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Characterization of waste cooking oil and waste engine oil on physical properties of aged bitumen

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ABSTRACT

Waste cooking oil (WCO) and waste engine oil (WEO) have been generated in huge quantities in recent years as a result of the improvement of society's living standards and the advancement of automobiles and The molecular structure of WCO and WEO is similar to bitumen, indicating their potential for usage in highway construction to mitigate the hardening effect of recovered asphalt pavement materials. In this study, five different ratios of WCO and WEO were blended with VG40 grade bitumen under ageing conditions in accordance with the adaptability of the paving bitumen specification (IS 73: 2013). The waste oil treated samples were artificially short-aged by means of the thin film oven test. The penetration, softening point, viscosity, temperature sensitivity, penetration ageing ratio, and ductility tests were used to evaluate the physical performance parameters of the WCO and WEO modified bitumen.

The results of the tests reveal that the blending of WCO and WEO with neat bitumen softens the workability of aged bitumen. The physical properties of aged bitumen improved when treated with WEO as compared to when treated with WCO. Based on the results of the analyses and the overall ranking, it has been found that a blend of 3 percent WEO and 3 percent WCO resulted in the most significant improvement in bitumen modification. Significant differences were observed when waste oil was blended with a higher percentage, resulting in a change in the grade of bitumen.

1. Introduction

Waste cooking oil (WCO) and waste engine oil (WEO) have been produced in huge quantities in recent years as a result of the advancement of automobiles and the improvement of society's living standards. With the increase in the number of vehicles on the road, the amount of WEO being generated around the world is increasing. As a result of continuous engine operation, the performance of the oil degrades with time, and it becomes increasingly difficult to recycle WEO as new motor oil. WEOs are by-products of petroleum products, such as discarded motor oil from automobiles, and they possess most of the same fundamental physical and chemical features as bitumen [1]. Furthermore, an increasing population has led to an increase in the production of food items, resulting in the generation of a large amount of kitchen waste. One of the most widely used kitchen items is edible cooking oil, which can be obtained from a wide range of feed ingredients, including plant and vegetable oils, animal fats, and a variety of other sources. When different types of edible vegetable oils, animal oils, and palm oil are used, waste cooking oil (WCO) is produced after the frying and cooking process. [2]. WEO and WCO have risen to the level of important environmental pollutants because they have the potential to pollute rivers and natural resources. The proper disposal of this waste oil is a major concern because it has the ability to increase environmental and municipal issues. Waste oil dumping into landfills or rivers, in general, has a negative impact on the environment since it is not processed before it is dumped. One of the most severe ecological issues that can arise is eutrophication, which occurs when sunlight cannot penetrate the surface of a river because of a thin coating of oil impeding its path. When eutrophication occurs in a river, the oxygen supply for marine life is disrupted over time. As a result, engine oil from automobiles and waste cooking oil are the most significant sources of river contamination. The responsibility for managing the high construction costs and reducing the waste disposal difficulties has prompted the practise of waste oil recycling as an option and alternative way of preventing these issues from occurring [3].

Treatment or recycling of these waste oils not only helps reduce pollution and save energy, but it is also an example of a new way of

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reusing waste. India consumes 102 billion litres of fuel and 23 million tonnes of edible oil every year, according to the International Energy Agency. Approximately 3 million tonnes of oil are thrown away after usage, and this is referred to as "used cooking oil." The combustion of WEO will release airborne pollutants into the atmosphere, which can enter people's lungs and cause serious health consequences. Food business operators (FBOs) are required to discard the cooking oil after four times of frying or when the total polar compound levels exceed 25. In the process of continually raising the temperature of oils to their boiling points, free reactive oxygen forms, which contributes to peroxidation by raising the levels of glucose, creatinine, and cholesterol in the body. Polyunsaturated fatty acid molecules in the oil are altered by repeated frying, leading to the development of reactive monomers, dimmers, and polymers that degrade into poisonous malondialdehyde, which has been linked to coronary heart disease and some malignancies. Researchers discovered that the molecular structure of WEO and WCO is comparable to that of bitumen, indicating that they have the potential to be used in highway construction to decrease the hardening effect of reclaimed flexible pavement materials after being reused. Bitumen, which is the residue left over following the distillation of crude oil, is divided into four fractions: saturates, aromatics, resins, and asphaltenes [3]. Saturates are the most abundant part, followed by aromatics and resins. The chemicals can be divided into two generic families, maltenes and asphaltenes, which are the most commonly encountered. Asphaltenes are the black-coloured portions that are insoluble in n-heptane and have the maximum polarity and molecular weight, whereas maltenes, which are also soluble in n-heptane, are composed of saturated and aromatic compounds as well as resins, whereas asphaltenes are composed of saturated and aromatic compounds as well as resins. A low viscosity material for recycling aged bitumen can be created using WEO and WCO, which are suitable for each other according to the suitability hypothesis of rejuvenation [1]. From the time of manufacturing until the end of the pavement's service life, bitumen will begin to deteriorate. It is believed that there are four major variables that contribute to the process of ageing: ultraviolet rays, moisture, time, and temperature. These factors create a change in the chemical structure and, consequently, the rheology of the substances of concern [4].

A number of researchers have previously suggested various bitumen rejuvenators and investigated their effects on the characteristics of aged bitumen. Overall, ageing can be divided into two categories: time duration and frequency of occurrence. Short-term ageing is defined as the period between the production of hot mix asphalt and the opening of the pavement to traffic, whereas long-term ageing is defined as the period between the opening of the pavement to traffic and the production of hot mix asphalt. In the laboratory, ageing can be simulated using standard and non-standard methods such as the thin film oven test, the pressure ageing vessel test, and oxidative ageing for both short and long-term ageing situations [5]. On the whole, several studies were presented, including the utilization of waste oil [6–11]. As a result, the recycling and reuse of oils in modified asphalt materials can serve as a source for the appropriate conversion of waste material properties into environmentally friendly materials. The proposed method has the potential to improve the properties of aged bitumen as well as provide an efficient way of restoring the usability of aged bitumen by utilizing waste oil.

2. Research objective

The purpose of this research is to develop a sustainable bitumen that can be used in place of bitumen in flexible pavement. To achieve this goal, it is necessary to integrate bio-based waste products with standard bitumen while simultaneously reducing the percentage of bitumen in the bituminous mixes. According to the adaptability of the paving bitumen specification by Indian Standard IS 73: 2013, five different ratios of WCO and WEO are blended with Viscosity Grade VG-40 bitumen under ageing conditions and evaluated for their performance. The thin film oven test (TFOT) was used to age the waste oil treated samples for an artificially short period of time. To further assess physical performance parameters, tests such as penetration, softening point, viscosity, penetration index, penetration ageing ratio, and ductility were performed on the samples. Based on the physical performance parameters, an optimal type and content of waste oil was suggested.

3. Materials used and experimental program

3.1. Bitumen

India has an averagely hot climate, with summer mean temperatures reaching 35–40°C and winter mean temperatures reaching more than −10°C. Accordingly, it is necessary to design pavements that are stable enough during the summer and winter seasons, respectively, while keeping this in mind. This investigation makes use of VG 40 (Viscosity Grade) bitumen supplied by Hindustan Colas Ltd. (HINCOL). It is necessary for paving bitumen to meet standard specifications in order to achieve uniform and safe operations in accordance with the Bureau of Indian Standards for Viscosity Grade, as specified in IS 73: 2013 [12]. In accordance with ASTM D1754 [13], the TFOT was conducted at 163°C for 300 min. It is possible to determine the effects of heat and air by comparing the physical properties of the samples measured before and after the oven condition, as well as the change in sample mass. Using this method, it is possible to estimate the approximate change in bitumen properties during conventional hot-mixing [14]. It produces a residue that is similar in appearance to the asphalt condition as it was incorporated into the pavement. The fundamental properties of VG 40 are shown in Table 1.

3.2. Waste engine oil (WEO)

The waste engine oil used in this study is a dark, oily liquid that is used as a solvent (Fig. 1a). Without any special treatment, it was collected directly from a nearby repair garage in Durgapur, West Bengal, India, and used in its natural form. The physical properties of this WEO are shown in Table 2.

3.3. Waste cooking oil (WCO)

Waste cooking oil (Fig. 1b) was a palmolein oil that was collected from various fritter shops and sieved on a 75 μm sieve to ensure that there were no particulate matters. It was filtered to remove any dirt or other suspended materials that might have been present. The basic properties of the WCO that have been tested, as shown in Table 2.

Table 1
Specification and values obtained for VG 40.

Characteristics	Requirements	Results
Penetration at 25 °C, 100 g, 5 s, 0.1 mm	Min. 35	36
Softening Point °C (R&B)	Min. 50	58.5
Flash Point °C (Cleveland open cup)	Min. 220	330
Kinematic viscosity at 135 °C, cSt	Min. 400	493.05
Ductility, cm	NA	100
Specific gravity	NA	1.02
Tests on residue from thin film oven test: Ductility, cm	Min. 25	32

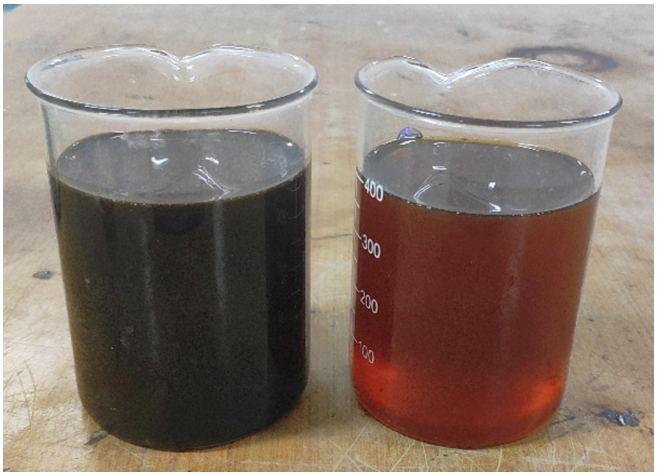

Fig. 1. (a) Waste engine oil; (b) Waste cooking oil.

Table 2
Physical Properties of WEO and WCO.

Items	WEO	WCO
Density (g/cc)	0.89	0.91
Viscosity (cP) at 40 °C	102	73
Flash Point (°C)	198	265

3.4. Experimental program

According to Table 1, conventional physical properties tests are used to determine the physical characteristics of the binder, including the penetration test, softening point test, ductility test, specific gravity test, and flash point test. Initial modifications were made to the VG 40 bitumen by replacing a portion of it with WCO and WEO at concentrations ranging from 1% to 2% to 3% to 4% to 5% by weight of the binder. In order to investigate the effect of waste oil on the physical properties of bitumen, this modified bitumen, also known as WCO and WEO modified bitumen, was used. The modified bitumen used in this study was created by manually mixing WCO and WEO with the VG 40 bitumen at a temperature of 150°C until a visibly relatively homogenous mix was formed. Following that, the modified bitumen was subjected to the following tests.

3.4.1. Penetration test

The consistency and deformation resistance of the bitumen are determined through the penetration test. In bituminous materials, penetration is defined as the distance, measured in tenths of millimetres, that a standard needle will penetrate vertically when subjected to a standard temperature of 25°C, 100g load, and 5s time duration. The test is carried out in accordance with IS: 1203–1978 [15]. A higher penetration value represents a softer consistency, while lower values indicate the reverse. Additionally, the penetration ageing ratio can be used to determine the effect of ageing on modified binder with waste oils. The penetration ageing ratio of aged bitumen compared to unaged bitumen reflects the change in characteristics of the bitumen as a result of the ageing of the asphalt [16].

3.4.2. Softening point test

The softening point of a material determines its thermal sensitivity at a higher temperature at which it achieves a specific degree of softening. The softening point test was performed in accordance with IS: 1205–1978 [17], using the ring and ball apparatus. This test indicates the material's tendency to flow at higher temperatures. The softening point is measured on the basis of the temperatures at which the two rings soften sufficiently to allow each ball of 9.5mm in diameter, weighing 3.5g, covered in bitumen, to fall 25mm [18].

3.4.3. Viscosity test

The coefficient of viscosity is based on the relationship between the applied shear stress and the rate of shear in a fluid. The viscosity of bitumen is the characteristic that allows it to resist flow and thus provide resistance to it. Bitumen exhibits both viscous and elastic properties, and it is important to note that the viscosity of bitumen is highly dependent on its temperature and gets reduced with an increase in temperature [19]. This test method demonstrates how to measure apparent viscosity with a rotational viscometer. A Brookfield Rotational Viscometer was used for the test, which was carried out in accordance with ASTM D 4402–06 [20].

3.4.4. Ductility test

It is important for a binder to generate a thin ductile film around the aggregates in a flexible pavement design to increase the aggregates structural interlocking and improve the overall performance. The ductility test is carried out in accordance with IS: 1208–1978 [21]. This test determines the adhesive properties of bitumen as well as its capacity to stretch under certain conditions. The ductility of bitumen is defined as the distance in centimetres, to which the bitumen filled in a standardized briquette elongates before the thread of bitumen breaks.

3.4.5. Temperature sensitivity test

The penetration index of bitumen is a measure of the material's temperature sensitivity. This index is based on the values of the penetration and softening points of bituminous materials. The greater the penetration index value, the lower the vulnerability to temperature changes. This feature can be used to anticipate the behaviour of bitumen under a variety of climatic situations, as well as to describe the flexibility and deformability of asphalt binders, among other applications. The rise in the penetration index value increases the flexibility and deformability of asphalt binders, which are both beneficial properties. A high penetration index number for bitumen makes them more acceptable for use in cold areas, whereas a low penetration index value makes them more ideal for use in warm climates [18].

4. Test results and discussion

4.1. Effect of WEO and WCO on penetration value

The penetration and softening point tests are the two most essential tests that are performed to examine the physical properties of bituminous materials. Fig. 2 depicts the results of a penetration test conducted on bitumen that has been treated with WCO and WEO. When tested in aged conditions, the VG 40 bitumen sample had a penetration value of 29mm, and under standard conditions a penetration value of 36mm was observed. An increase in penetration value was achieved by the addition of WEO, which resulted in an increase with a linear slope of R^2 = 0.97, while the addition of WCO resulted in an increase with a linear slope of R^2 = 0.98. This rise was observed within a 45-mm limit (Clause 6.2 IS: 73–2013 for VG 30 grade) up to mixing values of 3 percent of the waste oils. Variations in the physical properties of modified bitumen with varying oil content can be attributed to the majority of the observed changes in the results. Irrespective of whether WEO or WCO was utilized to modify the bitumen, the values

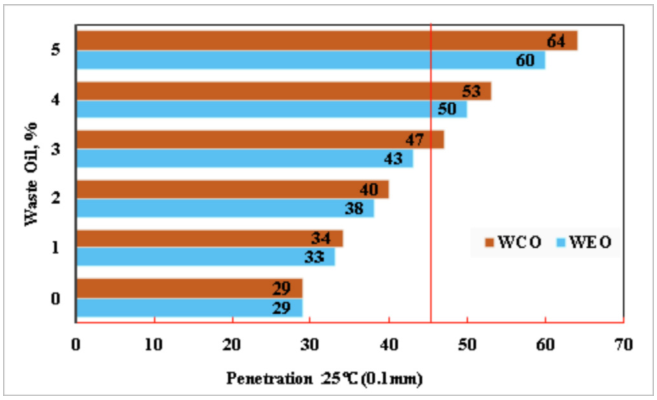

Fig. 2. Effect of WEO and WCO on penetration value.

obtained for aged bitumen followed the same pattern, since all of the aged bitumen softened as the WEO or WCO dosages were increased. As a result, only 3% of waste oil was deemed optimal because it produced satisfactory results.

4.2. Effect of WEO and WCO on softening point

A bitumen with a higher softening point is preferable because bitumen is considered stiff and provides mixtures that are less susceptible to deformations and fatigue cracking when exposed to high temperatures. As illustrated in Fig. 3, the effects of WCO and WEO mixing on the softening point of bitumen samples are demonstrated. A linear reduction in the value of the softening point was seen as the waste oil percentage was increased (R^2 = 0.98). In this investigation, it was observed that replacing the VG 40 bitumen with WEO and WCO decreased the softening point of the resulting modified bitumen. As the amount of WEO and WCO in the solution increased, so was the drop in softening point. Compared to the WEO modified bitumen, the WCO modified bitumen took more time to solidify. When WEO and WCO were compared, no significant differences were found; however, up to 3% of waste oil usage was considered ideal because it was within a 47°C limit (Clause 6.2 IS: 73–2013 for VG 30 grade).

4.3. Effect of WEO and WCO on viscosity

The viscosity of bitumen during flow deformation was a representation of the frictional resistance between the internal molecules of the bitumen. The rotational viscosity of asphalt at 135°C was shown to be closely related to the frictional resistance between the internal molecules of the asphalt [3] when the mixing and compaction temperatures of the bituminous mixes were determined. Fig. 4 shows the impact of WCO and WEO on the viscosity of aged asphalt at 135°C. All viscosity values reduced as the amount of WEO or WCO in the solution increased. It was observed that when the VG 40 bitumen sample was tested under aged conditions, the viscosity value was 543cSt, whereas when the sample was tested under standard conditions, the viscosity value was 493cSt. With the addition of WEO, a decrease in viscosity was attained, whereas the addition of WCO resulted in an increase with a linear slope of R^2 = 0.97, and the addition of WCO resulted in an increase with a linear slope of R^2 = 0.99, respectively. According to the findings, 4% of waste oil is optimal because it produces results that are satisfactory in nature. Itwas discovered that the drop was within the acceptable range of 350cSt (Clause 6.2 of IS: 73–2013 for VG 30 grade) under consideration.

4.4. Effect of WEO and WCO on ductility

Ductility is a property of bitumen that is used to demonstrate its adhesive and cohesiveness. Fig. 5 illustrates that ductility increases as the percentage of waste oil in the mixture increases, which is related to the softness of bitumen. The ductility of an aged VG 40 sample was 32cm, and the ductility of all WCO and WEO modified binders in excess of 3 percent was greater than 100cm and could not be recorded since the highest ductility limit of the ductility machine used was only 100cm. A further increase in the oil content of the modified bitumen samples had no effect on the ductility value of the samples. When the amount of waste oil is increased, the ductility values remain constant after 3 percent, indicating that the WEO or WCO has little influence on the cohesiveness property of the bitumen. In this study, the ductility of WCO-modified bitumen was higher than that of WEO-modified bitumen, which means that WCO could help make aged bitumen more resistant to cracking and more temperature-resistant after being used.

4.5. Effect of WEO and WCO on penetration index and ageing ratio

An index was calculated using the measured penetrations and softening point temperatures to obtain the Penetration Index values. With a higher penetration index, temperature sensitivity is reduced but hardness is increased. [22]. Fig. 6 represents the relationship between the penetration index (PI) and the amount of WCO and WEO used. The figure indicates that the PI increases as the amount of oil present increases. The penetration index ranges from −1 to + 1 for the majority of bituminous materials. It is considered that bituminous materials with PI values of less than −2

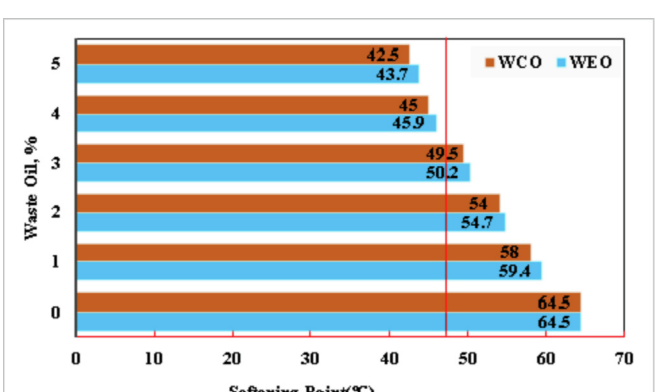

Fig. 3. Effect of WEO and WCO on softening point value.

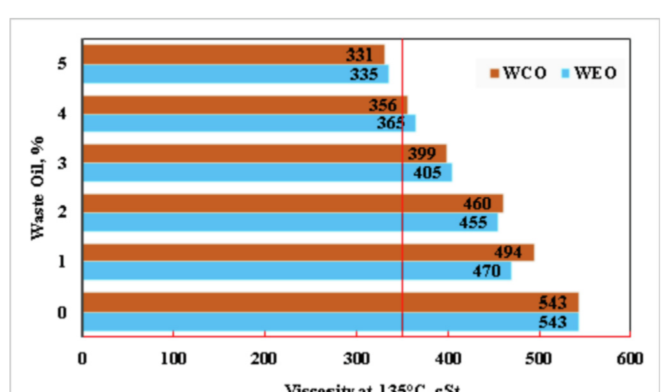

Fig. 4. Effect of WEO and WCO on viscosity.

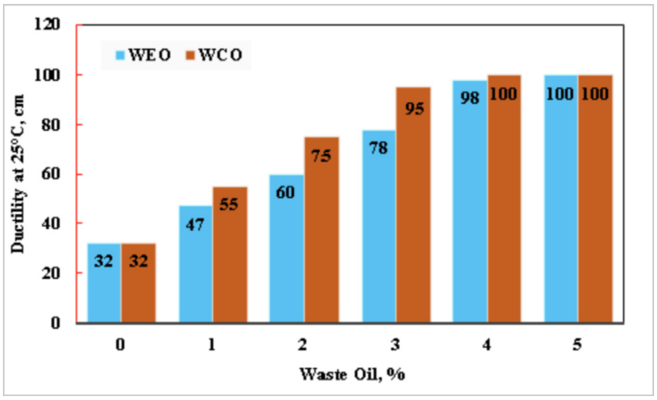

Fig. 5. Effect of WEO and WCO on ductility.

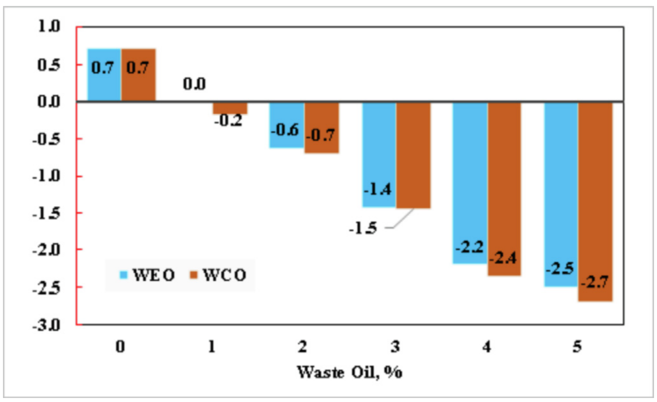

Fig. 6. Effect of WEO and WCO on penetration index.

are highly temperature sensitive and will become more brittle at lower temperatures [23]. All of the modified bitumen samples that contained more than 3% waste oil fell outside of the PI range for conventional bitumen. When it comes to the softening point and penetration characteristics of the modified bitumen, the addition of waste oil to the bitumen has been shown to have a counterbalancing effect. On the other hand, it can be shown that the penetration ageing ratio of VG 40 bitumen is 81, which is in relationship to the aged condition value of 29mm and the standard condition value of 36mm.

5. Conclusions and recommendations

The following conclusions were obtained from the results of the present study:.

1. Under aged conditions, the modified binders including WCO and WEO demonstrated increased penetration values as well as reduced softening point temperatures when compared to VG 40 bitumen. Among the modified binders, the WEO effect in modified asphalt with VG 40 was more significant than the WCO effect in modified asphalt with VG 40.
2. The modification of VG 40 bitumen with WCO and WEO resulted in bitumen with a lower viscosity, and the use of up to 4% waste oil can be found to optimally maintain bitumen grade. The amount of waste oil is increased, the ductility values remain constant until 3 percent, showing that the WEO or WCO has no effect on the cohesiveness of the bitumen.
3. Waste cooking and engine oils can be used to successfully improve the physical qualities of bitumen. This observation indicates that when a higher percentage of waste oil was blended with bitumen, variability was observed, which resulted in a change in the quality of the bitumen that was formed. Overall, modified bitumen samples containing up to 3% waste oil produced the best results.

Considering the findings of this study, the following recommendations are made:.

1. Further investigation should be carried out to determine the effect of WEO and WCO on modified asphalt that has been enhanced with polymer, crumb rubber, or any other warm mix additives.
2. The dynamic shear rheometer and a bending beam rheometer should be used to measure the performance of the bitumen at high and low temperatures in order to successfully determine the effect of waste oil on the temperature sensitivity of the bitumen.
3. It is also recommended to conduct a life cycle cost analysis on the aged asphalt that has been modified by WCO and WEO before applying it to the bituminous mixing plant.

CRediT authorship contribution statement

Arijit Kumar Banerji: Conceptualization, Writing - review & editing, Project administration, Supervision. **Dibakar Chakraborty:** Methodology, Formal analysis, Investigation, Writing - original draft, Visualization. **Aparajita Mudi:** Methodology, Formal analysis, Investigation, Writing - original draft, Visualization. **Priyanka Chauhan:** Writing - original draft, Investigation, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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