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REVIEW ARTICLE

An Estimate of Time-Dependent Transmission of COVID-19 Pandemic in Katsina State from June to November 2021

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ABSTRACT
This paper investigates the spread of COVID-19 pandemic in Katsina state from 23rd June to 27th November, 2021, using graphical tools to visually analyse infection over time and time-dependent reproduction number to quantify the transmissibility of the disease. Study data consist of diagnostic results of reverse transcriptase real-time quantitative polymerase chain reaction assays (RT-PCR) on nine hundred and eighty-nine nasal swab samples from suspected COVID-19 cases, collected from public and private health facilities across Local government areas of the State and analysed by the Molecular Laboratory of the Federal Medical Centre Katsina, recording a total of 137 positive cases. Our investigation revealed that, over the study period, COVID-19 transmission reaches its peak on 17th October 2021 (Epidemic Week 41), with a mean Reproduction number (R_t) of 3.22 and a standard deviation of 0.5976 (95% CI: 2.6193 - 3.8145), culminating in 19 new infections on Wednesday the 27th (Epidemic Week 43). The combined age groups 21-30 and 31-40 constituted the most affected cases with 29 (21.17%) and 19 (13.87%) positive cases, respectively. This was closely followed by age group 51-60 with 19 (13.87%) positive cases. On gender basis, 70 (51%) females tested positive compared to 67 (49%) males. We therefore conclude that for the third wave of COVID-19 pandemic in Katsina State, disease transmission reaches its peak in Epidemic Week 41 in October, then rapidly diminishes to R_t values of less than one, indicating that no new infections were expected by the end of November, with female gender and age groups in the range 21 to 40 years being most infected. We recommend that mitigation strategies that take into consideration features inherent in female gender and more pronounced in young (21 to 40 years) and middle-aged (51-60 years) adults should be adopted in case of future waves.

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COVID-19 Transmission, Graphical Visualization, Infection, Reproduction Number

INTRODUCTION

The December 2019 manifestation of a novel Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-COV-2) pathogen in Wuhan, China (WHO, 2020a), poses an existential challenge to the humankind and spurred governments and international organisations into a frenzy towards developing strategies for mitigation, control, treatment, and prevention of the disease. The World Health Organization (WHO) named the disease "COVID-19" (WHO, 2020b), declared that the outbreak constitutes a public health emergency of international concern (PHEIC) on 30th January, 2020 (WHO, 2020c) and, prompted by the exponential increase of case fatalities, declared the disease a pandemic on 11th March, 2020 (WHO, 2020d). Mitigation strategies such as mask wearing, social distancing, banning of gatherings and travellings, lock-downs and the use of non-pharmaceutical interventions such as quarantine, hand-washing with sanitizers and body temperature readings, were adopted and implemented across the globe. To achieve the goals of such and other mitigation strategies, there is need for a proper and in-depth understanding of the disease's behaviour and mode of transmission. A critical step towards containing the disease should incorporate an understanding of its transmission dynamics: how the disease spreads from one person to another, the infectiousness and infectivity of an individual within a population, between populations and the media, factors and environmental conditions that facilitate transmission. Several studies were conducted towards understanding the spreading behaviour of COVID-19 over time (Hao *et al.*, 2020; Turasie, 2020; Wilasang *et al.*, 2022, Hwang *et al.*, 2022), space (Slater *et al*, 2022) or both (Olusola *et al.*, 2020; D'Angelo *et al*, 2021; Li and Dey, 2022) and naturally the best place to start is Wuhan, China.

Hao *et al.* (2020) studied the temporal transmission dy namics of COVID-19 in Wuhan, China, by quantifying the infectiousness of asymptomatic and pre-symptomatic individuals between 1st January 2020 and 8th March 2020 using the basic reproduction number

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(R_o). Their study of 32,583 laboratory confirmed positive cases revealed very high infectiousness of asymptomatic individuals (87%) and very high transmissibility with a basic reproduction number of 3.54. They observed that simultaneous mitigation efforts implemented in Wuhan were very effective in controlling the spread of the disease, reducing the basic reproduction number to 0.28, and by projection, infection to only 4% of diagnosed cases. One limitation of their approach is the assumption of equal spreading capacity of individuals among different age, gender and socio-economic groups. It is well-known in the literature that, based on individual variations, some have a very high spreading capacity or are superspreaders (Rambo *et al.*, 2021; Li *et al.*, 2022a) while age and gender are important risk factors that increase susceptibility to COVID-19 infection (Goldstein *et al.*, 2021; Permata *et al.*, 2021).

In Africa, Turasie (2020) investigated the transmission dynamics of COVID-19 in twelve countries across the continent using Epidemic curves for visual analysis of the disease, time-dependent reproduction number (R_t) to measure short-range transmissibility and explored the use of an Autoregressive Conditional Poisson (ACP) model in assessing long-range transmissibility. His results showed that Epidemic curves provide a visual means of tracking the transmission over time, identifying different waves of the disease and possibly inconsistent incidence patterns. They also revealed a consistent R_t value of one or more across all countries over the study period, indicating that an infected individual will likely infect atleast one person with the disease.

In Nigeria, Elimian *et al.* (2020, 2022) and collaborators from the Nigeria Center for Disease Control (NCDC) and elsewhere studied the risk factors associated with COVID-19 positivity (Elimian *et al.*, 2020) and mortality rates (Elimian *et al.*, 2022) during the first and second waves of the pandemic. Their studies revealed that older age and gender (male at higher risk), together with some presenting symptoms, were the main risk factors for positivity to and mortality from the disease. Similar results were also reported for Nigeria by Utulu *et al.* (2022), for Ondo state by Isere *et al.* (2021) and for Delta state by Otovwe *et al.* (2022). Ladan (2020) studied the impact of measures adopted and implemented by Katsina State Government towards preventing the spread of the disease. A good understanding of COVID-19 transmission patterns and behaviour is critical in providing evidence-based framework that will inform effective policies towards the improvement of the adopted and review of alternative measures for preventing the spread of COVID-19 in the State.

Therefore, we utilised some techniques for the graphical representation of data to provide a tool for visualising the pattern of transmission of COVID-19 in the State. These representations can help inform the general public about the pandemic's significant risk factors and effective mitigation strategies (Chen *et al.,* 2021). In addition, we obtained an estimate of a quantitative metric of the spread: the time-dependent reproduction number (R_t), to provide a more versatile measure of transmissibility (Nash *et al.*, 2022) that can be utilised to inform decisions and reviews on the impact of adopted measures and the prospects of the alternatives. This research aims to utilise graphical tools to visualise the transmission of COVID-19 and estimate time-dependent reproduction number (R_t) to quantify the spreading capacity of infected individuals in the State. Our results will facilitate public understanding of COVID-19 transmission and provide Katsina State Government with a viable framework for decision-makingng on prevention and control measures against future waves and epidemics.

MATERIALS AND METHODS

Data Source, Structure and Summary

Data source is the Molecular Laboratory of the Federal Medical Center (FMC) Katsina. The FMC was chosen by the State government as the leading center (Ladan, 2020) for diagnosis and isolation of COVID-19 suspected cases from all local government areas of the state.

The data consisted of diagnostic results of reverse transcriptase real-time quantitative polymerase chain reaction (RT-PCR) assays on nine hundred and eighty nine (989) nasal swab samples collected from suspected COVID-19 cases across sixteen Local government areas of the State, recording a total of one hundred and thirty-seven (137) positive cases (infected individuals). The data has eighteen variables recorded using the COVID-19 Laboratory Linelist Reporting Form, however for this research, we only utilized four variables: Age, Gender, Month and RT-PCR assay results. We adapted the method proposed by Cori *et al.* (2013) and utilised the "EpiEstim" package of the "R" software (R Core Team, 2023) to estimate the real-time values of the R_t. Summary of these variables are given in the following tables:

Table 1: RT-PCR assays results by Zones and LGAs across the State.

Zone	LGA	RT-PCR INCONCLUSIVE	RT-PCR NEGATIVE	RT-PCR POSITIVE	LGA Total	ZONE Total
Daura	Daura	8	230	4	242	**315**
	Kankia	0	33	18	51	
	Mani	0	0	1	1	
	Ingawa	0	19	2	21	
Funtua	Bakori	0	0	1	1	**73**
	Kafur	4	40	2	46	
	Malumfashi	0	26	0	26	
Katsina	Batsari	0	45	1	46	**601**
	Batagarawa	0	35	7	42	
	Charanchi	0	0	1	1	
	Dutsinma	0	28	6	34	
	Jibia	0	13	1	14	
	Kaita	6	201	18	225	
	Katsina	0	117	75	192	
	Musawa	0	27	0	27	
	Safana	0	20	0	20	
Test Total		18	834	137	989	**989**

Table 2: RT-PCR assay results by month and gender of the 989 diagnosed suspected cases

Gender	RT-PCR	June	July	August	September	October	November	Test Total
Female	Inconclusive	2	0	3	7	0	0	12
	Negative	24	14	53	118	116	59	384
	Positive	0	2	1	5	27	35	70
Male	Inconclusive	0	2	3	1	0	0	6
	Negative	56	45	43	150	100	56	450
	Positive	0	2	0	4	39	22	67
Month Total		**82**	**65**	**103**	**285**	**282**	**172**	**989**

Table 3: Age group distribution of the 989 diagnosed suspected cases of COVID-19

RT-PCR	0 -10	11 -20	21 -30	31 -40	41 -50	51 -60	61-70	70+	Total
Inconclusive	0	8	6	1	0	2	1	0	18
Negative	61	173	211	124	102	59	34	20	784
Positive	1	9	29	19	14	19	18	11	120
Total	62	190	246	144	116	80	53	31	922*

*Note that sixty-seven age records were missing (50 Negative, 17 Positive)

From Tables 2 and 3, we extracted information on the corresponding positive cases of COVID-19 over the study period to produce Tables 4 and 5, respectively.

Table 4: Monthly RT-PCR assay results for the 137 diagnosed positive cases of COVID-19

Gender	RT-PCR	June	July	August	September	October	November	Total
Female	Positive	0	2	1	5	27	35	70
Male	Positive	0	2	0	4	39	22	67
Month Total		0	4	1	9	66	57	137

Table 5: Age group distribution of the 137 diagnosed positive cases of COVID-19

Gender	RT-PCR	0 -10	11 - 20	21 -30	31 - 40	41 - 50	51 -60	61-70	70+	Total
Female	Positive	0	7	13	12	8	8	6	6	60
Male	Positive	1	2	16	7	6	11	12	5	60
Age-group Total		1	9	29	19	14	19	18	11	120*

*Note that seventeen age records were missing (10 Female, 7 Male)

Estimation/Determination of Time-varying Reproduction Number: R_t

Time-varying Reproduction number (R_t) is one of the standard metrics used in measuring transmission based on spreading capacity (You *et al.* 2020; Li 2022b). It accurately measures the average number of new infections (secondary) caused by a single infected (primary) individual. It provides a tool for real-time tracking of increases ($R_t>1$) or decreases ($R_t<1$) in the transmission dynamics. A recent review by Nash *et al.* (2022) provided insight into the different methods of estimation, application and the challenges faced in using Time-varying Reproduction number (R_t).

In this paper, we estimated the R_t by utilising a method proposed by Cori *et al.* (2013), as follows:

$$R_t = \frac{I_t}{T_t} = \frac{I_t}{\sum_{s=1}^{t} I_{t-s} W_s}$$

where I_t: Number of new infections generated at time step 't,'

T_t: The sum of infectiousness of infected individuals at time't,'

I_{t-s}: Incidence at time step t-s

W_s: Infectivity profile

S: Time since infection

t : Calendar time

We utilised the "R" software package "EpiEstim" (Thompson *et al.* 2019; R Core Team, 2023) to obtain an estimate of the R_t and its associated Epidemic curve.

RESULTS

Visualisation of COVID-19 Data

The FMC Molecular laboratory received and diagnosed nasal swab samples from suspected cases and Table 1 represent the RT-PCR assay results during the third wave of the pandemic across zones and Local Government Areas (LGAs) of the State. The highest number 242 of suspected cases was recorded by Daura LGA, but with only four cases confirmed positive. It was followed by Kaita and Katsina LGAs with 225 and 192 suspected and 18 and 75 confirmed cases, respectively. We gleaned more information on the assay results across the state from a visual representation in Figure 1.

A careful study of Table 2 revealed a steady increase in suspected cases from June to October, followed by a rapid decrease in November. However, the number of confirmed cases increased from 3.16% in September (9 out of 285), to 23.4% in October (66 out of 282) and eventually to 33.4% in November (57 out of 172), respectively. We gleaned more information by utilising the R package "EpiCurve" (R Core Team, 2023) to visualise the daily incidence of the transmission over the study period, as shown in Figure 2.

There were 18 inconclusive RT-PCR diagnostic assay results (12 Female, 6 Male) out of the 989 cases and all were obtained between June and September. Figure 2 revealed that no inconclusive assay results were obtained beyond the 27th of September, indicating an increase in the efficiency of the RT-PCR diagnosis.

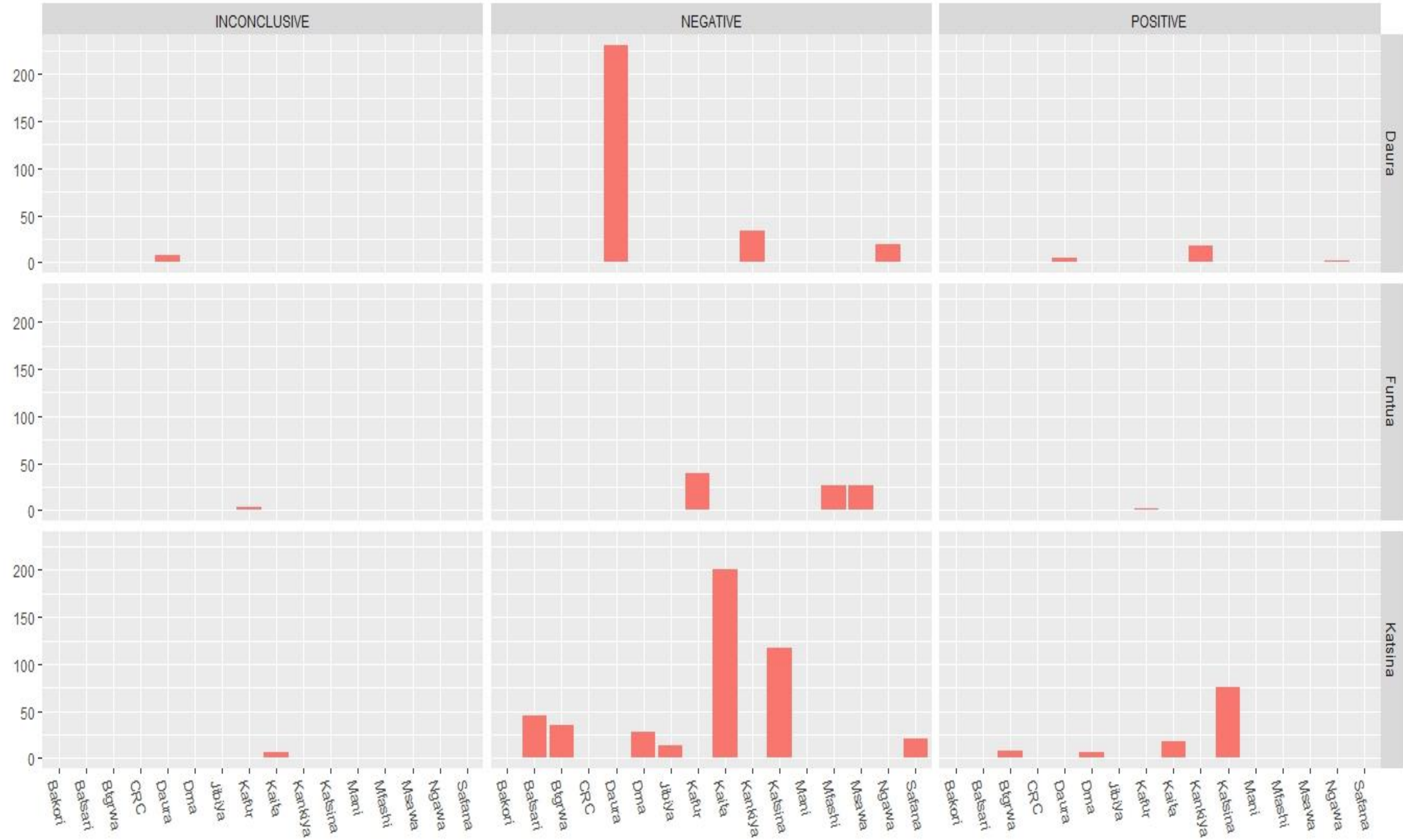

Figure 1: Daily RT-PCR assay results across zones and Local Government Areas of Katsina State.

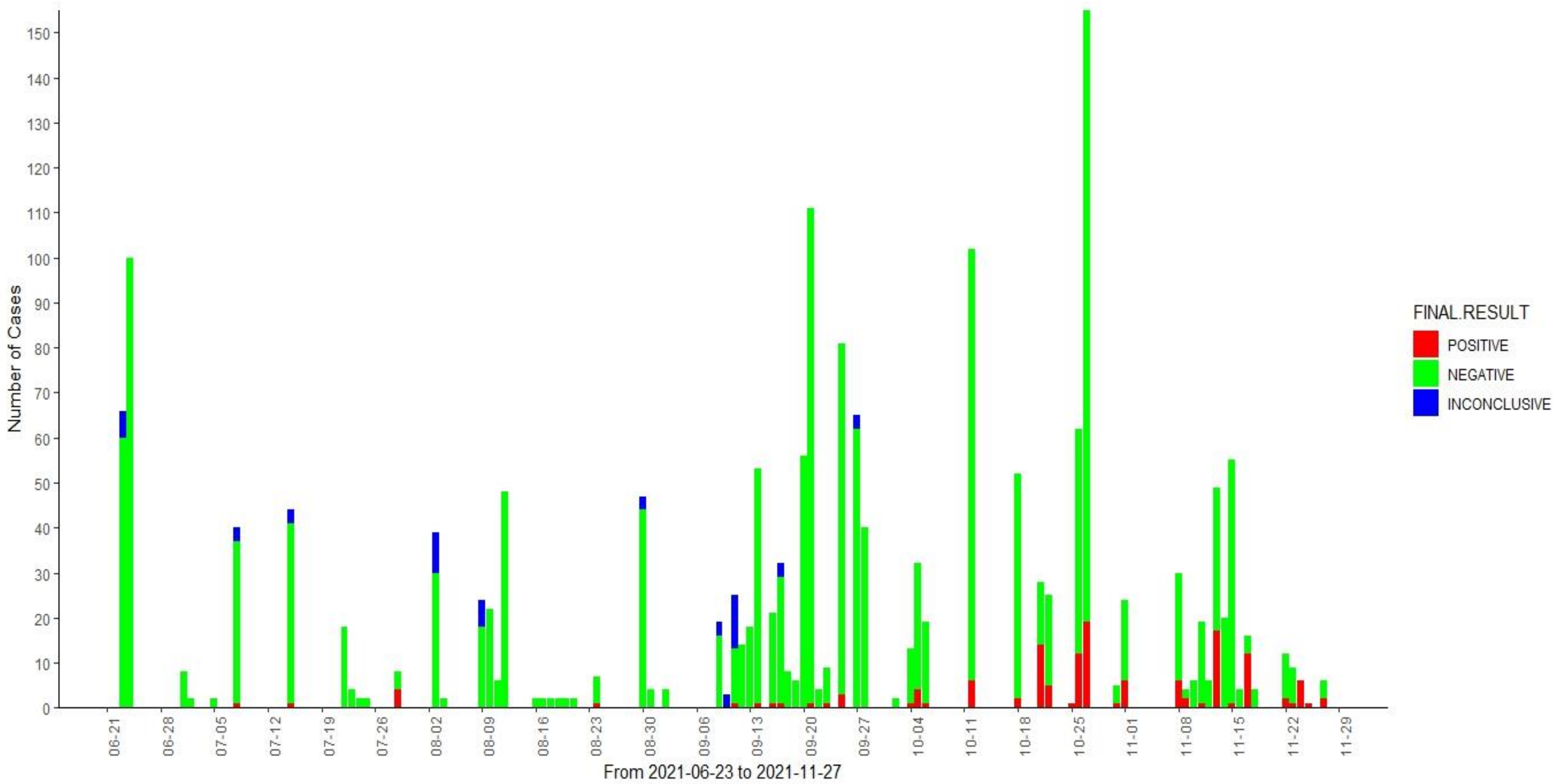

Figure 2: Daily RT-PCR assay results for the 989 diagnosed suspected cases of COVID-19

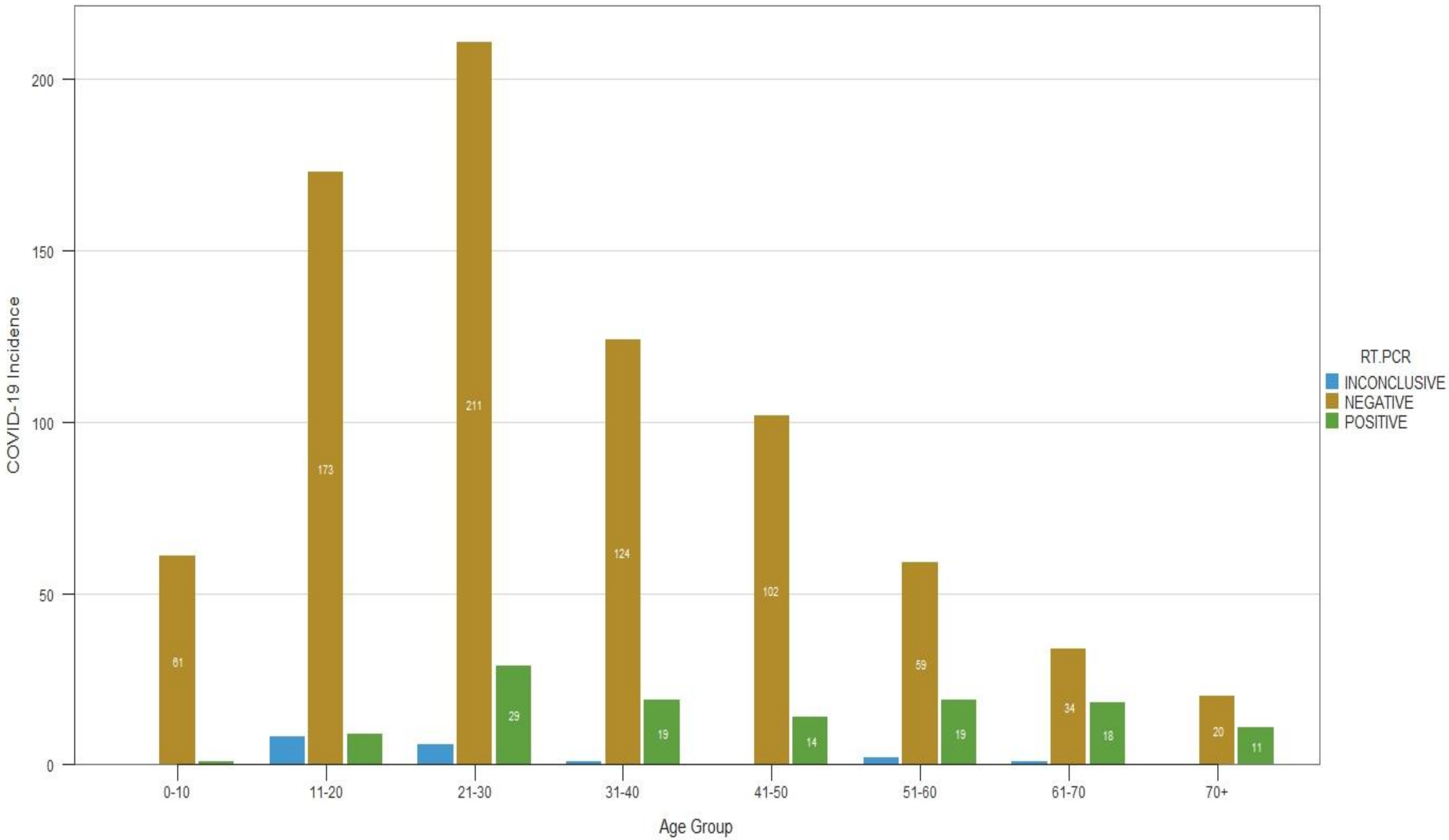

Figure 3: Age distribution of the 989 diagnosed suspected cases of COVID-19

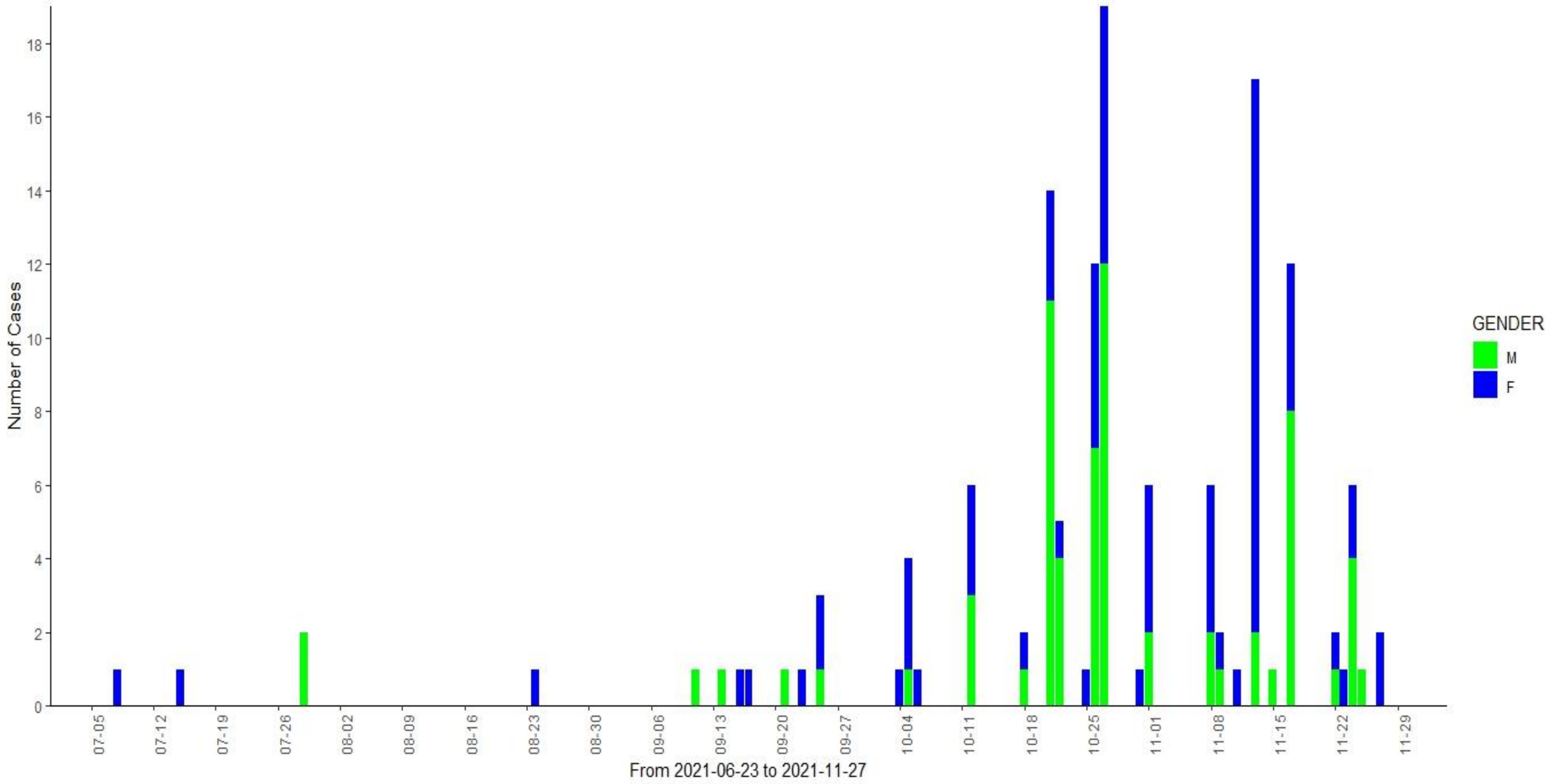

Figure 4: Daily RT-PCR assay results by gender of the 137 confirmed cases of COVID-19

Table 3 represents the age distribution of the 989 suspected cases. It is apparent that the age group 21-30 has the highest number of suspected cases (246 of 922 or 26.68%), followed by age groups 11-20 (190 of 922 or 20.61%) and 31-40 (144 of 922 or 15.62%), respectively. However, from Figure 3, it is clear that overall COVID-19 infection is less than 14% (137 of 989 or 13.85%) and relatively proportional to the number of diagnosed suspected cases.

Table 4 represents the monthly confirmed cases by gender, revealing no positive cases in June and a relatively equal number of male and female cases until the peak in October, in which males (39) have a higher number of cases than females (27).

To glean more information, Figure 4 provides a visual representation of daily records of COVID-19. It revealed that, although the number of cases for males and females was relatively equal, the number of cases for males was higher on the day of peaked infection (27th October, 2021). Table 5 represents the age group distribution by gender of confirmed cases. It is apparent that age group 21-30 is the most infected for both male and female categories, with females in age group 31-40 more infected while males in age group 51-60 were more infected. This information is represented in Figure 5.

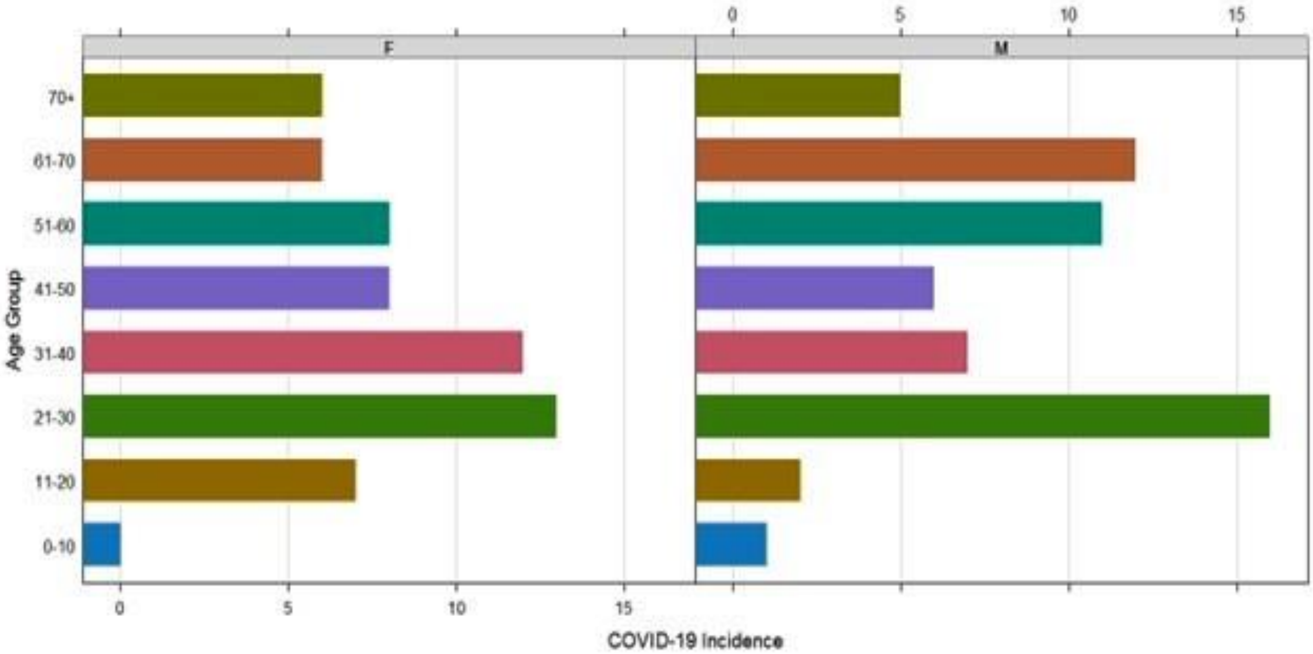

Figure 5: Age group distribution by gender of diagnosed positive cases of COVID-19

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Time-Dependent Reproduction Number

Table 6 provided daily incidence cases of COVID-19 over the study period, starting from the first incidence on 8th July, 2021, giving a total of 69 sliding weeks or Serial intervals. With no prior record of infection and 2 cases within two consecutive sliding weeks or Serial intervals, the R_t was high at the onset with a value of 3.72, suggesting that an infected individual will on average cause infection in at least four (secondary) individuals. However, with only 12 additional cases up to the end of September, this value rapidly declined and remained around one, except for the sliding weeks around which a case was recorded.

This suggested that an individual has the capability of infecting one (secondary) individual except around the aforementioned sliding weeks.

The R_t value started in October at 2.20 and rapidly increased, reaching a peak of 3.22 on 18th October, 2021. Then it rapidly decreased to 1.09 on 9th November 2021. This is not unexpected since October has the highest number of positive cases (66). Although the Presidential Steering Committee (PSC) on COVID-19 officially announced the beginning of the third wave in Nigeria on 2nd August 2021 (NCDC, 2021), it is apparent that for Katsina State, the third wave reached its peak in October with 19 cases recorded on 27th October 2021 and the risk of transmission and infection of the disease diminished significantly from 10th November 2021, except in some consecutive sliding weeks around which 12 positive cases were recorded.

Temporal-Dynamics of the R_t values were plotted against the sliding weeks in Figure 6. Observe that the confidence interval was wider in sliding weeks with no or a few records, but narrowed as the cumulative number of cases increased. Also observe that from around the 62nd day of the study period, R_t values remained approximately less than one, suggesting that the risk of COVID-19 transmission has diminished significantly and no new infection was expected

Table 6: Daily Mean values of R_t with Incidence and sliding weeks or Serial Intervals (SI_)

S/N	date	Incidence	SI_start	SI_end	R_t	S/N	date	Incidence	SI_start	SI_end	R_t
1	08/07/2021	1	1	7	-	36	22/09/2021	0	36	42	1.26
2	15/07/2021	1	2	8	3.72	37	23/09/2021	1	37	43	1.92
3	22/07/2021	0	3	9	2.64	38	25/09/2021	3	38	44	1.70
4	23/07/2021	0	4	10	2.21	39	27/09/2021	0	39	45	1.52
5	24/07/2021	0	5	11	1.97	40	28/09/2021	0	40	46	1.43
6	25/07/2021	0	6	12	3.03	41	02/10/2021	0	41	47	1.37
7	29/07/2021	2	7	13	1.86	42	04/10/2021	1	42	48	2.20
8	03/08/2021	0	8	14	1.23	43	05/10/2021	4	43	49	1.83
9	04/08/2021	0	9	15	1.28	44	06/10/2021	1	44	50	2.04
10	09/08/2021	0	10	16	1.33	45	12/10/2021	6	45	51	1.98
11	10/08/2021	0	11	17	1.35	46	18/10/2021	2	46	52	3.22
12	11/08/2021	0	12	18	1.36	47	21/10/2021	14	47	53	2.62
13	12/08/2021	0	13	19	0.45	48	22/10/2021	5	48	54	1.93
14	16/08/2021	0	14	20	0.56	49	25/10/2021	1	49	55	2.00
15	17/08/2021	0	15	21	0.72	50	26/10/2021	12	50	56	2.39
16	18/08/2021	0	16	22	0.89	51	27/10/2021	19	51	57	1.71
17	19/08/2021	0	17	23	1.06	52	31/10/2021	1	52	58	1.58
18	20/08/2021	0	18	24	1.25	53	01/11/2021	6	53	59	1.24
19	21/08/2021	0	19	25	2.90	54	08/11/2021	6	54	60	1.12
20	24/08/2021	1	20	26	2.49	55	09/11/2021	2	55	61	1.09
21	30/08/2021	0	21	27	2.14	56	10/11/2021	0	56	62	0.83
22	31/08/2021	0	22	28	1.99	57	11/11/2021	1	57	63	0.41
23	02/09/2021	0	23	29	1.90	58	12/11/2021	0	58	64	0.92
24	09/09/2021	0	24	30	1.85	59	13/11/2021	17	59	65	0.79
25	10/09/2021	0	25	31	2.71	60	14/11/2021	0	60	66	0.67
26	11/09/2021	1	26	32	1.51	61	15/11/2021	1	61	67	0.66
27	12/09/2021	0	27	33	1.49	62	16/11/2021	0	62	68	1.15
28	13/09/2021	0	28	34	2.35	63	17/11/2021	12	63	69	1.09
29	14/09/2021	1	29	35	2.75	64	18/11/2021	0	64	70	1.12
30	16/09/2021	1	30	36	2.71	65	22/11/2021	2	65	71	0.56
31	17/09/2021	1	31	37	2.11	66	23/11/2021	1	66	72	0.84
32	18/09/2021	0	32	38	1.44	67	24/11/2021	6	67	73	0.89
33	19/09/2021	0	33	39	1.39	68	25/11/2021	1	68	74	0.99
34	20/09/2021	0	34	40	1.74	69	27/11/2021	2	69	75	-
35	21/09/2021	1	35	41	1.28						

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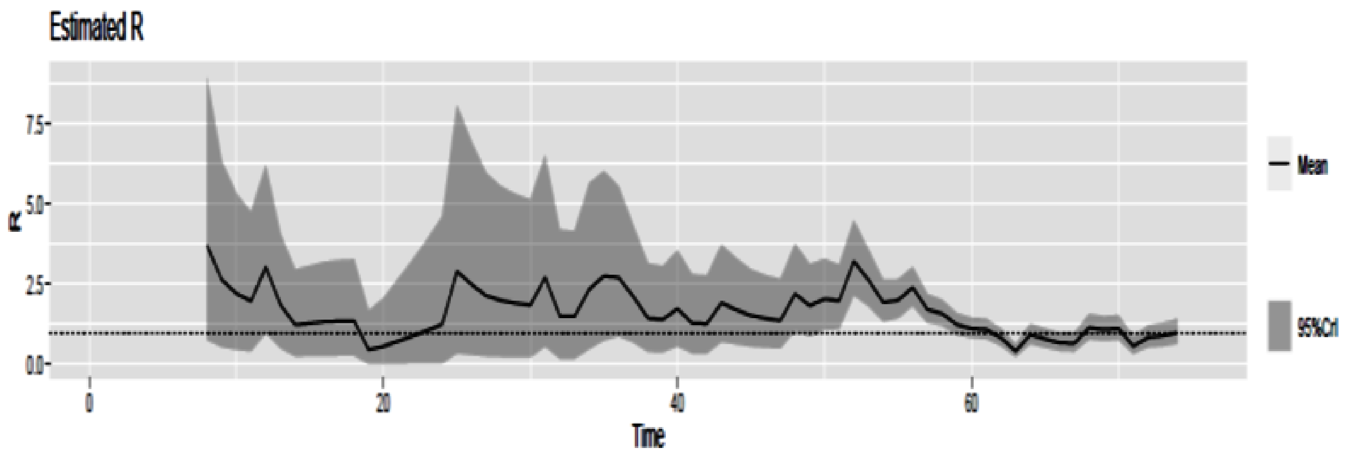

Figure 6: Mean values of R_t over the weekly sliding windows and a 95% Confidence Interval

DISCUSSION

Evolution of the COVID-19 virus poses serious challenges to prevention, control and mitigation strategies, with several variants identified through different waves of the pandemic and recent research efforts in Nigeria (Badmus *et al.*, 2023; Omede *et al.*, 2023; Onwube *et al.*, 2023; Adeyemi *et al.*, 2023; Moroh *et al*, 2023; Taiwo *et al.*, 2023) and elsewhere around the world (Triambak *et al.*, 2023; Jameel *et al.*, 2023; Mitra *et al.*, 2023) focusing on understanding the behaviour of the disease through modelling, reproduction metrics, risk factors and other research approaches.

In this paper, we investigated the transmission of the disease using time-varying reproduction number (R_t) metric and studied the effect of age and gender as risk factors during the third wave of the pandemic in Katsina state. Our findings revealed, as significant factors, a median age of 41.3 years, a starting R_t value of 2.2 with peak at 3.22, female gender constituting 51% of positive cases and age ranges 21-40 and more than 50 years constituting 40% each of the total infections. We compare our results with several studies on the third and other waves of the pandemic.

Ofori *et al.* (2022) studied the transmission dynamics of the disease in Ghana, reporting a peak R_t value of more than 2 at the national level, Greater Accra and the Ashanti region and an R_t value of more than 3 in other regions. This is in good agreement with our findings. However, in Lorestan, west of Iran, Rahimi *et al.* (2021) reported a peak R_t value of 4.97, which is far higher than our value. This should not be unexpected since Iran is the epicentre of the pandemic in the Middle East. In the United States, Politis *et al.* (2022) investigated the time-varying reproduction number in Arkansas and Kentucky, reporting peak values of 1.15 and 1.10, respectively. These lower values were achieved through policies and measures that effectively slowed transmission of the pandemic (Politis *et al.*, 2022)

From pandemic onset, age and gender have been identified as significant risk factors (Goldstein *et al.*, 2021; Permata *et al.*, 2021; Hu *et al.*, 2021) in the dynamics of COVID-19 transmission. A study of the third wave of the pandemic in New York City by Tandon *et al.* (2022) revealed that males were the most affected, with mean age of 60±19 years at infection. In Baqubah, Iraq, a study of COVID-19 risk factors by Jameel *et al.* (2023) revealed that male (54.3%) gender is the most affected with age group 31-40 constituting 60.6% of positive cases. Similar results were reported in Tirana, Albania, by Petri *et al.* (2022), with age group 31-40 (17.3%) and male gender (61.6%) most affected. These two results closely agree with our findings on the effect of age group on the pandemic, but not the gender. However, in Nigeria, Adeyemi *et al.* (2023) reported female (56.8%) as the most affected gender, corroborating our findings. In yet another study of the third wave in the Gujarat state of India, Mitra *et al.* (2023) reported the age group 18-30 (73%) and female (55.4%) gender as the most affected. This closely agrees with our findings.

CONCLUSSION

It is apparent that COVID-19 pandemic has passed, especially with the recent declaration by WHO Director-General (WHO, 2023) that COVID-19 is no longer a public health emergency of international concern, and the follow-up statement issued by the NCDC (NCDC, 2023). However, with international travelling restrictions lifted and COVID-19 protocols relaxed, both WHO and the NCDC cautioned that the dangers posed by the virus still remains within communities and hence a significant risk of transmitting a strain or new variants across the globe. The aim of the declaration was to guide and enable countries focus on long term management of the diseases, vaccination roll outs and implementing recent WHO initiatives and action plans on the pandemic.

Based on these observations and our research findings, it is apparent that research on COVID-19 is now even more important with COVID-19 being an established and ongoing health issue, especially in disease management (see for example Aryana *et al.* 2023) and population immunity through vaccinations (see for example Sokunbi *et al.* 2023; Olawa *et al.* 2023) and other initiatives.

For mitigation strategies against future waves, a Modeling approach can provide a framework for prediction, prevention and control of the disease. The diagnosed swab samples were collected from sixteen local government areas across the State, as shown in Table 2. Identifying Local governments or zones in which the adopted mitigation strategies reported by Ladan (2020) failed or where the population is prone to a high risk of transmission and infection (see for example Taiwo *et al.* 2023) can also help the State in designing policies against future waves of the pandemic.

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