Strathmore UNIVERSITY

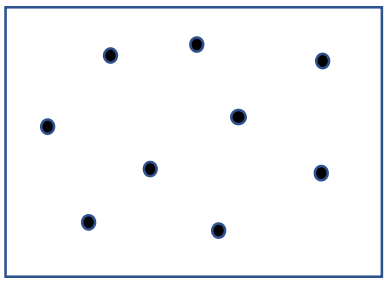
STRATHMORE INSTITUTE OF MATHEMATICAL SCIENCE (SIMS)
MASTER OF SCIENCE IN BIOMATHEMATICS
END OF SEMESTER EXAMINATION
BMA 8308: ENVIRONMENTAL MODELLING

DATE: 16th April 2024 **TIME: 3 Hours**

INSTRUCTIONS
1. This examination consists of FIVE questions.
2. Answer Question ONE (COMPULSORY) and any other TWO questions.

QUESTION ONE (30 MARKS)

a) Use the following sketch of datapoints to construct
   i) Delaunay triangles. (2 marks)
   ii) Voronoi polygons. (2 marks)



b) Buffering can be used in GIS to define riparian zones to protect riparian vegetation around rivers or lakes. Assume the `lakes.shp` shapefile is already loaded in ArcMap from the `GIS4EnvSci` datasets and the `Buffer` tool dialog box is already displayed. Then outline the steps taken to create 200m buffers around the lakes. (6 marks)

c) In ordinary kriging method of spatial interpolation, the weights are obtained by solving the following system of linear equations;

$$\sum_{j=1}^{k} w_j \gamma(h_{ij}) + \mu = \gamma(h_{i0}), \quad i = 1,2,\cdots n$$

$$\sum_{i=1}^{k} w_i = 1,$$

   i) State what k, w_i, $\gamma(h_{i0})$, μ represent. (4 marks)
   ii) Modify this system of linear equations to obtain the weights for a universal kriging method. (2 marks)

d) The nearest neighbor analysis of spatial patterns involves calculating the mean distance between points and their nearest neighbors to produce the nearest neighbor

statistic R. State the rules used to describe a spatial pattern as either clustered, random or dispersed using the statistic R. (3 marks)

e) The spatial distribution of wildlife animals due to environmental factors such as rainfall, temperature or habitat type can be investigated by geographically weighted regression (GWR) method. Assume an ArcMap with `gauges.shp` shapefile already loaded from the `GIS4EnvSci` dataset, and the Geographically Weighted Regression dialog box is already displayed. Outline the steps done to implement GWR regression in ArcGIS. (6 marks)

f) In modeling surface water contamination, the rate of change of dissolve oxygen (DO) and biochemical oxygen demand (BOD) in a parcel of water as it travels downstream is given by;

$$\frac{\mathrm{dDO}}{\mathrm{dt}} = k_2\big(DO_{sat} - DO(t)\big) - k_1 BOD(t)$$

$$\frac{\mathrm{dBOD}}{\mathrm{dt}} = \mathrm{A} - k_1 BOD(t)$$

where k_1 is the deoxygenation coefficient, k_2 is the reoxygenation coefficient, DO_{sat} is the saturation of dissolved oxygen and A is the constant inflow of BOD from organic effluent and decay of plants and animals within the parcel. Obtain the steady-state levels of DO and BOD in terms of A. (5 marks)

QUESTION TWO (15 MARKS)

a) Name two spatial data models used in geographical information systems. (2 marks)

b) illustrate how the following geographical features can be represented in a vector data model;
   i) Road.
   ii) Lake. (3 marks)

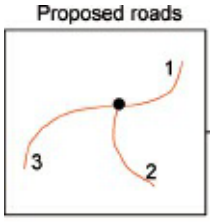
c) Distinguish between query by attribute and query by location, using a suitable example in each type. (4 marks)

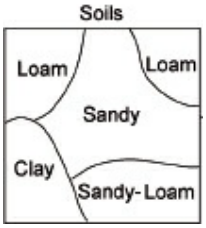
d) Consider ArcMap in which the `landcover, pheasant` and `rivers` feature classes are already uploaded from `GIS4EnvSci` datasets. Outline the steps done in `Select by Location` dialog box to display the pheasant sighting locations within 200 meters from rivers. (6 marks)

QUESTION THREE (15 MARKS)

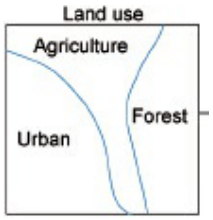
Overlay analysis involves stacking multiple data layers so that the relationships between features at each location can be analyzed. Using the data layers given below for a line-in-polygon and polygon-on-polygon vector overlays respectively, sketch the resulting data layer AND draw the attribute table.

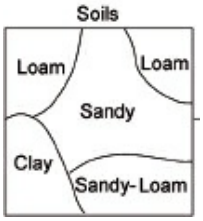
a) line-in-polygon (7 marks)





b) polygon-on-polygon (8 marks)





QUESTION FOUR (15 MARKS)

a) Illustrate, with two 4x4 raster layers, the concept of raster data overlay by addition (4 marks)

b) Sketch a semivariogram indicating the range and nugget variance. (4 marks)

c) Consider an ArcMap in which the `gauges.shp` shapefile and `boundary` feature class are already uploaded from the `GIS4EnvSci` datasets. Using the `Geostatistical Wizard` outline the steps taken to interpolate an average annual rainfall surface using universal kriging method. (7 marks)

QUESTION FIVE (15 MARKS)

The model equations below describe the greenhouse gases effect and the process by which the earth balances energy flows, and how these flows affect atmospheric temperature;

$$\frac{\mathrm{dE}}{\mathrm{dt}} = (1-f_b)(1-a)\varphi_s + R_a A(t) - E(t), \quad E(0) = 491.31$$

$$\frac{\mathrm{dA}}{\mathrm{dt}} = f_b(1-a)\varphi_s + (t_e + f_a(1-t_e))E(t) - A(t), \quad A(0) = 518.15$$

where E is the amount of energy per area in the earth, φ_s is the solar flux, A is the amount of energy per area in the atmosphere, R_a is the fraction of the atmosphere's energy density radiated to earth per time, t_e is the fraction of earth's energy density, f_b is the fraction of incoming solar energy absorbed by atmosphere, and f_a is the fraction of outgoing radiation from the earth that is absorbed by atmosphere, while $a = 0.313$;

a) Determine the expressions of A and E under steady-state conditions. (5 marks)

b) discretize the model equations using finite difference method. (3 marks)
Take $C_1 = (1-f_b)(1-a)\varphi_s$, $C_2 = f_b(1-a)\varphi_s$ and $C_3 = (t_e + f_a(1-t_e))$

c) write a MATLAB code named `GHGmodel` that implements the discrete model in b) above to solve for E(t) and A(t), and plot the solutions. (7 marks)
Take $\Delta t = 0.25,\ f_a = 0.907,\ f_b = 0.285,\ R_a = 0.624,\ t_e = 0.207,\ \varphi_s = 362$