Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 6916 - 6924
Received 25 April 2021; Accepted 08 May 2021.

Modeling Dynamics of Spread of Prostitution due to Poverty in the Society

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ABSTRACT

Womenprostitution isbeingpracticedsincefromancienttimes.Povertyis oneofthemajormotivatorforwomentobecomeprostitutes.Itisconsidered asinfectiousdiseasetothesociety.Hereadeterministicmodelhasformulatedand itexhibitstwoequilibriumpointsnamelyprostitutionfreeequilibriumpointand prostitution presentequilibriumpointandalsoanalyzedtheirstability locally. The basic reproduction number R_0has computed. Further, this deterministic modelhasextendedtostochasticdifferentialequation. Finally wecomparedboththedeterministicandstochasticmodelsusingnumericalsimulation.

Keywords: Poverty, Prostitution,Stability analysis,stochastic differential equation

1 Introduction

Prostitution,sometimesreferredtoastheworld'soldestprofession,hasbeen practiced sinceprehistoric era.Thetermprostitutioniscommonlyusedtorefertothetrade of sexualservicesformonetaryorin-kindremuneration,andhencetoatypeof social interactionthatisbothsexualandeconomic [4].Inessentialaspects,sextrafficking andprostitutionoverlap.Bothtargetedforcommercialsexualexploitationhavesome criticaldemographictraits,includingpoverty,young,minoritystatusinthecountryof exploitation,ahistoryofabuse,andlimitedfamilysupport.Bothpreyonvulnerablewomenandgirlsasaresultofwomen andgirlsasaresultofpoverty,discrimination,andabuse,leavingthemtraumatized,unwell,andpoor.Bothsexualandmone taryrewardsaregiventopredators, henceincreasingdemandandcriminalactivitiesthatassuresupply [10].

Ifamarriedcouplearebothimpoverished,hecansellhiswife'sbodyinthebazaar. Thisdoesnotfunctionintheoppositedirection.Maledominancecreatesprostitution, andinequalityexposesspecificgroupsofwomentosexualexploitation [8].Womenin thesextradearerapedandmurderedatthegreatestratesof anygroupof womenon theglobe [6].AssexualbehaviorisanimportantdeterminantintransmittingHIVand sexuallytransmitteddiseases(STDs),sexworkers(SWs),transgenderandclientsare oftenlabeled asa"highriskgroup"inthecontextofHIVandSTDs[7].

TheCOVID-19hasimpacted onalltypeofpeoplegloballybysystemicpoverty.Duringthiscrisisthesexworkersalsofacedmanyhindrances.Preventionfro mCOVID-19 andprotectionofsexworkershavediscussedin[13][3].Mostimportantly,sexworkers needbetterskilltraining,opportunitiestoleadtheirlifepeacefullytoovercome poverty aswell asprostitution.

Consideringthisasareallife problemweconstructedamathematicalmodeltoreduce thespreadofprostitutionduetopoverty.Thereareexistingmathematical modelson several socialissuessuchas[2],[11].Also in [1] the authors discussed prostitution caused by poverty in Nigeria.Inthisarticlewe framedamathematical modelwiththepopulationofpovertywomen,populationofprostitutesandrehabilitationwomenpopulation.

Thisarticlehasorganized as follows: InSection2weconstructeda deterministic modeland analyzedits equilibrium points inSection3.Thebasicreproductionnumberforthismodelhas found. Stability analysis has presented in Section 4.FurtherthisODE modelhasextendedtostochasticdifferentialequation inSection5. Numericalsimulationhasdoneinthe Section6.FinallyweconcludedinSection7

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2. TheModel

WedevelopedthedeterministicmodelusingthecompartmentsPovertywomenpopulationP_V,Prostitutewomenpopulation P_S,Rehabilitationwomenpopulation(R). Alsothetotalpopulationis $T = P_V + P_S + R$.Themodelhasframedbyconsideringthe followingassumptions. The povertywomenpopulationhasrecruitedintheregionat therateofΛ.Whenthesepovertywomenindividualsinteractwiththeprostitutesthen they becomeprostitutestofulfilltheirfinancialrequirements.Thishasrepresented asbilineartypeincidence$\beta P_V P_S$.Alsointherate$\alpha_1$womenindividualsmoveto rehabilitationtoeradicatetheirpoverty.Oncetheprostitutesrealizedtheirphysical andmentalhealththeymovetorehabilitationtolead properlifewithoutprostitution. Ashumanlifeisambiguous so ithasconsidered as,atthereducedrate δwomen who

areinrehabilitationturntoprostitutionwhentheyinteractwithprostitutes.This representstheterm$\delta\beta R P_S$.Withtheseassumptionsweconstructedthefollowingmodel:

$$\begin{aligned} \frac{dP_V}{dt} &= \Lambda - \beta P_V P_S - \alpha_1 P_V - \mu P_V \\ \frac{dP_S}{dt} &= \beta P_V P_S + \delta\, \beta P_S R - \alpha_2 P_S - \mu P_S - \mu_1 P_S \\ \frac{dR}{dt} &= \alpha_1 P_V + \alpha_2 P_S + \delta\, \beta P_S R - \mu R \end{aligned} \tag{1}$$

The abovemodel(1) canalsoberewrittenas

$$\begin{aligned} \frac{dP_V}{dt} &= \Lambda - \beta P_V P_S - k_1 P_V \\ \frac{dP_S}{dt} &= \beta P_V P_S + \delta\, \beta P_S R - k_2 P_S \\ \frac{dR}{dt} &= \alpha_1 P_V + \alpha_2 P_S + \delta\, \beta P_S R - \mu R \end{aligned} \tag{2}$$

Where$k_1 = (\alpha_1 + \mu)$, $k_2 = (\alpha_2 + \mu + \mu_1)$.

Table1:Tableof Parameters

Parameter	Description
Λ	Recruitmentrate of populationofwomen
β	Rateof interactionbetweenpoverty womenandprostitutes
α_1	Rateof poverty womenmovefrom$P_V$to$R$
α_2	Rateof prostitutesmovefrom$P_V$to$R$
$\delta\, \beta P_S R$	Reducedrate progressionof$R$backtoP_S
μ	Naturaldeathrateofwomen
μ_1	Rateof deathduetosexuallytransmitteddisease

3. Existence ofequilibrium points &Basicreproductionnumber

Themodel(2)hasexhibitedtwo equilibriumpointsnamelyprostitutionfreeequilibrium pointandprostitutionpresentequilibriumpoint.

3.1 Prostitution free equilibrium point

The prostitution free equilibrium point is $\mathcal{E}_0 = (P_V^0, 0, R^0)$ where$P_V^0 = \frac{\Lambda}{k_1}$, $R^0 = \frac{\alpha_1 \Lambda}{k_1 \mu}$for the system (2).

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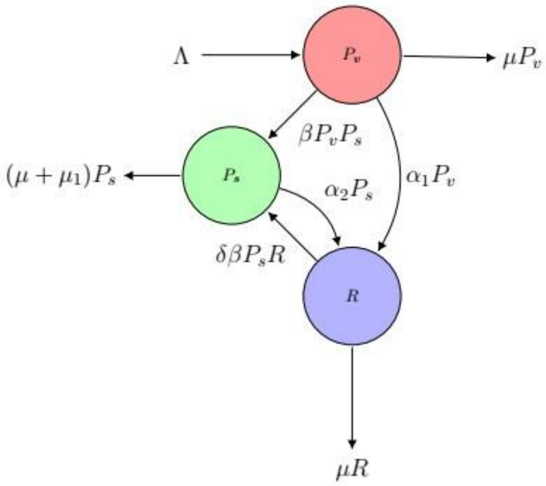

Figure1:Schematicdiagramofmodel (1)

3.2Basicreproduction number$\mathcal{R}_0$

Next generation method [15] as adopted to find the basic reproduction number at prostitution free equilibrium point$\mathcal{E}_0$. Here $\mathcal{F}_i(t)$ be the primary women prostitute,$\mathcal{V}_i^+(t)$be the inflow of transfer rate of individuals into the compartment and $\mathcal{V}_i^-(t)$be the outflow of the compartment with the index i. Using (2) we constructed a column matrices$\mathcal{F}(t)$,$\mathcal{V}^+(t)$and,$\mathcal{V}^-(t)$ as follows

$$\mathcal{F}(t)=\begin{pmatrix}0\\ \beta P_V P_S+\delta\,\beta P_S R\\ 0\end{pmatrix}\qquad \mathcal{V}^+(t)=\begin{pmatrix}\Lambda\\ 0\\ \alpha_1 P_V+\alpha_2 P_S\end{pmatrix}\ \mathcal{V}^-(t)=\begin{pmatrix}\Lambda\beta P_V P_S+k_1 P_V\\ k_2 P_S\\ \delta\,\beta P_S R+\mu R\end{pmatrix}$$

Also

$$[\dot{P_V}\quad \dot{P_S}\quad \dot{R}]^T=\mathcal{F}(t)-\mathcal{V}(t)\text{Where}\mathcal{V}(t)=\mathcal{V}^-(t)-\mathcal{V}^+(t)$$

The spectral radius of the matrix $FV^{-1}$is $\mathcal{R}_0$has given below

$$\mathcal{R}_0=\frac{\Lambda\beta(1+\delta)}{k_1k_2}=\frac{\Lambda\beta(1+\delta)}{(\alpha_1+\mu)(\alpha_2+\mu+\mu_1)}\qquad (3)$$

Where F represents Jacobian matrix of $\mathcal{F}(t)$ evaluated at $\mathcal{E}_0$and V represents Jacobian matrix of $\mathcal{V}(t)$ evaluated at $\mathcal{E}_0$

3.3.ProstitutionPresentEquilibriumPoint

Theprostitutionpresentequilibriumpointforthe system (2) is

$\mathcal{E}_1=(P_V^*,P_S^*,R^*)$where$P_V^*=\frac{k_2}{\beta(\delta+1)}$, $P_S^*=\frac{\Lambda\beta(1+\delta)-k_1k_2}{k_2\beta}$ $and\ R^*=\frac{\Lambda\alpha_2\beta(1+\delta)^2-\Lambda\beta k_2\delta(1+\delta)-\alpha_2k_1k_2(\delta+1)+k_2^2(\alpha_1+k_1\delta)}{\beta\mu k_2(\delta+1)}$,

4.StabilityAnalysis

The Jacobianmatrixforthesystem(2)isgivenby

$$\mathcal{J}=\begin{pmatrix}-P_S\beta-k_1 & -P_V\beta & 0\\ P_S\beta\delta+P_S\beta & P_V\beta\delta+P_V\beta-k_2 & 0\\ -P_S\beta\delta+\alpha_1 & -P_V\beta\delta+\alpha_2 & -\mu\end{pmatrix}$$

The local stability of these two equilibrium points have presented below

4.1 LocalStabilityofProstitutionFreeEquilibriumPoint

The stability of prostitution free equilibrium point $\mathcal{E}_0$ has examined from the Jacobian matrix $\mathcal{J}$ at$\mathcal{E}_0$. Then we have

$$\mathcal{J}_0=\begin{pmatrix}-k_1 & -P_V^0\beta & 0\\ 0 & P_V^0\beta\delta+P_V^0\beta-k_2 & 0\\ \alpha_1 & -P_V^0\beta\delta+\alpha_2 & -\mu\end{pmatrix}$$

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The above matrix has produced three eigen values $-\mu, -k_1$ and $\frac{\Lambda\beta(1+\delta)-k_1k_2}{k_1} = k_2(\mathcal{R}_0 - 1) < 0$ since $\mathcal{R}_0 < 1$. Therefore all three eigen values are negative. This proves the prostitution free equilibrium point is stable when $\mathcal{R}_0 < 1$. Further, we have checked the local stability of prostitution present equilibrium point $\mathcal{E}_1$.

4.2 Localstability of ProstitutionPresentEquilibriumPoint

The stability of prostitution free equilibrium point $\mathcal{E}_1$ has examined from the Jacobian matrix $\mathcal{J}$ at $\mathcal{E}_1$. Then we have

$$\mathcal{J}_1 = \begin{pmatrix} -P_S^*\beta - k_1 & -P_V^*\beta & 0 \\ P_S^*\beta\delta + P_S^*\beta & P_V^*\beta\delta + P_V^*\beta - k_2 & 0 \\ -P_S^*\beta\delta + \alpha_1 & -P_V^*\beta\delta + \alpha_2 & -\mu \end{pmatrix}$$

The eigen values of the above matrix are $-\mu$, $-\frac{\Lambda\beta(1+\delta)-\sqrt{\mathcal{R}_0^2k_1^2k_2^2-4k_1k_2^3(\mathcal{R}_0-1)}}{2k_2}$ and $-\frac{\Lambda\beta(1+\delta)+\sqrt{\mathcal{R}_0^2k_1^2k_2^2-4k_1k_2^3(\mathcal{R}_0-1)}}{2k_2}$. Here the eigen values are either negative or have negative real part. Therefore the prostitution present equilibrium point is locally asymptotically stable.

5 Stochasticmodel

Tostudythestochasticnatureofthedeterministicmodelweextendourdeterministic modeltostochasticmodel[16],[5][12][14].Considerthecontinuousrandomvariable $X(t) = (X_1(t), X_2(t), X_3(t))^T$ for $(P_V(t), P_S(t), R(t))^T$ where T denotesthetransposeof the matrix.

Let $\Delta X = X(t+\Delta t) - X(t) = (\Delta X_1, \Delta X_2, \Delta X_3)^T$ betherandomvector for the change in randomvariablesduringtimeinterval Δt.All the possible changes betweenstatesintheSDEmodelcanbedefinedbythetransitionmap[9].Fromour model(1),thereexist10possiblechangesbetweenstatesinasmall-timeinterval Δt. Statechangesandtheirprobabilitiesareelucidatedin Table2.Forillustration,when apovertywomaninteractwiththeprostitute. Then thestatechange ΔX isdenotedby $(\Delta X) = (-1,1,0)^T$ and its probability is given by

$Prob\{(\Delta X_1, \Delta X_2, \Delta X_3) = (-1,1,0) | (X_1(t), X_2(t), X_3(t))\} = P_2 = \beta X_1 X_2 \Delta t + O(\Delta t)$ Forstatechange ΔX, $Exp(\Delta X)$ and $Var(\Delta X)$ areexpectationchangeandits covariancematrixrespectivelywithneglectedtermshigherthan $O(\Delta X)$.Theexpectationchange

$$Exp(\Delta X) = \sum_1^{10} P_i(\Delta X)_i \Delta t$$

$$= \begin{bmatrix} \Lambda - \beta X_1X_2 - \alpha_1 X_1 - \mu X_1 \\ \beta X_1X_2 + \delta\beta X_2X_3 - \alpha_2X_2 - \mu_1X_2 - \mu X_2 \\ \alpha_1X_1 + \alpha_2X_2 - \delta\beta X_2X_3 - \mu X_3 \end{bmatrix} \Delta t \quad (4)$$

$$= f(X_1(t), X_2(t), X_3(t))\Delta t \quad (5)$$

From the above calculation the expectation vector and the function f are of same form as in deterministic system (1). Further we find the covariance matrix $Var(X) = Exp((\Delta X)(\Delta X))^T - Exp(\Delta X)Exp((\Delta X)^T)$ and $Exp(\Delta X)Exp((\Delta X)^T) = f(X)(f(X)^T)$, it can be approximated with diffusion matrix Ω times Δt by neglecting the term of $(\Delta t)^2$ such that $Var(\Delta X) \approx Exp(\Delta X)Exp((\Delta X)^T)$

$$Exp(\Delta X)Exp((\Delta X)^T) = \sum_1^{10} P_i((\Delta X)_i(\Delta X)_i{}^T) \quad \Delta t = \begin{pmatrix} V_{11} & V_{12} & V_{13} \\ V_{21} & V_{22} & V_{23} \\ V_{31} & V_{32} & V_{33} \end{pmatrix} \Delta t = \Omega.\Delta t$$

Where the above diffusion matrix is symmetric, positive definite and each component of this 3×3 diffusion matrix are given by

$V_{11} = \Lambda + \beta X_1X_2 + \alpha_2X_2 + \mu X_1 = P_1 + P_2 + P_3 + P_6$, $V_{12} = V_{21} = -\beta X_1X_2 = -P_2$, $V_{13} = V_{31} = -\alpha_1X_1 = -P_3$, $V_{22} = \beta X_1X_2 + \delta\beta X_2X_3 + \alpha_2X_2 + \mu X_2 + \mu_1X_2 = P_2 + P_4 + P_5 + P_7 + P_8$, $V_{23} = V_{32} = -\delta\beta X_2X_3 - \alpha_2X_2 = -P_4 - P_5$, $V_{33} = \alpha_2X_2 + \delta\beta X_2X_3 + \alpha_2X_2 + \mu X_3 = P_3 + P_4 + P_5 + P_9$. Further we used the method in [16] and constructed a matrix M such that $V = MM^T$, where M is 3×6 matrix

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$$\begin{pmatrix} \sqrt{P_1+P_6} & \sqrt{P_2} & \sqrt{P_3} & 0 & 0 & 0 \\ 0 & -\sqrt{P_2} & 0 & \sqrt{P_4+P_5} & \sqrt{P_7+P_8} & 0 \\ 0 & 0 & -\sqrt{P_3} & -\sqrt{P_4+P_5} & 0 & \sqrt{P_9} \end{pmatrix}$$

Then, the Ito stochastic differential model has the following form:

$$d\big(X(t)\big) = f(X_1, X_2, X_3)dt + MdW(t)$$

With initial condition $X(0) = \big(X_1(0), X_2(0), X_3(0)\big)^T$ and a Wiener process, $W(t) = \big(W_1(t), W_2(t), W_3(t)\big)^T$. In view of the above facts, we construct the SDE model as follows: $dP_V = (\Lambda - \beta P_V P_S - \alpha_1 P_V - \mu P_V)dt + \sqrt{\Lambda + \mu P_V}\, dW_1 + \sqrt{\beta P_V P_S}\, dW_2 + \sqrt{\alpha_1 P_V}\, dW_3$

$dP_S =$

$(\beta P_V P_S + \delta\, \beta P_S R - \alpha_2 P_S - \mu P_S - \mu_1 P_S)dt - \sqrt{\beta P_V P_S}\, dW_2 + \sqrt{\delta\, \beta P_S R + \alpha_2 P_S}\, dW_4 + \sqrt{(\mu + \mu_1) P_s}\, dW_5$

(6)

$dR = (\alpha_1 P_V + \alpha_2 P_S + \delta\, \beta P_S R - \mu R)dt - \sqrt{\alpha_1 P_V}\, dW_3 - \sqrt{\delta\, \beta P_S R + \alpha_2 P_S}\, dW_4 - \sqrt{\mu R}dW_6$

Table2:Tableof Parameter

Possiblestatechange	**Probabilityofstatechange**
$(\Delta X)_1 = (1, 0, 0)^T$Recruitmentrate of poverty women Population	$P_1 = \Lambda \Delta t + O(\Delta t)$
$(\Delta X)_2 = (-1, 1, 0)^T$Changewhenpoverty woman becomeprostitutewoman	$P_2 = \beta X_1 X_2 \Delta t + O(\Delta t)$
$(\Delta X)_3 = (-1,0,1)^T$Changewhenpoverty woman joinrehabilitationclass	$P_3 = \alpha_1 X_1 \Delta t + O(\Delta t)$
$(\Delta X)_4 = (0,1,-1)^T$Changewhenwomaninrehabilitationclass againjointoprostituteclass	$P_4 = \beta\delta X_2 X_3 \Delta t + O(\Delta t)$
$(\Delta X)_5 = (0,-1,1)^T$Changewhenprostitutewoman joinrehabilitationclass	$P_5 = \alpha_2 X_2 \Delta t + O(\Delta t)$
$(\Delta X)_6 = (-1,0,0)^T$Naturaldeathof povertywomenpopulation	$P_6 = \square X_1 \Delta t + O(\Delta t)$
$(\Delta X)_7 = (0,-1,0)^T$Naturaldeathof prostitutewomenpopulation	$P_7 = \square X_2 \Delta t + O(\Delta t)$
$(\Delta X)_8 = (0,-1,0)^T$Changeduetosexuallytransmitteddisease ofprostitutes	$P_8 = \square_1 X_2 \Delta t + O(\Delta t)$
$(\Delta X)_9 = (0,0,-1)^T$Naturaldeathof womeninrehabilitationclass	$P_9 = \square X_3 \Delta t + O(\Delta t)$
$(\Delta X)_{10} = (0,0,0)^T$ There is no change	$P_{10} = \left(1 - \sum_1^9 P_i\right)\Delta t + O(\Delta t)$

6.Numerical Simulation

In this section, we have done numerical simulation for our deterministic model (1) forboth the equilibrium points namely prostitution free equilibrium point and prostitutionpresent equilibrium point. For prostitution free equilibrium point the parametric set:$\Lambda = 100$, $\beta = 0.00001$, $\alpha_1 = 0.002, \mu = 0.0143$, $\mu_1 = 0.025, \delta = 0.02, \alpha_2 = 0.04$ For the corresponding parametric values the $\mathcal{R}_0$= 0:67 (Figure 2) and the prostitution freeequilibrium point is $\mathcal{E}_0 = (2915{:}\,45;\ 0;\ 4077{:}\,55)$. For prostitution present equilibriumpoint the parametric set: $\Lambda = 500, \beta = 0.00002, \alpha_1 = 0.02, \mu = 0.0143, \mu_1 = 0.025, \delta = 0.01, \alpha_2 = 0.6$ For the corresponding parametric values the$\mathcal{R}_0$ = 2:96 (Figure 2) and the prostitution present equilibrium point is $\mathcal{E}_1$ = (4915:84; 3370:59; 20785:93). Further, we simulated our SDE model (6) by using Euler-Maruyama method for the following set of parameters:$\Lambda = 500, \beta = 0.00002, \alpha_1 = 0.02, \mu = 0.0143, \mu_1 = 0.025, \delta = 0.02, \alpha_2 =$

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0.06 We compare the mean of 100 runs of stochastic model simulation with the results of corresponding deterministic model. And this fact is shown in Figures 4-6.

7.Conclusion

In this article a nonlinear mathematical model to study the dynamics of the spread of prostitution in the society is formulated and analyzed. The threshold (basic reproduction number $\mathcal{R}_0$) is obtained which determines whether prostitution will persist in the society or will die out. The existence and stability of different equilibria are discussed. Finally, thedeterministic model is converted to stochastic model and the results ofstochastic model are compared with corresponding deterministic model. It is observed that the level of rehabilitation women population in stochastic simulation is slightly higher than the simulation result of corresponding deterministic model. Additionally, it is found that increase in the parameters α_1 and α_2 decreases the poverty women population and prostitute women population in both deterministic and stochastic simulation.

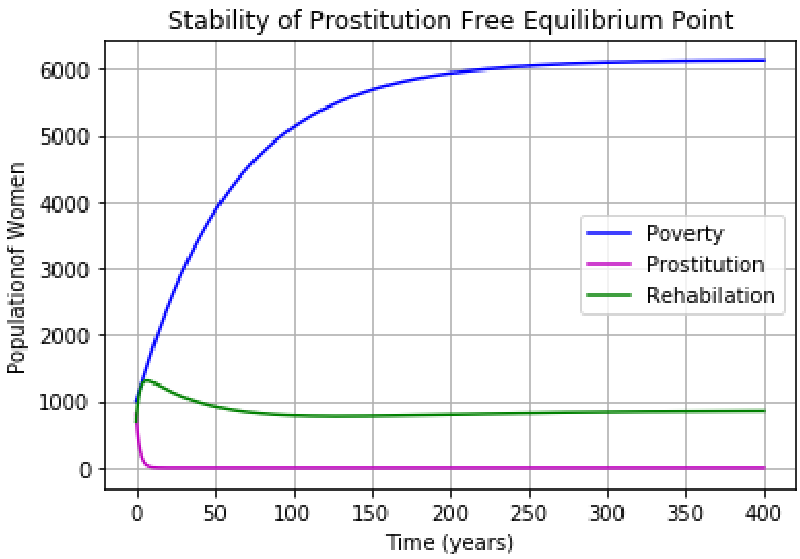

Figure2:Variationofwomenpopulationunderprostitutionfreeequilibriumpoint$\mathcal{E}_0$

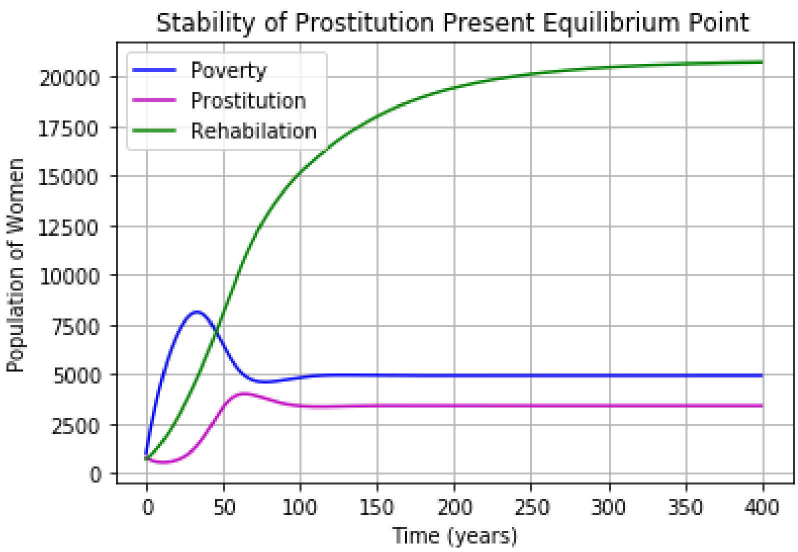

Figure3:Variationofwomenpopulationunderprostitutionpresentequilibriumpoint$\mathcal{E}_1$

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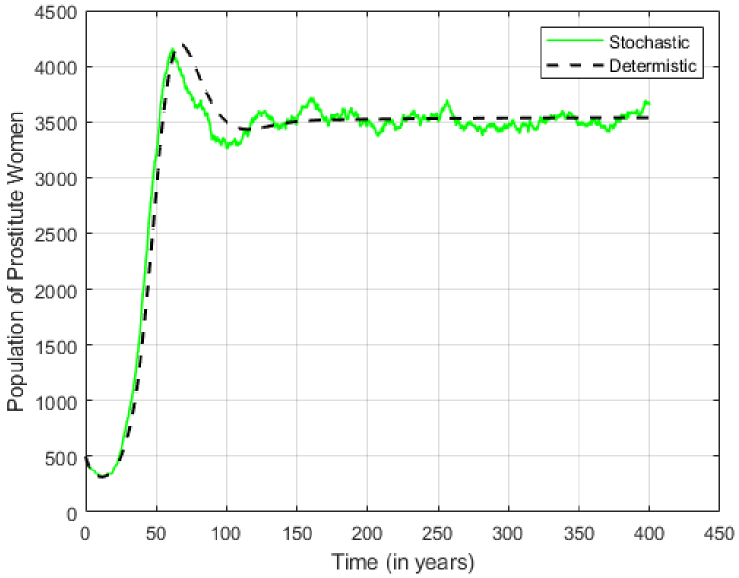

Figure4:Variationofpoverty womenpopulationwithtime.

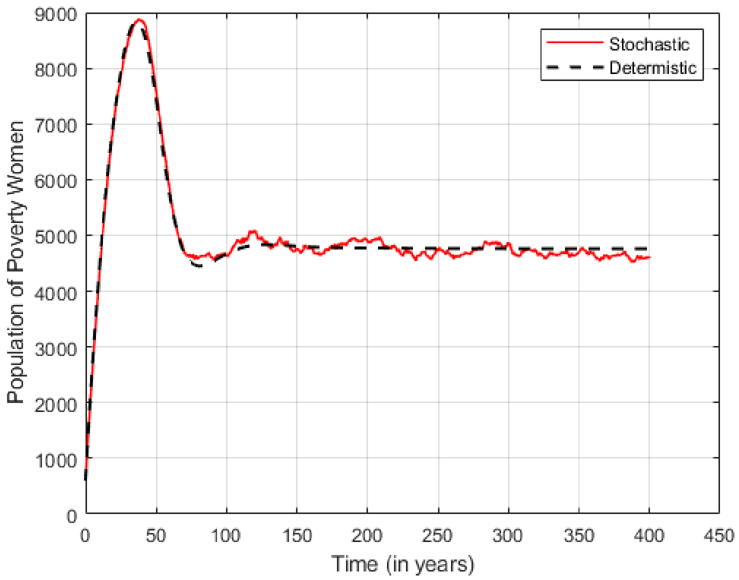

Figure5:Variationofprostitutewomenpopulationwithtime.

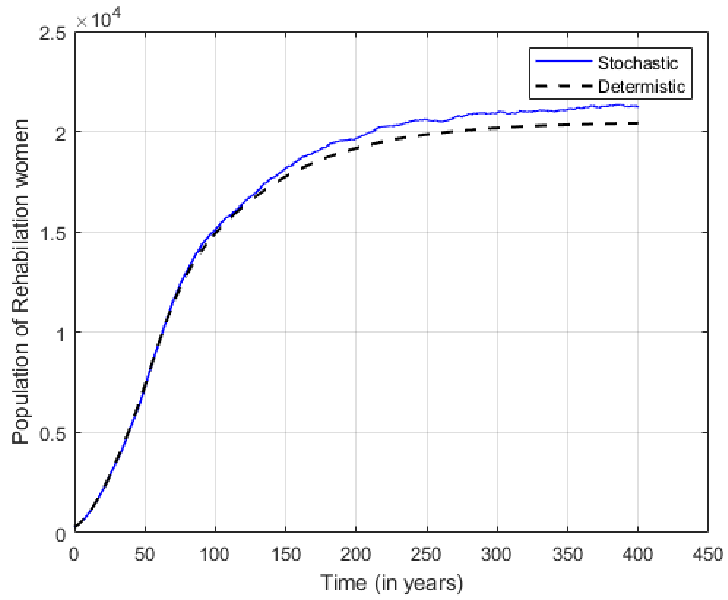

Figure6:Variationofrehabilitationwomenpopulationwithtime.

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