

## TABLE OF CONTENTS

|       |  |    |
|-------|--|----|
| 1     | INTRODUCTION .....   | 1  |
| 1.1   | Structure of the thesis .....  | 3  |
| 1.2   | Systems approach in hydrology and the river catchment as a system.....                               | 5  |
| 1.2.1 | System identification .....  | 7  |
| 1.2.2 | Digital filters and the differential and difference equations description<br>of dynamic systems..... | 11 |
| 1.2.3 | External model description .....   | 12 |
| 1.2.4 | State- space representation of the general models of dynamic systems .                               | 13 |
| 1.2.5 | Transfer function (TF) models of dynamic stochastic systems .....                                    | 16 |
| 1.3   | Background to the study .....  | 17 |
| 1.4   | Research question and objectives .....   | 21 |
| 2     | THE STUDY AREA.....  | 22 |
| 2.1   | Introduction .....   | 22 |
| 2.2   | Climate.....   | 24 |
| 2.2.1 | Rainfall .....   | 24 |
| 2.2.2 | Potential evapotranspiration.....  | 24 |
| 2.3   | Land cover and use .....   | 26 |
| 2.4   | Hydrology .....  | 27 |
| 2.4.1 | Drainage.....  | 27 |
| 2.4.2 | Stream flow distribution .....   | 29 |
| 2.5   | Hydrogeology .....   | 29 |
| 2.5.1 | Geology .....  | 29 |
| 2.5.2 | Groundwater occurrence and flow.....   | 30 |
| 2.5.3 | Borehole yields .....  | 31 |
| 2.6   | Water use in the basin.....  | 32 |
| 2.7   | Water resources management problems in the basin.....  | 33 |
| 3     | EXPLORATORY DATA ANALYSIS .....  | 36 |
| 3.1   | Introduction .....   | 36 |
| 3.2   | Rainfall-runoff characteristics of the monthly riverflow data.....                                   | 43 |
| 3.2.1 | Persistence in river runoff.....   | 55 |
| 3.2.2 | Autoregressive and moving average modelling of monthly runoff.....                                   | 58 |
| 3.2.3 | Non-linearity in monthly rainfall-runoff relationship.....   | 69 |
| 3.3   | Conclusions .....  | 73 |
| 4     | SPATIO-TEMPORAL MODEL FOR FILLING GAPS IN DAILY<br>STREAM FLOW SERIES.....                           | 74 |
| 4.1   | Introduction .....   | 74 |
| 4.2   | The discrete spatio-temporal dynamic modelling framework.....  | 76 |
| 4.3   | Missing observations .....   | 84 |
| 4.4   | System matrices parameterisation .....   | 84 |
| 4.5   | Application of the modelling framework .....   | 85 |
| 4.6   | Results and discussion .....   | 87 |
| 4.7   | Conclusions .....  | 93 |

|       |  |     |
|-------|--|-----|
| 5     | MODELLING STREAMFLOWS USING NARMAX POLYNOMIAL MODELS .....                                     | 95  |
| 5.1   | Introduction .....   | 95  |
| 5.2   | The NARMAX polynomial model .....  | 95  |
| 5.2.1 | Formulation of the model.....  | 97  |
| 5.2.2 | Error reduction ratio and selection of significant terms.....                                  | 98  |
| 5.3   | Application of the model .....   | 98  |
| 5.4   | Results and discussion .....   | 101 |
| 5.5   | Conclusions and recommendations .....  | 111 |
| 6     | DATA-BASED MECHANISTIC MODELLING OF STREAMFLOWS .....  | 112 |
| 6.1   | Introduction .....   | 112 |
| 6.2   | Runoff Models in Hydrology .....   | 112 |
| 6.2.1 | Difference equation representation of the rainfall-runoff linear filter..                      | 117 |
| 6.2.2 | Transfer function representation of the rainfall-runoff linear time-varying (LTV) filter ..... | 119 |
| 6.3   | The HMC modelling framework .....  | 122 |
| 6.4   | Fixed interval smoothing (FIS) method of parameter estimation of LTV-SDP models .....          | 125 |
| 6.5   | Application of the modelling framework to rainfall-runoff series in the Volta Basin .....      | 128 |
| 6.6   | Results and discussion .....   | 131 |
| 6.7   | Conclusions and recommendations .....  | 145 |
| 7     | SUMMARY AND RESEARCH FINDINGS.....   | 147 |
| 7.1   | Introduction .....   | 147 |
| 7.2   | Exploratory data analysis.....   | 148 |
| 7.3   | Filling gaps in stream flow data .....   | 149 |
| 7.4   | Modelling streamflow using NARMAX polynomial models .....                                      | 149 |
| 7.5   | Data-based mechanistic modelling of streamflow.....  | 149 |
| 7.6   | Recommendations for further research.....  | 150 |
| 8     | REFERENCES.....  | 152 |
| 9     | APPENDIX.....  | 160 |

## ACKNOWLEDGEMENTS