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Designing a waste management system suitable for developing countries

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Abstract

Developing countries are often plagued by inefficient waste management. However, developing countries in the tropics have an advantage of high organic content and high temperatures which make processing of large proportion of waste i.e. organic waste easier. However, this advantage is lost when waste is not segregated as soon as it generated. It is here that this study focuses. We ran an experiment in Mymensingh with 1577 households. We find that households change their waste disposal behavior on receipt of information, however the segregation rates for this group are not as strong as the groups that received plastic bags or dustbins in addition to information

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1. Introduction

Waste management systems in developing countries are plagued by inefficiencies in disposal at the point of generation and inefficiencies in technologies used for processing waste. Optimal technology for waste processing is not only dependent on the kind of waste generated but also climatic conditions of the place. Countries in tropical regions have an added advantage of having high temperatures and high proportion of organic waste. So, the question that arises is, can we design a system that will use this advantage to the best extent possible?

Inefficiencies at the household level occur as a result of disposal of waste in a mixed manner which leads to contamination of organic and inorganic waste, thus rendering reuse of either costly or impossible. Secondly, inefficiencies can also occur at the level of collectors and transporters. In case households segregate but collectors mix it up while collecting, all effort of households goes to nought. Lastly, inefficiencies at the processing level (in case there is no mixing at the first two stages) can occur if inappropriate technology is used to process the waste. Also, inefficiency at any stage will lead to inefficiencies at subsequent stages.

Efficiently managing waste becomes immensely important for a densely populated country like Bangladesh. Organic waste constitutes about 70% of the municipal solid waste generated in urban centers in Bangladesh (Alam and Qiao, 2020). This study looks at a scenario in which inefficiencies exist at the first two stages. We conducted an experiment to understand households waste disposal behavior in Mymensingh where a fecal sludge management plant is operational. A fecal sludge management plant requires organic waste for processing fecal sludge. Existence of an operational fecal sludge management plant provides us with a unique opportunity to design a collection system that would remove inefficiencies occurring at the first two stages. We do this using a carefully designed experiment that monitors the behavior of 1577 households. We provided households within a building complex with information and permanent/ temporary infrastructure to segregate. Further, buildings in the treatment group were also provided with a collection service akin to kerbside collection service. We monitor households for ten weeks to collect information on whether waste is segregated or not, weight of garbage generated. We also collect information on material wise waste collected at the fecal sludge management plant. Monitoring at the household level and plant level helps us to assess whether segregation at household level leads to increased sellable inorganics at the plant level. Understanding the impact of segregation at the household level on sellable inorganics is essential to developing a financially sustainable collection system. This continuous monitoring allows us to follow the trends of segregation and subsequent waste collected at the plant. We also conducted a follow up survey to explore the extent to which the treatment households are likely to segregate. For the control households, we inquired how likely are they begin segregation.

We find a sharp increase in segregation rates even for households that were provided with information only at the household level in addition to the kerbside waste collection service.

Our study contributes to the literature in several ways. First, a unique feature of our study is that we collect data at the household and the waste processing plant level. This provides concrete evidence on

how segregation at household level translates to increased collection of sellable inorganics at the plant level.

Secondly, we provide a collection service akin to the kerbside collection for inorganics in treatment buildings. Since the study follows a cluster randomization approach at the building complex and some households within the building complex might not consent to be a part of the study, as a result of which unsegregated garbage disposal from them could contaminate segregated garbage disposed by other houses. To reduce this contamination, dustbins were installed even at the building level to collect inroganics. This dustbin served another purpose of reducing illegal dumping of inorganics by households. Also, provision of such a service is cheaper than providing a door to door collection service for inorganics. We acknowledge that since some households in treatment buildings might not have consented to being in the study and hence would not have received information on how to segregate and hence might throw mixed waste in these bins. To reduce this we pasted a brochure on these bins which depicted the waste that can be thrown in them.

The paper proceeds as follows. Section 2 provides backgrounds of waste segregation policies and practices in Bangladesh and waste collection and segregation realities in our study site. Section 3 describes the experiment. Section 4 provides the results. Section 5 discusses the physical and behavioral mechanisms, including the policy implications. Section 6 provides the cost effectiveness analysis. Section 7 concludes.

2. Background and Study Site

2.1. Waste Policies in Bangladesh

Dhaka Declaration on Waste Management by SAARC countries, 2004 had a focus on segregation at source. Poverty Reduction Strategy Paper of 2005 also emphasized segregation of organic and inorganic waste at the household level. More recently in 2014, National Strategy for Water Supply and sanitation also promoted source level waste segregation. We also promoted segregation into organic and inorganic material following Poverty Reduction Strategy Paper of 2005.

2.2. Study Site

We conducted the experiment in Mymensingh. Mymensingh is located to the north of Dhaka with a population density of 44,458/km^2, making it the second most densely populated city in Bangladesh. Mymensingh municipal corporation provides street cleaning services along with picking garbage from secondary collection points. Households employ garbage collectors or dump garbage themselves at secondary collection points or even indulge in illegal dumping. We chose to work with building complexes as households in these complexes employed a garbage collector for door to door collection service as illegal dumping behavior is hard to monitor. Despite policy emphasis on source level segregation, households are unaware of the practice.

Most waste segregation occur in the form of post-collection segregation, where ragpickers sort the sellable recyclable waste such as plastic bottles, metals, cardboard papers out of the mixed waste at

the dumpsites. Such segregation is not only harmful to garbage collectors but also increases the cost of recycling/reuse.

3. Experimental Design

In this section we provide an overview of the experiment design. The experiment has three major components: a household level intervention wherein we provided households with information brochure and permanent or temporary infrastructure for segregating waste; a kerbside collection service for inorganics; and thirdly, manpower for further sorting of waste at the plant level.

3.1 Household level intervention

Although policies emphasize waste segregation at source in developing countries, households are often unaware of these requirements or the know how to segregate properly. We provided a household-level one-shot informational campaign that aimed to raise awareness of such requirement and deliver the know-how on waste segregation at source. The information was delivered to the households in person by our enumerators in form of a brochure. Along with the informational brochures, we also provided some households with additional "nudges" for waste segregation, which further separates out intervention into three different treatment groups.

For households in first treatment group (T1), we only provided each household with an information brochure. The brochure introduces the national strategies on waste segregation at source and detailed information on how to segregate solid waste into two categories: organic and inorganics.

For households in the second treatment (T2), in addition to the brochures in T1, we also provided each household with a dustbin for free. Households were told that the dustbins were for storing inorganic waste, although there was no way to enforce or monitor this. The dustbin and its stated purpose could directly reduce the behavioral cost of segregation as in-door waste segregation "infrastructure", it could also as reminder for the households given its physical existence and the designed purpose attached to it. Hence, we expect that treatment T2 would have a stronger effect than T1.

In the third treatment group (T3), we follow a similar idea as in T2, but instead of providing each household with an additional dustbin, we provided them with plastic bags to be used as garbage bags for waste segregation. For storing inorganic waste, the plastic bags could service the purpose as well as the dustbins, and perhaps have advantages such as being cleaner and can better adopt to waste of irregular shape. However, the bags can be easier put out of sight and hence lacks of the visual cue the dustbins can offer. They can also be used for several other purposes. Therefore, we expect that T2 and T3 has similar effect on households if households' waste segregation decisions are not subject to behavioral distortions such as inattention/ other uses. However, behavioral factors play an important role and households need to be reminded, we expect that the effect of T3 would be weaker than T2, but still larger than T1. Another important aspect of T3 is that we offer a fixed number of plastic bags to the households. The dustbins can be with the households for a very long time, but the plastic bags will run out fairly fast. Dustbins can be viewed as permanent infrastructure for segregation while plastic bags are temporary. By comparing the effect of T3 and T2 after the plastic bags run out, we could

explore to what extent the initial behavioral change as a result of a behavioral nudge leads to a sustained/persistent behavioral change.

Besides the three treatment groups, we also have a control group where we did not provide any household-level campaign.

Given that we conducted this study in urban area where households mostly living in apartment buildings, to minimize potential contamination across households under different treatment conditions, we randomized the assignment to treatment and control group at building-level. All sampled households in the same building would receive the same treatment condition.

3.2 Segregated Collection service

Often times, households stop segregating in absence of appropriate infrastructure to ensure segregated waste is not mixed subsequently ((Nepal et al., 2022; Wadehra & Mishra, 2018). However, provision of a additional collection service only for inorganics/ segregated waste is a drain on financial system (Wadehra, Nie and Alpizar, unpublished) and also redundant. To reduce the financial burden while also ensuring that there is provision for segregated collection, we provided a kerbside collection service for inorganics. Garbage collectors in our study collect waste from households as well as these dustbins installed in the buildings. Additional garbage bins in the buildings ensured that households not in the study also had an option of disposing waste in a segregated manner, thus would not discourage households participating in the study from segregating.

Measuring waste segregation: waste monitoring

The goal of this study is to evaluate households' behavioral changes with regard to waste segregation at home. We measure waste segregation behavior at the household level by having a team of two persons, an enumerator and a garbage collector, actually inspecting and weighing mixed waste and segregated waste. The enumerators would weigh the waste and observe if the households handed over different types of waste separately or not. Enumerators were given strict instructions to mark as unsegregated if they found more than one plastic/packaging item in the organic bin. Monitoring in the manner described above was repeated every six days. In total, there were ten rounds of waste monitoring, once at the baseline and eight rounds post-intervention.

At the baseline, we collected information on weight of garbage and also administered a questionnaire to capture information on socio-economic and demographic variables. Secondly, we collected pre-intervention data thrice to get a stable measure of segregation rate and waste genertaed. In this way, we believe that our baseline waste monitor captures the natural state of households' segregation behavior.

4. Data Collection

We conducted the main body of the experiment during December 2022 – March 2023 in Mymensingh, Bangladesh. Wards from were waste was going to the FSTP and those nearest to FSTP formed the sampling frame of the study. From these wards we chose all building complexes as houses in these complexes were serviced by a garbage collector as opposed to independent houses that may/ may not be served by a garbage collector. All houses in these building complexes were asked to be a part of the study. In total, 1577 households were part of the study at the baseline. Being served by a garbage collector was essential to the study as that ensured that garbage is not disposed off by households as soon as it is generated, rather is kept by them. This facilitated the monitoring and weighing of garbage.

5. Results and Discussion

5.1 Descriptive Statistics

We first give a brief description of our sample and check if the randomized treatment allocation actually generated a balanced sample across groups. Table 1 describes the demographic and economic characteristics of the households in our sample, as well as for the subsamples of the treatment and control groups. The information is obtained from our baseline household survey. Most of the respondents are middle-aged female, which is expected as women are mostly responsible for waste management. Most of the respondents in our have finished class 12 or are graduates. Average household size is 4.2 members. A quarter of them own a microwave. 28% of the respondents live in their own house while others live in a rented or a govt. accommodation. Self-reported monthly income concentrates around Taka 0 - 59999.

Table 1. Summary Statistics by treatment conditions

	Total	Control	T1	T2	T3
No. of obs.	1572	380	360	404	428
Respondent's characteristics					
Age*	38.4	38.7	37.7	39.0	38.2
Female**	59.1%	54.2%	60.3%	61.6%	60.1%
Education levels***					
Illiterate	0.5%	0.79%	0.28%	-	0.93%
Up to class 5	2.8%	2.37%	3.62%	1.49%	3.74%
Up to class 8	1.46%	1.58%	1.39%	1.24%	1.64%
Up to class 10	9.17%	6.86%	7.52%	9.65%	12.15%
Up to class 12	30%	34.04%	29.81%	29.46%	27.1%
Diploma and certificate	5.73%	5.28%	4.74%	5.45%	7.24%
Graduate	32.29%	30.87%	35.65%	35.15%	28.04%
Post graduate and above	18.03%	18.21%	16.99%	17.57%	19.16%
Household characteristics					
Household size*	4.2	4.24	4.23	4.04	4.2
Have microwave	25.11%	29.35%	25.51%	21.88%	23.7%
House ownership	28.07%	36.68%	30%	23.76%	22.9%
Household income****:					
Below Taka 20000	4.46%	3.43%	5.87%	2.72%	5.84%
Taka 20000-39999	18.48%	17.15%	16.76%	17.57%	21.96%
Taka 40000-59999	22.12%	23.75%	18.72%	24.01%	21.73%
Taka 60,000-79,999	9.82%	9.76%	7.82%	11.14%	10.28%
Taka 80,000-99.999	2.42%	2.11%	1.4%	2.97%	3.04%
Above Rs. 1 lakh	1.4%	1.85%	1.4%	1.73%	0.7%

Note: Calculated by the authors from the data.

*There are 2 missing values for age of the respondent, household size

**There are 5 missing values for gender of the respondent. Only 1567 households with valid information in total, with 378 in Control, 358 in T1, 404 in T2 and 427 in T3.

*** Education levels: Upto to class 5, class 8, class 10 and class 12 refer to 5 years, 8 years, 10 years and 12 years (completion) of schooling. Disploma and certificate refer to short term courses done after school. Graduate refers to completion of 3/ 4 years of bachelor's degree after completing 12 years of schooling. Post Graduate and above refers to a master's degree. ****648 respondents refused to answer

The above table shows that demographic and economic characteristics of groups are balanced. A key variable on which we see large differences is house ownership. There are large differences when it comes to house ownership and a proportion test shows that there are significant differences between control and treatment groups, However, we do see significant differences in house ownership between control and T2, control and T3, T1 and T3 at 5% level.

5.2 Treatment effect on household waste segregation

We then examine the treatment effects of our waste segregation interventions. Figure 2 plots the evolution of the share of households that segregated their waste over entire study period by the treatment conditions. The horizontal axis represents the waste monitoring rounds. Round 1-2 are baseline waste monitoring rounds before the intervention. Round 4-9 are the post-intervention monitoring rounds. The intervention happened between the time of the waste monitoring Round 3. It was supposed to overlap with the treatment delivery and formed a pre-intervention monitoring round. However, due to some administrative difficulty, the actually monitoring Round 3 happened pre-intervention for some households and post-intervention for others. For this reason, in the later formal analysis, we exclude Round 3, using only Round 1-2 as pre-intervention observations and Round 4-9 as post-intervention observations for treatment effects estimation.

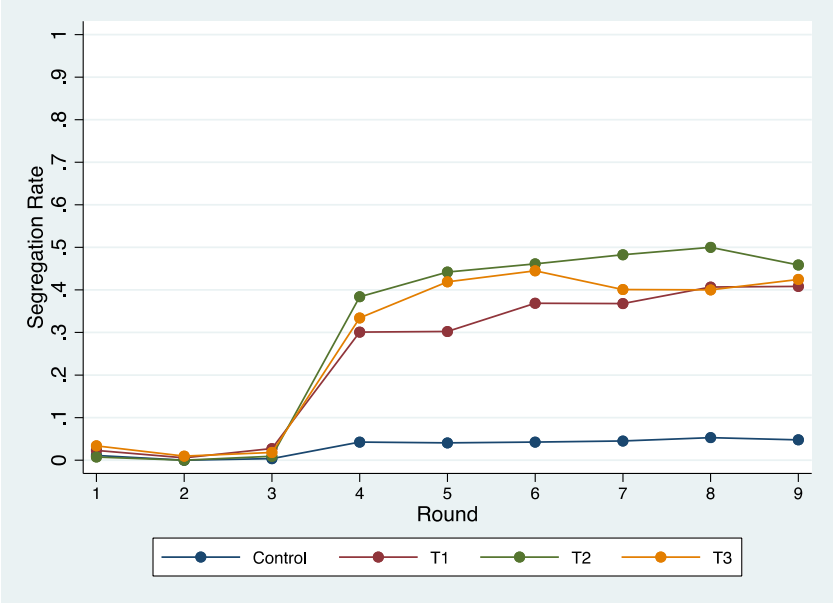

Figure 2. Change in segregation rates of households across groups

Figure 2 shows that households from all groups starting on an equal foot at the baseline when waste segregation was very rare. In the first round of waste monitoring, only 29 households (out of a total 1,572 households) were observed to have segregated their waste and the number dropped to a mere 6. There are little differences across groups as expected.

However, waste segregation behavior of households in different groups diverges greatly over the course of the post-intervention period. We first look at the control group. The waste segregation rate in the control groups sees a slight increase in Round 4 to about 4%, and levels off after that. The lack of

changes help alleviates the concern of the experimenter demand effect that might undermine our interpretation of the treatment effect due to our repeated waste monitoring. We find that waste monitoring has very limited role in increasing household segregation. The lack of changes in the control group over the course of the experiment also point to the limited role that waste collection service alone can play. Even though we lack a "pure" control group to properly identify the causal effect of the provision of the segregated waste collection service, the near zero segregation at the baseline suggests that at best the collection service could have increased the segregation rate by 4 percentage points. This is very low by its absolute level. This is also consistent with the results in [Wadehra, Nie and Alpizar, unpublished], where a segregated waste collection service was provides to households, but in a door-to-door collection manner.

We then move on to the treatment groups. In stark contrast to the control group, households in the treatment groups show sharp increase in waste segregation post-intervention. In Round 4, on average six days after the delivery of the intervention, the segregation rates jumped to 30%, 38% and 33% in the in the three treatment groups T1, T2 and T3 respectively. Comparing with the very low segregation rates in the baseline and the in the control group, such increase represents huge impact on the households. Between treatment groups, we also see some differences in relative effectiveness. Providing households with dustbins for segregation seems to have additional impacts on households comparing with providing information provision alone.

Next, we formally estimate the size of the effects of the interventions using linear probability regressions. We estimated the average treatment effects for the entire study period. Specifically, we estimate the following regression model:

$$Y_{it} = \alpha + \beta_1 T1_i * Post_t + \beta_2 T2_i * Post_t + \beta_2 T3_i * Post_t + \boldsymbol{\theta T_i} + Post_t + DoW_{it} + \varepsilon_{it}. \qquad (1)$$

Y_{it} is a binary variable indicating whether a household i is segregating or not at monitoring round t. It equals 1 if the household i is segregating, otherwise 0 ; ***T1, T2* and *T3*** are the treatment status dummies signalling whether a household was exposed to treatment T1, T2 or T3; *Post* indicates post intervention period (Round 4 to 9); DoW_{it} are the week of day dummies capturing the potential weekday/weekend patterns. Coefficients of the two interaction terms, β_1, β_2, and β_3 are the parameters of interest, representing the average treatment effect of the interventions.

Table 3 shows the results. The one-shot informational campaign alone improved the household segregation rate by almost 30 percentage points during the post-intervention period. This is a huge impact given that almost no one segregated their waste to begin with. Adding a dustbin for segregation to the campaign leads to an additional increase in waste segregation rate of 11 percentage points (0.406-0.296=0.11, p=0.034). Providing a physical structure such a dustbin to the households seems to further help the households to segregation, as expected, due to the dustbin could be used for waste segregation directly and serve as a reminder to the households, even though they were not forced to use it or keep it.

Another interesting result is that when we compare the dustbins in T2 with plastic garbage bags in T3, the treatment had weaker and statistically insignificant additional impact beyond the informational

campaign (0.34-0.296=0.044, or 4.4 percentage points, p=0.341). Technically, the plastic bags could be used the same way as the dustbins for segregation and perhaps more flexible and cleaner for use. It is curious to explore how their effects are different.

One particular detail in our design is that we only offered a fixed number of plastic bags to the households. This means that for households that are willing to use them as garbage bags for waste segregation every day, the bags would run out after about four weeks. Given the timeline of the study, it would mean that household could run out of bags around Round 7 of the waste monitoring. Looking back at Figure 2, we did see a pattern that T2 and T3 have similar segregation rate between Round 4 to 6, and then the segregation in T3 dropped to the level of T1 since Round 7. In column (2) of Table 3, we formally test this pattern, separate the post-intervention period into two phases: Round 4-6 when the plastic bags were enough in numbers, and Round 7-9 when the bags would have run out for daily users.

We see that in Round 4-6 the effect of T2 is still lighter weak than that of T3, but the difference is not significant (0.339-0.385=-0.046, p=0.352). However, in Round 7-9, the gap between the effect of T2 and T3 gets much larger, almost twice of the size of that in the previous phase (0.341 - 0.427 = -0.086, p=0.155). This is the result of the effect of T2 gets larger over time (from 0.385 to 0.427, p=0.145), while the effect of T2 stayed virtually unchanged (from 0.339 to 0.341, p = 0.944). As a matter of fact, as the effect of the informational campaign T1 gets stronger over time (from 0.265 to 0.327, p=0.027), we see no difference between the effect of T3 and the effect of T1 anymore in Round 7-9 (0.327 vs. 0.341, p=0.790), after the bags were supposed to run out.

To summarize, the results in column (2) show that providing plastic bags does not work as well as the providing the dustbin. The additional effect of the plastic bags is smaller, and taper off as the bags ran out, while the additional impact of dustbins is larger and sustained during the experimental period. This seems to suggest that the physical presence of the dustbins potentially as reminders at least partially explain its role in promoting waste segregation. Plastic garbage bags, despite serving the same purpose, does not work as well, possibly due to that they are prone to be forgotten/ require an additional effort from households to purchase once the initial amount is over. The fact that the effect of the plastic bags disappears after Round 6 also suggests the additional effect from bags, and potential dustbins, is not the result of sustained habit changes, rather that they are the result of households being nudged on the spot.

Another interesting result is the one-shot campaign generates a not only sustained but also increasing effect over the experimental period. The effect in Round 7-9 is 6.2 percentage points higher than in Round 4-6 (0.327-0.265=0.062, p=0. 027). The slight increasing trend is also evident in the Figure 2. While we do not want to over-interpret the results given that we only observed waste segregation behavior for a limited period time, the increasing trend here is consistent with [Wadehra, Nie and Alpizar, unpublished]. We suspect that it takes some time for some households to discover the credibility of the collection services and hence the delayed behavioral changes in waste segregation.

Table 3. Treatment Effect on Household Waste Segregation

	(1) Waste Segregation		(2) Waste Segregation
T1 * Post	0.296*** (0.0347)	T1 * Round 4-6	0.265*** (0.0360)
T2 * Post	0.406*** (0.0433)	T2 * Round 4-6	0.385*** (0.0398)
T3 * Post	0.340*** (0.0363)	T3 * Round 4-6	0.339*** (0.0366)
		T1 * Round 7-9	0.327*** (0.0387)
		T2 * Round 7-9	0.427*** (0.0506)
		T3 * Round 7-9	0.341*** (0.0393)
Post	0.0467*** (0.0148)	Round 4-6	0.0412*** (0.0156)
		Round 7-9	0.0528*** (0.0160)
T1: Brochures	0.0118 (0.00853)	T1: Brochures	0.0115 (0.00853)
T2: Brochures + Dustbins	-0.00191 (0.00607)	T2: Brochures + Dustbins	-0.00223 (0.00609)
T3: Brochures + Plastic Bags	0.0179 (0.0110)	T3: Brochures + Plastic Bags	0.0178 (0.0111)
Day of Week dummies	Yes	Day of Week dummies	Yes
Constant	-0.0117 (0.0200)	Constant	-0.0123 (0.0201)
Observations	12321		12321
R^2	0.203		0.205

Note: Standard errors clustered at building level are reported in the parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

6. Conclusion

Tropical countries have a dual advantage when it comes to municipal waste generation- greater proportion of organic waste, and high temperatures. However, this dual advantage is squandered away when waste is not segregated at source. As a result, absence of efficient processing of waste stays a concern in these developing countries. Mixing of organic and inorganic waste at source often renders any technological solution sub optimal. Bangladesh is no exception. Despite an emphasis by policies on segregation at source, this is hardly being implemented by municipalities or practiced by households. In this study, we aimed to study the impact of information brochures, information brochures and permanent sorting devices and information and temporary sorting devices. We also implemented a kerbside pickup service for households to further facilitate segregation at source. Another interesting aspect of this study is that we study the impact of segregation at source at increased cleaner organic/ inorganic waste collected at the plant level. Our results indicate that providing mere information at the household level increases the probability of segregation at the household level, although the increase is not as high as in the case of providing dustbins or plastic

bags. As expected, we see that segregation rates start to taper off for plastic bags intervention once the bas are over.

There are two main policy implications. We demonstrate how policy makers can get households to bring about a change in their behavior and further, how to sustain it over time. although this is unable to sustain segregation behavior in the long run. We also show that though dustbins might have a higher one time cost in comparison to plastic bags but are able to sustain behavior loner as compared to plastic bags.

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Appendix

Round 0: 17/12/2022-4/1/2023

Round 1: 8/1/2023-14/1/2023

Round 2:15/1/2023-21/1/2023

Interventions: 16/1/2023-19/1/2023

Round 3: 22/1/2023-26/1/2023

Round 4:28/1/2023-2/2/2023

Round 5: 4/2/2023-9/2/2023

Round 6:11/2/2023-16/2/2023

Round 7: 18/2/2023-23/2/2023

Round 8: 25/2/2023-2/3/2023

Endline: 14/3/2023-28/3/2023

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