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Mathematical Modelling Of Meningitis Disease Epidemics And Pandemics Of Zamfara State 2017

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ABSTRACT

In this research work we introduce a mathematical model to study the behaviour of the meningitis disease. Studies show that this disease can kill in a few hours of infection and about 10% of the infected population die, even with treatment and about 20% of the survivors will have disabilities. The objectives of this work is to describe a mathematical model that can model the transmission of meningitis using Euler method and shows that the disease dies out if the basic reproductive number Ro<1 while the diseases may be come epidemic if Ro >1. At end we run some numerical simulation to elaborate the result. Method: Here, we modelled the meningitis epidemics and pandemics using Euler techniques and to understand the effect of a vaccine in small community of human population, we used an SVCIRS model and SEIRDS model. The model consists of a set of ordinary different equations. We apply Euler method to analysis the effect of the vaccine. A quantitative result will be present.

Keywords: mathematical model, meningitis disease, Euler techniques

INTRODUCTION

Meningitis is inflammation of the meninges, the covering of the brain and the spinal cord. it is mostly caused by infection (bacterial, viral, or fungal), but can also be produce by chemical irritation, subarachnoid haemorrhage, cancer and other condition (WHO Meningitis).The meningitis belt consists of 26 countries. This outbreak region stretches from Senegal in the west Africa to Ethiopia in the east, the epidemic of bacterial meningitis are most likely to occur in sub- Sahara Africa. Neisseria Meningitis group A is responsible for the majority of epidemics in Africa. Every year bacterial meningitis affect more than 450 million people living in the 26 countries of the African countries meningitis belt. In the years 1996- 2010 over 800,000 cases were reported in this area. Among this cases 10% resulted in deaths and 10% to 20% developing neurological sequelae. Only human can be infects by Neisseria meningitis, there is no animal reservoir, contact with respiratory droplet of infected individual or throat secretion through person to person contact even with appropriate treatment about 10% of infected person die. In developed countries the fatality rate can be between 3% and 10% as high as 20% in African countries, permanent health problem of up to 20% of survivor as a result of the disease (deafness, epilepsy, cerebral palsy speech disorder, loss of limbs and mental retardation). Once infected there is no immunity. At any time about 10% on average of the population carry the germs for at least day's weeks or months. Overcrowding and climatic conditions such as dry seasons or prolong drought and dust storm are conducive to spreading of *Neisseria meningitis* Elmojtaba and Adam (2017). In some African's countries a new meningococcal A conjugate vaccine was introduce in 2010 with the total of 20 million person's vaccinated age between 1 to 29 years. There were increase in number of person immunized across the other African countries in 2011 and 2012. Mathematical model can be used to identify the spread of infectious disease in a community and understand infectious dynamics; any time an outbreak of a communicable disease occurs, to forecast characteristics of the outbreak, models can be used. For example, size and duration of the outbreak to build epidemic scenarios and model the impact of possible interventions**.**

After transmission of the virus, susceptible individuals S move to the exposed class E before they become infectious individuals, that either recover and survive R or die D. 1/ and 1/are average durations of incubation and infectiousness. The case fatality rate is given by f. The transmission rate in absence of control measures is constant, i.e., The measures are introduced at a time the transmission rate was assumed to decay exponentially at rate K i.e.

MATHEMATICAL MODEL:

Model structure, building and use.

Mathematical model can be used to identify the spread of infectious disease in a community and understand infectious dynamics, any time an outbreak of communicable disease occurs, to forecast characteristics of the outbreak, models can be used. For example, size and duration of outbreak, to build epidemic scenarios and model the impact of possible interventions. Moreover, it helps in guidance to control strategies and policy decisions. Models can also be useful in estimating important epidemiological parameters from the outbreak data. In addition, the models can be used for the preparedness and moderation planning of future epidemics retrospective analysis in support of policy development. To ease mathematical models for these purposes of it is essential to conceptualize the dynamic epidemic process and measure diseases transmission. Ideally, it is important to choose the modelling procedure, to plan the model structure and epidemiological assumptions and parameters. Basically, two main types of modelare commonly distinguished. These include deterministic and non-deterministic or stochastic. The model can be run from simple to compartmental deterministic models to complex spatially stochastic and (individually) social-based network models (Louz, et al., 2010). The selection of model its complication and parameters to specify is context dependent and largely drive by the type of disease, the main purpose, the available data, the questions to be answered, and expertise available (Louz et al., 2010). Generally speaking, a useful model should be fitted to its purpose, involve all necessary features and be parameterizable from available data (Louz et al., 2010). Thus; details and complications to integrate to the models purpose can be skilful and complex task. Policy decisions may need the outcomes of more than one type of approach or model. The selection of what control measures and respond scheme to implement is context dependent and is usually a compromise between the magnitude of intervention and their logistical and economic feasibility (Louzet al., 2010).

Model Formulation

Most of the models in epidemiology are compartmental and based on systems of differential equation reflecting disease dynamics and rates at which population move from one epidemiological state or compartment to another. Either deterministic or stochastic can be one of the compartmental models. The classic standard, the so called deterministic compartmental SIR (Susceptible-Infectious-Recovered) theoretical account or model was first introduced by Kermack and McKendrick in the 1930s (Louzet al., 2010). Moreover, two otherbasic models are also commonly distinguished these include SI (Susceptible-Infectious) and SIS (Susceptible-Infectious-Susceptible). The (SIR) is consider as the foundation for majority of mathematical epidemiological or compartmental models. The SIR model separates host populations in susceptible S (individuals hosts that are susceptible for the disease), infectious, I (individuals that are infectious), R (individuals that recovered with immunity or are classified as removed by either death or isolation) S(t), I(t) and R(t) represent the actual number of individual hosts at time t per compartment. This theoretical account or model is made mathematically by formulating a set of nonlinear differential equations (Louz et al., 2010).The above equations describe the transmission dynamics of the infection movement from one compartment to another that are control by the rate of coefficients resulting in to a flow of chart. The SIR model in it elementary form is based on the following assumption (1) all susceptible individual hosts in the population are equally at risk for contracting the disease which known as 'Homogeneous mixing' (2) All infected individual hosts is presumed to be equal and constant with the infectiousness. (3) Population size is fixed in totality as there were demographic turnover i.e. closed population and birth or death is taken into consideration (Louzet al., 2010). By definition S(t)+I(t)+R(t)=N(t) since demographic effects is ignored and N(t) represent the total population size. Contacts between the susceptible and infectious individuals are assumed to take place at a rate proportional to their numbers in the population. Movement charts usually show rates of flow rather than total numbers that moves from one compartment to another and the average time individuals remain in compartment I is equal to while is the rate of new infections with contact rate . However, more compartments reflecting different states of the infection process, for example, Exposed (E) or passive immune (M), may be added to the model structure, in the same manner a series of conventional deterministic compartment models have been innovated over last century and successfully applied ever since. Models such as SEIS, SEIR and MSEIRS are the most commonly used acronyms and extension of basic SI, SIS and SIR models (Louzet al., 2010). Disease transmission in an existing populations frequently involves complex social and spatial structures characterized by heterogeneity in contacts networks and accordingly in the effect of control measures (Louzet al., 2010). To include more details and realisms, additional compartments or subclasses representing age structure, social behaviour, social economical demographics, and spatial element or control strategies such as quarantine and isolation were include by newer generations of model. To include more complicated element requires more parameters, variables and detailed assumption about the nature of the underlying processes tends to introduce more unknown parameters. Models that are more complicate usually requires numerical solution to differential equation or stochastics simultaneous analysis (Louzet al., 2010). Note that, conceptually more complicated models are not necessarily mathematically more difficult to resolve. Generally, using more complex and detailed models result to greater resolution and accuracy of modelling results which is necessary for example, control policy guidance. However, it is sufficient enough to gain more insights of general infection dynamics by the use of simple model. Hence, it depends on the preciseness or generality and purpose of the question to be answered, models can be vary in the level of detail they incorporate. There exist an exchange between simplicity, the absence of details and whether inclusion of additional parameters and complexity will lead to improvement of predictive power. The use of simple (basic deterministic compartmental) models may represent an effective tool as an initial step when little is known of the disease and its parameter values. Subsequently, more complexity can be added to the suit the model's purpose and the question to be answered (Louzet al., 2010). Although the basis of mathematical modelling is deterministic compartmental, they are based on assumptions that are usually epidemiologically unrealistic as previously mention.

Transmission

Neisseria meningitis only infect humans; there is no animal reservoir. The bacteria are transmitted from person through droplets of respiratory or throat secretions from carries smoking, close prolonged contact – such as kissing , sneezing or coughing on someone, or living in close quarters with carrier- facilitated during mass gathering (recent examples include the Hajj pilgrimage, jamborees) WHO IVB 6 Dec 2020.

Symptoms Of Meningitis

Average incubation or latent period. The average incubation period is four days (4 days), but can range between two and ten days the common symptoms are stiff neck, high fever sensitivity light, confusion, headaches and vomiting. In addition in infants bulging fontanelle and ragdollappearance are commonly found 8% to 15% of patient dies often within 24 hours to 48 hours after onset of symptoms. If untreated meningococcal meningitis is fatal in50% of cases and may result in brain damage, hearing loss or disability in 10% to 20% of survivors. Meningococcal Meningitis is associated with high fatality (up to 50% when untreated (Trotteet al., 2005).

The Basic Reproductive Number

Is the basic reproductive number Ro also known as the reproduction ratio or rate or the basic reproductive rate, is an epidemiological metric used to portray the contagiousness or transmissibility of infectious / Agent. Ro is affected by numerous biology socio behavioural and environmental factors that govern pathogen transmission and therefore, is usually estimated with various type complex. (Delamater et al., 2019).The basic reproduction number Ro is in the centre of parameterization of epidemic mathematical model. This key epidemiologic variable characterized the transmission potential of disease within a population. Is defined as the average number of secondary cases generated as a result of an initial single infectious case in a totally susceptible population in the absence of infection control measures (Louzet al., 2010). The value Ro equals to 1 (one) is considered to be the threshold. In general, an outbreak will lead to an epidemic if we assumed that. An outbreak will fade out whenever if Ro 1. Ro set a basis for measuring transmission potentiality between different viruses and other diseases. Ro is not a fixed property for a particular disease but definedfor a certain host population governed by a specific contacts (behavioural) pattern, duration of infectiousness, and probability of transmission. Different populations may be associated with different values of Ro for the same disease. In addition, Ro is a dimensionless quantity that can provide an indication of the risk of an epidemic as well as intensity of measure needed for infection control (Louzet al., 2010). The efficacy of infection control measures can be measured in terms of ability to reduce Ro to a value less than one. It is more convenient to use Rt the effective reproduction number when an infection is spreading, which is defined as the actual average number of secondary cases per primary case at time t during the outbreak. The value of Ro is usually greater than the value of Rt reflecting the impacts of infection control measures or build-up of immunity (Louzet al., 2010).

Scope and Limitation of This Study

In this research work we intended to study and model the meningitis outbreak of 2017\18 in Zamfara state and we collect data from five general hospital in the state and apply Euler method to analysis the data.

Problem Statement/Justification

With increase in communicable diseases around the sub-Sahara Africa and other pathogenic disease like Meningitis, flu, such as A/ H1N1, SARS, Swine flu, Ebola virus etc. It became necessary, to come out with a way to control the spread of the disease among the populated communities. So as to avoid further spread and higher mortality. Meningitis as one of the latest pandemic in 2017 which cover a larger geographical area around the sub-Sahara Africa, with about 800,000 cases reported 1996 to 2010. This lead to introduction of different modelling technique to help in reducing the effect and even eradicating of the disease among the affected communities.

Objective(s) of the Study

i) To collect the data from text book and published journal articles of Meningitis outbreak online and run simulation by applying Euler method.

ii)To describe a mathematical model that can model the transmission of meningitis disease using Euler method and shows that the disease dies out if the basic reproductive number Ro<1 while the diseases may be come epidemic if Ro >1. At end we run some numerical simulation to elaborate the result.

iii) To analyse and interpret the result and see how accurate the method applied compare to other method.

iv) Make remark on accuracy, similarities or differences where possible between the method and techniques if exist.

LITERATURE REVIEW

To minimize the spread of infectious disease, it is absolutely essential and worthy to quarantine each individual who is likely been expose for a sufficient time for either transmission to occur or until it can be guarantee that there is no probability of transmission. Stated by the centre for Disease Control and

Prevention (Haas. 2014).In a situation where somebody has been exposed to an infectious disease and he or she is not yet known whether they have been caught the disease in this case quarantine or separation from others who have not been exposed to the disease is necessary. People who are exposed may be ask to stay or remain in their respective residences to avoid further possible spread of the diseases. A special care and attention for early symptoms of the disease should be granted (Haas 2014). According to the national emergency management agency (NEMA) as of 24th march, (2009) 156 people have died of meningitis in Nigeria of some 1,500 infected, one-third of the deaths were in the northeast, which includes Bauchi, Gombe, Adamawa, Yobe, Barno, and Taraba State.During the same period of last year Nigerian had nine times as many infections (13,298 cases).It has become necessary for people to sleep outside due to the unbearable heat, because sleeping indoors can cause CSM (cerebrospinal meningitis). Most facilities now sleep on their verandas and in some cases the men sleep in front of their homes.The disease transmitted by nose and throat secretion, speeds more easily in overcrowded conditions mostly during the dry months in sub-Saharan African from December to June.As of 15 march, (2009) the most affected cases and 328 deaths, and Chad with 1,282 cases and 13 deaths, according to the world health organization (WHO) six districts in Bukina Faso and five districts in Chad are in epidemic phase, with at least 10 of 100,000 people infected. Even when diagnosed and treated early meningitis kills up to 10% of those infected, typically within 48 hours after onset of symptoms, according to (WHO).Nigeria and Niger are hardest hit by 2009 meningitis epidemic, crowded markets and living quarters in Nigeria's most populated State, Kano increase the risk of a meningitis outbreak. 27 march 2009, a vast majority of the nearly 25,000 suspected meningitis cases and more than 5,000 deaths worldwide in the first three months of 2009 have occurred in the so- called African meningitis belt. Hitting Nigeria and Niger the hardest, the United Nations health agency has reported. The bulk of case in the meningitis belt, stretching from Senegal to Somilia, have been in northern Nigeria, reporting 17,462 suspected and 960 deaths and Niger with 4,513 suspected case and 169 deaths according to the world health organization (WHO).Vaccination campaigns re-underway in the two countries, with the support of WHO and UN children's fund (UNICEF) and nongovernmental organization, Medicines sans Frontiers (MSF). World health organization report,(2009).

METHODOLOGY

This chapter explained in details the next step in the research process, which is the development of methodology. The methodology involves what you will actually do so as to address the specific objectives and research question you have develop (Newing et al., 2011).

Research is a careful investigation, systematic investigation towards increasing the sum of knowledge (Newing et al., 2011).

In this research work data was collected from different relevant published journals that adopted different mathematical modelling of meningitis disease outbreak. Various author used different modelling techniques to analyses the meningitis disease. But in this research work Euler method has been used to make an analysis with different methods adopt. In this research work, a quantitative analysis has been applied, because it involved numerical data to carry out the analysis.

Method

The transmission of Meningitis follows SEIRS model (susceptible-Vaccinated-Carrie or Expose-Infectious - Recovered) dynamics and can be described by the set of six ordinary differential equations (ODEs) (Althaus 2014). In this research work we develop a transmission models for meningococcal infection to investigate how well simple compartmental models are able to qualitatively capture the patterns of disease observed in the meningitis belt. Although we aim to keep the models as simple as possible (ignoring for example the spatial heterogeneity in disease incidence that is known to exist), several key features must be incorporated to adequately represent the dynamics of meningococcal infection. Where there is uncertainty in the most appropriate model structures and assumptions we have examined a range of options.

Assumptions

Assumption 1, very susceptible individual (S) in the community is free of the disease before becoming expose to the disease and inter a latent period. Here birth is very important we can use SEIR model with demography. So here the birth rate inters in to the susceptible correspond with new-borns while the corresponding going out of the E, I and R compartments is the death rate i.e. represent both birth and death rate.

Assumption 2, we assumed an individual who is carrier or expose can be represented by (c or E)

Assumption 3, we assume individual become infected (I) after being expose or passing through a latent period.

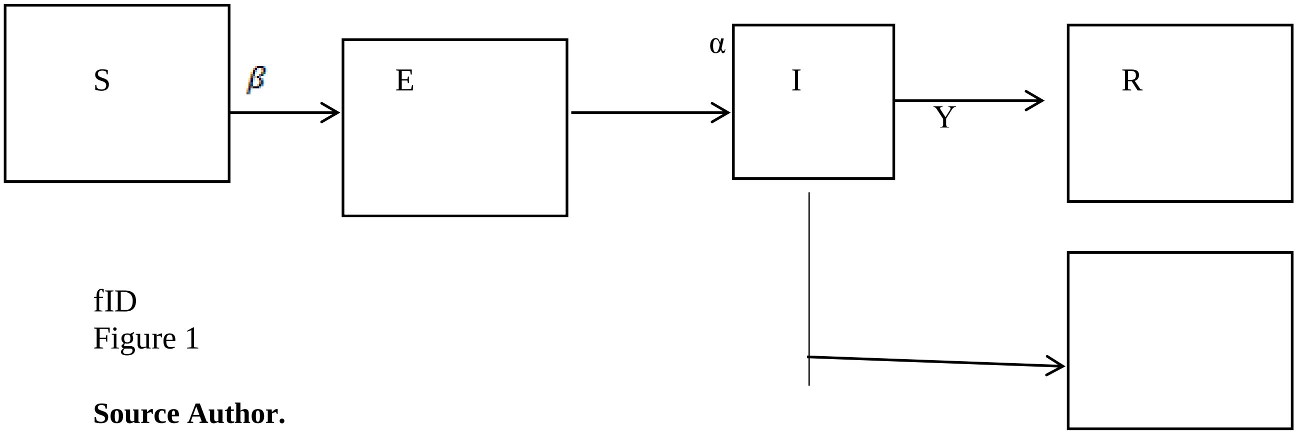
Assumption 4, we assumed that every infected individual recovers or die from the infection and returns to the susceptible class.

Assumption 5, is the average duration of the latent period

Other Assumption: Are β is the product of the contact rate and the transmission probability and the ϒ is the recovery rate while is the incubation or latent period.

The transmission of Meningitis follows SEIR (susceptible-expose- infectious- recovered) dynamics and can be described by the following set of ordinary differential equations (ODEs) (Althaus 2014).Given the above ODEs, we use them to developed a black box or compartmental boxes which indicate the movement of individual from one states of infection to another and also the rate of transmission and recovery during the infectious period. The compartmental boxes below are representing the proportion of individuals at a particular period of time during the infectious period.

Black Boxes



fID

Figure 1

Source Author.

After transmission of the virus, susceptible individuals S move to the exposed class E before they become infectious individuals, that either recover and survive R or die D. 1/ and 1/are average durations of incubation and infectiousness. The case fatality rate is given by f. The transmission rate in absence of control measures is constant, i.e., The measures are introduced at a time the transmission rate was assumed to decay exponentially at rate K i.e. .

Euler Method

The Euler method gives the following sequence of approximation of the above ODEs. The transmission of meningitis follows SEIR model (Susceptible –Expose-Infectious-Recovered) dynamics and can be described by the following set of ordinary differential equations ODEs.

The model can be formulated as follows:

$$\frac{dS}{dt} = \mu - \beta SI - \mu S$$

$$\frac{dE}{dt} = \beta SI - \sigma E - \mu E$$
$$\frac{dI}{dt} = \sigma E - \mu I - \gamma I$$
$$\frac{dR}{dt} = \gamma I - \mu R$$

$$S = \quad \mu - \beta SI - \mu S \Rightarrow S_{n+1} = \quad S_{n+h}(\mu - \beta S_n I_n - \mu S_n)$$

$$E = \quad \beta SI - \sigma E - \mu E \Rightarrow E_{n+1} = \quad E_{n+h}(\beta S_n I_n - \sigma E_n - \mu E_n)$$

$$I = \quad \sigma E - \mu I - \gamma I \Rightarrow \qquad I_{n+1} = \quad I_{n+h}(\sigma E_n - \mu I_n - \gamma I_n)$$

$$R = \quad \gamma I - \mu R \Rightarrow \qquad R_{n+1} = \quad R_{n+h}(\gamma I_n - \mu R_n)$$

The Euler method gives the following sequence of approximation of the above ordinary differential equations (ODEs). These sequence of approximation will be programme in to excel together with the parameters values obtain in the table 1 below to produce the graph in figure 2 below.

$$t_{n+1} = t_{n+h} \Rightarrow \qquad = A5 + \$C\$2$$

$$S_{n+1} = \quad S_{n+h}(\mu - \beta S_n I_n - \mu S_n$$

`=B5+$C$2*($E$1-$G$1*B5*D5+$E$1*B5)`

$$E_{n+1} = \quad E_{n+h}(\beta S_n I_n - \sigma E_n - \mu E_n)$$

`=C5+$C$*($G$1*B5*D5*$S$1*C5)`

$$I_{n+1} = \quad I_{n+h}(\sigma E_n - \mu I_n - \gamma I_n)$$

`=D5+$I$2*($I$1*C5-$E$1*D5-$K$1*D5)`

$$R_{n+1} = \quad R_{n+h}(\gamma I_n - \mu R_n)$$

`=E5+$C$2*($K$1*D5-$E$1*E5)`
With the initial conditions $S(0) > 0,\ E(0) \geq 0 I(0) \geq 0, R \geq (\ 0)$.

RESULT

The basic reproductive number is commonly denoted as and defines as the number of secondary cases generated by primary infectious case during its entire period of infectiousness in a completely susceptible population. One of the objectives of public health is to minimize this quantity to a number less than one as soon as possible. Therefore when R0>!is greater than one, an epidemic can occur while a basic reproductive number less than one will not sustain an epidemic. For R0<1 the infection or epidemics should be eliminated.

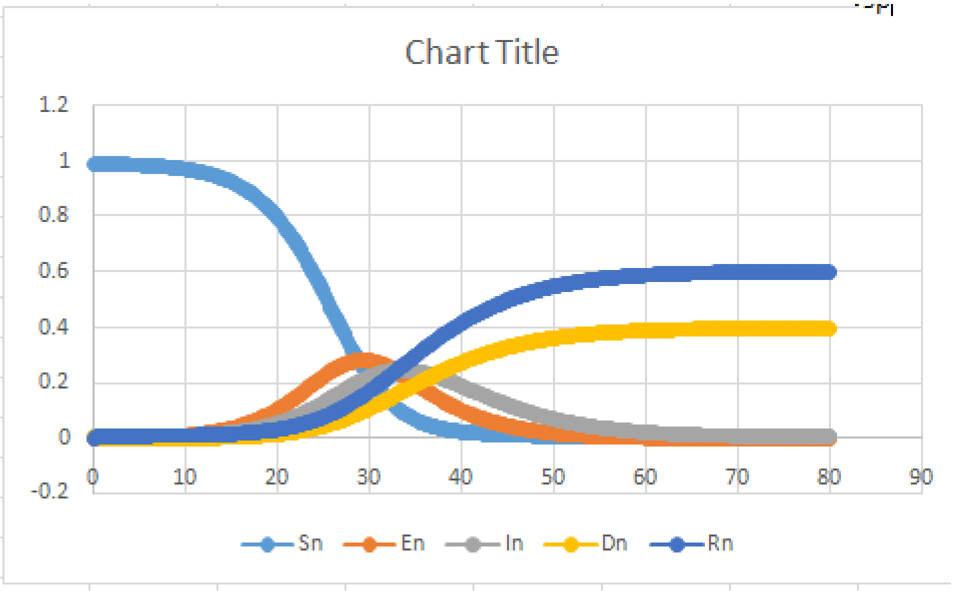


Figure 2
Source: author

Numerical result was generated using Euler techniques. The systems of ordinary differential equation were solved numerically by using Euler. The outcome of the modelling in (figure 2) clearly show that 99% of the total population was susceptible which indicate that 99% of the total population are capable of getting infected, and about 30% of the population were expose to the meningitis during the epidemic and within (20 days) days the exposure reach it maximum peak of about 30% of the population and continue to decline thereafter. Also from the above model figure 2, about 25% were infected between (0 to 20 days) of the outbreak with Meningitis, infection attaint it highest peak between (0 to 20 days), similarly, both the number of people recovery and death reach up to 60% and 40% respectively, this can be seen from the model chart of figure 2, where the thick blue indicate the recovered and that of dead curve with yellow. And this is clear evidence which show that the model is accurate and exhibit a good characteristic of Euler method. Both expose and infectious were seen to have vanish after 40 days and this can be seen from above chart both expose and infected curve lies on x axis and banish after 70 to 80 days.

CONCLUSION RECOMENDATION

In conclusion we find out that meningitis is an acute fatal infectious disease cause by the Neisseria meningitis group A is responsible for the majority of epidemics in Africa. Every year bacterial meningitis affects 450 million people living in the 26 countries of the meningitis belt. In the year 1996-2010 over 800,000 cases were reported in these areas. In this research work we introduce a mathematical model to study the behaviour of meningitis disease. Studies show that this disease can kill in a few hours of infection and about 10% of the infected die, even with the treatment and about 20% of the survivor will have disabilities. To model the meningitis disease we recommend that the bigger model should be introduce which will cover a larger population size, should in case of emergence of an outbreak in a very densely populated area or big cities. That is, the models which consider different structure to the population than one homogeneous assumption because of the vast area of West Africa, more especially the meningitis disease pandemics area of West Africa which constitute disperse and highly densely populated cities, town and villages. For further future work method like Rung- kutta can be apply to carry out the analysis

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