SEARC Mathematical Modeling of Drug Addiction in South Sulawesi Province

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Abstract. This study aims to build a SEARC mathematical model of drug addiction in South Sulawesi. The purpose of this study was to analyze and predict the number of drug addiction cases in South Sulawesi. The data used in this study is secondary data from the Provincial National Narcotics Agency (BNNP) of South Sulawesi and the Rehabilitation Center of the National Narcotics Agency (BNN) Baddoka Makassar. The steps in this study are to make assumptions and determine the SEARC model for drug addiction, determine the equilibrium point of the model obtained, analyze the stability of the equilibrium point, perform simulations with the Maple program, and conclude. The results of this study obtained the SEARC mathematical model of drug addiction in the form of a five dimensional system of differential equations, and also obtained an addiction-free equilibrium point and a stable endemic equilibrium point, as well as the basic reproduction number R0= 0.05 which shows that the rate of drug addiction cases in South Sulawesi can be controlled but preventive measures still need to be taken. Based on the simulation, it is found that the rehabilitation program can reduce the number of drug addicts so that by improving rehabilitation facilities and services, it can reduce the number of drug addicts effectively.

1 Introduction

Mathematics has a very important role in studying the dynamics of a disease outbreak, starting from finding sources, spreading, predicting patterns, to handling strategies [1]. Many problems arise from various fields of science, such as the fields of health, chemistry, biology, and others for which mathematical models can be made [2]. The process of translating real-world issues into mathematical assertions is known as mathematical modelling [3]. The issue of drug addiction is one of the dynamics that may be mathematically represented and is still a concern in the real world. One method for examining the dynamics of the spread of drug misuse is mathematical modeling [4]. SIR, SEIR, and SEIRS are three mathematical models that can be used to analyze how epidemics spread throughout a territory.

Narcotics, psychotropics, and other dangerous substances (Drugs) are a group of compounds that generally have a risk of addiction for users [5]. Drugs themselves in ICD X have a disease code. This means that narcotics addicts are sick people, so they must be cured with rehabilitation [6].

Addiction is the result of engaging in a pleasurable activity to the point when one forgets about other things and loses self-control [7]. Drug addiction can provide serenity and hallucinations, making its use very difficult to stop. If it can't be separated from the item, the dose will increase over time [8]. Drug addiction generally has an effect on a person's physical, psychological, and social well-being. In the event of drug withdrawal (not taking the drug on time), physical dependence will result in intense pain (sakaw) and psychological impulses in the form of a strong desire to consume. (slang suggest). These psychological and physical symptoms are linked to social phenomena including the desire to steal, lie to parents, be angry, manipulate others, etc. [9].

As a global organization tackling drug issues, the United Nations Office on Drugs and Crime (UNODC) reported that at least 271 million people worldwide, or 5.5% of the world's population with an age range of 15 to 64 years, used drugs at least once in 2017. Drug usage was a contributing factor in almost 500,000 fatalities globally in 2017 [10].

According to the National Narcotics Agency's (BNN) assessment, the Indonesian narcotics problem continues to require constant high attention and vigilance from all parts of the Indonesian country. The prevalence ranged from 2.23% in 2011 to 2.18% in 2014 to 1.77% in 2017 to 1.80% in 2019. This number is higher than it was in 2019 [11].

The South Sulawesi Region continues to see an annual increase in drug users, according to the National Narcotics Agency (BNN). based on the number of addicts undergoing recovery during the last few years [12], there are more people using drugs. According to Provincial National Narcotics Agency records, there were 198 clients in 2017, 1,336 clients in 2018, and 1,334 clients in 2019 who had received rehabilitation during the previous three years [13].

Numerous scholars have undertaken studies on drug addiction, including the study by [14], which covers the issue of drug users but does not take a mathematical perspective on it. Research on the transmission of

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hepatitis B, dengue fever, skin cancer, Covid-19, as well as research on mathematical modeling applied to social problems regarding social media addiction and online game addiction, has been conducted by SEIR by [15–20]. These researches has not applied the SEIR model to social problems, specifically the problem of drug addiction. Because, SEIR (Susceptible, Exposed, Infected, Recovered) is a population mathematical model used to determine the spread of a disease [18][25]. In the case of the spread of drug addiction, the SEIR model can be used to understand the dynamics of interactions between individuals who may be exposed to drugs, infected, and recovered [26]. This model helps to predict and understand trends in drug spread in the population [27], thus assisting in determining effective prevention and control strategies [28].

This study discusses mathematical and social science modeling, especially on the problem of drug addiction, entitled "SEARC Mathematical Modeling of Drug Addiction in South Sulawesi Province". This study modifies the SEIR model into a model that is closer to drug addiction cases in the real world, namely SEARC with S=Susceptible, E=Exposed, A=Addicted, R=Rehabilitation, C=Clean. This modification is necessary because drug addiction has different characteristics from typical diseases. In the SEARC model, the "Addiction" variable accounts for individuals who have been infected with drugs and have become addicted.

The "Clean" variable accounts for individuals who are free from drug addiction. This helps to understand the dynamics of interactions between individuals who may be exposed to drugs, infected, and free from drug addiction. This model helps to predict and understand trends in drug addiction spread in the population [29], thus assisting in determining effective prevention and control strategies [30].

2 Research method

This study was carried out utilizing an interdisciplinary approach to literature study or the library method. Reading and analyzing other sources, both from books and other pertinent sources, is a technique employed in literature research. While the interdisciplinary method uses a review from multiple angles of the pertinent cognate science in an integrated manner to solve a problem. The theory was taken from publications that cover the mathematical model of drug addiction in books and articles.

3 Result

3.1 SEARC model

This research was conducted by modifying the model of drug addiction as shown in Figure 1:

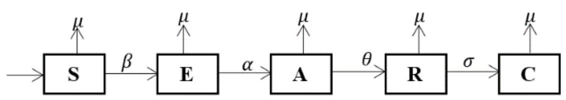

Fig. 1. SEARC Mathematical Model Chart against Drug Addiction.

and the following is a definition of a model SEARC.

Table 1. SEARC Model Parameters against Drug Addiction.

Variable / Parameter	Definition
N	Population
β	The rate at which individuals move from groups of those who are drug-prone (S) to those who attempt drug use (E).
α	The rate at which populations move from those who first take drugs (E) to those who develop drug addiction (A)
θ	The rate of movement from groups of people who are addicted to drugs (A) to groups of drug addicts who carry out rehabilitation (R)
σ	The rate of movement from a group of addicts who are doing rehabilitation to a group of users who are confirmed to be clean from drugs (C)
μ	The rate of natural birth and death

The SEARC model is generally identical to modifying the SEIR model, only changing variables, namely by choosing a variable that is closer to the case of drug addiction. In the SEIR model, Infection (I) is a group of individuals who are infected with the disease, while in SEARC, Addicted (A) is a group that is infected with drugs or also known as drug addiction. In addition, in the SEARC model there is an additional variable, namely the Rehabilitation (R) variable as a group of people who are addicted to drugs and are undergoing rehabilitation.

Equation (1) - (5), which represents the SEARC mathematical model for drug addiction, is derived from Figure 1.

$$\frac{dS}{dt} = \mu N - \mu S - \beta SA \quad (1)$$

$$\frac{dE}{dt} = \beta AS - \alpha E - \mu E \quad (2)$$

$$\frac{dA}{dt} = \alpha E - \theta A - \mu A \quad (3)$$

$$\frac{dR}{dt} = \theta A - \sigma R - \mu R \quad (4)$$

$$\frac{dC}{dt} = \sigma R - \mu C \quad (5)$$

3.2 Model analysis

3.2.1 The equilibrium point of the SEARC model against drug addiction free in South Sulawesi

The Drug Addiction Free Rate is based on the premise that no one is drug dependent. The equilibrium point of the unemployment-free rate can be determined by setting the left side of equations (1) to (5) be zero. Then, if $A = 0$, the drug addiction-free equilibrium point will occur $S, E, A, R, C = (N, 0,0,0,0)$.

3.2.2 The equilibrium point of SEARC model against drug addiction in South Sulawesi

Making the left side of Equations (1) to (5) zero will reveal the equilibrium point that is still affected by drug addiction. From there, you can search for a solution by determining the values of the variables S, E, A, R, and C. In this way, the drug addiction equilibrium point is reached, which is:

$$\begin{pmatrix} S \\ E \\ A \\ R \\ C \end{pmatrix} = \begin{pmatrix} \dfrac{(\alpha+\mu)(\theta+\mu)}{\alpha\beta} \\ \dfrac{\beta\alpha\mu N - (\alpha+\mu)(\theta+\mu)\mu}{\alpha\beta(\alpha+\mu)} \\ \dfrac{\beta\alpha\mu N - (\alpha+\mu)(\theta+\mu)\mu}{(\alpha+\mu)(\theta+\mu)\beta} \\ \dfrac{\theta\beta\alpha\mu N - \theta(\alpha+\mu)(\theta+\mu)\mu}{(\alpha+\mu)(\theta+\mu)(\sigma+\mu)\beta} \\ \dfrac{\sigma\theta\beta\alpha\mu N - \sigma\theta(\alpha+\mu)(\theta+\mu)}{(\alpha+\mu)(\theta+\mu)(\sigma+\mu)\beta} \end{pmatrix}$$

3.2.3 Basic reproduction number

Equations (2) and (3) in the SEARC mathematical model are used to determine the basic reproduction number (R0), and the following result is obtained:

$$F = \begin{bmatrix} \beta AS \\ 0 \end{bmatrix} \quad (6)$$

$$\bar{F} = \begin{bmatrix} 0 & \beta N \\ 0 & 0 \end{bmatrix}, V = \begin{bmatrix} \alpha E + \mu E \\ \gamma A + \mu A - \alpha E \end{bmatrix}, \bar{V} = \begin{bmatrix} \alpha+\mu & 0 \\ -\alpha & \gamma+\mu \end{bmatrix}$$

$$\bar{V}^{-1} = \begin{bmatrix} \frac{1}{\alpha+\mu} & 0 \\ \frac{\alpha}{(\alpha+\mu)(\gamma+\mu)} & \frac{1}{\gamma+\mu} \end{bmatrix} \quad (7)$$

$$\bar{F}V^{-1} = \begin{bmatrix} 0 & \beta N \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \frac{1}{\alpha+\mu} & 0 \\ \frac{\alpha}{(\alpha+\mu)(\gamma+\mu)} & \frac{1}{\gamma+\mu} \end{bmatrix} = \begin{bmatrix} \frac{\alpha\beta N}{(\alpha+\mu)(\gamma+\mu)} & \frac{\beta N}{\gamma+\mu} \\ 0 & 0 \end{bmatrix}$$

$$R_0 = \frac{\alpha\beta N}{(\alpha+\mu)(\gamma+\mu)} \quad (8)$$

3.2.4 Drug addiction free rate stability analysis

Substitution of the disease-free equilibrium point, the result is obtained as follows:

$$J = \begin{bmatrix} -\mu & 0 & -\beta S & 0 & 0 \\ 0 & -\alpha-\mu & \beta S & 0 & 0 \\ 0 & \alpha & -\gamma-\mu & 0 & 0 \\ 0 & 0 & \gamma & -\omega-\mu & 0 \\ 0 & 0 & 0 & \omega & -\mu \end{bmatrix}$$

Then determine the eigenvalues with the following description:
Det $(\lambda I - J) = 0$

$$|\lambda I - J| = \left| \lambda \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} - \begin{bmatrix} -\mu & 0 & -\beta N & 0 & 0 \\ 0 & -\alpha-\mu & \beta N & 0 & 0 \\ 0 & \alpha & -\gamma-\mu & 0 & 0 \\ 0 & 0 & \gamma & -\omega-\mu & 0 \\ 0 & 0 & 0 & \omega & -\mu \end{bmatrix} \right| = 0$$

$$|\lambda I - J| = \begin{bmatrix} \lambda+\mu & 0 & \beta N & 0 & 0 \\ 0 & \lambda+\alpha+\mu & -\beta N & 0 & 0 \\ 0 & -\alpha & \lambda+\gamma+\mu & 0 & 0 \\ 0 & 0 & -\gamma & \lambda+\omega+\mu & 0 \\ 0 & 0 & 0 & -\omega & \lambda+\mu \end{bmatrix} = 0$$

$$|\lambda I - J| = (\lambda+\mu)(\lambda+\mu)(\lambda+\mu+\omega)(\lambda^2 + (\alpha+\mu+\gamma+\mu)\lambda + (\alpha+\mu)(\gamma+\mu) - \alpha\beta N) = 0$$

$$(\alpha+\mu)(\gamma+\mu) - \alpha\beta N > 0$$

$$(\alpha+\mu)(\gamma+\mu) > \alpha\beta N$$

$$1 > \frac{\alpha\beta N}{(\alpha+\mu)(\gamma+\mu)}$$

$$1 > R_0$$

3.2.5 Analysis of drug addiction level stability

The result is as follows when the disease-free equilibrium point is substituted:

$$J = \begin{bmatrix} -\beta A-\mu & 0 & -\beta S' & 0 & 0 \\ \beta A' & -\alpha-\mu & \beta S' & 0 & 0 \\ 0 & \alpha & -\theta-\mu & 0 & 0 \\ 0 & 0 & \gamma & -\omega-\mu & 0 \\ 0 & 0 & 0 & \omega & -\mu \end{bmatrix}$$

$$|\lambda I - J| = 0$$

$$\left| \lambda \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} - \begin{bmatrix} -\beta A-\mu & 0 & -\beta S' & 0 & 0 \\ \beta A' & -\alpha-\mu & \beta S' & 0 & 0 \\ 0 & \alpha & -\gamma-\mu & 0 & 0 \\ 0 & 0 & \gamma & -\omega-\mu & 0 \\ 0 & 0 & 0 & \omega & -\mu \end{bmatrix} \right| = 0$$

$$\begin{bmatrix} \lambda+\beta A+\mu & 0 & \beta S' & 0 & 0 \\ \beta A' & \lambda+\alpha+\mu & -\beta S' & 0 & 0 \\ 0 & -\alpha & \lambda+\theta+\mu & 0 & 0 \\ 0 & 0 & -\theta & \lambda+\sigma+\mu & 0 \\ 0 & 0 & 0 & -\sigma & \lambda+\mu \end{bmatrix}$$

$$(\lambda+\mu)(\lambda+\omega+\mu)\left[(\lambda+\beta A'+\mu)\left((\lambda+\alpha+\mu)(\lambda+\gamma+\mu) - \alpha\beta S'\right) + \alpha\beta^2 A'S'\right] = 0$$

3.3 SEARC model simulation

To give an overview of numerical simulations of mathematical models in drug addiction situations in

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South Sulawesi Province, mathematical simulations were conducted. This simulation is run using software, substituting initial values that were determined using research data and a number of parameters cited in various papers.

Table 2. Initial Value of the SEARC Mathematical Model on Drug Addiction.

Variable	Initial value of sample	Initial Value in Proportion	Source
S	9,048,777	$\frac{9{,}048{,}777}{9{,}060{,}000} = 0.99876$	[21]
E	8125	$\frac{8{,}125}{9{,}060{,}000} = 0.00089$	National Narcotics Agency of South Sulawesi Province.
A	1137	$\frac{1{,}137}{9{,}060{,}000} = 0.00012$	Rehabilitation Centre of BNN Baddoka Makassar
R	1137	$\frac{1{,}137}{9{,}060{,}000} = 0.00012$	Rehabilitation Centre of BNN Baddoka Makassar
C	827	$\frac{827}{9{,}060{,}000} = 0.000009$	Rehabilitation Centre of BNN Baddoka Makassar

Table 3. Initial Value of the SEARC Mathematical Model on Drug Addiction.

Parameter	Value	Source
μ	0.031	[22]
β	0.005	[23]
α	0.045	[22]
θ	0.028	[23]
σ	0.060	[24]

For $R_0 \leq 1$

The SEIIR model set, which already has the parameters for the province of South Sulawesi established, is used to find the equilibrium point. Equation (18), the equilibrium points of the SEIIR model of the spread of tuberculosis, with the parameter values from Table 2. To obtain, substitute the parameter values from Table 3 into Equations (1) through (5).

$$\frac{dS}{dt} = 0.031N - 0.031S - 0.005SA$$

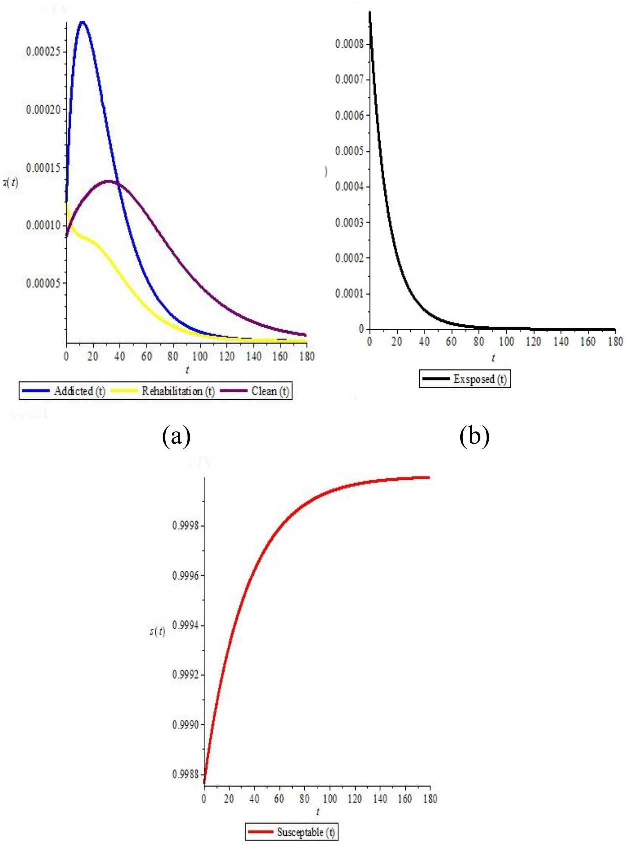
$$\frac{dE}{dt} = 0.005AS - 0.045E - 0.031E$$

$$\frac{dA}{dt} = 0.045E - 0.028A - 0.031A$$

$$\frac{dR}{dt} = 0.028A - 0.06R - 0.031R$$

$$\frac{dC}{dt} = 0.06R - 0.031C$$

Furthermore, by substituting the parameter values in Table 3 to the equilibrium point of the free-rate unemployment, the equilibrium point of the drug addiction-free rate is obtained, namely (S,E,A,R,C) = (N,0,0,0,0). By using Maple software, the eigenvalues are obtained λ, namely $\lambda_1 = -0.031$, $\lambda_2 = -0.031$, $\lambda_3 = -0.091$, $\lambda_4 = -0.050$, $\lambda_5 = -0.084$. Because values λ obtained are all negative, then the type of stability at this equilibrium point is stable,



(a) (b)

(c)

Fig. 2. Result of SEARC Model Simulation

Based on Figure 2, it is found that starting from the first 200 days the number of population susceptible to drug addiction increases and is in a state of equilibrium after day 200. The number of people who start using drugs on the first day has decreased and is in a state of equilibrium after the eighty day. The number of people who are addicted to drugs in the first 20 days has increased and decreased from day 20 to day 120 and is in a state of equilibrium after day 120. The number of people addicted to drugs who are undergoing rehabilitation has decreased until the first 140 days and are in a state of equilibrium after the 140th day. People who become drug addicts within the first 50 days had a rise and a decline from that point until the 250th day, after which they reached a condition of equilibrium.

4 Discussion

The Rehabilitation Center of BNN Baddoka Makassar and the Provincial National Narcotics Agency (BNNP) of South Sulawesi provided the primary data for this study. Following that, a simulation of the model is run using the collected data. From the study's findings, the value of R0 = 0.05017841214 was determined. This suggests that the system solution leads to an equilibrium without addiction, resulting in a decrease in the population's rate of drug addiction cases in South Sulawesi. According to previous research on the issue of addiction, [19] the number of students who are addicted to social media use will decline over time, while the number of students who have high self-control will rise, if the rate of students recovering from social media addiction with high self-control is higher. Additionally, research done [20] shown that it is anticipated that online gaming addiction would continue to decline with effective management, such as warnings that playing online games negatively affects students' psychology. According to these findings, addiction is not an endemic disorder and will continue to decline with treatment. Mathematical modeling can be used to solve social problems, including drug addiction issues.

According to previous studies on drug addiction cases, [14] residents of therapeutic communities believe that the program has been operating successfully and that it will continue to do so. Even with the method, the resident's personality can be changed to help them overcome their drug addiction. According to this study's findings, which are in line with his own research, drug addiction may be treated very successfully through a rehabilitation program, and it is expected that this effectiveness will only increase with good care—specifically, participation in a recovery program.

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5 Conclusion

The variety of drug addiction cases in South Sulawesi can be managed, but preventive measures must still be implemented, according to the analysis and simulation findings of the SEARC mathematical model used to anticipate the number of drug addicts in the province. Based on the simulation, it is determined that the rehabilitation program can lower the number of drug addicts, allowing for a more effective decrease in the number of drug addicts through improved rehabilitation services and facilities.

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