

SIRI Mathematical Modeling on the Spread of Typhoid Disease in South Sulawesi and Batik Motifs from the Simulation

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Abstract: Typhoid disease is one of the significant public health problems in Indonesia, especially in the South Sulawesi region. In an effort to understand and control the spread of this disease, the mathematical modeling of SIRI (Susceptible, Infected, Recovered, and Immune) can be used as an effective analysis tool. This journal aims to explore the dynamics of the spread of typhoid disease in South Sulawesi by using the SIRI model, as well as connecting it with batik motifs inspired by the patterns of the spread of the disease. Through the simulation carried out, the modeling results show that factors such as population density, sanitation, and community behavior play an important role in determining the rate of spread of typhus. Statistical data from the Health Office shows that the incidence of typhus in South Sulawesi has experienced significant fluctuations, with the peak incidence in certain months related to the rainy season. In addition, the batik motif produced from the results of this simulation reflects the complexity and beauty of the disease spread pattern, which can be used as an educational medium to increase public awareness about the importance of disease prevention. Thus, this journal not only provides insight into the spread of typhus, but also invites the public to better understand and appreciate local culture through batik art.

Keywords: Mathematical Modeling, SIRI, Typhoid Disease, South Sulawesi, Batik Motif.

Introduction

Mathematical modeling is a branch of applied mathematics that describes real phenomena in the form of a system of equations that can be analyzed and simulated. Through mathematical models, various complex phenomena such as disease spread, population dynamics, and social interactions can be understood quantitatively. One important application of mathematical modeling in the health sector is epidemic models, such as the SIR (Susceptible–Infected–Recovered) model, SEIR (Susceptible–Exposed–Infected–Recovered) model, and their variations. These models are used to describe the dynamics of the spread of infectious diseases in a population and predict the spread conditions at a given time.

In the context of infectious diseases in Indonesia, typhoid fever is still a common problem, particularly in South Sulawesi Province. This disease is caused by the *Salmonella typhi* bacteria and is closely linked to poor environmental sanitation. According to data from the South Sulawesi Provincial Health Office, typhoid is among the four most frequently reported infectious diseases in the province. The high incidence of typhoid provides an important basis for developing a mathematical model capable of mapping its spread patterns and identifying factors influencing infection rates, recovery rates, and the likelihood of reinfection.

The SIRI (Susceptible–Infected–Recovered–Infected) model is a modification of the classic SIR model, adding the assumption that recovered individuals can become reinfected. This

assumption is relevant for typhus because the causative bacteria can remain dormant in the body and reactivate when the immune system weakens. Therefore, the SIRC model is more appropriate for describing the dynamics of typhus transmission than the standard SIR model.

In addition to numerical analysis, the results of the SIRC model simulation can be visualized in the form of patterns or images that depict the dynamics of population change over time. In this study, these visual patterns are interpreted as batik motifs that represent the dynamics of the spread of typhus in South Sulawesi. Each element of the motif, such as curves, waves, and equilibrium points, has a mathematical meaning that reflects the stability of the system, the rate of transmission, and the processes of healing and reinfection. This approach not only provides scientific value in the field of applied mathematics but also contains aesthetic and cultural values through the depiction of batik motifs inspired by the dynamics of the model.

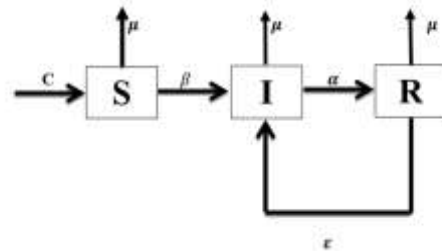
Mathematical Model

In this model, the total population (N) is divided into three main components, namely the susceptible group ($S(t)$) consisting of individuals at risk of contracting Typhus, the infected group ($I(t)$), namely individuals who are currently suffering from Typhus, and the recovered group ($R(t)$), namely individuals who have recovered from the disease. This study uses several basic assumptions to build a model of the spread of Typhus (Haslinda, 2016), including:

1. In a population, there is a continuous process of birth and death.
2. Every newborn individual is automatically included in the vulnerable group.
3. Individuals exposed to the bacteria that cause typhus will move into the infected group.
4. The incubation period for typhus is relatively short, namely around 7 – 21 days.
5. This disease is serious because it can cause death in infected individuals.
6. Recovered individuals are at risk of reinfection if their health declines. This is because the

bacteria in the body are not completely killed, but rather remain dormant and can reactivate when the immune system weakens. This can occur, for example, due to fatigue or lack of rest.

Based on these assumptions, the SIRC (Susceptible–Infected–Recovered–Infected) model was developed to describe the dynamics of the spread of Typhus. The relationship between components in this model is visualized through a flow diagram shown in the figure below.



Information:

$S(t)$: Number of susceptible individuals in the population at time t

$I(t)$: Number of infected individuals in the population at time t

$R(t)$: Number of individuals who recovered in the population at time t

C : Birth rate

μ : Natural death rate

β : Rate of disease transmission

α : Disease healing rate

ε : Rate of individuals being reinfected

Based on the assumptions that have been explained and the relationship between the variables and parameters in the image above, this relationship can be expressed through the following equation.

$$\begin{aligned}\frac{dS}{dt} &= C - (\mu + \beta)S \\ \frac{dI}{dt} &= \beta S + \varepsilon R - (\mu + \alpha)I \\ \frac{dR}{dt} &= \alpha I - (\mu + \varepsilon)R\end{aligned}\quad (1)$$

With $N = S(t) + I(t) + R(t)$

a. Equilibrium Point

Disease-Free Equilibrium Point (E_0)

The disease-free equilibrium point is a condition where there is no transmission of infectious diseases in the population. This equilibrium point occurs when $\left(\frac{dS}{dt}, \frac{dI}{dt}, \frac{dR}{dt}\right) = (0, 0, 0)$. Based on equation (1), the following equation is obtained.

$$\begin{aligned} C - (\mu + \beta)S &= 0 \\ \beta S + \varepsilon R - (\mu + \alpha)I &= 0 \\ \alpha I - (\mu + \varepsilon)R &= 0 \end{aligned} \quad (2)$$

To find the disease-free equilibrium point (E_0), it is assumed that $I = 0$, which means $\beta = 0$ that no individuals are infected. From equation (2), the following equilibrium point is obtained.

$$\begin{aligned} C - (\mu + \beta)S &= 0 \\ (\mu + \beta)S &= C \\ S &= \frac{C}{\mu} \end{aligned}$$

And

$$\begin{aligned} \alpha I - (\mu + \varepsilon)R &= 0 \\ 0 - (\mu + \varepsilon)R &= 0 \\ R &= \frac{0}{(\mu + \varepsilon)} \\ R &= 0 \end{aligned}$$

So the equilibrium point is free disease $E_0 = (S_0, I_0, R_0) = \left(\frac{C}{\mu}, 0, 0\right)$.

Endemic Equilibrium Point (E_1) (There is an outbreak of infectious diseases)

The endemic equilibrium point is a condition where an infectious disease continues to spread and persist in the population. The endemic equilibrium point can be determined by assuming $I \neq 0$ that the result is $\beta \neq 0$. Using equation (2), the following equilibrium point is obtained.

$$\begin{aligned} C - (\mu + \beta)S &= 0 \\ (\mu + \beta)S &= C \\ S &= \frac{C}{(\mu + \beta)} \end{aligned}$$

$$\begin{aligned} \alpha I - (\mu + \varepsilon)R &= 0 \\ R &= \frac{\alpha I}{(\mu + \varepsilon)} \dots (*) \end{aligned}$$

$$\begin{aligned} \beta S + \varepsilon R - (\mu + \alpha)I &= 0 \\ \beta \left(\frac{C}{(\mu + \beta)} \right) + \varepsilon R - (\mu + \alpha)I &= 0 \\ (\mu + \alpha)I &= \beta \left(\frac{C}{(\mu + \beta)} \right) + \varepsilon R \\ I &= \frac{1}{(\mu + \alpha)} \left(\frac{\beta C}{(\mu + \beta)} + \varepsilon R \right) \\ I &= \frac{\beta C}{(\mu + \alpha)(\mu + \beta)} + \frac{\varepsilon R}{(\mu + \alpha)} \\ I &= \frac{\beta C}{(\mu + \alpha)(\mu + \beta)} + \frac{\varepsilon}{(\mu + \alpha)} \cdot \frac{\alpha I}{(\mu + \varepsilon)} \\ I &= \frac{\beta C}{(\mu + \alpha)(\mu + \beta)} + \frac{\alpha \varepsilon}{(\mu + \alpha)(\mu + \varepsilon)} \cdot I \\ I - \frac{\alpha \varepsilon}{(\mu + \alpha)(\mu + \varepsilon)} \cdot I &= \frac{\beta C}{(\mu + \alpha)(\mu + \beta)} \\ I \left(1 - \frac{\alpha \varepsilon}{(\mu + \alpha)(\mu + \varepsilon)} \right) &= \frac{\beta C}{(\mu + \alpha)(\mu + \beta)} \\ I \left(\frac{(\mu + \alpha)(\mu + \varepsilon) - \alpha \varepsilon}{(\mu + \alpha)(\mu + \varepsilon)} \right) &= \frac{\beta C}{(\mu + \alpha)(\mu + \beta)} \\ I \left(\frac{\mu^2 + \mu \varepsilon + \mu \alpha + \alpha \varepsilon - \alpha \varepsilon}{(\mu + \alpha)(\mu + \varepsilon)} \right) &= \frac{\beta C}{(\mu + \alpha)(\mu + \beta)} \\ I \left(\frac{\mu(\varepsilon + \alpha + \mu)}{(\mu + \alpha)(\mu + \varepsilon)} \right) &= \frac{\beta C}{(\mu + \alpha)(\mu + \beta)} \end{aligned}$$

$$I = \frac{\beta C}{(\mu + \alpha)(\mu + \beta)} \cdot \frac{(\mu + \alpha)(\mu + \varepsilon)}{\mu(\varepsilon + \alpha + \mu)}$$

$$I = \frac{\beta C(\mu + \varepsilon)}{\mu(\mu + \beta)(\varepsilon + \alpha + \mu)}$$

$$I = \frac{\beta C(\mu + \varepsilon)}{\mu(\mu^2 + \mu\varepsilon + \mu\alpha + \mu\beta + \beta\varepsilon + \beta\alpha)}$$

Substitution I to press. (*)

$$R = \frac{\alpha}{(\mu + \varepsilon)} \left(\frac{\beta C(\mu + \varepsilon)}{\mu(\mu^2 + \mu\varepsilon + \mu\alpha + \mu\beta + \beta\varepsilon + \beta\alpha)} \right)$$

$$R = \frac{\alpha\beta C}{\mu(\mu^2 + \mu\varepsilon + \mu\alpha + \mu\beta + \beta\varepsilon + \beta\alpha)}$$

So the endemic equilibrium point:

$$.E_1 = (S_1, I_1, R_1) =$$

$$\left(\frac{C}{(\mu + \beta)}, \frac{\beta C(\mu + \varepsilon)}{\mu(\mu^2 + \mu\varepsilon + \mu\alpha + \mu\beta + \beta\varepsilon + \beta\alpha)}, \frac{\alpha\beta C}{\mu(\mu^2 + \mu\varepsilon + \mu\alpha + \mu\beta + \beta\varepsilon + \beta\alpha)} \right)$$

b. Existence of Equilibrium Point

$$\beta C(\mu + \varepsilon) \geq 0 \rightarrow \beta C\mu + \beta C\varepsilon \geq 0$$

c. Equilibrium Point Stability Analysis

$$f_1 = \frac{dS}{dt} = C - (\mu + \beta)S$$

$$f_2 = \frac{dI}{dt} = \beta S + \varepsilon R - (\mu + \alpha)I$$

$$f_3 = \frac{dR}{dt} = \alpha I - (\mu + \varepsilon)R$$

$$\frac{df_1}{dS} = -(\mu + \beta); \frac{df_1}{dI} = 0; \frac{df_1}{dR} = 0$$

$$\frac{df_2}{dS} = \beta; \frac{df_2}{dI} = -(\mu + \alpha); \frac{df_2}{dR} = \varepsilon$$

$$\frac{df_3}{dS} = 0; \frac{df_3}{dI} = \alpha; \frac{df_3}{dR} = -(\mu + \varepsilon)$$

Jacobian matrix of disease-free equilibrium points

$$J(S_0, I_0, R_0) = \begin{bmatrix} \frac{df_1}{dS} & \frac{df_1}{dI} & \frac{df_1}{dR} \\ \frac{df_2}{dS} & \frac{df_2}{dI} & \frac{df_2}{dR} \\ \frac{df_3}{dS} & \frac{df_3}{dI} & \frac{df_3}{dR} \end{bmatrix}$$

$$J\left(\frac{C}{\mu}, 0, 0\right) = \begin{bmatrix} -(\mu + \beta) & 0 & 0 \\ \beta & -(\mu + \alpha) & \varepsilon \\ 0 & \alpha & -(\mu + \varepsilon) \end{bmatrix}$$

To find out stability E_0 , first look for the eigenvalues. If λ_i with $i = 1, 2, 3$ is the eigenvalue of $J E_0$ then $\det(\lambda I - J E_0) = 0$.

$$\det \left(\lambda \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \right.$$

$$\left. - \begin{bmatrix} -(\mu + \beta) & 0 & 0 \\ \beta & -(\mu + \alpha) & \varepsilon \\ 0 & \alpha & -(\mu + \varepsilon) \end{bmatrix} \right) = 0$$

$$\det \left(\begin{bmatrix} \lambda & 0 & 0 \\ 0 & \lambda & 0 \\ 0 & 0 & \lambda \end{bmatrix} \right.$$

$$\left. - \begin{bmatrix} -(\mu + \beta) & 0 & 0 \\ \beta & -(\mu + \alpha) & \varepsilon \\ 0 & \alpha & -(\mu + \varepsilon) \end{bmatrix} \right) = 0$$

$$\det \left(\begin{bmatrix} (\lambda + \mu + \beta) & 0 & 0 \\ \beta & (\lambda + \mu + \alpha) & \varepsilon \\ 0 & \alpha & (\lambda + \mu + \varepsilon) \end{bmatrix} \right) = 0$$

$$= ((\lambda + \mu\beta)(\lambda + \mu + \alpha)(\lambda + \mu + \varepsilon)) + (0 \cdot (-\varepsilon) \cdot 0) + (0 \cdot (-\beta)(-\alpha) - (0(\lambda + \mu + \alpha) \cdot 0) - ((\lambda + \mu + \beta)(-\varepsilon)(-\alpha)) - 0(-\beta)(\lambda + \mu + \varepsilon))$$

$$= ((\lambda + \mu + \beta)(\lambda + \mu + \alpha)(\lambda + \mu + \varepsilon)) + 0 + 0 - 0 - (\lambda + \mu + \beta)(-\varepsilon)(-\alpha) - 0$$

$$= (\lambda^2 + \lambda\mu + \lambda\alpha + \mu\lambda + \mu^2 + \mu\alpha + \beta\lambda + \beta\mu + \beta\alpha)(\lambda + \mu + \varepsilon)$$

The above equation can be written as the following equation.

$$(\lambda + \mu + \varepsilon)(\lambda^2 + a\lambda + b) = 0 \quad (3)$$

with:

$$a = (\mu + \alpha + \mu + \beta)$$

$$b = (\mu^2 + \mu\alpha + \beta\mu + \beta\alpha)$$

$$\lambda_1 = -\mu - \varepsilon; \lambda_2 = \frac{-a + \sqrt{a^2 - 4ab}}{2}; \lambda_3 = \frac{-a - \sqrt{a^2 - 4ab}}{2}$$

$$\lambda_2 < 0; \lambda_3 < 0 \rightarrow (\text{stable conditions})$$

For second order polynomials

$$P(S) = a_2 S^2 + a_1 S + a_0 = 0$$

all coefficients must be positive:

$$a_i > 0 \text{ for } i=1,2,3$$

$$P(\lambda) = a_2 \lambda^2 + a_1 \lambda + a_0$$

$$a_2 = 1 > 0$$

$$a_1 = a > 0$$

$$a_0 = b > 0$$

(fulfilled to be stable)

d. Simulation

The simulation was performed using the initial values presented in the table below.

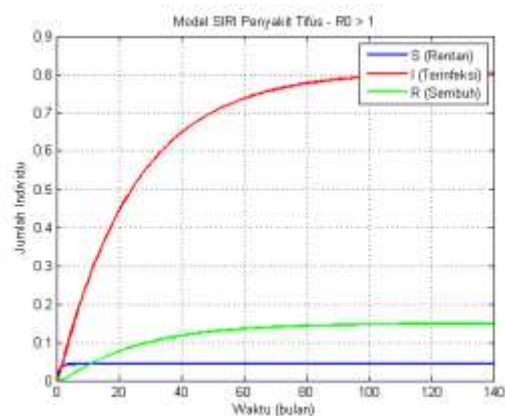
Variable	Initial Value		
s	10%	50%	90%
S(0)	$\frac{36158}{8612931}$	$\frac{36158}{8612931}$	$\frac{36158}{8612931}$
I(0)	$\frac{33165}{8612931}$	$\frac{33165}{8612931}$	$\frac{33165}{8612931}$
R(0)	$\frac{3347}{8612931}$	$\frac{16733}{8612931}$	$\frac{30119}{8612931}$

The parameters used in the model can be seen in the table below.

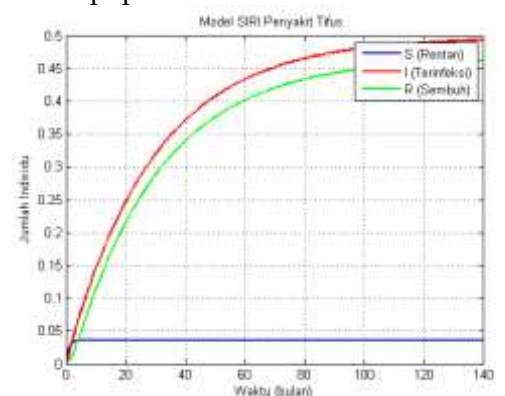
Parameter	Formulation
C	0.041
C	0.034
C	0.030
β	0.9
μ	0.041
μ	0.034
μ	0.030
α	0.1
α	0.5
α	0.9
ε	0.5

SIRS Model Simulation Using Software

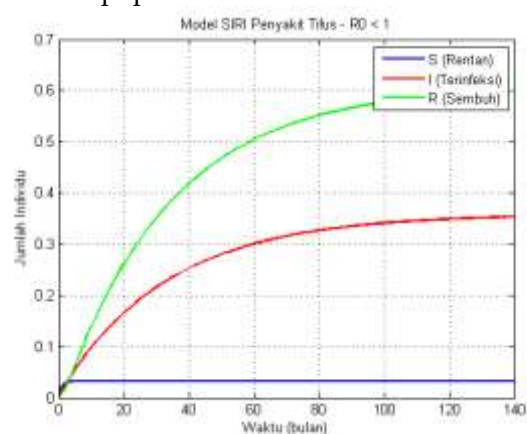
- Simulation of susceptible, infected, and recovered populations with the proportion of recovered individuals (R) of 10% of the total infected population.



- Simulation of susceptible, infected, and recovered populations with the proportion of recovered individuals (R) of 50% of the total infected population.



- Simulation of susceptible, infected, and recovered populations with the proportion of recovered individuals (R) of 90% of the total infected population.



e. Interpretation of Simulation

- Simulation of susceptible, infected, and recovered populations with the proportion of recovered individuals (R) of 10% of the total infected population.

Chart show results simulation dynamics susceptible (S), infected (I), and recovered (R)

populations in the SIRI model for disease typhus with mark $R_0 > 1$. The number of susceptible individuals (S), depicted by the blue line, appears stable throughout the simulation period (0 – 140 months). This indicates that the number of individuals at risk of contracting the disease has not changed significantly. Meanwhile, the number of infected individuals (I), indicated by the red line, experienced a very rapid increase from the beginning of the simulation until around month 100, then began to level off. At the end, approximately 80% of the total population was infected. If the total population as much as 8.612.931 people, then the number of infected individuals reaches approximately 6.890.345 people. The recovered population (R), represented by the green line, also shows a gradual upward trend from the beginning to the end of the observation period. The proportion of recovered individuals reaches approximately 15% of the total population, or equivalent to 1.291.940 people in the entire population.

2. Simulation of susceptible, infected, and recovered populations with the proportion of recovered individuals (R) of 50% of the total infected population.

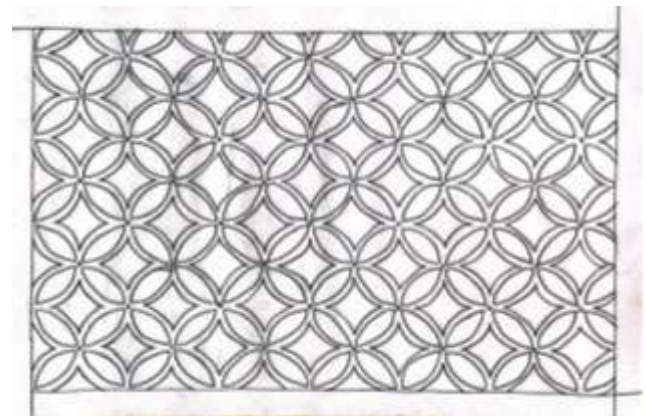
Chart show results SIRI model simulation that describes dynamics susceptible, infected, and recovered populations disease typhus during period time 0 – 140 months. Based on the graph, the number of susceptible individuals (S) indicated by the blue line appears stable over time, with a relatively small proportion compared to the other groups. This indicates that most of the population has been exposed to the infection and only a few individuals remain in the susceptible group. Furthermore, the number of infected individuals (I) depicted by the red line experiences a rapid increase at the beginning of the simulation period (around month 0 – 60), then its growth slow down until reach condition approach stable at around 45% of the total population. If the total population as much as 8.612.931 souls, then the number of infected individuals reaches around 3.876.000 people. The recovered population (R) represented by the green line shows a significant increase, especially in 60 the first month, before reaching a

stable range of 40 – 45% of the total population, or around 3.445.000 people.

3. Simulation of susceptible, infected, and recovered populations with the proportion of recovered individuals (R) of 90% of the total infected population.

The graph shows the results of the SIRI model simulation for typhoid with a basic reproduction number value of $R_0 < 1$. The graph illustrates the dynamics of changes in the susceptible, infected, and recovered populations over a period of 0 – 140 months. From the simulation results, the number of susceptible individuals (S) depicted by the blue line appears constant over time, indicating that this group did not experience significant changes during the observation period. The infected population (I) represented by the red line experienced an increase at the beginning of the simulation, but its growth slowed and then reached stability in the range 30 – 35% of the total population. If the total population is 8.612.931 people, then the number of infected individuals ranges between 2.583.000 – 3.014.000. Meanwhile, the recovered population (R) indicated by the green line experienced a faster and more dominant increase compared to the other groups. At the end of the simulation, the proportion of recovered individuals reached approximately 60% of the total population, or equivalent to 5.167.000 people from the entire population.

Batik



a. Philosophical Meaning

Philosophically, the batik motif developed from the SIRI (Susceptible, Infected, Recovered, Infected) model of typhus represents the human life cycle that continuously repeats itself through phases of weakness, testing, and recovery. Each component in the model, such as the vulnerable group (S), infected (I), and recovered (R), contains symbolic meaning that depicts the human journey in facing life's challenges. The vulnerable group (S) symbolizes the basic human nature that is easily influenced by the environment and trials. Infected (I) depicts the phase when humans are tested by suffering or mistakes that must be faced. Meanwhile, the recovered group (R) reflects the process of awareness, learning, and recovery towards a stronger and wiser condition.

The interconnected and repetitive patterns in the motifs demonstrate the cyclical and dynamic nature of life, meaning that after experiencing hardship, humans have the potential to grow and recover to achieve a new balance. The overall motifs reflect the philosophy that in every illness or hardship lies a lesson and an opportunity to strengthen oneself, both physically and spiritually. Thus, batik conveys a message of resilience, balance, and wisdom in facing life's changes.

b. Biological Meaning

The batik motif developed from the SIRI model simulation represents the biological dynamics of the spread of infectious diseases, particularly typhus, within a population. Visually, the interconnected and repeating patterns in the motif depict the interactions between the three main compartments in the SIRI model: susceptible (S), infected (I), and recovered (R). From a biological perspective, this motif has several important meanings, namely:

1. Representation of Biological Population Dynamics

The recurring, interconnected patterns depict the continuous change in the status of individuals within a population, from susceptible to infected, then recovered, and then partially susceptible again. This reflects the concept of the biological cycle of infectious disease, where interactions between individuals determine the rate of transmission and recovery.

2. Symbol of Ecological Balance in Biological Systems

The balance of form and symmetry in the motif symbolizes the dynamic stability of a biological system, such as the balance between the number of infected, recovered, and susceptible individuals in endemic conditions. When $R_0 > 1$, the dominant pattern depicts rapid and widespread spread, while when $R_0 < 1$, the motif reflects a system state moving towards stability and disease control.

3. Visualization of the Process of Biological Adaptation and Regeneration

The motif's elements, resembling petals or interconnected cells, can be seen as symbols of biological regeneration, where recovered individuals contribute to population immunity. Thus, this motif reflects the ability of biological systems to adapt and recover from disease.

4. Integration between Biological Science and Aesthetics

The transformation of mathematical simulation results into batik visuals reflects a biomimetic design approach, where mathematical patterns and biological processes serve as sources of artistic inspiration. Thus, batik not only has aesthetic value but also serves as an educational medium for understanding the concepts of epidemiology and the dynamics of infectious diseases.

c. Meaning of Mathematics

Mathematically, the batik motifs developed from the SIRI (Susceptible, Infected, Recovered, Infected) model reflect the transformation of the concept of nonlinear system dynamics into an aesthetic visual form. The SIRI model is expressed through a system of differential equations that describe the change in the number of individuals in three compartments: susceptible (S), infected (I), and recovered (R) over time. The repetitive patterns in the batik motifs represent the dynamic solutions of the SIRI model, indicating the stability of the system after going through a transient phase. The visual balance of the motifs reflects the equilibrium point in the model, namely the condition when the rates of infection and recovery reach stability. Meanwhile, the symmetry and repetition illustrate the periodicity and continuity of variable changes in the differential system, indicating that the

process of disease spread and recovery is repetitive and mutually influencing.

The geometric regularity and proportions in the motifs reflect the applied mathematical principles of epidemiology, namely how the basic reproduction number (R_0) determines the direction and stability of a system. When $R_0 > 1$, the dominant pattern expands, indicating increasing infection, while when $R_0 < 1$, the pattern decreases towards stability, symbolizing disease control. Thus, batik is not only a work of art, but also a visualization of a dynamic mathematical model that describes the order, balance, and interrelationships between variables in a biological system.

Conclusion

The research successfully developed a batik motif based on the SIRS (Susceptible, Infected, Recovered, Infected) model as a form of integration between mathematics, biology, and fine arts. The SIRS model used utilizes a system of nonlinear differential equations to describe the dynamics of disease spread through three population compartments, namely susceptible individuals (S), infected (I), and recovered R . From the modeling results, a numerical pattern is obtained which is then transformed into a visualization of the batik motif through a process of mapping variable values to geometric coordinates.

Biologically, batik represents the dynamics of disease spread and recovery within a population, reflecting the balance of the ecosystem and the cycle of life. Mathematically, batik motifs reflect the behavior of the SIRS system, which reaches stability after a transient phase, with repeating and symmetrical patterns depicting the equilibrium point and the influence of the basic reproductive (R_0) rate on infection dynamics. Philosophically, batik symbolizes the continuity of human life, passing through phases of vulnerability, testing, recovery, and returning to a new equilibrium.

Thus, the results of this study demonstrate that the SIRS mathematical model not only plays a crucial role in understanding the dynamics of disease spread but can also be creatively applied to visual art forms such as batik. This confirms that the integration of science and art can produce innovations that possess not only aesthetic value but also educational and philosophical implications.

Reference

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