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Mathematical Modelling of Financial Literacy and Loan Repayment in Savings and Credit Cooperative Societies of Tanzania

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Abstract. Loan Repayment (LR) is one of the key performance indicators in SACCOS. Given the importance of LR, researchers and policymakers have dedicated their attention to the phenomenon by implementing strategies and policies aimed at improving the LR rate to reduce defaulting on loan repayments. To complement the efforts of policymakers, several empirical studies have been conducted regarding LR models. However, few studies exist on the use of mathematical modelling in LR of SACCOS, especially in the Tanzanian context. Therefore, this study seeks to fill this gap, in Tanzania specifically, by modelling the financial literacy (FL) effect on LR using a 2D advection-diffusion equation (ADE). Both primary and secondary data are used in the study. The findings reveal that there is a significant and positive relationship between FL and LR in SACCOS. The mathematical modelling (partial differential equations) indicates the increase of FL in SACCOS members leads to a rise of LR in SACCOS. The findings of the study at hand shed new light on using mathematical modelling especially partial differential equations in modelling FL and LR in SACCOS in the Tanzanian context.

Keywords: SACCOS, mathematical modelling, advection-diffusion equation, loan repayment

AMS Mathematics Subject Classification (2010): 91B26, 62P05

1. Introduction

The loan repayment (LR) is one of the vital performance indicators in Savings and Credit Cooperative Societies (SACCOS) that has attracted several researchers' interests and concerns in Tanzania and the world at large [1]-[3]. The timely and effective LR in SACCOS ensures the sustainability of financial institutions, the overall stability of the lending ecosystem and the promotion of economic growth in the country [4]. Furthermore, the LR facilitates easy identification of borrowers with a higher risk in SACCOS hence finding measures to reduce the risk in advance [5].

The given LR in SACCOS cannot just occur in a vacuum but is influenced by numerous factors including the provision of various types of loans, borrower responsibility and good repayment methods [6]. Additionally, LR in SACCOS is influenced by penalties for late payment and default, good support mechanisms, loan restructuring, proper regulatory framework, FL and the economic condition of borrowers (United Republic of Tanzania Microfinance Act, 2019). On top of that, LR in SACCOS is influenced by age, education, income, marital status, employment status, timeliness of credit, suitability of repayment time, the trend of repayment and training appropriateness, loan size, interest rate and supervision by regulatory boards of SACCOS [7-9].

Despite the knowledge of factors that positively and negatively influence LR, poor LR remains prevalent in SACCOS. In Tanzania, SACCOS face challenges of poor LR which impact negatively both the borrower's and SACCOS's performance [10,11]. The poor LR in SACCOS is generally caused by limited financial capacity, lack of FL, unpredictable cash flow, lack of collateral, unemployment, poverty, economic instability, inadequate credit risk assessment and limited regulatory framework [12].

The poor LR in SACCOS is strongly suggested to be solved by FL [13]. In other words, FL is registered as a stronger factor for effective LR in SACCOS compared to other factors [2], [14,15]. FL refers to the knowledge, skills, attitude and understanding of financial concepts such as budgeting, saving, investing, and debt management [16]. It plays a crucial role in individuals' financial decision-making processes and hence determines the success of LR in SACCOS [17-18]. It increases member education and awareness with the necessary knowledge and skills in making informed financial decisions [19]. It makes the SACCOS members financially literate on SACCOS loan products, budgeting, cash flow management, debt management strategies, risk management, contingency planning, effective communication and support from management [20]. SACCOS members who are more financially literate are more likely to repay loans received relative to their less financially literate counterparts [2,14,21,22]. Alternatively, members who are more financially literate can manage their financial resources effectively and meet all their repayment obligations in SACCOS.

That being the case, the modelling of FL and LR in SACCOS attracted several researchers [2,14,23,-25]. For instance, [23] modelled the effect of FL on LR in Urwego Rwanda using Pearson correlation (*r*). The study revealed that there is a positive and significant relationship between FL and LR. [14] modelled effects of FL on LR among small and medium entrepreneurs of microfinance institutions with the case study of Inozamihigo Umurenge SACCO in Nyaruguru district using Pearson correlation and multiple linear regression model. The findings of the given study show a high positive correlation and relationship between FL and LR. [2] modelled if FL matters in the improvement of LR in Ghana by employing the binary probity regression. The results uncover a positive and significant relationship between FL and LR. [24] Modelled FL and LR of small and medium enterprises within SACCOS in Rwanda using Pearson product-moment correlation coefficient (*r*). The findings disclose a high positive correlation between FL and LR. [25] Modelled moderating effects of gender on FL and LR behaviour of small and medium enterprises (SMES) in Kano state, Nigeria using Structural Equation Model (SEM). The study exposes that, FL has a positive effect on LR.

Most of the aforementioned researchers [2,14,23-25] modelled FL and LR in SACCOS using models such as logistics regression, multiple linear regression, structural model equations (SEM) and binary probity regression which are statistical models. However, none of the given studies have explored the mathematical modelling of FL and LR in SACCOS using partial differential equations and specifically the Advection Diffusion equation (ADE). The ADE is frequently used in physics and engineering to describe processes [26, 27, 28-35, 36-38]. These processes are transportation of solute, sediment, suspended, bed-load, braided river development, dispersion of contaminants in shallow lakes, thermal pollution in rivers, dispersion of tracers in porous media, landscape evolution and pollutants transfer in the atmosphere. The same concept of the ADE as used in the given processes in physics and engineering, is employed in modelling FL and LR in SACCOS. The use of the equation in the context of SACCOS was expected to reveal unique results different from the previously used models [2, 14, 23-25]. Concerning the knowledge of ADE as used in physics and engineering, the equation is adopted in this study to mathematically model FL and LR in SACCOS of Tanzania.

The use of ADE in the context of SACCOS is grounded on the work done by [39-40] which is about how macro transactions describe the evolution and fluctuation of financial variables. In so doing, [40] shows the dynamics and fluctuations of economic and financial variables based on the description of transactions between agents. The given study modelled macro variables via the description of transactions between agents. The considered macro variables were credit–loans and loans–repayment while agents were transactions which led to derive economic hydrodynamic-like equations. Transactions between agents are regarded as only tools for the implementation of economic and financial processes. Transactions between agents change an agent's extensive set of variables and that induces changes in the corresponding macro variables. The aggregation of transactions between agents at points x and y defines the macro transactions between different points x and y in the economic space, and the dynamics of such transactions are described using economic hydrodynamic-like equations.

In this study, hydrodynamic-like equations are termed as 2D ADE and the macro variables which we considered are Credit-Loan and Loan-Repayment. The addition of FL was termed as another macroeconomic variable from which testing the changes are induced in Credit-Loan and loan repayment in SACCO's context.

2. Materials and methods

Concerning the modification of the previously stated 2D ADE model developed by [40], the study at hand involved firstly model formulation and secondly model analysis as outlined below:

2.1. Model formulation

To formulate equations used in this study we take note of the mutual dependence between two conjugate transactions, which are credit–loan $CL(t, x, y)$ and loan–repayment $LR(t, x, y)$. Loan–repayment $LR(t, x, y)$ is defined as transactions as all payoffs that are made by e-particles at point y related to credits received from point x at moment t during the time frame dt. Transactions $CL(t, x, y)$ describe credits issued from point x to point y at moment t during the time frame dt. Credit–loan $CL(t, x, y)$ and loan–repayment $LR(t, x, y)$

transactions describe the core economic properties of SACCOS. These transactions are responsible for the economic growth and financial sustainability of SACCOS. The introduction of the e-space allows the establishment of the model.

The model for effective FL formulated in this study is a system of partial differential equations that takes into account the simplest mutual dependence between transactions and motion of credit loan *CL*(*t*, *x*, *y*) and loan repayment *LR*(*t*, *x*, *y*). The variables and definitions of the parameters of the Model are presented in Tables 1 and 2 below:

Table 1: Description of the model variables

Variable	Description
LR(t, x,y)	All payments that are made by e-particles at point y related to credits received from point x at moment t during the time frame dt
CL(t,x, y)	Credits issued from point x to point y at moment t during the time frame dt
v(x,y)	The growth of credit–loan flux and that may increase loan–repayment LR(t, x, y)
u(x,y)	The growth of loans–repayment that may attract creditors at point x to increase their credits at pointy.
FL(t,x,y)	Concentration of FL among members of the SACCOS in the economic space (x, y).
μ(t,x,y)	Velocity of LR due to diffusion of FL
γ(t,x,y)	The velocity of CL due to diffusion of FL.

Table 2: Model parameters

Parameter	Definition
a_1	The coefficient of disturbances of CL on LR.
a_2	The coefficient of disturbances of LR on CL
b_1	The coefficient of velocity of LR.
b_2	the coefficient of the velocity of CL
c_1	Diffusion coefficient of the FL in y direction
c_2	Diffusion coefficient of the FL in x direction.

2.2. Model assumptions

The assumptions of the model are:

a. The model assumes that transactions between e-particles at point x and e-particles at point y are determined by the exchange of mutual variables i.e., credit loan and loan repayment.

b. CL at moment *t* depends on LR at moment *t* only.

c. All model parameters are non-negative

2.3. Model equations

Using assumptions, variables and parameters stated above, we formulated the basic mathematical model which describes the relationship between CL, LR and FL using the 2D ADE as shown below:

$$\frac{\partial CL}{\partial t} + \nabla.(vCL) = a_2 LR(t,x,y)\nabla.u(t,x,y) \qquad (1)$$

$$\frac{\partial LR}{\partial t} + \nabla.(vLR) = a_1 CL(t,x,y)\nabla.v(t,x,y) \quad (2)$$

$$CL(x,y)\left(\frac{\partial v}{\partial t} + (\mathbf{u}.\nabla)v\right) = b_2 \nabla LR(t,x,y) \quad (3)$$

$$LR(x,y)\left(\frac{\partial u}{\partial t} + (\mathbf{v}.\nabla)u\right) = b_1 \nabla CL(t,x,y) \quad (4)$$

2.4. Incorporation of FL on ADE

FL is modelled in this study as the variable which can be diffused into SACCO's members and subsequently lead to improvement of LR of the SACCOS. In ADE the variable and its parameter were added to the equation (1), (2), (3) and (4) and its effect was tested to show its relationship with LR and CL.

Therefore, considering the fluid dynamics equation of concentration of species, the mathematical equation of FL becomes

$$\frac{\partial FL}{\partial t} + \mu\frac{\partial FL}{\partial x} + \gamma\frac{\partial FL}{\partial y} = s_1\frac{\partial^2 C}{\partial y^2} + s_2\frac{\partial^2 C}{\partial x^2} \; 0 \le x \le 1, 0 \le y \le 1, 0 \le t \le T \quad (5)$$

Due to the introduction of FL equation (5) then equations (3) and (4) are modified to become;

$$CL(x,y)\left(\frac{\partial v}{\partial t} + (\mathbf{u}.\nabla)v\right) = b_2 \nabla LR(t,x,y) + FL(x,y,t) \quad (6)$$

$$LR(x,y)\left(\frac{\partial u}{\partial t} + (\mathbf{v}.\nabla)u\right) = b_1 \nabla CL(t,x,y) + FL(x,y,t) \quad (7)$$

2.5. Boundary conditions

Due to the assumption that economic space where the FL was diffused to improve CL and LR in SACCOS is finite, the initial and boundary condition for this study are as follows;

$$\mu(x,y,0) = 0$$
$$\gamma(x,y,0) = 0$$
$$\mu(x,y,T) = u_0$$
$$\gamma(x,y,T) = v_0$$
$$CL(x,0,t) = CL_0$$
$$CL(x,1,t) = CL_0 + \alpha_1$$
$$CL(0,y,t) = CL_0 + \alpha_2$$
$$LR(x,0,t) = LR_0$$
$$LR(0,y,t) = LR_0 + \alpha_1$$
$$LR(x,1,t) = LR_0 + \alpha_2$$
$$FL(0,y,t) = FL_0$$
$$FL(x,0,t) = FL_0 \quad (8)$$

2. Model analysis and numerical simulation

To solve the equations (6) and (7), the velocity vector is expressed as

$\mathbf{u} = u\mathbf{i} + v\mathbf{j}$; $\mathbf{u} = \mathbf{v}$.

Therefore, the specific model equations are given by;

$$CL(x,y)\left[\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right] = b_2\left(\frac{\partial LR}{\partial x} + \frac{\partial LR}{\partial y}\right) + FL(x,y,t) \quad (9)$$

$$LR(x,y)\left[\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right] = b_1\left(\frac{\partial CL}{\partial x} + \frac{\partial CL}{\partial y}\right) + FL(x,y,t) \quad (10)$$

$$\frac{\partial CL}{\partial t} + u\frac{\partial CL}{\partial x} + v\frac{\partial CL}{\partial y} + CL\frac{\partial u}{\partial x} + CL\frac{\partial v}{\partial y} = a_2 LR(t,x,y)\left\{\frac{\partial u}{\partial t} + \frac{\partial v}{\partial t}\right\} \quad (11)$$

$$\frac{\partial LR}{\partial t} + u\frac{\partial LR}{\partial x} + v\frac{\partial LR}{\partial y} + LR\frac{\partial u}{\partial x} + LR\frac{\partial v}{\partial y} = a_1 CL(t,x,y)\left\{\frac{\partial u}{\partial t} + \frac{\partial v}{\partial t}\right\} \quad (12)$$

The above equations hold due to the given assumptions

$$FL_{CL}\alpha\, CL = c_1 CL(t,x,y) \quad (13)$$

$$FL_{LR}\alpha LR = c_2 LR(t,x,y) \quad (14)$$

In this study, the Implicit Finite Difference Method (FDM) scheme have been used to approximate the solution of the model equations. The simulation started by perturbing CL and observing its effect. To achieve this, the parameters of LR, velocity of LR and velocity of CL were set to be constants and the coefficient a_1 which shows the disturbance of CL varied. The Figure 1 below is the plot which shows that overtime, a very minor disturbances on a_1 lead to changes on CL. The plot in Figure 1 below indicates that even slight perturbations on the coefficient of disturbances of CL on LR lead to changes in CL over time. As the value of coefficient of disturbance of CL on LR rises, so does the value of CL over time.

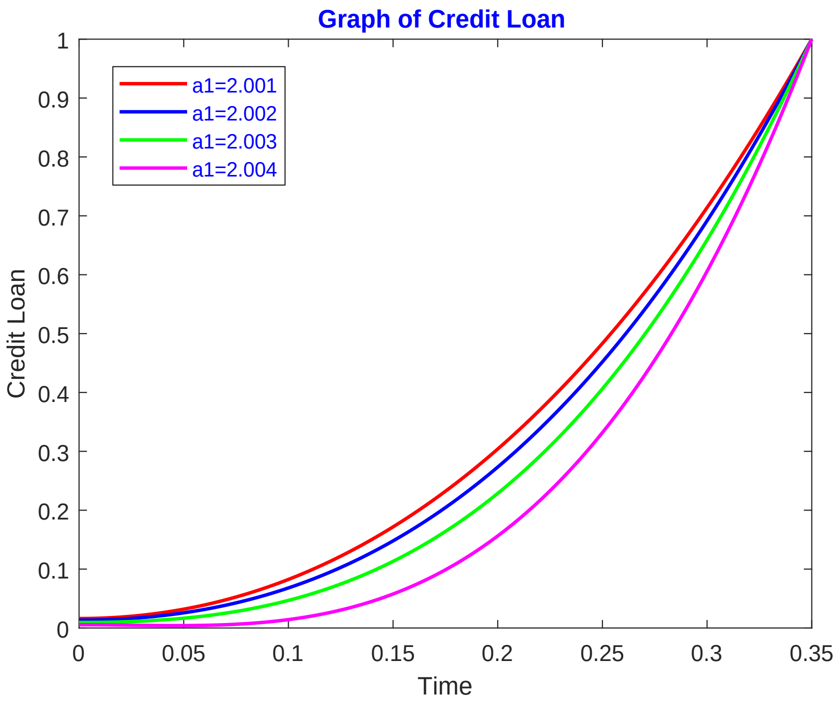

Figure 1: Numerical simulation of Credit Loan

In Figure 2, parameters of CL, velocity of CL and FL was fixed to be constants and the coefficient a_2 is varied. Figure 2 below is the plot which shows that over time very minor disturbances on the coefficient of disturbances of LR on CL lead to significant disturbances of LR. As the value of the coefficient of disturbances of LR on CL rises, so does the value of LR over time.

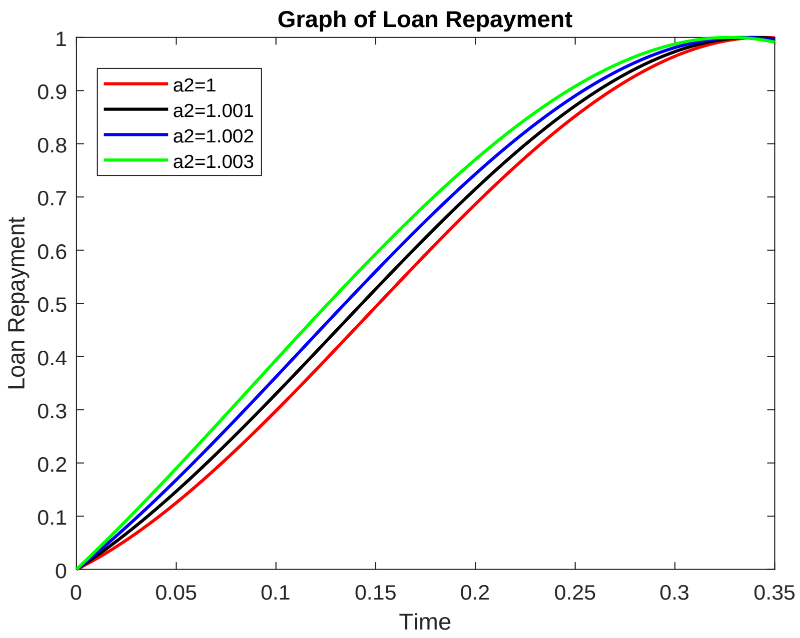

Figure 2: Simulation of Loan repayment

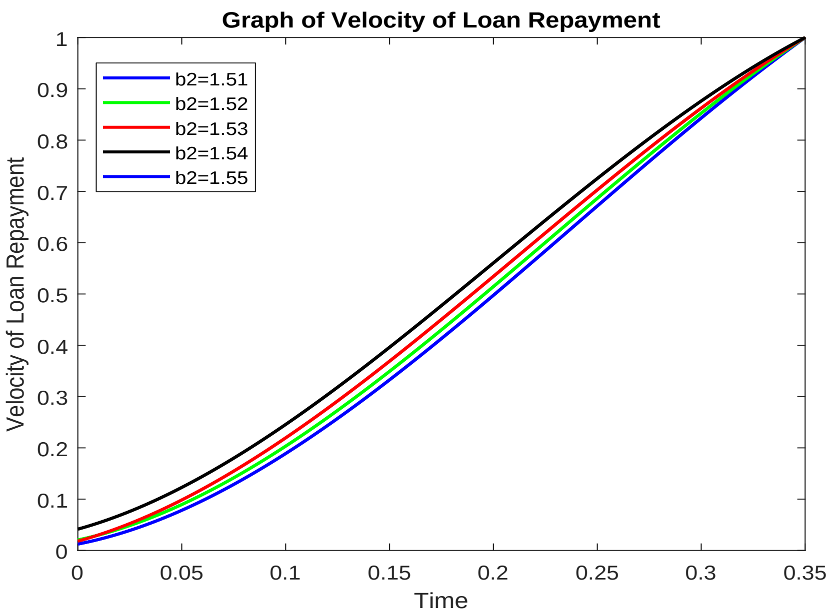

Figure 3: Simulation of velocity of Loan Repayment

In Figure 3, parameters of CL, LR, velocity of CL and FL was situated to be constants and the coefficient b_1 which shows the velocity of LR varies with time. The Figure 3 below is the plot which shows that over time, a very minor disturbances on the coefficient of velocity of LR led to significant disturbances of velocity of LR. This shows the positive relationship of coefficient of velocity of LR overtime.

In Figure 4, parameters of CL, LR, velocity of LR and FL are set to be constants and the coefficient b_2 which shows the velocity of CL varies with time. The Figure 4 below is the plot which shows that over period of time, a very minor disturbances on the coefficient of velocity of CL led significant disturbances on velocity of CL. Hence show the positive relationship between coefficients of velocity of CL over the period of time.

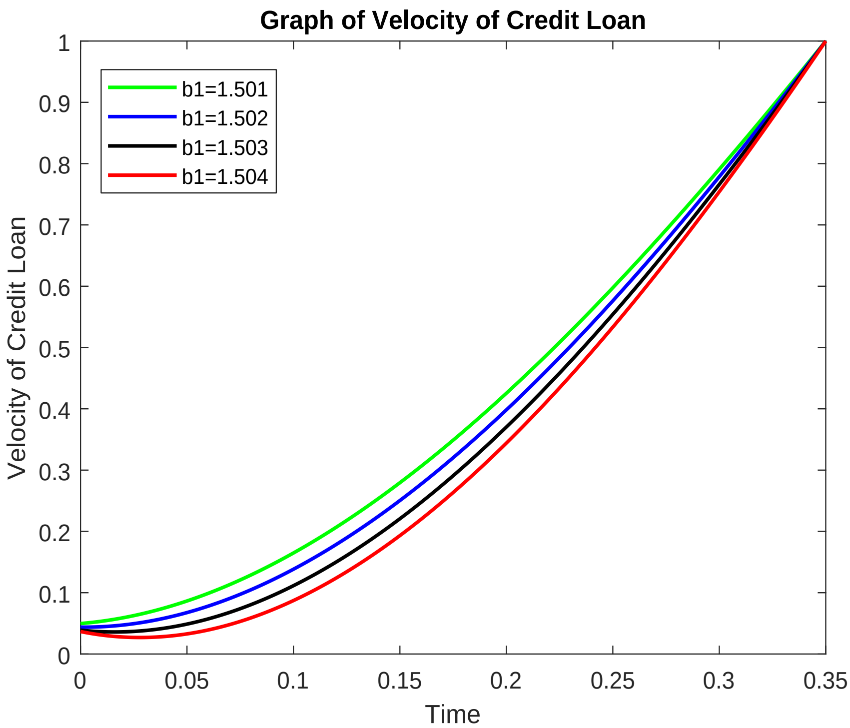

Figure 4: Simulation of velocity of CL

In Figure 5, parameters of CL and LR and velocities are set to be constants and the coefficient c_2 which shows the values of FL varies with time. The Figure 5 below is the plot which shows that over time, a very minute disturbance on diffusion coefficient of the FL in relation to CL lead to significant change in CL. That is to say, the increase of diffusion coefficient of the FL led to increase of CL which is positive relationship with time.

In Figure 6, parameters of CL and LR and velocities are set to be constants and the coefficient c_1 which shows the values of FL varies with time. The Figure 6 below is the plot which shows that over time, a very minute disturbance on diffusion coefficient of the FL in y direction lead to significant change in LR. That is to say, the increase of diffusion coefficient of the FL in y direction led to increase of FL which is positive relationship with time.

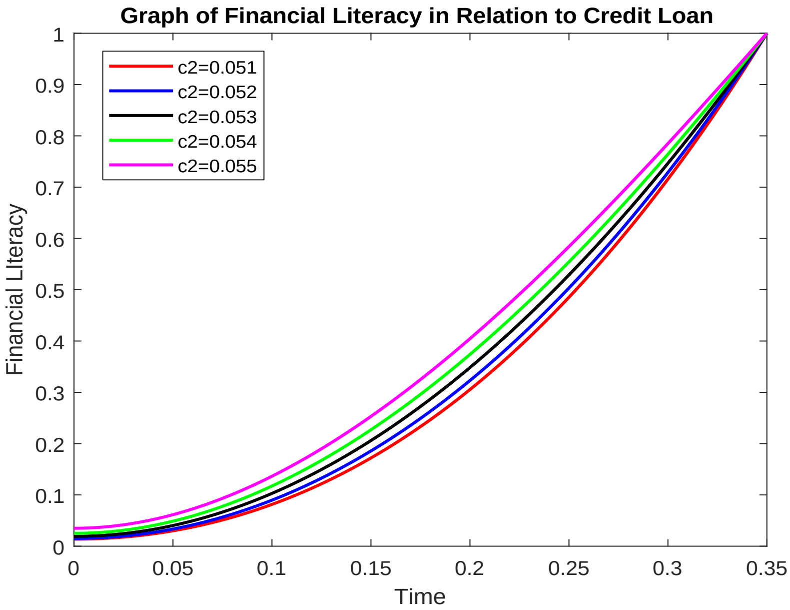

Figure 5: Simulation of Financial Literacy in relation to CL

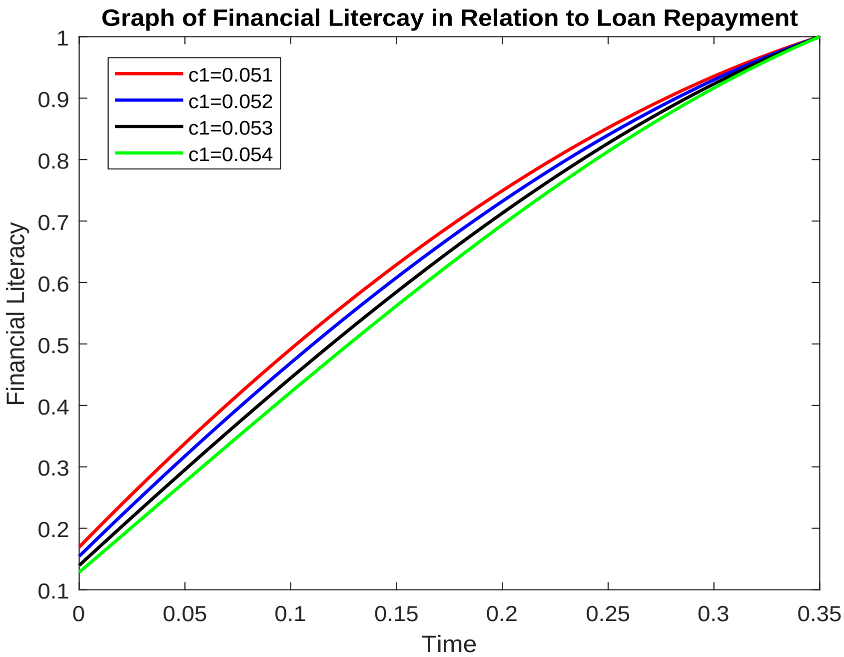

Figure 6: Simulation of Financial Literacy in relation to LR

3. Conclusion and recommendation

This study examined the mathematical modelling of FL and LR in SACCOS of Tanzania. In such modelling, it is concluded that there is a significant relationship between FL and LR in SACCOS of Tanzania. As other previously used non-mathematical models, the partial differential equations likewise prove the significant and positive influence of FL on LR in SACCOS. The findings of this study shed new light on the use of mathematical modelling (partial differential equations) in modelling FL and LR in SACCOS concerning the Tanzanian context.

Regarding work motivation, this study contributes theoretically and empirically to the body of existing knowledge about the use of mathematical modelling in financial mathematics especially the relationship between FL and LR in SACCOS. It specifically, introduces mathematical modelling (advection-diffusion equations) in financial mathematics different from the commonly used statistical models (regression, SEM, probity model). The study also sheds light on policy implications. The policymakers and other SACCO's key stakeholders can now consider the use of mathematical models in SACCOS and microfinance institutions at large especially when modelling LR about FL or other factors. Generally, the mathematical modelling would be now considered as input for policy making and reviewing particularly on factors influencing LR in SACCOS.

Therefore, this study advocates for the use of mathematical models in modelling LR in SACCOS apart from the other commonly used models. The study recommends testing of mathematical modelling in other developed and developing countries using bigger samples than the sample used in this study. Finally, similar testing of the model can be done in other microfinance, commercial and financial institutions apart from SACCOS.

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Authors' contributions. All authors contributed equally to this work.

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