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An Analytical Approaches to Solve a Lung Infection Model

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Abstract:

Acute respiratory infections cause morality in young childhood. We assessed the effects of water(W), sanitation(S), hand hygiene(H) and nutritional(N) interventions on childhood ARI. Geographic cluster of kids from rural and urban places are taken a random survey of WSHN. Acute respiratory illness was defined as caregiver-reported persistent cough, panting, wheezing or difficult in breathing. The main limitations of this study include low adherence to some of the targeted behaviours, reliance on caregiver-reported outcomes (excluding visible runny nose), subjected to bias, the data are collected from World Health Organization- defined pneumonia. The idea of our study is to make the people understand the importance of cleanliness by the dynamical behaviour of infections. Media plays a vital role in improving the urgency of habitual change in day-to-day life.

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1. Introduction

Many people associate pneumonia with the elderly but it is actually the biggest it claims the lives of more than 6 million humans, under the age of 10 including new born and adolescence who are particularly vulnerable to infection. Pneumonia may be caused by bacteria, viruses or fungus. One or both of the lungs might become infected with pneumonia. It makes the lungs air sacs or alveoli swell with fluid or pus. An infection of the lungs called pneumonia. An infection of the lower respiratory tract is another name for it. In children three years of age and below, viruses are the main cause of pneumonia. Most pneumonia instances in older kids and teens are brought on by bacterial infections. A youngster may get a viral pneumonia at first, which might later develop into a bacterial pneumonia. Numerous methods exist for spreading pneumonia. When breathed, the common viruses and bacteria in a child’s nose or throat can infect the lungs. Additionally, airborne droplets from a cough or sneeze might transmit them. Additionally, particularly during and right after childbirth, pneumonia can spread through blood. The many pneumonia-causing bacteria and the modes of transmission require more study since they are crucial for both therapy and prevention. Every day at least one child dies every 45 seconds from pneumonia where almost all of these deaths are preventable. Lung infection caused by bacteria is easily preventable with vaccine. However, more than 50% of children around the world are not fully protected with primary vaccine to prevent pneumonia - the Pneumococcal (PCV) vaccine [20]. A new vaccine for one of the main viral causes of pneumonia is under development. In adults, Pneumonia can show signs and symptoms include a cough that produces green, yellow or even red mucus, fever, perspiration chills that shake respiration difficulty and quick breathing. Chest discomfort that is piercing or stabbing and that worsens when you cough or breathe deeply poor energy, weariness and loss of appetite [5]. The existing model has significant drawbacks, despite the fact that our Inf-Net segmented infected areas with promising results. The Inf-Net first concentrates on COVID-19 patient lung infection segmentation. On the other hand, in clinical practice, it frequently necessitates classifying COVID-19 patients before segmenting the infection zones for further therapy. The quantitative response caused by the deposition of a test substance could be indicated in the various parts of the lung model surface if test bacteria with a suitable bio luminescent reporter system were used to seed the agar coating the lung model surface, this would allow local deposition levels to be precisely determined [9].

Now-a-days media takes vital part in creating awareness to public through health care units. Treating pneumonia requires health workers to be with easy reach of families and to have the right training in medicine handling and diagnostic tools. Here, media helps to reach each and every family in all part of the world by giving precautions about the virus or ongoing pandemic, preventing measures and most importantly about vaccination.

2. Mathematical Modeling

This chapter examines the SIVMR (Susceptible-Infected-Vaccinated-Media Awareness-Recovery) lung infection using DTM, CFDTM and LPDTM methods. Utilizing a variety of examples [4, 7, 8, 10–15, 17–19], the mathematical model is framed with five compartments of susceptible, infected, media awareness, vaccinated and recovery, whereas the solutions has been provided.

$$
\begin{aligned}
s'(t) &= \alpha - \beta\, s(t)\, i(t) - m\, s(t) m(t) - \mu\, s(t) - \phi\, s(t) \\
v'(t) &= \phi\, s(t) - (d + \mu)\, v(t) \\
i'(t) &= \beta\, s(t)\, i(t) - (\mu + \nu + \sigma)\, i(t) \\
r'(t) &= i(t) - \mu\, r(t) \\
m'(t) &= m\, s(t)\, m(t) - \mu\, i(t).
\end{aligned} \tag{1}
$$

To the series solution with LPDTM, we employed DTM for equation (1) with the initial conditions $S(0) = S_0 \geq 0$, $V(0) = V_0 \geq 0$, $I(0) = I_0 \geq 0$, $R(0) = R_0 \geq 0$ and $M(0) = M_0 \geq 0$, to obtain the recursion relation

$$S(p+1) = \frac{1}{(p+1)}\left[\alpha\, \delta(p) - \beta \sum_{r=0}^{p} S(p-r)\, I(r) - \mu\, S(p) - \phi\, S(p) - m \sum_{r=0}^{p} S(p-r) M(r)\right]$$

$$V(p+1) = \frac{1}{(p+1)}\left[\phi\, S(p) - (d + \mu)\, V(p)\right]$$

$$I(p+1) = \frac{1}{(p+1)}\left[\beta \sum_{r=0}^{p} S(p-r)\, I(r) - (\mu + \nu + \sigma)\, I(p)\right] \tag{2}$$

$$R(p+1) = \frac{1}{(p+1)}[\nu\, I(p) - \mu\, R(p)]$$

$$M(p+1) = \frac{1}{(p+1)}\left[m \sum_{r=0}^{p} S(p-r)\, M(r) - \mu\, I(p)\right]$$

Initial Conditions:

$$\begin{cases} S(0) = 10000, \quad V(0) = 200, \quad I(0) = 200 \\ R(0) = 20, \quad M(0) = 200. \end{cases} \tag{3}$$

Table 1. **Parameter values and its descriptions**

α	Recruitment rate	271.23
β	Force of infection	0.10
m	Rate of publicity od awareness program	0.04
ϕ	Rate at which susceptible are vaccinated	0.9
d	Disease induced death rate	0.004
μ	Natural death rate	0.18
σ	Rate of news collection from the infectives	0.025

3. Differential Transform Method and its Properties

The fundamental concepts and operational characteristics of the differential transformation technique were covered in this section. A predetermined system of differential equations and associated beginning conditions make up this methodology. These are converted into a set of recurrence equations, which in turn become a set of algebraic equations whose solutions are the coefficients of a power series solution.

The following is the definition of a function's differential transformation:

$$Z(l) = \frac{1}{l\,!}\left[\frac{d^{\,l} z(t)}{dt^{\,l}}\right]_{t=t_0} \tag{4}$$

In equation (4), $Z(l)$ is the transformed function, sometimes known as the T −function, while $z(t)$ is the original function. The definition of a differential inverse transform for $Z(l)$ is:

$$z(t) = \sum_{l=0}^{\infty} Z(l)(t - t_0)^l \tag{5}$$

From equation (4) and (5), we obtain

$$z(t) = \sum_{l=0}^{\infty} \frac{(t - t_0)^l}{l!} \left[\frac{d^{\,l} z(t)}{dt^{\,l}}\right]_{t=t_0} \tag{6}$$

Equation (6) suggests that the Taylor series expansion is where the idea of a differential transform comes from and that relative derivatives are determined in an iterative manner as indicated by the altered equations of the original functions. Finite series are used to express the function $z(t)$, then (5) can be written

$$z(t) \approx \sum_{l=0}^{\infty} Z(l)\,(t - t_0)^l \tag{7}$$

with N is a convergence of natural frequency. For the properties and its applications one can refer [1, 3, 6, 16, 23, 24].

4. **Pade Approximation**

A Maclaurin's expansion-based analytical function $z(t)$ is given

$$z(t) = \sum_{n=0}^{\infty} z_n\, t^n, \qquad 0 \le t \le T. \tag{8}$$

The Pade approximation to $z(t)$ of order $[L,\ M]$ which we denote by $\left[\frac{L}{M}\right]_z(t)$ is defined by [2]

$$\left[\frac{L}{M}\right]_z(t) = \frac{p_0 + p_1 + \cdots + p_L t^L}{1 + q_1 t + \cdots + q_M t^M}\,, \tag{9}$$

when $q_0 = 1$ was taken into account and there are no common factors between the numerator and denominator.

In the equation (9), the numerator and denominator are designed so that $z(t)$ and $[L\,/M]_z(t)$ and the derivatives of them coincide at $t = 0$ up to $L + M$. Which is

$$z(t) - \left[\frac{L}{M}\right]_z(t) = O(t^{L+M+1}). \tag{10}$$

From (10), we have

$$z(t) \sum_{n=0}^{M} q_n\, t^n - \sum_{n=0}^{L} p_n\, t^n = O(t^{L+M+1}) \tag{11}$$

From (11), the following algebraic linear systems are obtained:

$$z_L\, q_1 + \cdots + z_{L-M+1} q_M = -z_{L+1}$$
$$z_{L+1}\, q_1 + \cdots + z_{L-M+2}\, q_M = -z_{L+2}$$

$$\vdots \tag{12}$$

$$z_{L+M-1}\, q_1 + \cdots + z_L\, q_M = -z_{L+M}$$

$$\begin{aligned} p_0 &= z_0 \\ p_1 &= z_1 + z_0\, q_1 \\ &\vdots \\ p_L &= z_L + z_{L-1}\, q_1 + \cdots + z_0\, q_{L.} \end{aligned} \tag{13}$$

From (12), we calculate first all the coefficients q_n , $1 \le n \le M$. Then, we determine the coefficients p_n , $0 \le n \le L$ from (13).

It should be noted that error (10) occurs for a fixed value of $L + M + 1$ when the denominator and numerator of (9) have the identical grade or where the value of the numerator has a degree that is one more than the denominator [2].

5. Method of Laplace-Pade Re-summation

Solutions in the form of polynomial power series are provided via many approximations. However, this kind of solutions may lack substantial areas of convergence. As a result, the Laplace-Pade re-summation approach is employed in literature to broaden the range of solutions that may be found by convergent analysis or to identify all possible solutions.

You may sum up the Laplace-Pade approach as follows:

1) Initially, power sequences are subjected to the Laplace transformation (5).
2) Following that, in the resultant equation, $1/t$ is used to replace s.
3) Later, by generating its Pade approximation of order $[N\ /M]$, we change the altered series into a metamorphic function. Although N and M were picked at random, they should be less than the order of the power series, order to improve accuracy and convergence, the Pade approximation increases the domain of the truncated series solution at this step.
4) Now $1/s$ is used to replace t.
5) At last, we arrive to the precise or approximate solution via the inverse Laplace s transformation.

Applying the parameter values and initial conditions in (2), we obtain up to certain order solution as follows:

$$\begin{aligned} s(t) &= \sum_{p=0}^{\infty} S(p) \times t^p \\ &= 10000 - 290528.7700\,\mathrm{t} - 111721211.6\, t^2 - 30978513960.0\, t^3 \\ &\quad -5924327228000.0\, t^4 - 609173762600000.0\, t^5 + \cdots \end{aligned}$$

$$v(t) = \sum_{p=0}^{\infty} V(p) \times t^p$$
$$= 200 + 8814.0\,\mathrm{t} - 134836.4565\, t^2 - 33474564.17\, t^3$$
$$-6962382805.0\, t^4 - 1065083898000.0\, t^5 + \cdots$$

$$i(t) = \sum_{p=0}^{\infty} I(p) \times t^p$$
$$= 200 + 199893.0\,\mathrm{t} + 96987740.90\, t^2 + 29631320500.0\, t^3 \qquad (14)$$
$$+ 5986223935000.0\, t^4 + 660172409800000.0\, t^5 + \cdots$$

$$r(t) = \sum_{p=0}^{\infty} R(p) \times t^p$$
$$= 20 + 62.40000000\,\mathrm{t} + 32976.72900\, t^2 + 10666672.90\, t^3$$
$$+ 2444103941.0\, t^4 + 395002792000.0\, t^5 + \cdots$$

$$m(t) = \sum_{p=0}^{\infty} M(p) \times t^p$$
$$= 200 + 79995.0\,\mathrm{t} + 14834386.26\, t^2 + 1369308719.0\, t^3$$
$$-57680894920.0\, t^4 - 50389449540000.0\, t^5 + \cdots$$

To enhance the exactness of DTM equation (14) solution series, we applied a $t -$ Laplace transform, later replace s by $1/t$ and implement Pade approximation to the transformed series. Finally, t is replaced by $1/s$ and applied inverse Laplace $s -$transform for the generated interpretation to acquire the estimate.

Put in Laplace transform to equation (14) yields

$$\mathcal{L}[s(t)] = 10000\, s^{-1} - 290528.7700\, s^{-2} - 223442423.2\, s^{-3} - 185871083800.0\, s^{-4}$$
$$-142183853500000.0\, s^{-5} - 73100851510000000.0\, s^{-6} + \cdots$$
$$\mathcal{L}[v(t)] = 200\, s^{-1} + 8814.0\, s^{-2} - 269672.9130\, s^{-3} - 200847385.0\, s^{-4}$$
$$-167097187300.0\, s^{-5} - 127810067800000.0\, s^{-6} + \cdots$$
$$\mathcal{L}[i(t)] = 200\, s^{-1} + 199893.0\, s^{-2} + 193975481.8\, s^{-3} + 177787923000.0\, s^{-4}$$
$$+143669374400000.0\, s^{-5} + 79220689180000000.0\, s^{-6} + \cdots \qquad (15)$$
$$\mathcal{L}[r(t)] = 20\, s^{-1} + 62.40000000\, s^{-2} + 65953.45800\, s^{-3} + 64000037.40\, s^{-4}$$
$$+58658494580.0\, s^{-5} + 47400335040000.0\, s^{-6} + \cdots$$
$$\mathcal{L}[m(t)] = 200\, s^{-1} + 8814.0\, s^{-2} - 269672.9130 s^{-3} - 200847385.0\, s^{-4}$$

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$$-167097187300.0\, s^{-5} - 127810067800000.0\, s^{-6} + \cdots$$

For the purpose of clarity, we substitute $s = 1/t$ in (15) to acquire:

$$\mathcal{L}[s(t)] = 10000\, t - 290528.7700\, t^2 - 223442423.2\, t^3 - 185871083800.0\, t^4$$
$$-142183853500000.0\, t^5 - 73100851510000000.0\, t^6 + \cdots$$
$$\mathcal{L}[v(t)] = 200\, t + 8814.0\, t^2 - 269672.9130\, t^3 - 200847385.0\, t^4$$
$$-167097187300.0\, t^5 - 127810067800000.0\, t^6 + \cdots$$
$$\mathcal{L}[i(t)] = 200\, t + 199893.0\, t^2 + 193975481.8\, t^3 + 177787923000.0\, t^4$$
$$+143669374400000.0\, t^5 + 79220689180000000.0\, t^6 + \cdots \quad (15)$$
$$\mathcal{L}[r(t)] = 20\, t + 62.40000000\, t^2 + 65953.45800\, t^3 + 64000037.40\, t^4$$
$$+58658494580.0\, t^5 + 47400335040000.0\, t^6 + \cdots$$
$$\mathcal{L}[m(t)] = 200\, t + 8814.0\, t^2 - 269672.9130 t^3 - 200847385.0\, t^4$$
$$-167097187300.0\, t^5 - 127810067800000.0\, t^6 + \cdots$$

Following (16); we workout Pade approximates of order $[5/4]$ to each equation in (16) of transformed series, we acquire:

$$\left[\frac{5}{4}\right]_s = \frac{10000.0\,\mathrm{t} + 3159069\, t^2 - 766424340\, t^3 + 11966339\, t^4 - 63343485\, t^5}{1.0 + 3188.12\,\mathrm{t} - 7549275\, t^2 + 118368350\, t^3 - 60856609310\, t^4}$$

$$\left[\frac{5}{4}\right]_v = \frac{200.0\,\mathrm{t} + 8157.77\, t^2 + 85211.1\, t^3 - 38241998\, t^4 + 24576395900\, t^5}{1.0 - 3.28112\,\mathrm{t} + 1919.01\, t^2 - 1820575\, t^3 + 139253041\, t^4}$$

$$\left[\frac{5}{4}\right]_i = \frac{200.0\,\mathrm{t} - 601369\, t^2 + 245732\, t^3 - 2856058\, t^4 + 1995223\, t^5}{1.0 - 4006.31\,\mathrm{t} + 1532090\, t^2 - 265963\, t^3 + 14665463\, t^4} \quad (17)$$

$$\left[\frac{5}{4}\right]_r = \frac{20.0\,\mathrm{t} + 12005.9\, t^2 + 3931762\, t^3 - 2675397980\, t^4 + 215764814500\, t^5}{1.0 + 597.178\,\mathrm{t} + 1960720\, t^2 - 133882766\, t^3 + 10818702450\, t^4}$$

$$\left[\frac{5}{4}\right]_m = \frac{200.0\,\mathrm{t} + 145496.3\, t^2 + 7750203\, t^3 + 23075868\, t^4 + 1844297578\, t^5}{1.0 + 327.5068\,\mathrm{t} + 108171.7\, t^2 - 17549540.31\, t^3 + 76655610\, t^4}$$

Applying $t = 1/s$, we obtain $[5/4]_s$, $[5/4]_v$, $[5/4]_i$, $[5/4]_r$ and $[5/4]_m$ in terms of s and taking inverse Laplace the following series obtained.

$$s(t) = 10408.64526 + 0.5820268\,(x) - 4.455814 \times 10^{-12} e^{-0.0001943056\, x}$$

$$+ (0.00000344015 + 0.00000238646\,\mathrm{i})e^{(0.000377555-0.000684391\,i)x}$$
$$+ (0.0000034401 - 0.00000238646\,\mathrm{i})e^{(0.000377555+0.000684391\,i)x}$$
$$+0.00080717\, e^{0.0013842\,x}$$

$$v(t) = 176.4873186 - 0.0438851\,(\mathrm{x})$$
$$-(0.000025997 - 0.000001192\,\mathrm{i})e^{(-0.0017612-0.0020394\,i)\,x}$$
$$-(0.000025997 + 0.000001192\,\mathrm{i})e^{(-0.0017612+0.0020394\,i)\,x}$$
$$-(0.000011790 - 0.00012290\,\mathrm{i})e^{(0.0024149-0.0020143\,i)x}$$
$$-(0.000011790 + 0.00012290\,\mathrm{i})e^{(0.0024149+0.0020143\,i)x}$$

$$i(t) = 1.360491042 - 0.192279\,(\mathrm{x})$$
$$-(0.000000001931 + 0.0000000003505\,\mathrm{i})e^{(0.000079009 - 0.00030585\,i)\,x}$$
$$-(0.000000001931 - 0.0000000003505\,\mathrm{i})e^{(0.000079009+ 0.00030585\,i)\,x} \quad (18)$$
$$+ 0.00013612\, e^{0.00078436\,x} - 0.00031868\, e^{0.0008711\,x}$$

$$r(t) = 19.9436869 - 0.00004882\,(\mathrm{x})$$
$$-(2.43212167 \times 10^{-15} - 2.864294 \times 10^{-12}\, i)e^{(-0.0001973-0.000307\,i)\,x}$$
$$-(2.43212167 \times 10^{-15} + 2.864294 \times 10^{-12}\, i)e^{(-0.0001973+0.000307\,i)\,x}$$
$$- (0.00000002033 - 0.0000000018\,\mathrm{i})e^{(0.0008161-0.0001611\,i)\,x}$$
$$- (0.0000000203 + 0.0000000018\,\mathrm{i})e^{(0.0008161+0.0001611\,i)\,x}$$

$$m(t) = 240.5952508 + 0.35611\,(\mathrm{x})$$
$$-(0.00002962 - 0.00002697\,\mathrm{i})\, e^{(-0.001179474 - 0.0011528\,i)\,x}$$
$$-(0.000029621 + 0.00002697\,\mathrm{i})\, e^{(-0.001179474+ 0.0011528\,i)\,x}$$
$$+ (0.00040615 - 0.00018201\,\mathrm{i})\, e^{(0.001293 - 0.0017666\,i)\,x}$$
$$+ (0.00040615 + 0.00018201\,\mathrm{i})\, e^{(0.001293+ 0.0017666\,i)\,x}$$

7. Result and Discussion

Although most types of lung infection are treatable and most people recover, their infections are very dangerous too. Especially in case of infants, older adults and people with lung infections or weak immune system. In this chapter, the lung infection model is taken into account as deterministic epidemic model. There are five compartments framed including vaccination and media awareness. In past few years the world-wide pandemic has shown us the importance of vaccine and also through media the awareness is created about vaccine and self-discipline. The five compartments that we considered are susceptible $s(t)$, vaccination $v(t)$, infected class $i(t)$, media awareness $m(t)$ and recovery class $r(t)$. In the above calculations, we employed a hybrid technique called Laplace-Pade Differential Transform Method (LPDTM) for the considered deterministic compartment model. With initial values of each compartment (3) and parameter values from Table 1, we generated a recurrence relation of each equation in (1) up to certain order. In particular, we discussed the two important compartments that is infected class and recovery class. In infected class that includes susceptible, vaccination and death rate of infected, whereas in recovery class, media and vaccination plays a vital role. Equations (15) - (18) describes the LPDTM procedure and Figure 1 - 2 gives us the picture view of infected class and recovery class.

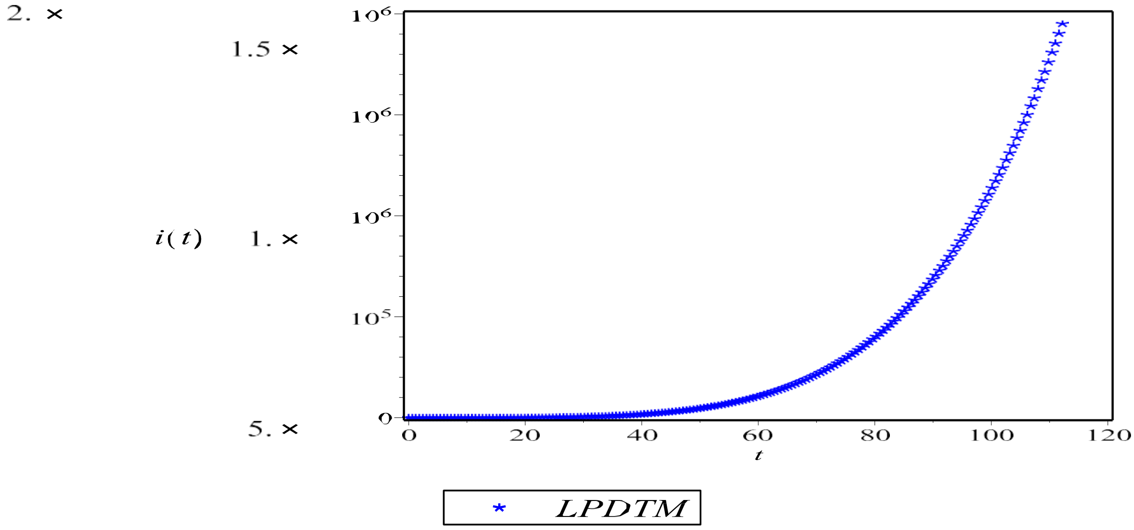

FIGURE 1. : Infected individuals $i(t)$ by $LPDTM$

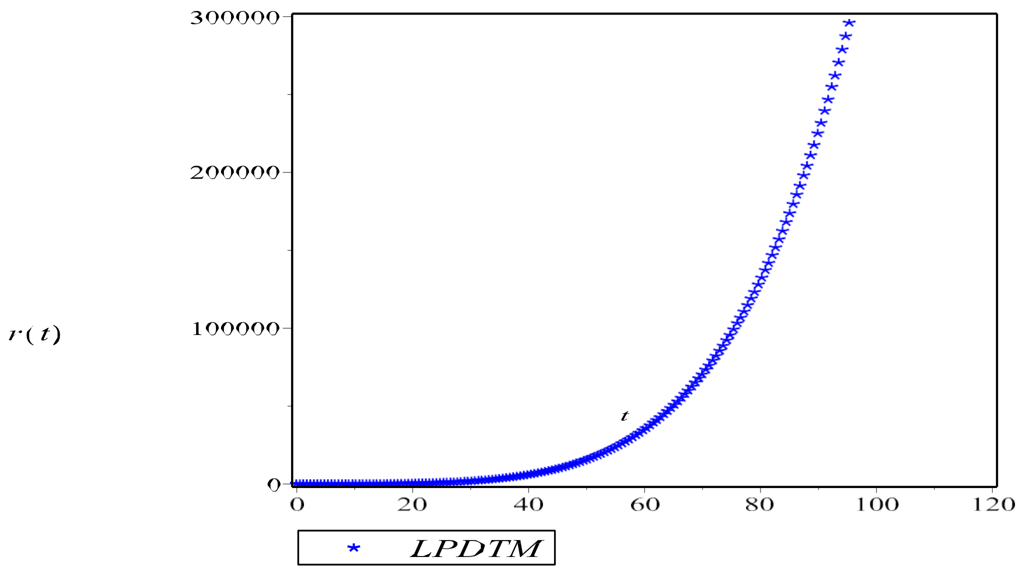

FIGURE 2. : Recovered individuals $r(t)$ by $LPDTM$

8. **Conclusion**

The present study gives the better understanding of the Laplace Pade Differential Transform Method and its applications which results the convergence of analytical solution. DTM is effectively applied to the system of nonlinear differential equations and analysed that this method can be implemented to various real life problem models for predicting the causes and prevention.

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