mg/l [7]. Temperature is the degree of hotness or coldness. The amount of O_2, diffusion rate, and photosynthetic activity almost depend upon the rate of change of temperature. Temperature governs the kinds of organisms that can live in rivers and lakes. Total dissolved solids may cause hardness, scaly deposits, bitter taste, and corrosion of pipes and fittings. Water with high TDS greater than 2000 mg/l is of inferior palatability and may induce gastro-intestinal irritation [2]. Total Hardness is the amount of dissolved Ca and Mg ions in the water. TH results due to the presence of divalent cations of which Ca and Mg ions. In drinking water, the acceptable limit of hardness is 200 mg/l, and the cause of rejection is 600 mg/l [7]. Turbidity depends upon the number of suspended particles in the water. It is found that the value of turbidity in Ganga water in the study area is greater than the acceptable limit for drinking purposes.

4 Conclusions

Aquatic plants and fishes are safely sustaining in Ganga water as DO in our study has been found to be more than 4 mg/l. As calculated by the weighted arithmetic mean method, it was found that Gulbi ghat is the most pollutant ghat because of the crematory. It was found that the BOD level is greater at Kali Ghat due to the supply of Sewage. According to both indices, i.e. Weighted Arithmetic Mean method and Oregon Water Quality Index method are indicated the same quality of water at all Ghats. It can be concluded that the water of river Ganga is found not to be suitable for drinking purposes without proper treatment although the physicochemical parameters are within limits. The water quality index comes out as unsafe for drinking but it can be used for bathing and irrigation purposes. The Government has to do the proper arrangement of wastewater treatment plants so that sewage water is disposed of after treatment. The river water quality has to been continuously monitored.

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Filling the Health Gap in Energy Performance Certificates to Reduce Pulmonary Diseases Due to Bad Indoor Air Quality

Alexandre Soares dos Reis, Marta Ferreira Dias, and Alice Tavares

Abstract Good indoor air quality (IAQ) levels in buildings are among the essential benefits and drivers as they lead to better health and comfort of the occupants. However, this research identified a health gap in dwellings' energy performance certificates (EPCs) in Portugal, as IAQ seems not to be appropriately covered. Volatile organic compounds (VOCs) are gases containing various chemicals emitted from liquids or solids. Additionally, biomass-burning stoves are significant contributors to fine particle matter ($PM_{2.5}$) concentrations that may cause cancer and respiratory diseases. Therefore, it is crucial to formulate strategies to control and enhance IAQ. As air pollutants often enter the human body through inhalation, the respiratory system is regularly the main target of Indoor Air Pollution (IAP), resulting in pulmonary diseases and allergies. These facts emphasize the need to track IAQ properly. Depending on indoor air pollutants, several rules and criteria are the basis of the current published work on IAQ indicators. According to our findings, in the planning stage, understandable and straightforward criteria for VOCs, $PM_{2.5}$, and proper ventilation schemes, could help architects and engineers to enhance IAQ. Finally, next-generation EPCs could consider the proposed IAQ score to fill the identified health gap.

Keywords Energy performance certificates · Indoor air quality · VOCs · $PM_{2.5}$ · Ventilation

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1 Introduction

The 2019 United Nations Climate Change Conference (COP25), headed in Madrid, incorporated the 25th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC), the 15th meeting of the parties to the Kyoto Protocol (CMP15), and the second meeting of the parties to the Paris Agreement (CMA2). The agreement recognized the importance of people in the fight against climate change and that they should inevitably be at the heart of the response to the climate emergency—in short, people first [1].

It is clear the European Union's (EU) commitment to developing an energy system on the track to carbon neutrality as established in the energy performance of buildings directive (EPBD) from 2010 [2] and 2018 [3]. According to the EPBD, it is the exclusive responsibility of Member States (MS) to set minimum requirements for the energy performance of buildings and building components. Improvements should be made in the building stock, bringing them to nearly zero-energy buildings (NZEBs).

The EPBD also refers to good health and wellbeing, which depends on indoor air quality (IAQ) since people spend most of their time indoors [4]. IAQ may determine how comfortable and healthy occupants may be inside buildings [5], especially when sleeping, due to its essential role in human welfare [6]. IAQ refers to the contribution of the building components to the good health and wellbeing of the occupants [7], and enhancing ventilation effectiveness may improve IAQ [8]. In the long term, a weak IAQ may seriously compromise the health and wellbeing of people inside buildings [9], especially children [10]. Sleep disorders, allergies, a dry throat, respiratory problems, eye irritation, headaches, or loss of concentration are possible effects [11], especially for those with existing health issues [12]. Hence, architects and engineers should take additional care in the planning stage [13] to minimize human exposure to contaminants [14], prioritizing people's health instead of energy efficiency as indoor air pollutants are likely to accumulate inside houses due to airtightness [15]. High thermal insulation and insufficient ventilation [16] may become a breeding ground for molds [17], viruses, and bacteria. Among the risks for health are also a variety of volatile organic compounds (VOCs) [18], particulate matter (PM) [19], and carbon dioxide (CO_2), which presence in buildings are extensively described in the literature. Several authors have monitored indoor air pollutants for the characterization of IAQ. PM, formaldehyde [20], CO_2—likely associated with consequent higher emissions through breathing and metabolic processes [21], and carbon monoxide (CO) are among the most referred air pollutants. Additionally, inside buildings, several contaminants can also be found as benzene, toluene [22], nitrogen dioxide (NO_2), ozone (O_3) acetaldehyde [23], siloxanes, flame retardants, synthetic phenolic antioxidants [24], acrolein [25], bioaerosols [26], ethylbenzene and xylenes [27].

Oil paints and PVC floors are sources of VOCs, and the radiation amount of all pollutants increases with temperature increase [28]. Materials (finishes and furnishing) are one of the primary sources of indoor air pollution (IAP) [29]. IAP is a severe threat to human health, causing millions of deaths each year [30]. Commonly reported plausible health effects associated with IAP are respiratory symptoms, sick building syndrome (SBS) [24], and cancer risk [31]. As the renovation increases, the concentration of formaldehyde, one of the most widespread VOCs, increases significantly due to finishing materials [32]. Formaldehyde and total VOCs (TVOCs) concentrations in apartments may be critical [33]. $PM_{2.5}$ may cause respiratory diseases and affect mental health [34]. Hence, the planning stage plays an essential role in achieving a good IAQ [35].

In Portugal, for non-residential buildings, EPCs consider fresh air flows depending on the number of occupants, interior finishing materials, and activities developed in each space [36]. However, in dwellings' EPCs, the ventilation is based on the air changes per hour (ACH) in the whole house [37], so it does not consider minimum fresh air flows as the methodology for non-residential buildings.

The main objectives of this study are to define clear criteria to reduce the concentration of VOCs and $PM_{2.5}$ and suggest proper ventilation schemes in dwellings to enhance IAQ. The final goal is to propose a score base criteria for IAQ.

This paper is structured as follows. Section 1 introduces the problem and provides a literature review about the health problems related to VOCs and $PM_{2.5}$ as the importance of proper ventilation. The adopted methodology and the discussion of results are described in Sect. 2. Finally, Sect. 3 presents the conclusions.

1.1 VOCs

Nowadays, as people spend most of their time inside buildings, mainly at home or at the workplace [38], researchers started to change the focus from outdoor air quality (OAQ) [39] to IAQ. According to Hanif et al. [40], VOCs are widely recognized to cause significant adverse health effects on humans. Huang et al. [41] have concluded that VOCs concentration indoor may become at least ten times higher than outdoor. One of the most widespread VOC is formaldehyde, a colorless, flammable, strong-smelling chemical used in building materials like varnishes, paints, and glues [42]. They come into the interior of buildings mainly from internal sources due to building materials, flooring, composite wood products, adhesives, brand new furniture [43], cleaning agents, and other consumer products [44]. According to Kotzias [45], VOCs significantly impact IAQ, thus, human health and wellbeing, as they may lead to chronic or severe diseases [46]. Suzuki et al. [47] found a substantial relationship between VOCs concentration and building-related symptoms (BRS). They realized that people with a medical history of allergies and those with a high sensitivity to chemicals tended to experience BRS. Therefore, in the planning stage, architects and engineers should carefully choose interior building components. Liang [48], while assessing VOCs risks to construction workers, found that TVOCs concentration was the highest during the doors and doorframes stage. Formaldehyde constituted 78% and 66% of the cancer risk for painters and carpenters, respectively.

Additionally, Jung et al. [49] measured the concentrations of VOCs and inorganic gaseous pollutants in around 5000 households in Japan, concluding that toluene, formaldehyde, and acetaldehyde were the dominant indoor VOCs. Stamp et al. [50] state that improved guidance and product labeling schemes may be required to achieve the guideline concentrations of formaldehyde and reduce associated health risks. On the other hand, while studying the indoor total volatile organic compound concentrations in densely occupied university buildings, Jia et al. [51] realized that the indoor TVOCs concentration variation was similar to the indoor CO_2 values. However, Liang et al. [52] found that when variations of CO_2 concentrations occur, the levels of CO_2 may not be used as an indicator for formaldehyde, despite their positive correlation. Additionally, according to Persily, there have been many instances in which CO_2 concentration measurements have been misinterpreted and misunderstood [53], stating that an indoor CO_2 limit is not a good indicator of ventilation or IAQ [54].

The focus on energy performance might influence architects and engineers to design airtight buildings that may lead to the accumulation of VOCs indoors, thus changing the philosophy stated in the EPBD for a healthy indoor environmental quality.

1.2 $PM_{2.5}$

PM is a complex mixture of solid and liquid particles suspended in the air [55]. These particles can vary in size, shape, and composition. PM that are 10 μm in diameter or smaller (for instance, $PM_{2.5}$) are inhalable and can affect the lungs, causing acute respiratory disorders [56]. $PM_{2.5}$ may also play a role in mental health conditions, such as major depressive disorder [34].

Last years have witnessed a surge in publications about the influence of biomass burning on PM's concentration and chemical composition. Combustion of biomass fuel is among the leading environmental risk factors for preventable disease, as stated by Fandiño-Del-Rio et al. [57]. According to Baris et al. [58], domestic burning of biomass fuel is one of the most critical risk factors for developing respiratory diseases and infant mortality. Especially in areas where the winters are long, and the biomass stove is indoors. Hadeed et al. [59] concluded that dwellings heated with coal or wood had elevated indoor $PM_{2.5}$ concentrations that exceeded both the U.S. Environmental Protection Agency (EPA) ambient standard and the World Health Organization (WHO) guideline. Abdel-Salam [60] observed a robust seasonal variability, with air quality being inferior in winter. Due to increased ventilation rates in summer, indoor air pollutants were less critical. In contrast, indoor concentrations in winter were more strongly affected by indoor sources due to increased human activities and poor ventilation. Fulvio Amato et al. [61] demonstrated that, during the winter period, biomass equipment used for residential heating represents one of the leading PM sources in urban areas, contributing up to over 20% of $PM_{2.5}$ values. OAQ may be directly related to IAQ, as Frasca et al. showed [62]. While studying PM inside two flats with airtight biomass systems, they realized that infiltration from the outdoor is the primary source of fine particles. Furthermore, mainly due to the cleaning operations required to remove residual ash, biomass stoves may be a significant source of indoor pollution. In fact, during regular operation, the combustion products are isolated from the surrounding environment, but the periodical removal of residual ash results in its dispersion inside the flats.

In addition, Zhou et al. [63] have also developed a method that analyses the variation of $PM_{2.5}$ inside dwellings between seasons that suggests significant infiltrations from outside. Rice et al. [64] studied the impact of exposure to secondhand smoke and indoor combustion from gas heaters, wood stoves, and fireplaces on respiratory symptoms in children with bronchopulmonary dysplasia (BPD). They found that 75% of the children were exposed to at least one combustible source of air pollution in the home. This exposure was associated with an increased risk of hospitalization. Their conclusions state that exposure to combustible sources of indoor air pollution was associated with increased respiratory morbidity in a group of high-risk children with BPD. Ventilation frequency and duration, biomass equipment characteristics, design, and location could be essential to improve the IAQ and preserving human health, as de Gennaro et al. [65] stated. Investigations carried out by Carvalho et al. [66] showed that the adjustment of fuel loads to heating requirements could result in a tendency of the efficiency of new biomass stoves to be higher than 80%.

On the other hand, airtight installations may reduce wood consumption by more than 50% compared with fireplaces. PM emissions may be reduced by more than 30% when using automated systems instead of manual control of combustion air inlets. Noonan et al. [67] have made the follow-up of a changeout program of old wood stoves to new lower emission ones and found a 53% reduction of $PM_{2.5}$ emissions. Carvalho et al. [68] developed a system consisting of an outer chimney installed around the existing chimney of a wood stove. In this way, the outgoing air going up preheated the outdoor air coming down through the external chimney before entering the combustion chamber. With this heat transfer system, the thermal efficiency of the wood stove increased from 62% to up to 79%. To sum up, secondary air was supplied to the wood stove reducing the carbon monoxide (CO) emissions by 39%. The two measures resulted in a better heat release from the wood stove, more stability, and reduced the average $PM_{2.5}$ emission factor by 22%. Lai et al. [69] also conclude that to reduce PM emissions associated with biomass stoves in dwellings is essential to study the combustion conditions. Saraga et al. [70] highlighted the increase of PM mass concentration, both outside and inside homes, due to biomass burning. On average, outdoor $PM_{2.5}$ concentration levels were up to two times higher during biomass burning hours. They have also realized that the indoor air was significantly influenced by the burden outdoor atmosphere in flats where no biomass burning occurred. McNamara et al. [71] have proposed air filtration units to reduce $PM_{2.5}$. Vicente et al. [72] tested several fuels in an automatic pellet stove and concluded that the pellet composition greatly influences PM emissions.

This literature review shows that fine particulate matter inside homes may directly contribute to pulmonary diseases, emphasizing the need to establish criteria to minimize the exposure to $PM_{2.5}$.

1.3 Ventilation

The general purpose of ventilation in buildings is to provide healthy air for breathing by diluting the pollutants originating in the building and removing the contaminants [73]. Low ventilation rates are regularly associated with pulmonary diseases, including cancer [74]. Lin et al. [75] concluded that the excess lifetime cancer risk shows a need to lower exposure by reducing or removing VOCs, especially formaldehyde, or increasing ventilation rates. Sun et al. [76] found that low ventilation rates in bedrooms caused elevated concentrations of formaldehyde and an increased prevalence of SBS [76]. Moreover, Bornehag et al. [77] realized that a decrease in the air changes in single-family houses coincides with the increase in allergic diseases among children and adults. Hence, appropriate ventilation regimes are needed. Huang et al. [78] stated that improved ventilation effectively reduced the indoor concentrations of VOCs. Gabriel et al. [23] state that the promotion of ventilation is essential for improving air quality in households and promoting children's health. Burguelle et al. [79] found that mechanical supply and exhaust ventilation yielded an overall improvement of IAQ. However, also natural ventilation may positively impact IAQ. Assuring a continuous entrance of outside air through windows provides to the indoor a feasible and affordable way to regulate and sustain low standards in the VOCs, as stated by Aguillar et al. [80]. They have proposed a method that allows outside air to regulate the VOCs inside buildings effectively. D'amico et al. [81] also highlighted the central role of ventilation in IAQ.

Furthermore, Amira et al. [82] stated that a sound ventilation system and a careful selection of construction materials are crucial for a good IAQ. Yang et al. [83] studied VOCs levels in 169 energy-efficiency dwellings in Switzerland, concluding that thermal retrofit of residential buildings and absence of mechanical ventilation system were associated with high levels of formaldehyde. The results suggest that actions should accompany energy efficiency measures in dwellings to mitigate VOCs exposures and avoid adverse health outcomes. In addition to this, according to Fan et al. [84], diluting indoor air pollutants with fresh outdoor air is the most convenient way to lower VOCs values. While assessing air pollutants in university buildings, Mundackal and Ngole-Jeme [85] observed high VOCs concentrations. They have recommended additional ventilation and frequent monitoring of IAQ. Kraus and Juhasova Senitkova [86] referred to a simulation tool that predicts the emission of VOCs from building surface materials and furnishings, helping to select low-emission materials and effective ventilation strategies.

Yang et al. [87] characterized the indoor environment at facilities for sensitive populations in Korea, investigating the effects of legal regulation on IAQ. They recommend installing efficient ventilation to reduce indoor pollutants concentrations while controlling the primary sources of pollutants. Holos et al. [88] studied the influence of ventilation on VOCs emission rates in newly built and renovated buildings. Their results may be used to assess practical ventilation strategies to keep the concentration of TVOCs within acceptable levels during hours of occupancy after completion of a new or renovated building. However, ventilation for itself might not be enough to ensure a good IAQ [89].

2 Methodology and Results

Existing published work about IAQ indexes is mainly based on real-time data generated by indoor air pollutants, like the one developed by Yuan et al. [90]. Based on the data collected from sensors in a classroom, Rastogi et al. [91] proposed a novel method for the determination of ventilation states using three indoor pollutants, $PM_{2.5}$, PM_{10}, and carbon monoxide (CO), with three levels of alerts: 1) "poor"; 2) "moderate"; and 3) "good". Balbis-Morejón et al. [92] proposed an Air Conditioning Performance Indicator (ACPI) based on six criteria: energy consumption, IAQ, thermal comfort, carbon emissions, investment costs, and finally, operation and maintenance costs. Piasecki and Kostyrko [93] developed a method based on a decision matrix that includes six attributes: actual indoor air CO_2 concentration, TVOCs, and formaldehyde concentration, and their anthropogenic and construction product emissions to the indoor environment with a combined weighting scheme for an IAQ index equation. Kim et al. [94] suggested an IAQ index which reflects $PM_{2.5}$ and CO_2, divided into five grades from "good" to "hazardous" with a scale of 1 to 100 points, as follows: "good" (0–20); "moderate" (21–40); "unhealthy for a sensitive group" (41–60), "bad" (61–80), and "hazardous" (81–100). Nimlyat [95] developed two indexes for indoor environmental quality (IEQ), the IEQ performance model (IEQ_{PM}), and the IEQ occupants· satisfaction (IEQ_{POS}) in hospital ward buildings. The IEQ_{PM} model indicated that thermal, acoustic, visual, and IAQ are significant determinants of IEQ performance. The author found out a substantial relationship between IEQ_{PM} and IEQ_{POS} and proposed the Comprehensive Occupant Satisfaction Index (COS_I), which may be used for the assessment of comfort of the IEQ criteria in Green Building Rating Systems (GBRS), according to the following scale: IEQ performance "above average" (COS_I = 0.90); "average" IEQ performance (COS_I = 0.80); IEQ performance "below average" (COS_I = 0.70). Javid et al. [96] aimed to develop a comprehensive index with fifteen parameters and 108 rules—the Fuzzy-Based Indoor Air Quality Index (FIAQI). Poirier et al. [13] built three emission rates classified for $PM_{2.5}$ and formaldehyde: "high", "medium," and "low", to be selected depending on the available data at the design stage. For instance, a "low" emission rate concerning formaldehyde may be considered only if A-class

IAQ-labelled materials are used. Sérafin et al. [97] present an original method for IAQ in office buildings by calculating a hazard quotient (HQ) and a hazard classification (CMRE). Based on the ventilation rate (VR) and on the Predicted Mean Vote (PMV), Rastogi et al. [98] developed an indicator for IAQ and thermal comfort, the Air Quality and Comfort Indicator (AQCI), with a three level scale: 1) "good"; 2) "moderate; and 3) "poor".

The literature review, the current published work about IAQ scores, and the Active House Specifications [99] inspired the adopted methodology. Active House Specifications have nine areas of performance indicators, graded on a four-level scale [100]. Bringing complicated and ambiguous scenarios is not the way to move forward [101], as this may negatively influence decision-makers, architects, and engineers [102]. As the weighting methods are regularly subjective [103], with essential differences between existing schemes [104], this research intends to give the same weight [105] to all criteria under a four-level scale from 1) "better" to 4) "worst" [100].

Measuring the concentrations of indoor air pollutants is the primary strategy used in the identified published work about IAQ indexes. According to the present knowledge, there is a gap in IAQ indexes to be followed in the planning stage. The proposed methodology will allow making essential decisions at the earliest level of a project: first, reducing the source of pollutants—VOCs and $PM_{2.5}$; second, enhancing ventilation. The final IAQ score would be the average of each score proposed, from 1 to 4, for VOCs, $PM_{2.5}$, and ventilation.

2.1 VOCs

The adopted approach to minimize the risk of VOCs inside homes was to follow the French guidelines *Étiquetage des émissions en polluants volatiles des produits de construction* [106] and the Portuguese Ministerial Order Nº353-A/2013 [36], with the criteria and scores showed in Table 1.

Table 1 Criteria and scores to minimize the risk of VOCs inside homes

VOCs	Score
By area, $\geq 75\%$ of paints and varnishes used follow the guidelines of *Étiquetage des émissions en polluants volatils des produits de construction* that leed to class A+	1
By area, $\geq 75\%$ of paints and varnishes used follow the guidelines of *Étiquetage des émissions en polluants volatils des produits de construction* that leed to class A+ or A	2
By area, 50–74% of paints and varnishes used follow the guidelines of *Étiquetage des émissions en polluants volatils des produits de construction* that leed to class A+ or A	3
Paints and varnishes used do not follow the guidelines of *Étiquetage des émissions en polluants volatils des produits de construction* that leed to class A+ or A	4

2.2 *$PM_{2.5}$*

Reducing indoor $PM_{2.5}$ levels may offer a more feasible and immediate way to save substantial lives and economic losses attributable to $PM_{2.5}$ exposure [92]. The main objective is to minimize the risk of releasing and spreading $PM_{2.5}$ inside homes. Hence, the proposed criteria aim to reduce the risk of $PM_{2.5}$ moving inside dwellings. The following Table 2 gives information about the proposed score for each criterion.

2.3 *Ventilation*

As ventilation plays a significant role in IAQ, the proposed criteria follow the recommendations of the Portuguese Ministerial Order N.º297/2019 [107] and the book *Manual de Apoio ao Projecto de Reabilitação de Edifícios Antigos* [108], defining simple and understandable criteria—Table 3.

For an air pollutant, the concentration is the amount of contaminant present in each unit volume or unit mass of air. Exposure usually refers to the product of pollutant concentration in the breathing zone of a room and the time the person spends in that room. For some indoor-generated pollutants, as VOCs and $PM_{2.5}$, outdoor exposures can become negligible compared to indoor exposures. A broad range of health effects may result from indoor pollutant exposures. Some pollutants increase the risk of cancers or other severe health effects. The evidence of health risks is sufficient to justify taking precautionary measures to limit VOCs and $PM_{2.5}$ inside homes. Nowadays, we spend most of our time inside buildings, especially inside our homes, so much of our exposure to air pollutants, as VOCs present in building materials or $PM_{2.5}$ released from wood-burning devices, occurs indoors.

Table 2 Proposed scores for each criterion to minimize the risk of release and spreading $PM_{2.5}$ inside homes

PM	Score
Air for biomass stoves comes from the outside, and the kitchen exhaust fan is not in the same room. Or no biomass stoves installed inside the house	1
Air for biomass stoves does not come from the outside, and the kitchen exhaust fan is not in the same room	2
Air for biomass comes from the outside, and the kitchen exhaust fan is in the same room	3
Air for biomass stoves does not come from the outside, and the kitchen exhaust fan is in the same room	4

Table 3 Proposed criteria and scores for ventilation

Ventilation	Score
Fresh air (at least 30 m^3/h in bedrooms and 60 m^3/h in living rooms) with self-regulating flap ventilators. Discharge of polluted air achieved mechanically, with variable flow units, at least in bathrooms. Or centralized mechanical ventilation system that assures fresh air (at least 30 m^3/h in bedrooms and 60 m^3/h in living rooms) and discharge of polluted air	1
Fresh air (at least 30 m^3/h in bedrooms and 60 m^3/h in living rooms) with self-regulating flap ventilators. Discharge of polluted air achieved through natural ventilation with static ventilators Class B—NF P 50 413	2
Fresh air in bedrooms and living rooms with self-ventilating flap ventilators or infiltrations through windows with airtightness class 2 or less	3
No fresh air in bedrooms and living rooms	4

Ventilation is an option for reducing existing indoor VOCs and $PM_{2.5}$ concentrations. Providing outdoor air will decrease the indoor air concentrations of pollutants released from indoor sources. However, considering a strategy to minimize the indoor pollutant sources would be crucial, as ventilation alone cannot optimize health conditions in homes. Hence, eliminating or limiting the indoor sources of VOCs and $PM_{2.5}$ should be the first option to consider. Reducing the sources of indoor pollutants, for example, by selecting low emitting building materials and the proper use of wooden stoves, diminishes the amount of ventilation needed to maintain low indoor pollutant concentrations. Pollutant source control often does not affect building energy use, while increasing ventilation increases energy consumption.

The proposed IAQ score, based not only on increasing ventilation but mainly on reducing the internal sources of VOCs and $PM_{2.5}$, would give precise information, on an early stage, to architects, engineers, builders, and building owners. From 1 to 4, score-based criteria for selecting materials that emit VOCs at a lower rate, properly installing wood-burning equipment and ventilation systems could contribute to a practical and straightforward way to a better IAQ in dwellings.

3 Conclusions

Poor indoor air quality negatively impacts occupants' health, as highlighted in this paper. In Portugal, due to the air changes per hour ventilation criteria in dwellings (Order Nº 15,793-K/2013), there might not be sufficient fresh air to dilute pollutants like VOCs and $PM_{2.5}$. Besides ventilation, it is also vital to reduce finishing materials that may spread VOCs like formaldehyde inside homes. The integration of biomass stoves should be carefully thought, in the planning stage, to avoid high concentrations of $PM_{2.5}$. Adequately ventilated rooms may minimize the high concentrations of VOCs, and $PM_{2.5}$ inside homes, reducing the risk of pulmonary diseases. Still, it is essential to mitigate the sources—as fewer VOCs and $PM_{2.5}$, better. A crucial need is to inform decision-makers and occupants of how proper ventilation, a good choice of finishing materials, and properly installing biomass stoves may contribute to a healthier indoor environment. Complicated and too detailed criteria might not be helpful for this purpose.

This research proposes an accessible and understandable criterion rated on a four-level scale from 1) "better" to 4) "worst". For VOCs, based on the French guidelines for paints and varnishes. For $PM_{2.5,}$ according to the literature review. Finally, for ventilation considering the Portuguese Ministerial Order Nº 297/2019 and the the book *Manual de Apoio ao Projecto de Reabilitação de Edifícios Antigos*.

The aim is to avoid inappropriate interventions during building renovation that could compromise the purpose of having healthy indoor conditions for a better life inside buildings, now more than ever, because people spend much time at home.

For better consumer understanding, future developments should consider applying a certification scale from A ("better") to G ("worst"), similar to the energy performance certificates. This health rating could also be part of the next-generation energy performance certificates, side by side with the energy rating.

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Impact of Covid-19 Pandemic Lockdown on the Managerial Aspects of Brick Manufacturing Unit—A Case Study on Post and Present Scenario

P. Murthi and K. Poongodi

Abstract Every commercial activity has exaggerated due to the ruthless covid-19 pandemic. Construction sector is one among the hardest affected industry and facing multiple challenges to proceed. The entire civil engineering related activities across the country had halted due to restrictions put in the place by the Central and State Governments of India. Cumulatively, the multiple consequences of the lock down situations would cause the socio-economic condition of the industry. In these circumstances, an insight investigation was carried out by using Likert scale based questionnaire and this study is focused on the managerial condition assessment of the stakeholder of a brick manufacturing chamber, a construction industry driven unit, situated in Warangal, Telangana State, India. The problems with respect to retention of migratory labours, consequence in economic aspects of production process including health aspects of labour and its effect on the present scenario are evaluated and presented.

Keywords Covid-19 · Construction industry · Brick manufacturing kiln · Managerial issues

1 Introduction

Clay brick is one of the most commonly used building materials in India. The bricks are used for construction of walls in most of the residential and commercial building. India is the second largest producer of bricks in the world next to China [1]. India alone produces more than 10% of the global production rate. It is estimated that India has more than 140,000 brick chamber units producing about 250

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billion bricks annually, employing about 15 million workers and consuming about 35 million tons of coal annually. It is appraised as the third largest industrial coal consumer in India next to steel and cement industry. The CO_2 emissions from the brick chambers are estimated to be 66–84 MT per year [1]. Bricks are produced normally rural based unorganized industrial sector. The size of brick manufacturing units are varied depends upon the topographical nature. The units established in the outskirt of urban are normally larger size compared to the units located in rural areas. However, the clustering of brick manufacturing units is quite common irrespective of their location. Though the alternate building materials are available in the market, the choice of bricks for construction of building is obvious and never decline due to the rapid growth of infrastructural industry and urbanization including fast economic growth [2, 3]. Such brick chamber units are facing complex environmental regulations issue though the profitability is less. At the same time, the poor working conditions and ignorance of existing labour laws and regulations leads to struggling the industrial operations. In addition, the scarcity of suitable management in construction activities and labour management for various operations of this kind of industry in the proximity is forced to employ the migratory and bonded labours [4, 5].

The brick kilns are spread across Telangana state almost in all the districts. The units located in the periphery of town are enrolled as authorized industry. But the small kilns situated in rural belt of Telangana state are not registered as an authenticated industry. However, nearly 2000 kilns are registered in the Telangana state labour department. According to the data released by the state government labour department, nearly 60,000 labours are working in 1100 brick kiln units. But this statistics may be varied due to the functioning of informal kilns. The brick kiln is highly labour intensive manufacturing sector [6]. The majority of workers in this brick kiln units are migratory category particularly come from Odisha state. These workers are employed for making bricks and kiln operations. The same time, the locally available labours are normally engaged for loading from kiln and unloading at market point during supply [2]. In a normal condition, a team of four labours can make 5 lakh bricks in a year.

Almost all the business across the globe is suffering and facing difficulty to operate due to the pandemic situation because of the uncontrolled spreading of coronavirus. The lockdown imposed by the Central and State Governments of India is triggered a sudden shot down of all kinds of industries and fronting tough time to face the post covid-19 scenario. The construction industry is almost halted, which was already reeling with various challenges. The restriction of movement of the labours or gatherings can create the pandemic condition of the construction sector, since, this industry is having higher percentage of migratory labour working [7]. Cumulatively, the worst condition of construction industry would cause the hindrance of associated business like brick manufacturing kiln. The Central and State Governments and the owners are extending their supports to the migratory labours by providing facilities and transportation to drive back to native. In this scenario, it is proposed to conduct a detailed survey on the effect of Covid-19 pandemic effect on the socio-economic condition of brick manufacturing kilns situated in Warangal Rural District.

2 Study Methods

The study was conducted by a micro level personal survey with a detailed set of questionnaire. There are three brick manufacturing units were considered and the information related to before covid-19 situation and current status were collected with respect to socio-economic parameters. The category of workers, wages, satisfactory level, ambiance of the working area such as occupational health aspects and safety culture for migratory labours and local labours were focused in this study as social factors. The details about production capacity, demand, manufacturing and selling cost per unit and profitability parameters were covered in the economic aspects. This study has covered almost all category of accessible labours working in all the three units along with the owners of these units for evaluating the present pandemic situation.

3 Category of Labours

A cursory look of the survey was illustrated that the labour force required in brick-kiln was grouped in to two different category such as local labours and migratory labours. The survey observed that the majority of the migratory labours are coming from the rural belt of Odissa state and they are seasonal farm workers in their nativity. The migrants are working for period of less than six months called short-term migrants and working regularly called as permanent migrant [8]. The reason to migrate can be varied such as employment, financially induced displacement, family commitments etc. The total labour force in brick-kiln is blended with both male and female workers. A significant contribution from female work force was noticed and the distribution of labours in the study area is shown in Fig. 1. An equal contribution of female labours are working due to the reason of family bounded labours. The distribution of labours is shown in Fig. 2. The share of the brick-kiln migrant workers was calculated as more than 60% among the total workers [8, 9]. The remaining labours are mobilized from local proximity. The impact of covid-19 lockout on the workforce available in the brick-kilns are also expressed in the Fig. 2.

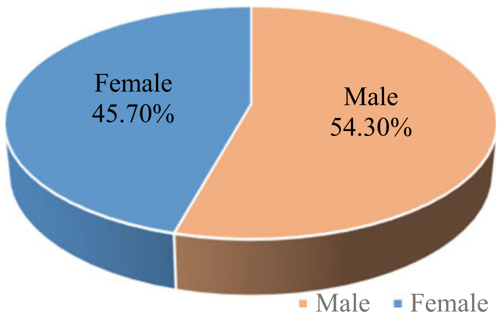

Fig. 1 Category of labours working in brick kiln based on gender before Covid-19

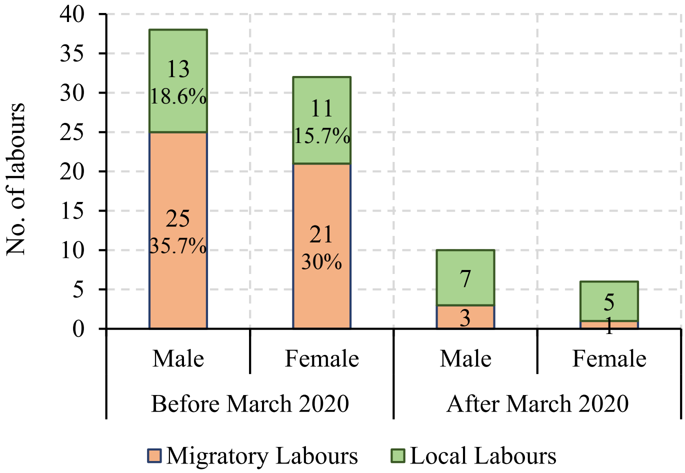

Fig. 2 No. of workers involved in brick kiln before and during Covid-19

4 Employment and Wage Category

A clear understanding was captured by this field studies which stated that the salary and wages are the prime factor of brick-kiln workers. It was noticed that there are two different categories of labours normally employed in brick kiln based on wage. A group of labours is categorized as piece-rate labours and the rest of the crew enrolled as daily wage basis. The field study had clearly pictured that the migratory labours are working under the category of piece-rate wage. These migratory labours are provided with living facilities and all sorts of working condition including occupational health requirements. Further, it was noticed that most of the piece-rate category migratory labours are characterized as bonded labour and the bondage was created due to the advance payment paid to their family. In order to improve the production, these crew are functioning with their family members as a team more than 10 h in a day. As per the information provided by the kiln owners that the size of a brick kiln has been decided by number of bricks manufactured in a day and hence the bonded labours are employed to increase the production rate under piece-rate. However, the daily wage labours are mobilized from the local villages and they are working with time bound nature of activities not involving the moulding and firing works in the kiln.

Supply of uninterrupted raw materials, preparing the required land for drying and transporting the sold bricks to the delivery points are the major responsibilities of these daily wage based labours. The payment was made based on the number days worked in a week. The average monthly wage of both the category of labour was arrived from the survey and it had clearly shown that though the piece-rate labours are working more time and more productivity, they are receiving lesser wage than the daily wage labours accordingly the piece rate was fixed and the collected survey results are shown in Fig. 3. Due to the sudden lockdown due to covid-19, the production has almost stopped and only the incomplete works and making bricks using the prepared clay are carrying out with the support of limited labours available on daily wage basis. As per the information provided by the owners of the kilns, the salary has been reduced about 60% to avoid the financial crises arise due to the current pandemic situation. The variation of wages before March 2020 and after 2020 are shown in Fig. 3.

The satisfactory level of both migratory and local labours on wage before the lockdown situation was assessed by Chi-square test ($\mathcal{K}^2$). The no satisfactory level about the wage for their work was considered as null hypothesis (H_0). In order to measure the level of job satisfaction of workers, five point scale was used. Scores were given from five to one depends upon the satisfaction level as shown Table 1.

The satisfactory level was categorized as High, Medium and Low based on the Arithmetic mean ($\overline{x}$) and Standard deviation (σ) score obtained from the respondents level of job satisfaction. The respondents whose scores were above the value of $\overline{x} + \sigma$ as high level and the below the value of $\overline{x} - \sigma$ were considered as low level. Those respondents scores were in between $\overline{x} + \sigma$ to $\overline{x} - \sigma$ classified as medium level of satisfaction. The observed and expected variables of this study are mentioned in Table 2. The degree of freedom was calculated as 2 and the significance level (α) was assumed as 5%.

Table 1 Five point scale on job satisfaction

Fully satisfied	Satisfied	No opinion	Not satisfied	Strongly not satisfied
5	4	3	2	1

Table 2 Actual and expected frequency on the satisfactory level

Category of Labours	No. of respondents (Actual and Expected)						
	High		Medium		Low		Total
	Actual	Expected	Actual	Expected	Actual	Expected	
Migratory	2	1.97	23	26.286	21	17.743	46
Local	1	1.03	17	13.714	6	9.257	24
Total	3	-	40	-	27	-	70

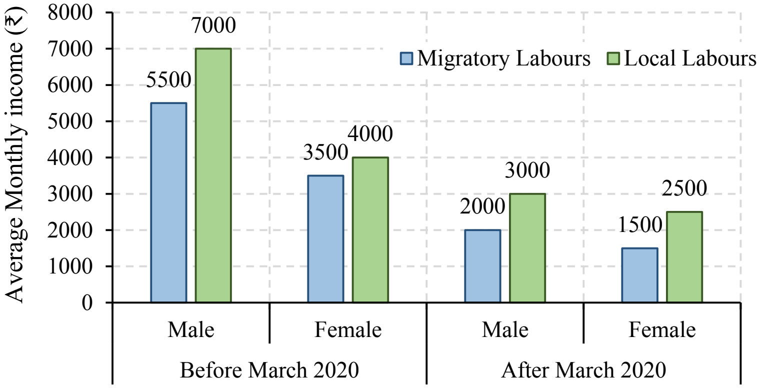

Fig. 3 Variations of monthly income

The Chi-square value (χ^2) was determined from the above values and the found tested value of χ^2 as 2.9431 and establish the corresponding p value as 0.023. The critical value of Chai-square (χ_c^2) from Chi-square table was found as 5.991. Since the calculated value is less than the critical value, χ^2 value not lies in the rejection area of the distribution curve and hence the null hypothesis (H_0) is accepted and proved that there no satisfactory of wage dispersed to the kiln workers before the lockdown situation [10, 11].

5 Production and Demand Scenario

The production process of brick is mainly geared up with the availability of migratory labours. Every year, the casting of bricks and sun dried during December-May dry season. The bonded labours mostly from Odissa state invited for production during November every year and return to their nativity during monsoon period for involving agricultural based activities particularly to sow the rain-fed crops. In the same time, the monsoon period is not a suitable period for making bricks and maintaining the quality of bricks is very difficult expressed by a worker presently working in a brick kiln. The data comparison of manufacturing of bricks in terms of numbers obtained from the identified three units during December 2018 to May 2019 with the same period of 2019–20 is shown in Fig. 4. A sudden decline was expressed and the number of bricks mentioned the year 2019–20 in Fig. 4 were cast before March 2020 itself. From March to May, the second half of the production period is the most important since both fabrication of bricks and burning in kiln are simultaneously executed but the current situation create under quality bricks due to improper firing operation of kiln and the owners are facing a critical situation to market the under quality bricks. Due to the sudden implementation of lockdown, the labours are evacuated to manage the situation and survive which affect the production scenario and shaking the sustainability of brick kiln units.

Brick production is directly depends on need of construction industry. The construction industry is also severely affected this pandemic and lock down situation. The construction industry has experienced a significant level of disruption due to the shortage of labours and all kind of material supply. Total shutdown of construction industry was observed during April and May 2020 and is directly affected the brick production. Perhaps the construction industry has starts recoup slowly but the scenario of brick kiln is pathetic even after June 2020. The demand of available stock in brick industry is not met the quality expectations of the construction industry [12, 13].

6 Present Scenario of Brick Kiln

The impact of Covid-19 will continue on the labour shortage to retrieve the operations in the kiln. It was pointed out from the survey that more than 90% of the migratory labours are not showing any interest to come back and majority labours said that we won't come back to the industry once the situation becomes normal even after the vaccination will be invented and available in market. Though the occupational health risk will meet by the owner, they are afraid about their life. They are expressed that searching alternate opportunities in their proximity is only the option. The mindset of the migratory labours are presented in the Fig. 5.

The labours are comes under the category of unorganized sector and hence expecting sufficient support from Government and Owners. To meet the required skilled labours in the mere future, needs further investment to hire the bonded labours. The survey was clearly pointed out that the owners of the brick kiln is currently facing a tough time for procuring the raw materials, financial setback, labour shortage and administrative related issues. The owner of a kiln was clearly pointed out during survey that the investment was more than a crore and land occupied the industry also a leased land. He pointed out fearfully that the

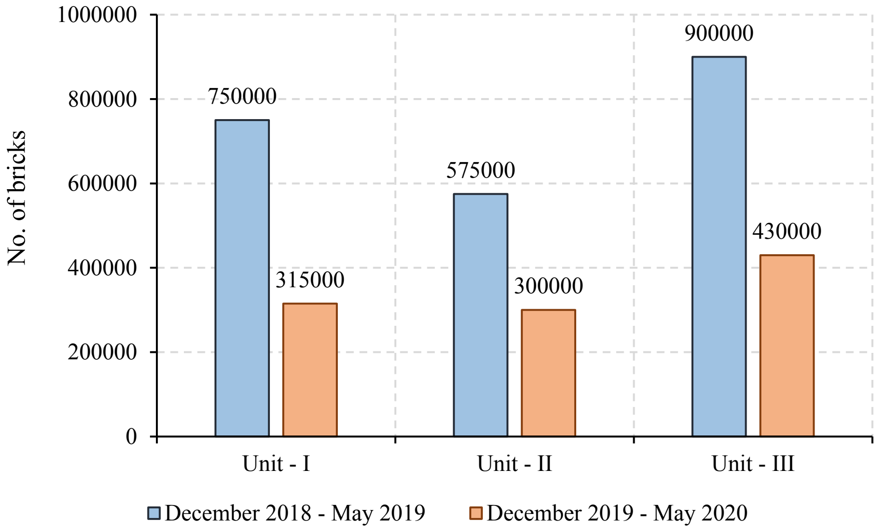

Fig. 4 Manufacturing of bricks in selected brick kiln

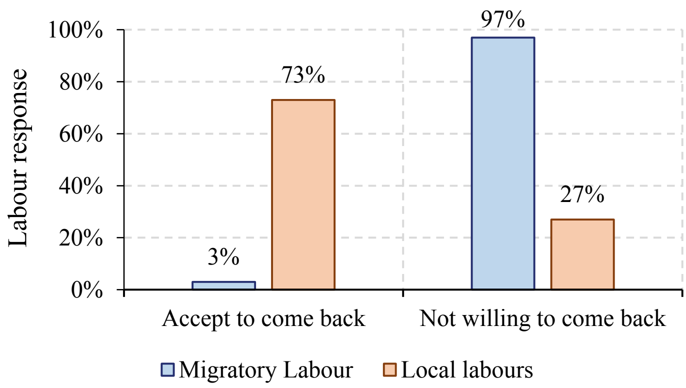

Fig. 5 Expected labour return after lockdown situation

re-payment against the principle and interest in all category of financial management had been stopped during these period due to slowdown of cash flow. Though all sorts of facilities provided to the labours in this hit hard condition, they are helpless from the government sector such as providing subsidy, revoking the bank interest and payment of insurance premium etc. The unsold bricks are kept in the kiln itself causing the problems in finance management and Fig. 5 shows a snapshot of unsold bricks kept in kiln. The land used for the brick casting was noticed that re-plugging has to be necessitated while recoup the kiln for functioning and the condition of working land of the kiln is shown in Figs. 6, 7 and 8.

(a) Brick kiln unit I (b) Brick kiln unit II

Fig. 6 Unsold bricks in kiln

Fig. 7 Present scenario of brick kiln

Fig. 8 Unburned sundried bricks site kept long time

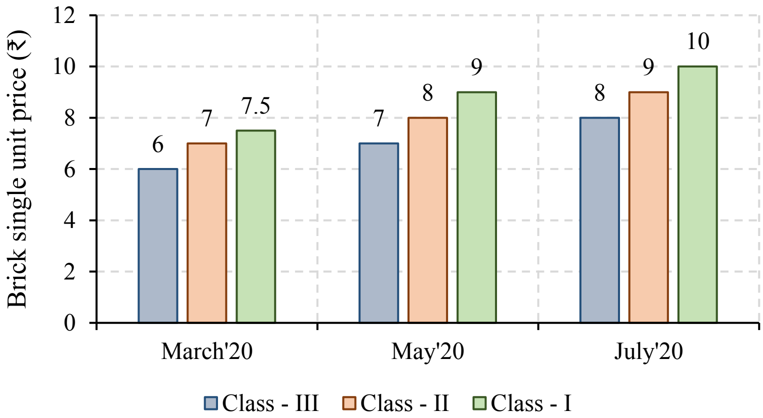

Fig. 9 Price variations of brick unit

7 Price Variations of Brick Unit

The economic vulnerability situation in the business was affected the marketing strategy of burned brick. Due to the price hike in the raw materials, insufficient cash flow, financial assistance to the labours particularly for migrant workers and other administrative commitment, the brick unit price is hiked up to 20% compared to the price before covid-19. The price variation of brick before and during covid-19 situation is shown in Fig. 9. However, the owners of all three brick-kiln are uniformly stated that though the price of a single brick had been increased up to 20%, the earning from the business was dropped more than 30%. One of the owner has answered in a single word as “we are forced to suspend the business and thinking to choose an alternate business”.

8 Expectations After Covid-19 Pandemic Situation

The kiln owners are expecting the following points in order to sustain the brick manufacturing business:

- Develop effective policies and regulations for effective functioning
- Design and Develop a suitable alternate technology for producing bricks throughout the year using mechanization
- Strict monitoring the environmental policies for sustain the environment
- Single window policies to be developed for improving the functional procedure and economic considerations
- Make suitable strategy for making the brick manufacturing kiln as organized sector

The labours are expecting the following points to work without panic.

- Providing better working environment
- Making as organized category labours
- Covering insurance and other medical assistance
- Ensure the safety provisions using the latest technology like IoT.

9 Conclusions

Form the details collected from this survey, the following conclusions are acquired:

1. Before covid-19, the share of workers based on gender was observed as 54.3% and 45.7% of male and female respectively. Among the total labours, more than 60% category workers are noted as migratory workers. Only less number of workers are presently involved in various petty works in the kilns.
2. There are two distinguished categories of workers employed namely piece-rate workers and daily wage workers. Mostly the migratory workers are working under piece-rate workers and local workers are considered as daily wage category workers.
3. Though the migratory workers are involved more working hours, they are getting relatively lesser monthly wages based on the production rate while compared to the daily wage based local workers.
4. The satisfactory level of workers was determined through the chi-square test and found that there is no satisfactory about the wages what they are getting.
5. The production rate was reduced below 50% during the covid-19 period and further it was noted that the already manufactured bricks are not able to market due to the slowdown of construction activities.
6. From this survey, it was highlighted the mindset of the migratory workers that nearly 97% workers are expressed their views as not willing to come back for kiln works and the scenario of worker shortage is expected in the mere future while resuming the kiln operations. Hence, kiln owners are focused in this issue as one of the important parameter before resuming during post covid-19 pandemic situation.
7. Because of the various issues, the price per brick was increased more than 20% in order to manage the manufacturing cost. However, the finished bricks are placed in stock due to the poor demand of bricks caused by the similar impact in construction industry.

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The Impact of the COVID19 Pandemic on Shopping Trips Behavior in Urban Areas

Abeer K. Jameel, Wafaa Kh. Luaibi, and Iman Alghalibi

Abstract The impact of COVID-19 pandemic is highly considered in the recent time because of its significant role in changing the behavior of trips. However, its effect on the shopping trips according to the shopping types is rarely considered. Therefore, this paper aims to investigate the changes in the behavior of shopping trips and their control factors during the COVID-19 pandemic according to the shopping types. The considered shopping types are food and drinks, cosmetics, clothes and shoes, electronic devices, dolls and children products, electricity devices and furniture. The time of COVID-19 pandemic is divided into six stages stating from December 2019 to the recent time. The collected data are categorized into two groups. The first group represents the changes in the behavior of shopping trips including frequency, mode choice, distance of trip, and time of trip. The second group represents the socio demographic factors such as age, gender, marital states, income level, education level, and car ownership. It also includes the experience in using electronic facilities and location factor. The questionnaire form is used as a method of data collection. The results show increase in the rate of food, electronic devices and dolls shopping despite the remarkable decline in the rate of other shopping types between March 2020 and October 2020, after that the behavior has been similar to the behavior of shopping trips before COVID-19 pandemic. However, the frequency of using e-shopping and using walking in short shopping trips is still higher than before pandemic even in post-pandemic period. This encourages using avoid-shift strategy to promote sustainable transportation system and cities.

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Keywords COVID-19 · Shopping trips · Trip behavior · Control factors · E-shopping · Sustainable transport mode

1 Introduction

Planning and allocating activities centers in urban areas is highly influenced by social development which is in turn affected by the human behavior and changes in public circumstances [1–4]. The variables reflecting social characteristics that are booting the travel and movement of peoples can be represented by income level, education level, car ownership, age, gender and marital states. The main variables of the travel behavior that reflect this integration is frequency of production and attraction trip, its origin and destination, travel distance, and mode choices [5].

Recently, since March 2020, movement is restricted due to applying physical distance policy and movement lockdown across the world because of the spread of Corona Virus (COVID-19) pandemic. The electronic activities such as e-learning and teleworking have been highly based on in this period. This has a significant impact on the human activities and the social life [6–10]. Observations and statistical reports show the change in human movement to get their necessities such as food and medicine. In addition, the general decline in the air, land and water travel rate has been noticeable [11, 12]. The effect of COVID-19 on the various activities in various aspects has been widely considered, especially on the daily out-of-home travel activities. Many researches have considered the changes in the travel behavior during the COVID–19 travel restrictions. The general and common conclusions highlight the significant reduction in the rate of long motorized trips by about 50%. However, the effect of the pandemic on the rate of trips according to their purposes is not the same. The pandemic has also significant effect on the behavior of trips in terms of trip length, travel time, transport mode [8, 11, 13].

People have restricted their travel to the most necessary purposes such as treatment, shopping, services and some governmental activities. The frequency of trips has been reduced by about 50% during the COVID-19 period [6, 7, 13–16], private trips by 75% and public transportation by 90% [13]. Furthermore, choosing the mode of transport is affected. The use of public transportation has been declined due to the policy of physical distancing; people should stay at safe distances of at least 0.5–2.0 m away from each other. The subsequent lockdown and unlock down has led to activate the use of public buses as the economic activities have resumed gradually and workers returned to their jobs [6, 10, 11, 13–16].

On the other hand, the purposes of trips are quite different in the era of COVID-19 as applying the rules of 'stay at home' encourages people to make trips for essential purposes which are shopping and medical purposes. Educational and work trips have been replaced with tele-modes [6, 7, 11]. The rate of groceries shopping trips has increased [6–8, 10, 17]. Works related to stores and health services trips have been highly recorded as well [7]. Most of these trips have been within short distances, approximately less than 3 km distance. However, it is noted that the change in the rate of shopping trips is different according to the type of shopping during the pandemic restrictions.

The behavior of shopping trips is important variable in planning urban cities and allocating big shopping centers. Worldwide, the rate of grocery shopping activities was raised to the highest, this includes in store and electronic trips. Statistics in the UK showed that the rate of Google search for food delivery increased by about 50% in April 2020 and about 90% of people changed their shopping behavior to use e-shopping. In addition, the demand of food groceries had been increased to be higher than the supplied groceries in sometimes [18].

However, the rate of changes in the behavior of shopping trips has fluctuated within the stages of pandemic. The COVID-19 pandemic has been developed in 6 stages [10, 15, 16]:

- Stage 1 was in the end of December 2019 and started when the first few cases of COVID-19 infected people have appeared in China. The effect of this stage was neglected, as there was no movement restriction was declared.
- Stage 2 started in January 2020 when the virus spread globally and the concern of its spread was declared.
- Stage 3 was started in the mid of March when the WHO declared that the COVID-19 is a global pandemic, so many governments declared the applying of full lockdown and restriction of social activities. In this stage, the most significant decline in trips was observed.
- Stage 4 started in May 2020 through applying the partial lockdown.
- Stage 5 started in summer 2020 through reopening and lockdowns for several states.
- Stage 6 started in October 2020 through appearing the British developed cases and Indian version of COVID-19.

Therefore, the aim of this paper is to investigate the behavior of shopping trips in the different time-terms of COVID-19 pandemic and investigate the control factors according to the types of shopping.

2 Methodology

To investigate the aim of this research, a survey has been carried out in Baghdad City using a self-designed questionnaire form. About 250 paper forms and 550 electronic forms were distributed to collect the needed data, with total of 800 forms as sample size of population size of 7,300,000 which represents the population size of Baghdad City. The sample size is calculated to be greater than the minimum number of necessary samples that meet the desired statistical constraints, having a confidence level of 95% that the real value is within ±3.5% of the surveyed value.

The needed data for this study are categorized into three groups, shopping trips behavior, shopping types and the data representing the control factors.

The data related to the behavior of shopping trips are the frequency of trips, the used mode, the distance of trips, and the time of trips. Shopping types considered in this research are essential groceries including food and drinks, clothes and shoes, cosmetics, dolls and children products, electronics devices, electricity and furniture. While the data related to the control factors are socio demographic such as age, education level, income level, gender, marital states and household size. The control factors include also internet experience, car ownership, and location factors.

The questionnaire form used in this research includes two parts. The first part includes the socio demographic data, internet experience, and car ownership. The second part contains questions related to the first group of data in addition to the shopping types and the location of stores. The answers of the second part of the questionnaire were repeated for each type of shopping.

The reliability and validity of the questionnaire were tested using SPSS IBM Statics 25. Pearson method was used to measure the reliability which was between 0,652 and 0,871 representing acceptable to high reliability and validity level. This means that the respondents of the questionnaire are valid to use as input data for this research to get the needed results.

3 Results

The results of analyzing the collected data are categorized into results related to the behavior of shopping trips in the series of COVID-19 stages according to the shopping types and results related to the affected factors.

3.1 The Changes in the Shopping Trips Behavior

Figures 1 and 2 show the changes in the frequency of in store and e-shopping in the different stages of COVID-19 pandemic. The value 1.0 in the vertical axis means there is no change and the rate during the stage is the same before starting COVID-19 pandemic. The values less than 1.0 means there was decline in the frequency and the values higher than 1.0 means that there was increase in the frequency of trips. The fluctuation of the trips frequency is clear in the stages 3 and

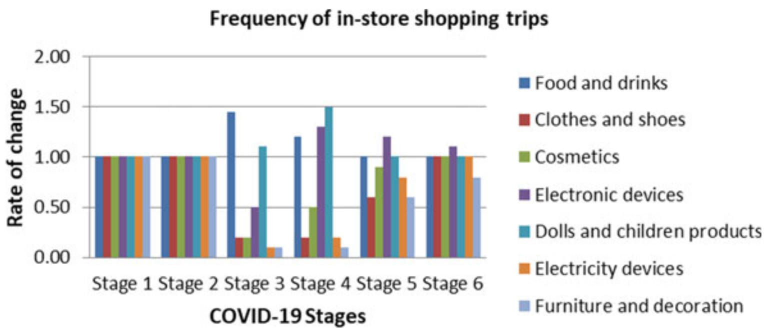

Fig. 1 The changes in the frequency of in-store shopping due to COVID-19 pandemic

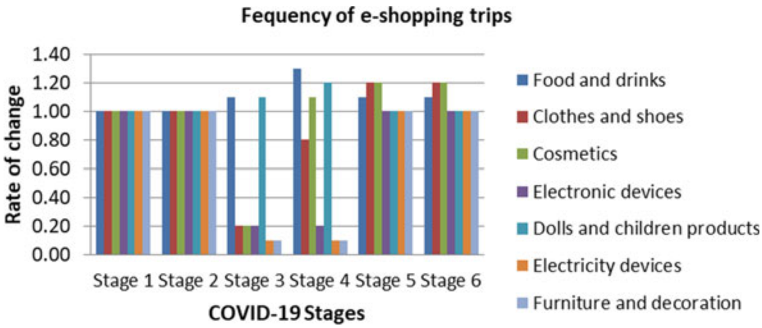

Fig. 2 The changes in the frequency of e-shopping due to COVID-19 pandemic

4 when the full and the followed partial lockdown have been applied. This is may be explained by the low percentages of people who took the risk of the virus seriously [10]. It can be noticed also that the rate of food and groceries shopping has been increased in the stages 3 and 4 as people had concerned of probabilities of continued full lockdown and a shortage in the food. The results show also that the rate of electronic devices was increased in stage 4 when electronic activities had been replacing the traditional activities. This increase is also noticed in other big cities such as the UK [6–8, 10, 17, 18].

In addition, it is noticed that the rate of buying children products had affected by the situation in March to summer 2020. These surprised results have been shown to some owners of and workers in dolls and children products shops. Their explaining of these results is that parents used to buy these kinds of products for their children in summer. Because there was no school when lockdown were applied, the season of increasing the demand of these products was changed to start in March 2020 rather than in summer. The owners showed that they have benefits of ending school season earlier in 2020. On the other hand, the other types of shopping were declined by an observed rate between March and summer 2020 but they returned to their normal rate after that. Regarding the use of e-shopping, the results show an increase in the use of e-shopping in stages 3 and 4 but with slight rate. The use of e-shopping to buy food increased more than other shopping. The owners of shop showed that the use of e-shopping is not effective as the in-store shopping and it is mostly used only to check availability and details of items. This may due to people have not been used to buy items without checking them. In addition, stores do not accept returned items. Therefore, the rate of in store shopping has been higher than e-shopping even in the different stages of COVID-19 pandemic with a slight rising in the use of e-shopping.

Figures 3, 4 and 5 show the changes in the mode use for shopping trips when COVID-19 pandemic started. It is shown that the rate of using private cars was higher than the use of public buses for all the types of shopping. The main reason is applying the social distancing rules that are not fit with the use of microbuses. In addition, the rate of using public buses has been increased by a significant rate in

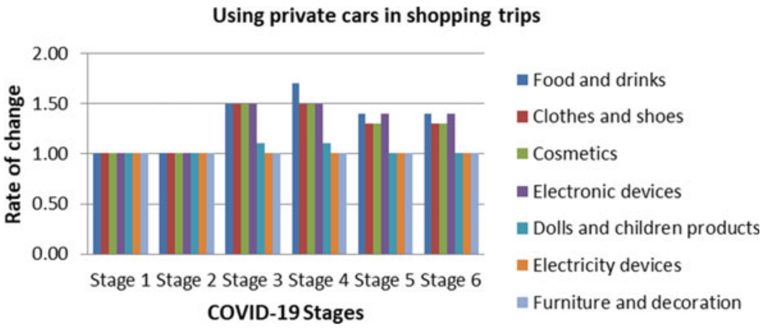

Fig. 3 The changes in the use of private cars due to COVID-19 pandemic

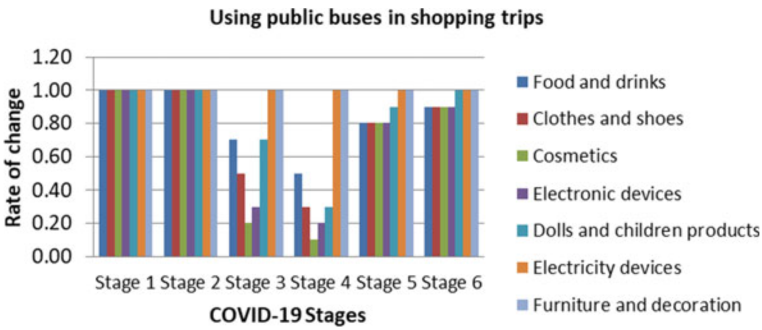

Fig. 4 The changes in the use of public buses due to COVID-19 pandemic

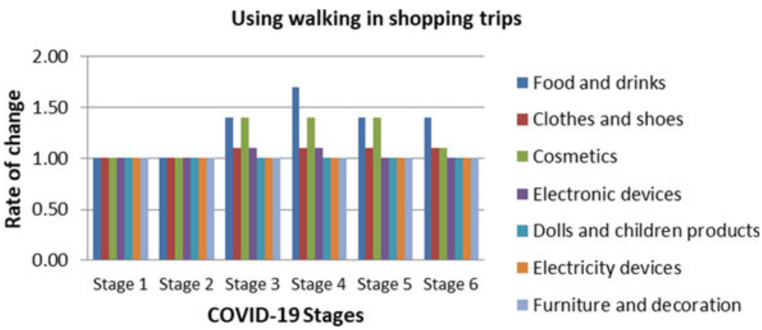

Fig. 5 The changes in the use of using walking due COVID-19 pandemic

stages 3 and 4 for the same reason. Regarding electricity and furniture shopping, the rate of change 1 means that there is no change in the use of public buses in this kind of shopping.

Figure 5 shows an improvement in the use of walking in shopping after COVID-19 because the majority of trips were short and for emergency purpose.

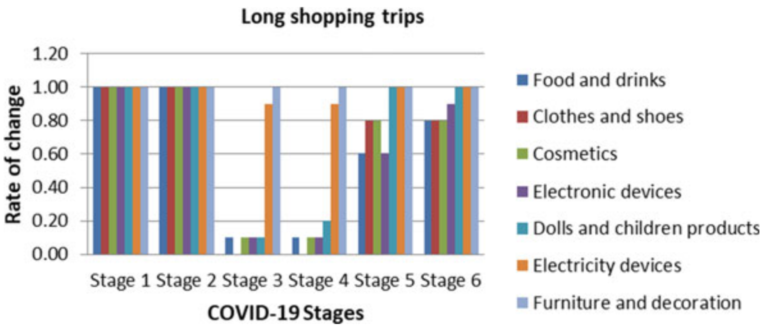

Fig. 6 The changes in the long shopping trips in the stages of COVID-19 pandemic

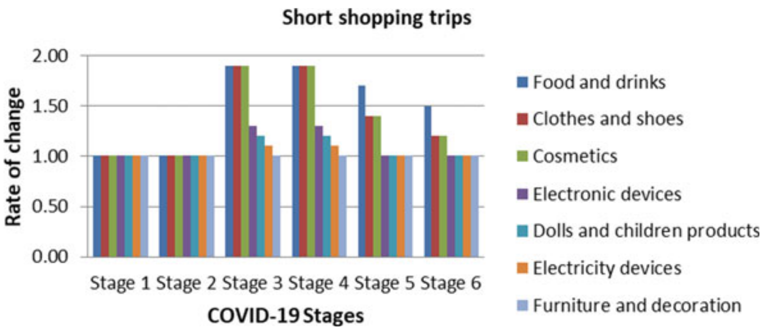

Fig. 7 The changes in the short shopping trips due to COVID-19 pandemic

People started to use walking to buy food, cosmetics, clothes or electronic devices from nearby local shops after COVID-19. However, the rate of using walking in the other types of shopping has not been changed.

Figures 6 and 7 show the rate of changes in the distance of shopping trips due to COVID-19 pandemic. There was a remarked decline in the rate of long distance shopping trips and increase in the short distance trips; especially in the stages 3 and 4. People started to do shopping from local shops to obey the rules of lockdown and provide the essential items such as food. It can be seen that clothes and cosmetic shopping was carried out from close local shopping. In addition, short distance shopping was used for electronic devices and children products. However, the rate of buying heavy items, such as furniture, is not affected as this kind of shopping is usually made in known big centers.

Regarding the time of shopping trips, Figs. 8 and 9 show that morning trips was the most common trips because of the partial lockdown rules. However, the rate of some types of shopping; such as electronic, dolls, electricity, were still in evening as local stores still opened in evening.

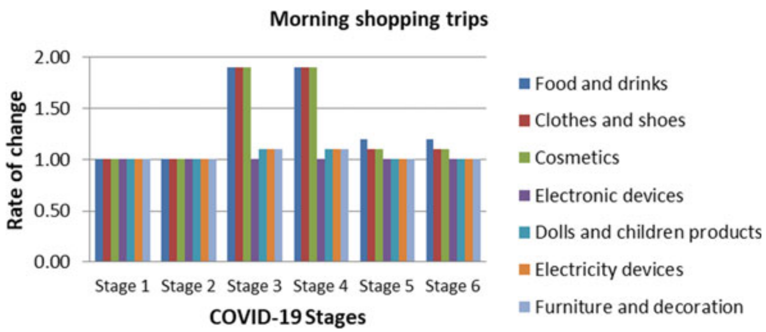

Fig. 8 The changes in the morning shopping trips due to COVID-19 pandemic

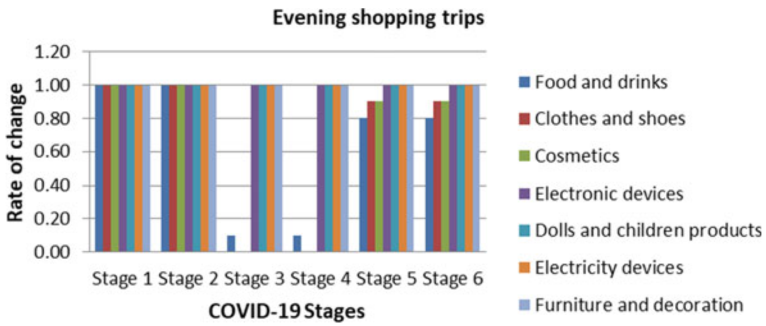

Fig. 9 The changes in the evening trips due to COVID-19 pandemic

Overall, the behavior of food shopping trips has significant changes resulted from COVID-19 pandemic. The significant changes were when the full lockdown and then partial lockdown has been applied since March 2020.

In the recent time, and after 20 months since starting the COVID-19 pandemic, the rate of changes has been reduced and the behavior of shopping trips returned to what they were before COVID-19 pandemic. Some slight changes have been continued till now. For example: the use of e-shopping has improved as people have tried to improve their e-shopping skills. In addition, some shops started to use return rules to attract more customers. Another example, the rate of short distance shopping has still higher even in the recent time and this is in consistence with using of walking as a mode of shopping trips. Before COVID-19, people used to do shopping from big and famous shopping centers. After COVID-19, the local shops started to supply the demand of residents in terms of price and quality. People, in the other hand, started to investigate the supplied items in the local shops and choose the items that fit with their desires. For example, the demand of electronic devices has increased as a result of using e-learning and e-work. So, the local shops have increased their supply.

3.2 The Control Factors of Shopping Trips

In this section, the results of the investigation of the effect of social demographic, internet experience and location as control factors of shopping trips are presented in Tables 1 and 2. Table 1 shows the mean of the rate of changes in the frequency of each of the shopping type trips according to each variable of social demographics. The p-value is also shown to reflect the correlation between each variable level and the frequency of trips. For example, the mean of the rate of changes in the frequency of food and drinks shopping trips is just 10% for age group less than 20 years, while the significance of correlation is 0.22. This means that the changes in this kind of shopping trips is not affected by the behavior of people in this group but it is more affected by the behavior of people in 20 to 60 years group. On the other hand, the shopping trips for people less than 40 years, both male and females, to buy electronic devices and children products have affected by the pandemic. While the female; especially single female trips to buy clothes and cosmetics are highly affected by the pandemic. Shopping trips done by married male and female people to buy foods have significantly changed after the pandemic disregarding the household size. The household size may affect the behavior of shopping trips to buy dolls and children products as bigger household size means almost higher number of children per household.

The income level has significant effect on the changes of all the types of shopping trips during the COVID-19 pandemic while the education level has not significant effect, it may have a role in increasing the electronic device shopping as higher educated people have improved their electronic skills in this period.

Car-ownership may have a role in the changes of long shopping trips for the most common shopping trip in the COVID-19 pandemic, as private cars have been the predominant transport mode since March 2020.

From the results shown in Table 2, it can be noticed that the experience in using electronic devices and internet has a significant role in changing the frequency of the most common shopping trip types. Higher experience motivates people to use electronic shopping. While the location factor has significant effect on the essential shopping trips, closure shops means higher frequent short shopping trips and far away shops with higher knowledge in using electronic facilities promotes using e-shopping.

4 Discussion

To reduce the frequency of shopping trips and change their behavior to meet the sustainable criteria, some of global strategies have been proposed and applied. The avoid-shift-improve strategy is one of them [19, 20].

Avoid shopping trips can be achieved through applying bans and restrictions in movement, full and partial lockdown is an example of “avoid” strategy and this has

Table 1 The mean and significance correlation test between the social demographic variables and the frequency of shopping trips

Social demography		Food and drinks		Clothes and shoes		Cosmetics		Electronic devices		Dolls and children products		Electricity		Furniture	
Variable	Levels of the variable	M*	P value	M	P value	M	P value	M	P value	M	P value	M	P value	M	P value
Age	<20	0.9	0.22	0.1	0.21	0.1	0.89	0.1	0.02	1.2	0.03	1.0	0.91	1.0	0.02
	20–40	1.5	0.04	0.2	0.10	0.4	0.77	1.4	0.02	1.1	0.02	0.7	3.5	0.9	3.2
	40–60	0.9	0.05	0.1	0.34	0.4	0.34	0.9	0.41	1.0	0.09	0.7	5.3	0.2	5.7
	>60	0.1	0.12	0.1	0.32	0.1	0.21	0.4	0.23	0.6	0.09	1.0	6.2	0.1	10.9
Income	Low	0.7	0.03	0.1	0.07	0.1	0.03	0.1	0.002	0.5	0.04	1.0	0.01	0.9	1.31
	Middle	1.5	0.04	0.2	0.05	0.4	0.04	0.9	0.01	1.0	0.01	1.0	0.001	0.6	0.03
	High	1.9	0.04	0.5	0.04	0.5	0.05	1.4	0.005	1.3	0.001	0.5	0.02	0.2	0.01
Gender	Male	1.1	0.06	0.1	0.12	0.1	0.65	1.2	0.04	1.1	0.65	0.6	3.2	0.5	4.6
	Female	1.6	0.04	0.4	0.02	0.4	0.04	1.1	0.05	1.2	1.34	0.7	6.3	0.3	3.6
Marital status	Single	0.6	0.02	0.3	0.01	0.4	0.45	0.9	0.05	0.2	0.08	1.0	1.3	0.6	5.4
	Married	1.6	0.01	0.1	0.10	0.3	0.21	1.2	0.08	1.3	0.02	0.6	0.05	0.4	9.0
Size of household	2	0.7	0.04	0.1	0.10	0.1	0.09	0.2	0.09	1.0	1.60	0.6	0.1	0.1	4.3
	3–5	1.6	0.03	0.2	0.13	0.5	0.05	1.1	0.05	1.1	0.01	0.4	0.02	0.9	12.1
	5–10	1.9	0.09	0.4	0.21	0.4	0.17	1.4	0.18	1.2	0.01	0.3	2.5	0.5	4.8
	>10	1.9	0.08	0.1	0.22	0.2	0.56	0.5	0.12	0.9	0.09	0.7	5.4	0.4	9.01
Level of education	Low	1.2	0.06	0.1	0.43	0.1	0.05	0.1	0.34	1.3	0.03	0.3	2.4	0.7	11.1
	Educated	1.5	0.03	0.3	1.22	0.4	0.09	1.1	0.002	1.1	1.90	0.4	2.3	0.8	10.3
	High level	1.1	0.07	0.1	0.98	0.2	0.11	1.2	0.004	0.9	2.22	0.5	5.4	0.2	1.23
Car Ownership	0	1.2	0.01	0.5	0.03	0.5	0.05	0.1	0.04	1.1	0.13	0.3	2.4	0.7	1.16
	1	1.5	0.02	0.3	0.02	0.4	0.09	1.6	0.02	1.2	1.55	0.4	2.3	0.8	6.4
	≥ 2	1.4	0.007	0.4	0.08	0.6	0.01	1.2	0.04	0.8	6.24	0.5	5.4	0.2	1.3

* M = Mean

Table 2 The mean and significance correlation test between the internet experience and location variables and the frequency of e-shopping trips

Control factors		Food and drinks		Clothes and shoes		Cosmetics		Electronic devices		Dolls and children products		Electricity		Furniture	
Variable	Levels of the variable	M*	P value	M	P value	M	P value	M	P value	M	P value	M	P value	M	P value
Internet experience	Low	1.0	0.02	1.0	0.07	0.5	0.09	0.7	0.06	1.0	0.03	0.3	0.34	0.2	0.42
	Middle	1.2	0.04	0.2	0.04	0.7	0.07	1.1	0.02	1.1	0.05	0.2	5.3	0.1	1.12
	High	1.5	0.05	0.8	0.04	0.4	0.04	0.9	0.01	1.0	0.05	0.1	12.1	0.5	0.7
Location factors	<1 km	1.1	0.02	0.6	0.16	0.3	0.25	1.0	0.14	1.1	0.25	0.3	0.23	0. 8	1.6
	1–5 km	1.6	0.04	0.8	0.12	0.8	0.14	0.5	0.25	1.2	1.04	0.1	0.34	0.3	3.6
	>5 km	1.5	0.04	0.9	0.34	0.8	0.23	0.2	0.55	1.0	1.01	0.1	0.29	0.3	9.1

* M = Mean

been already applied in stages 3 and 4. The results of this strategy are shown in this study and can be seen the significant changes in the behavior of non-essential shopping trips such as frequency, distance, time and the used mode of transport.

These changes have come in parallel with improvement in the skills of using electronic facilities and using electronic education, teleworking and virtual meetings. Stores owners and sellers have attempted to improve their skill in e-selling to avoid the issues of declining in the demand resulted from the condition of COVID-19 pandemic. In addition, during the COVID-19 pandemic, buyers changed their attitude in terms of doing shopping in local shopping area even when the quality of items is less. This has motivated the owners of local stores to improve the quality of the supplied items to meet the needs and desires of customers. Shopping in local and nearby centers is a stepwise toward promoting walking as a preferred transport mode. Shifting to use e-shopping and walking in shopping trips is another stepwise towards achieving sustainable transport and sustainable cities. However, the avoid-shift-improve strategy cannot achieve its target without implementing improvement plans of internet and electronic facilities and providing safer and more effective walking facilities. In addition, the affected factors should be considered in this strategy.

From the above results, the most correlated variables that should be considered in determining the types of shopping items and their demand are age of people, the electronic devices and dolls shopping are affected by the rate of people with age less than 20 years while older people are more interested in essential items like food and drinks. The marital states, gender and household size are important contributing factors in the most common types of shopping such as food, clothes, cosmetics and children products. Income level is important variables as well in forecasting all shopping types.

5 Conclusion

The aim of this study is to investigate the changes in the behaviour of shopping trips and identifying the control factors according to the types of shopping due to the COVID-19 pandemic. The time considered in this investigation is from December 2019 when the first case appeared in China to the time of conducting this research, May 2021. This time is divided into six stages and these stages are considered in collecting and analysing the data. The main conclusion points are:

- Despite the remarkable decline in the general rate of trips and shopping trips, the frequency of food and groceries shopping has been increased in the stages 3 and 4 when the first cases of COVID-19 appeared in Iraq and the government applied the full lockdown strategy. This may result from the raise in the concerned of shortage in the food.
- The rate of buying electronic devices was increased slightly in stage 4 when electronic activities had been replacing the traditional daily activities; especially

for age group less than 40 years as they include students and workers. The income level and education level are the most influenced factors.
- The rate of buying children products had increased during March to summer 2020 when there was no schools government gave long leave to students.
- In October 2020, most of the daily activities have returned to their normal level. However, the rate of e-shopping is still higher than before COVID-19 because peopled have used to use e-facilities in their daily life activities.
- The main control factors of shopping trips are age group, income level, and car-ownership. Other factors control various types of shopping.
- Location factor has an important role in promoting short trips in addition to the special circumstances of COVID-19 pandemic.

6 Recommendations

Restrictions in daily social activities and traffic movements have significant roles in achieving the objectives of Avoid-Shift strategy. Therefore, it is recommended to take advantages of these strategies to provide the conditions of sustainable transport and cities. However, “Improve” strategy is essential to achieve the overall aims of Avoid-Shift-Improve strategy. Therefore, it is recommended to.

- Improve the internet service to promote e-shopping as a replacing of shopping trips.
- Improve the walking facilities to promote walking as a mode of shopping trips.
- Promote local shopping centres to promote short distance trips.

For further research it is recommended to consider the various types of services and work trips in analysing trips behaviour that can be used in planning and locating service and work areas.

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