NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF ENVIRONMENTAL SCIENCE

DEPARTMENT OF ENVIRONMENTAL HEALTH

MASTER OF SCIENCE IN ENVIRONMENTAL HEALTH

EPIDEMIOLOGICAL MODELLING

EEH 5201

Examination Paper

April 2025

This examination paper consists of 4 pages

Time Allowed: **3 hours**

Total Marks: **100**

Special Requirements:

- Calculator

Examiner's Name: Mr T. Chirigo

INSTRUCTIONS

1. Each question carries 20 marks
2. Answer ALL questions in Section A and ANY three (3) questions in Section B.
3. Where a question contains subdivisions, the mark value for each subdivision is given in brackets
4. Illustrate your answer where appropriate with large, clearly labelled diagrams

MARK ALLOCATION

QUESTION	MARKS
1.	**20**
2.	**20**
3.	**20**
4.	**20**
5.	**20**
6.	**20**
TOTAL	**100**

SECTION A: Answer ALL Questions (40 marks)

Question 1

The following is a simplified TB model in which the population is partitioned into susceptible (S), exposed (E), non-infectious sputum-smear negative TB (L), infectious (I) and recovered (R) compartments.

$$S' = \mu N - \frac{\beta SI}{N} - \mu S,$$
$$E' = \frac{\beta SI}{N} - (\kappa + \mu)E,$$
$$L' = (1-\alpha)\kappa E - (\gamma_1 + \mu)L,$$
$$I' = \alpha\kappa E - (\gamma_2 + \mu)I,$$
$$R' = \gamma_1 L + \gamma_2 I - \mu R.$$

(a) Show that this is a constant population model **(4)**

(b) What do the parameters β, γ, κ and μ represent **(6)**

(c) Draw a schematic representation of this model **(5)**

(d) State five model assumptions **(5)**

Question 2

(a) Define the reproduction number of a disease in the context of epidemic modelling. Giving one example of its real world application, describe the value of a reproduction number **(6)**

(b) List two (2) examples of how epidemic modelling techniques have been used in addressing real world problems. State one success and one failure in each case **(6)**

(c) Define herd immunity and state two reasons why in real life it may be difficult to achieve it **(8)**

SECTION B: Answer Any three (3) Questions (60 marks)

Question 3

The following is a simple HIV/ AIDS model for a homosexual population.

$$\frac{dS}{dt} = \Pi - \mu S - c\left(\beta_s S\frac{I_s}{N} + \beta_r S\frac{I_r}{N}\right),$$
$$\frac{dI_s}{dt} = c\beta_s S\frac{I_s}{N} + (1-p)\alpha T - (\mu + \gamma_1)I_s,$$
$$\frac{dI_r}{dt} = c\beta_r S\frac{I_r}{N} + p\alpha T - (\mu + \alpha_1 + d)I_r,$$
$$\frac{dT}{dt} = \gamma_1 I_s + \alpha_1 I_r - (\mu + \alpha + \tau)T,$$
$$\frac{dA}{dt} = \tau T - (\mu + \delta)A.$$

Where $N(t) = S + I_s + I_r + T + A$; S, I_s, I_r, T and A are the susceptible, drug susceptible infectives, drug resistant infectives, infectives on treatment and AIDS populations, respectively.

a. Draw a schematic representation of this model **(5)**
b. State four assumptions for this model **(4)**
c. What do parameters γ_1, α, δ and τ represent? **(4)**
d. In view of modern trends in HIV/ AIDS management, state two limitations of this model **(2)**
e. Suppose that you modify the model by incorporating vertical transmission which occurs at per-capita rates υ_s and υ_r through infected drug susceptible and drug resistant mothers, write the modified model. **(5)**

Question 4

a. Distinguish between disease eradication and disease elimination **(2)**
b. The following is a vaccination model for an imperfect vaccine which is administered to a proportion p of a given population

$$\frac{dS}{dt} = (1-p)\Pi - \beta SI - \mu S - \varepsilon S + \delta S_v,$$
$$\frac{dS_v}{dt} = p\Pi + \varepsilon S - (1-\alpha)\beta S_v I - (\mu + \delta + \tau)S_v,$$
$$\frac{dI}{dt} = \beta SI + (1-\alpha)\beta S_v I - (\mu + \gamma)I,$$
$$\frac{dV}{dt} = \tau S_v + \gamma I - \mu V.$$

Where S, Sv, I and V are unvaccinated susceptibles, vaccinated susceptibles, infectives and fully vaccinated/ recovered, respectively; and N is the total population.

i. Define the "take", "degree" and "duration" of a vaccine. **(6)**
ii. Draw a schematic representation of this model **(5)**
iii. State any two model assumptions **(2)**
iv. Describe how the "take", "degree" and "duration" of a vaccine affects an epidemic. **(5)**

Question 5

a. State and describe any five (5) factors that affect the reproduction number. **(10)**
b. Identify any three roles and three limitations of epidemiological modelling **(6)**
c. Differentiate between a disease-free equilibrium point and an endemic equilibrium point. **(4)**

Question 6

The Provincial Medical Director (PMD) of Province X is worried about the increasing incidence of disease Y. The dynamics of the disease follows the SEIR model. As an Environmental Health Practitioner (EHP) you have been tasked to model the progression of the disease through the population.

a. Assuming the following:
    - Susceptible population is replenished at a constant rate proportional to the total population,
    - Exposed individuals are not infectious
    - Recovery is with temporary immunity
    - Birth rate is equal to natural death rate (demographic effects)
    - The disease is not fatal

        i. Draw a schematic representation of the SEIR model for the disease **(5)**

        ii. Write down the model equations **(4)**

        iii. Show that $\frac{dN}{dt} = 0$. What does this imply? **(3)**

b. Suppose that the exposed individuals are mildly infectious, sketch the modified model diagram and, hence, write down the new model equations. **(8)**