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Dynamical analysis of the cervical cancer epidemic model through the Levenberg-Marquardt algorithm in conjunction with artificial neural networks

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1. CERVICAL CANCER

Cervical cancer is the uncontrolled growth of abnormal cells in the cervix, the lower part of the uterus connected to the vagina. It is mainly caused by persistent infection with high-risk human papillomavirus (HPV).

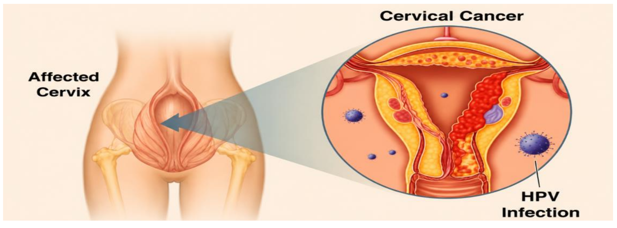


Figure 1. Origin of cervical cancer.

2. ARTIFICIAL NEURAL NETWORKs (ANNs)

ANNs are computational models inspired by the structure and functioning of the human brain, designed to learn patterns from data and solve complex problems.

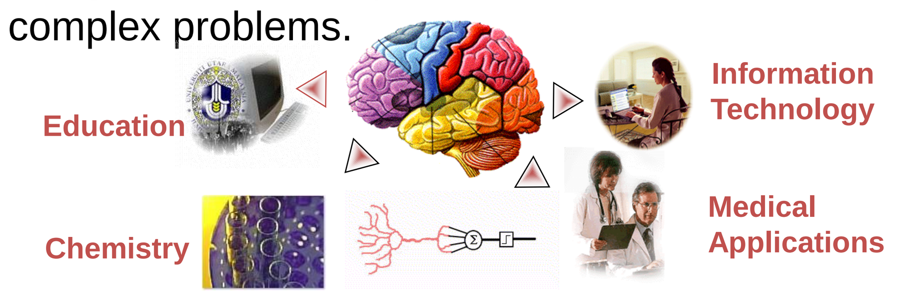


Figure 2. ANNs' applications.

3. PROBLEMS

1. Is it possible to employ artificial intelligence (AI)-based techniques to analyze nonlinear differential models representing specific real-world scenarios?

2. Do there exist AI techniques whose accuracy, convergent rate, efficiency, and reliability can first be analyzed and subsequently utilized for numerical simulations?

4. OBJECTIVES

1. To investigate the accuracy, convergence rate, efficiency, and reliability of the Levenberg-Marquardt algorithm in conjunction with artificial neural networks (LM-ANNs) through several analyses.

2. To analyze the dynamical behaviors of the cervical cancer compartments with respect to variations in different model parameters.

5. PARAMETERS & VARIABLES

Parameter	Description	Value
Λ	Rate of natural birth	0.1
P_H	Probability of HPV infection among women	1.6
η	Rate of natural death	0.1
P_C	Death probability of women from cervical cancer	0.7

Variable	Description
$W_S(t)$	Susceptible women
$W_H(t)$	Infected women with HPV
$W_{UC}(t)$	Infected women with HPV but not having cervical cancer
$W_{HC}(t)$	Infected women with both HPV and cervical cancer

6. MODELING

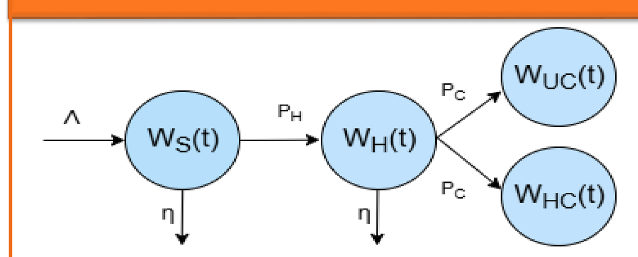


Figure 3. Model's compartments

7. CERVICAL CANCER MODEL

In this study, the proposed model is

$$W_S'(t) = \Lambda - P_H W_S W_H - \eta W_S$$

$$W_H'(t) = P_H W_S W_H - P_C W_H - \eta W_H$$

$$W_{HC}'(t) = P_C W_H - \eta W_{HC}$$

8. METHODOLOGY

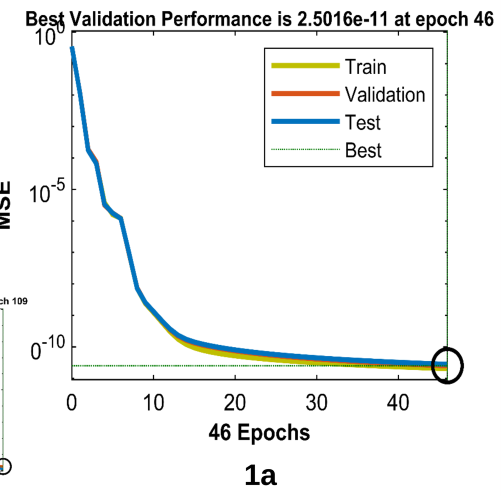
1. **Data Preparation** — Solved selected model using Adam Method. Designed scenarios, in which each have four cases. Generated target dataset of each case of both scenarios.
2. **Network Design** — Used ntstool and set neural network architecture with15 hidden neurons by dividing the each dataset into 70% training, 15% validation, and 15% testing sets.
3. **Train Datasets** — Trained each target dataset by using the Levenberg-Marquardt algorithm in conjunction with artificial neural networks (LM-ANNs) and performed several analyses.
4. **Save Results** — Saved analyses' results that satisfied required criteria and performed numerical simulation using LM-ANNs. When results did not satisfied criteria, gone to step 2 and started again.

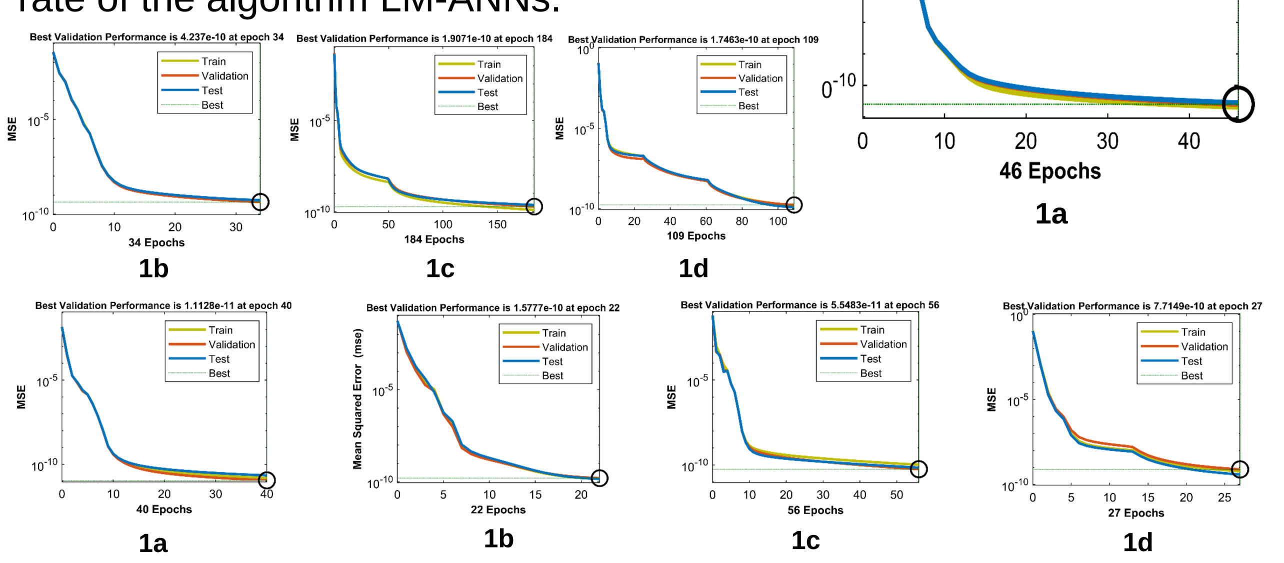
9. SCENARIOS

Scenario	Case	β	P_H	μ_h	P_c
1	a	0.1	0.7	0.1	0.7
	b	0.1	1	0.1	0.7
	c	0.1	1.3	0.1	0.7
	d	0.1	1.6	0.1	0.7
2	a	0.1	0.6	0.1	0.5
	b	0.1	0.6	0.1	0.6
	c	0.1	0.6	0.1	0.7
	d	0.1	0.6	0.1	1

10. CONVERGENCE ANALYSIS

In each plot, the increase or decrease in mean square errors w.r.t the number of epochs during training, validation and testing is shown through convergence curves which describes the convergence rate of the algorithm LM-ANNs.





11. MEAN SQUARE ERROR

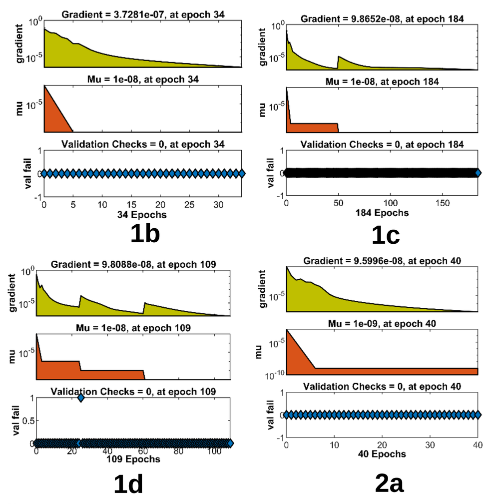
Scenario & Case	Mean Square Error: Training	Validation	Testing	Epoch	Time
1a	2.0343E-11	2.5016E-11	2.7868E-11	46	109s
1b	4.6340E-10	4.2370E-10	5.2896E-10	34	80s
1c	1.2671E-10	1.9071E-10	2.3603E-10	184	184s
1d	1.7029E-10	1.7463E-10	1.2478E-10	109	56s
2a	1.5191E-11	1.1128E-11	2.1763E-11	40	51s
2b	1.4325E-10	1.5777E-10	1.4286E-10	22	39s
2c	1.0199E-10	5.5483E-11	6.9172E-11	56	138s
2d	6.0283E-10	7.7149E-10	3.8952E-10	27	03s

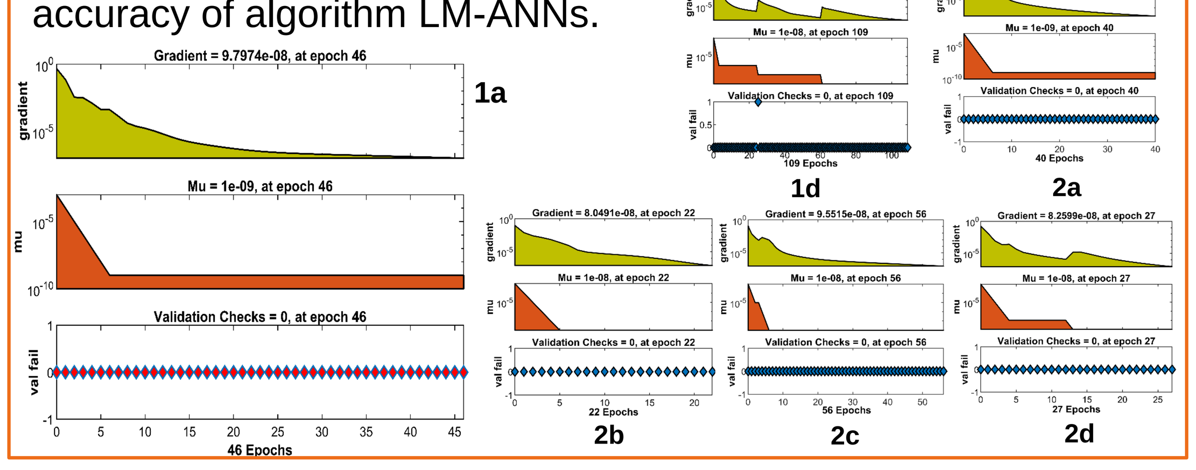
12. ABSOLUTE ERROR for SCENARIO 1a

Time	$W_S(t)$	$W_H(t)$	$W_{HC}(t)$
02	2.011088E-05	1.782235E-06	2.566741E-06
04	2.311215E-05	1.166905E-05	6.461823E-06
07	2.393860E-05	1.357581E-05	1.416366E-05
11	1.735863E-05	2.418634E-06	4.878643E-06
15	1.489013E-05	1.771900E-06	1.534676E-06
19	1.495027E-05	4.818158E-06	8.929983E-06
27	4.315245E-06	4.032847E-07	2.503079E-05
30	7.661377E-06	1.907829E-06	6.842644E-06
34	1.136525E-05	7.061416E-06	6.806215E-06
38	7.594035E-07	7.701189E-07	3.980607E-07
46	4.471006E-06	6.030278E-07	2.048261E-06
50	8.656733E-06	1.288175E-05	1.494896E-05
53	1.608004E-05	2.647264E-06	2.538174E-06
57	2.566046E-06	5.605003E-06	1.105498E-05
60	7.021070E-05	2.375865E-05	3.243686E-05

13. TRAINING STATE ANALYSIS

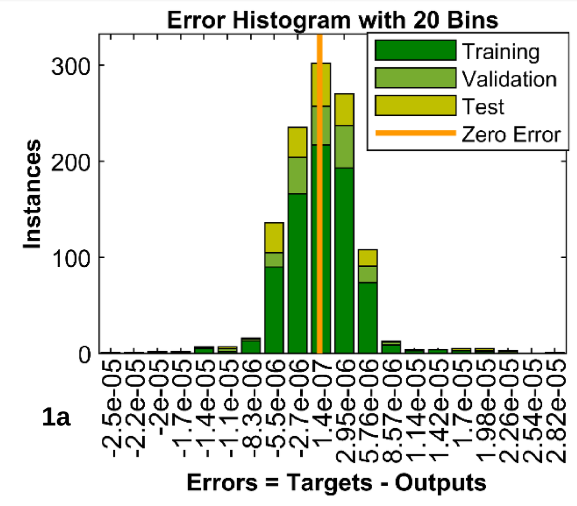
The value of a gradient at one thousand epochs shows a slope of the tangent at those points on which a high rate of change occurred. Further, the value of mu at 1000 epochs defines the high accuracy of algorithm LM-ANNs.

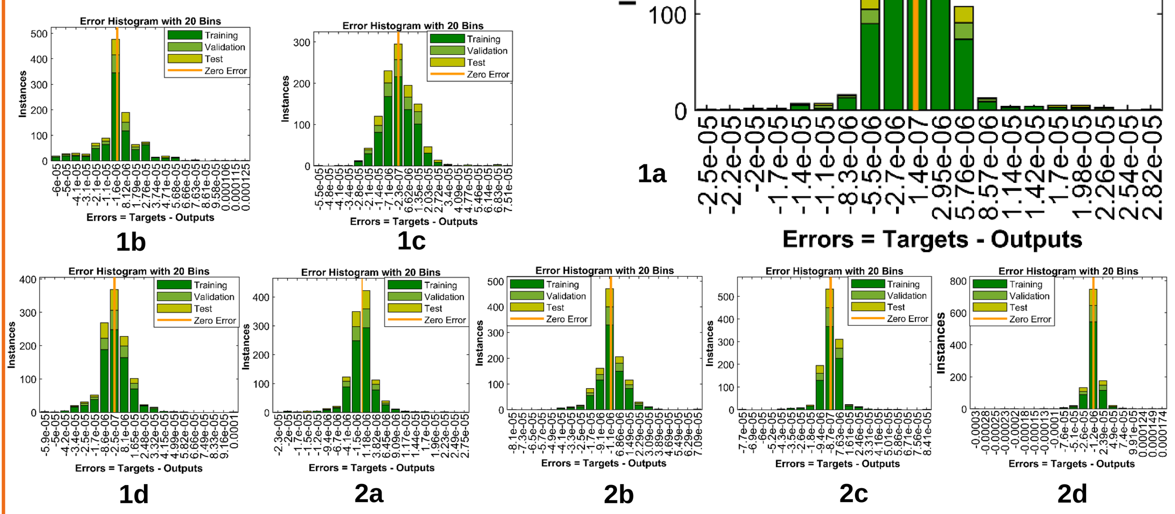




15. HISTOGRAM ERROR

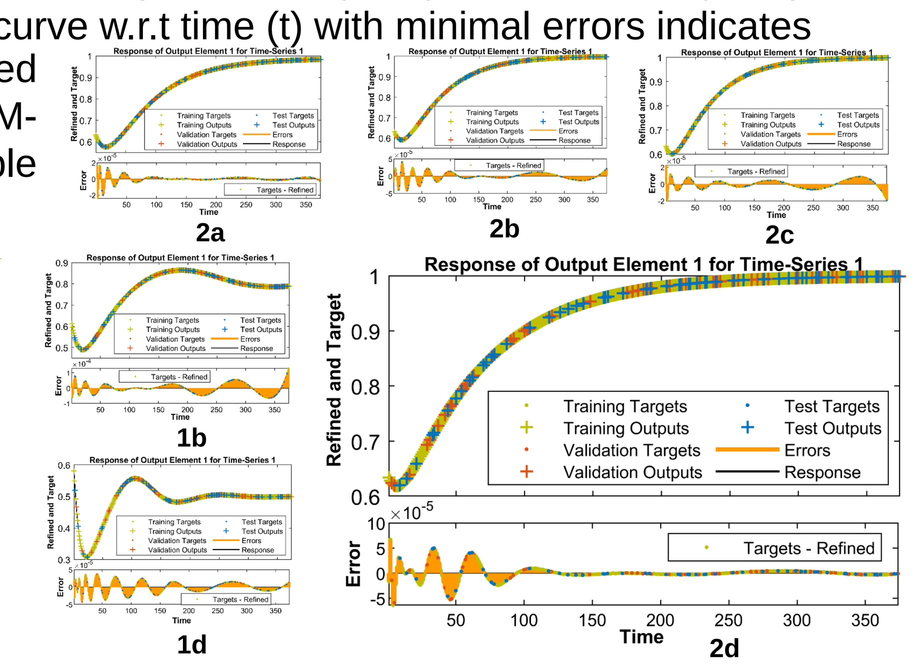
A few bars with a very small errors (approximate to zero) around the zero line indicate that the used algorithm has high accuracy and efficient.

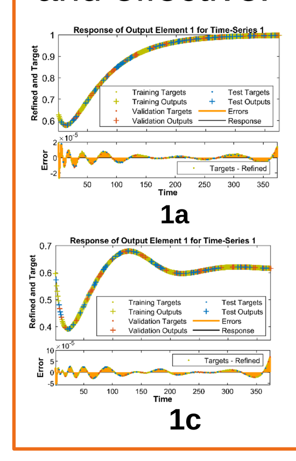




16. TIME SERIES ANALYSISS

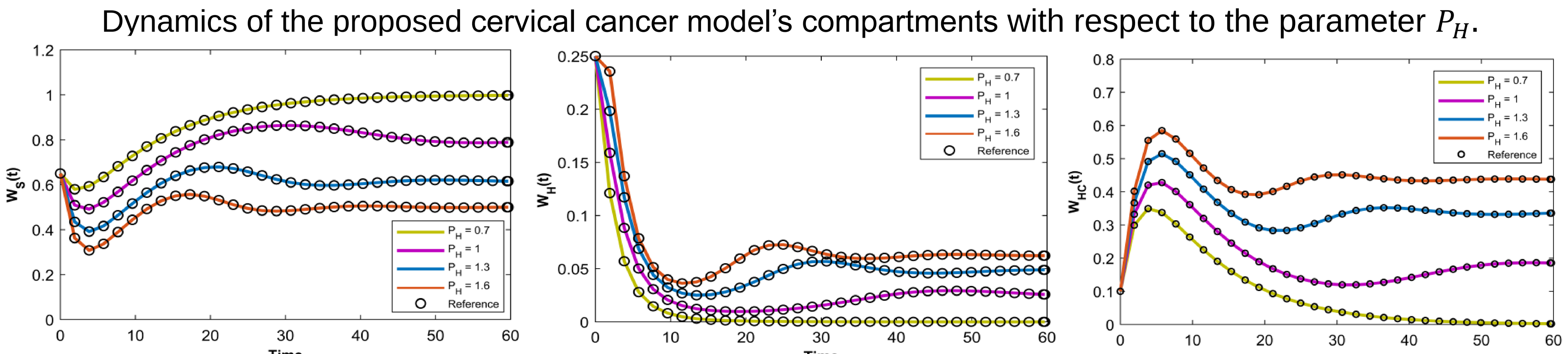
A significant overlap of training targets, training outputs, validation targets, validation outputs, testing targets, and testing outputs on the response curve w.r.t time (t) with minimal errors indicates that the used algorithm LM-ANNs is reliable and effective.



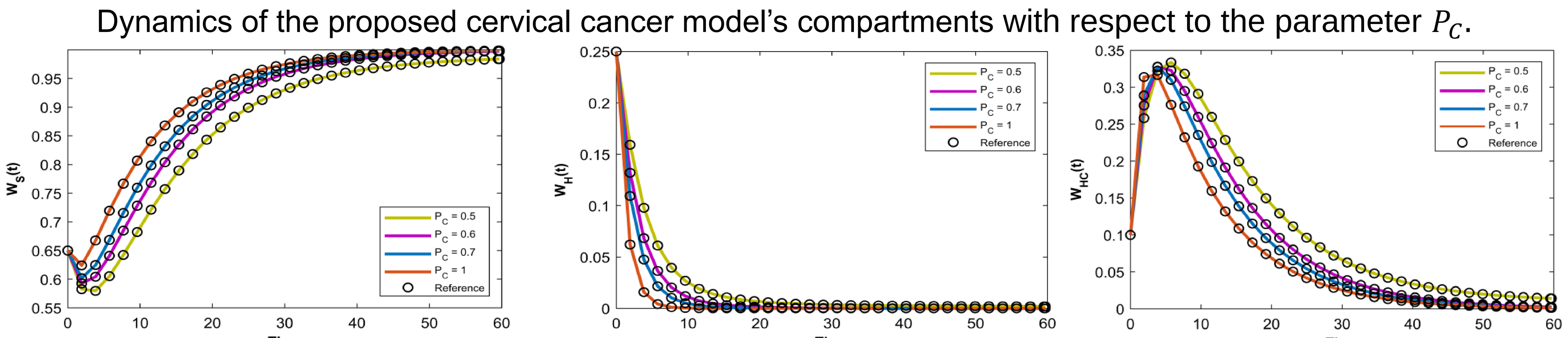


17. NUMERICAL RESULTS

Dynamics of the proposed cervical cancer model's compartments with respect to the parameter P_H.



Dynamics of the proposed cervical cancer model's compartments with respect to the parameter P_C.



14. GRADIENT & MU

Scenario	Case	Gradient	Mu	Scenario	Case	Gradient	Mu
1	a	9.7974E-08	1E-09	2	a	9.5996E-08	1E-09
	b	3.7281E-07	1E-08		b	8.0491E-08	1E-08
	c	9.8562E-08	1E-08		c	9.5515E-08	1E-08
	d	9.8088E-08	1E-08		d	8.2599E08	1E-08

18. CONCLUSIONS

- The obtained results from all analyses showed the LM-ANNs' effectiveness, strong convergence rate, high accuracy, and reliability.
- The numerical results defined that variations in model parameters significantly influence the dynamics of the model compartments.

19. FUTURE WORK

- The algorithm LM-ANNs will be implemented for the prediction of more complex nonlinear biological and epidemiological models.
- The model's compartments dynamics are analyzed w.r.t remaining parameters.

20. REFERENCES

- Butt, A. R., Saqib, A. A., Alshomrani, A. S., Bakar, A., & Inc, M. (2024). Dynamical analysis of a nonlinear fractional cervical cancer epidemic model with the nonstandard finite difference method. *Ain Shams Engineering Journal*, *15*(3), 102479.
- Pongsumpun, P. (2014). Mathematical model of cervical cancer due to human papillomavirus infection. *Mathematical Methods in Science and Engineering*.

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