Chapter 2

Research Methodology

This chapter presents the research method and process employed to acquire knowledge and data to answer the research problem. The chapter takes into account the reasoning behind the method to obtain and analyse the results of the study.

2.1 Introduction

A research methodology is a structured approach to solving a research problem. It is a science that studies the way to conduct research. In simple words, it is the process by which scholars go through the task of analysing, understanding, and projecting phenomena. Its main goal is to provide a scope of the research work. On the other hand, a research method is a tactic, procedure, or technique used to collect data or information for examination to reveal new knowledge or get a deeper insight into a subject.

Let us consider an example to distinguish between a research method and research methodology. To find the roots of a quadratic equation, we can apply one of these approaches - factoring, completing the square, or the quadratic formula. Each of these approaches is the research method to find the roots. On the other hand, the research methodology explains which approach or method should be applied and the process of application and calculation of the roots.

According to Rajasekar et al. (2013), a research can be broadly divided into two categories, which are fundamental or basic research and applied research. Basic research is the study of the fundamental concepts and causes of activity or phenomenon. It is the analysis or exploration of natural phenomena or a topic in pure research. A fundamental or basic research is also known as a theoretical research. A theoretical research has a unique or fundamental identity. It allows a research an in-depth understanding of an issue, derivation of rational scientific explanations and conclusions. It contributes to the creation of new information. On the other hand, in applied research, accepted hypotheses and concepts are used to tackle specific issues. The majority of experimental study and cross-disciplinary work comes under it. It is also defined as a study that has direct relevance as a result of its

findings. The results of theoretical research are the foundation for a lot of applied research. Researchers conducting applied research apply the findings of fundamental research. The works presented in the thesis are based on fundamental or basic research.

2.2 Aim and objectives

A research aim conveys the purpose or desire of the study in one sentence; it highlights what we intend to accomplish at the end of the work. Research objectives describe the activities that will lead to accomplishing the research aim. The objectives break down the aim into parts, where each part constitutes a crucial element of the study. The objectives are organized in a list, with each objective becoming a chapter of a thesis.

2.2.1 Aim

Our research aims to broaden our knowledge about the enigmatic DE and the dynamics of the mysterious universe, with the consideration of a 5D SS metric, within the framework of modified gravity theories.

2.2.2 Objectives

The objectives of our research are listed below.

- To find if modified theories of gravity can behave as DE sources.
- To calculate the present values of cosmological parameters and test the reliability by comparing them to observation data.
- To make (probably) the first attempt to find some kind of stabilizing conditions of extra dimensions in GR.
- To develop reliable cosmological models that would allow us to avoid the terrible fate of the universe, the cosmic doomsday.
- To construct a reliable model involving negative energy density.
- To research DE and the universe's expanding phenomena in higher dimension.
- To construct cosmological models that involves interaction of DE and DM.

2.3 Research design

The purpose of a research design is to offer a structure for research (Sileyew 2019). The point of consideration about investigation strategy is a highly critical choice in a research design as it defines how necessary knowledge for research will be acquired; nevertheless, a research design comprises several linked decisions (Aaker et al. 2000). In order to achieve the aim and objectives in our fundamental or basic research, the mixed method (MM) of research, which combines qualitative and quantitative approaches, will be the focus of investigation. The quantitative method is centred on determining a quantity or a measure of something. A study is explained or represented using one or maybe more quantities in this case. The conclusion of a study is a numeric figure or a group. Whereas, in qualitative research, non-numerical information is collected and analysed in order to better comprehend ideas, views, or situations. It can be utilized to get a detailed understanding of a research problem or to innovate new research findings. By the use of MM, the study in our research involves non-numerical analysis and interpretation of data, and numerical outcomes and comparisons. A detailed explanation of the qualitative and quantitative methods in the field of mathematical and physical sciences also can be found in the work of Rajasekar et al. (2013). In recent years, MM has evolved fast, becoming a well-known research method with a unique character (Denscombe 2008).

According to Creswell & Clark (2006), designs with mixed methods come in four kinds, which are triangulation, embedded, explanatory, and exploratory. Our study will deal with the explanatory and exploratory designs. Explanatory research sought to seek answers for occurrences and phenomena, such as the explanation of "Why is a thing the way it is?" or "Why is the universe expanding?". Whereas exploratory research aims to learn further about a subject or a research area, such as "Can the universe expand in the absence of dark energy?" or "Can a modified gravity theory behave as a dark energy source?". The pictorial depiction of the research design used in our study is highlighted in Fig. 2.1.

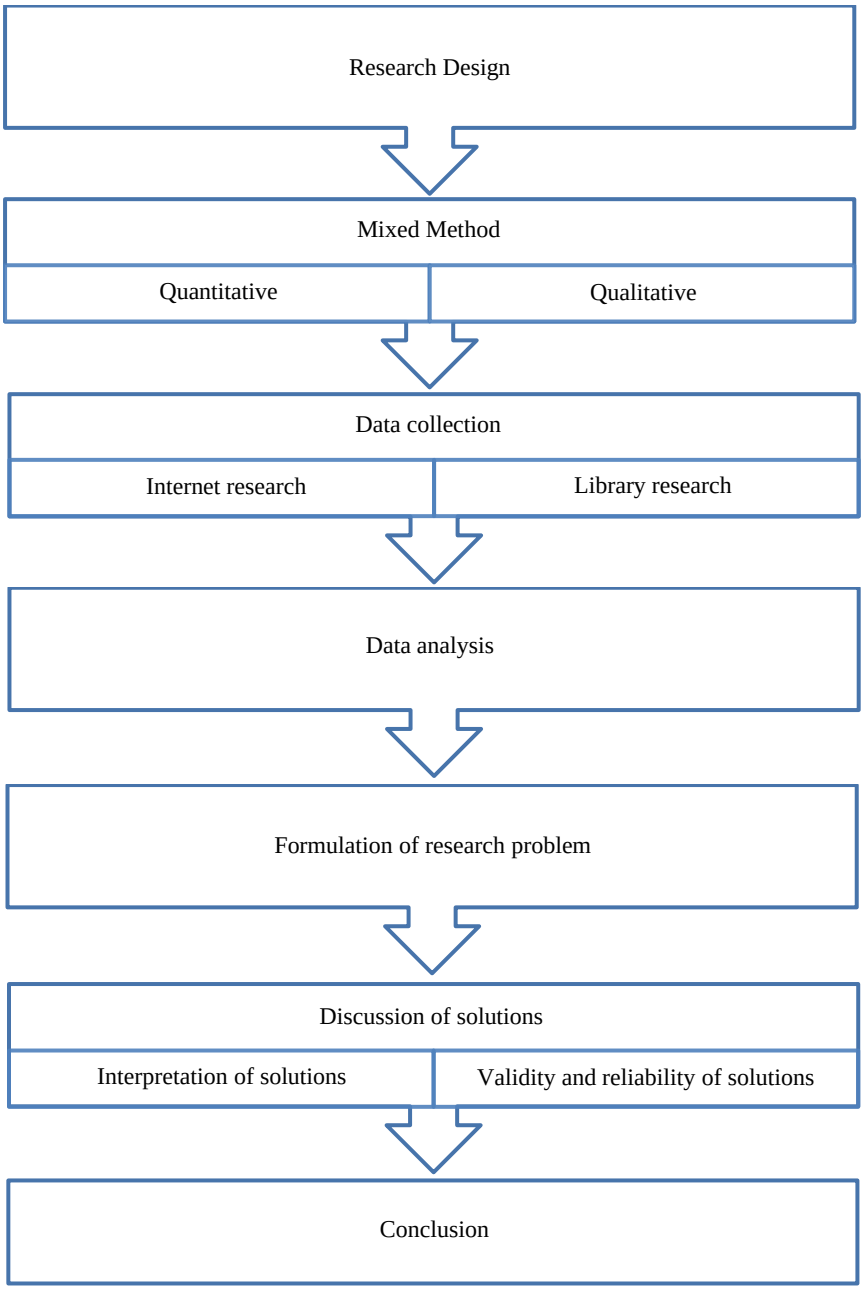

Figure 2.1: Research design.

2.4 Data collection

Data collection is a systematic procedure of obtaining and evaluating specific information to answer related queries and assess the outcomes. It emphasizes learning everything about a particular topic. Data gathered is put through inductive reasoning, which is used to try to understand a phenomenon. Research may be classified into two categories based on

the method of data collection - primary and secondary research. The main difference is that data is acquired first-hand in primary research, whereas it is collected from previous studies in secondary research. Secondary data is gathered from readily accessible sources such as books, journal articles, newspapers, etc. Our research is more of a secondary type character since it entails minimal first-hand data.

The feasibility of employing secondary data for the study has become increasingly popular since huge volumes of secondary data are being gathered and preserved by scientists throughout the globe (Johnston 2014). In our work, a desk review is undertaken to gather information from a different of sources. The secondary data of our research is collected through two main sources - internet research and library research. The collecting of data and information from library items such as books, journal articles, conference papers, dissertations, and theses is known as library research. Internet research is the collection of data through internet sources. Academic journals and online repositories provide access to research articles and books that may be downloaded or purchased. Copies of research papers are also requested from different authors through email. The internet is one of the most important sources of data collection in today's technological era. Technological advancements have resulted in massive volumes of secondary data being gathered, collated, and preserved, all of which are now readily available for research.

The minimal first-hand or primary data is collected from the expert's viewpoint on data comparisons and information on observational findings, in the form of feedback via conference presentations, informal discussions, independent observations, etc.

2.4.1 Inclusion and exclusion criteria

A set of specified features to select data or participants to be considered in a research project is referred to as inclusion criteria, whereas the features to exclude or remove after being considered for inclusion is term exclusion criteria (Salkind 2010). Inclusion criteria must be relevant to the goal of the research and must be met in order for it to be completed. The validity and reliability of the research outcomes will be improved, the relevance will be enhanced, the expenses will be minimized, and ethical issues can be avoided if the criteria are properly chosen.

The following are listed as the inclusion criteria of secondary data:

- Articles within the domain of the research.
- Articles published during the past one to two decades.

- Only the older articles that provide the basic foundations, definitions, and statements, stable results, etc.
- Secondary data which guarantee analytical quality.
- Data from reputed indexed journals or publishers.
- Articles published in the English language.

The following are the exclusion criteria of secondary data:

- Articles which are synopsis of a conference, seminar or workshop.
- Articles which are just abstract, presentation, or poster versions.
- The article that simply bears the appearance of a promotional leaflet, with no contents.
- Reviews and editorials.
- Duplicate works.

2.5 Data analysis

The research method relates to the way the scholar gathers, analyses, and understands the data (Creswell 2008). Secondary data analysis is a crucial part of the research and assessment process. Secondary data analysis has become so significant to many of the finest methodologists that they have overshadowed primary data analysis in relevance (Glass 1976). The formulation of research problems is the first phase in secondary data analysis (Johnston 2014).

Most research starts with an analysis to find what information is previously understood and what is needed to be learned (Creswell 2008), incorporating relevant and supplementary material and also taking into account already gathered secondary data on the subject. In Chapter 1, we examine the past and present work of different researchers and perform a detailed literature review of various articles on the relevant topics. The literature review aids us in recognising the various research methods and methodologies employed by different authors. Following the review, we were able to identify the knowledge gaps and the crucial concepts, leading to the formulation of research objectives based on the key results.

2.6 Formulation of problem and solutions

Formulation of a research problem entails stating the research issue in a form that can be investigated. It is the first and most crucial stage in conducting research. It is similar to deciding on the desired location before embarking on a trip. It refers to the process of shaping a research area so that it is suitable for scientific inquiry. A scholar must narrow the area and indicate explicitly what will be investigated about it. This is referred to as formulation of the problem, and it entails pinning down a wide study field into a particular topic of study and setting goals. When the research problem is defined, the topic is fully prepared to be investigated scientifically.

In our work, to formulate a research problem, keeping in mind the objectives of the research, we apply the 5D SS line element to a particular modified gravity theory. Under certain reasonable assumptions, the exact solutions of the field equations are obtained. Then, we find the expressions for the cosmic scale factors appearing in the SS line element. Using the expressions for the cosmic scale factors, the expressions/values of the related cosmological parameters are obtained as solutions to the research problem.

2.7 Research tools and techniques

The formulation and prediction of the solutions to the research problem employ certain tools and techniques. A research tool and techniques are anything that serves as a way of gathering or analysing data or that helps conduct the research. Gravity is involved in GR, which is a broad generalization of special relativity. The mathematical explanation of GR necessitates the idea of differential geometry, employing the concepts of metric, curvature, etc. The mathematical tools and techniques of calculus, differential equation, geometry, algebra, and tensor are also applied in our research. Above all, the Wolfram Mathematica software becomes handy in the graphical analysis of the solutions to the research problem.

2.8 Discussion of solutions

One of the crucial tasks of a scholar is to prepare manuscripts to analyse the results of the research, which isn't really simple (Sanli et al. 2013). The discussion section is the most essential, as well as the least appealing component to work on. In our work, we incorporate the following two components in the discussion.

- Interpretation of solutions.

- Validity and reliability of solutions.

2.8.1 Interpretation of solutions

A proper presentation of the true significance of the information provided as goals of the research being delivered, including the chapter and topic, is referred to as interpretation (Pandey & Pandey 2015). The Wolfram Mathematica software is used to analyse the research solutions of the research problem. Graphical representations of the solutions are generated by the software. In light of the current observational data and literature references, the graphical analysis aids in the interpretation of the solutions explaining the past, present, and future physical phenomena of the universe. The interpretation component of the discussion presents the fresh, unique, and insightful findings of the research. We also estimate the present values of some cosmological parameters in this section. The interpretation part is also intended to address the unanswered problems about different cosmological phenomena. It can sometimes generate new queries that can inspire further study.

2.8.2 Validity and reliability of solutions

Reliability and validity are the most crucial and essential aspects of fruitful research, and these must be presented briefly and clearly in the research methodology chapter (Mohajan 2017). These aspects improve the clarity of qualitative research and decrease the risk of bias (Singh 2014). The stability of results is termed reliability, whereas the accuracy of results is referred to as validity (Altheide & Johnson 1994). A comprehensive review of reliability and validity includes techniques employed to acquire data (Saunders et al. 2009). For validity and reliability, we discuss the solutions considering the latest results predicted by standard experiments, for example, the Planck 2018 results. We also compare our results with the findings of the latest research articles published in indexed academic journals of repute.

2.9 Research conclusions

The Conclusions portion summarises the main elements of the discussion, the crucial aspects of our model, or the most important findings of our research. Its purpose is to bring the narrative of our study to a close, it:

- is presented in a way that closely relates to the aim and objectives of our research.
- shows the degree whereby the objectives are met.

- highlights the key results, opinions, or observations of our research.
- admits the limitations and provide suggestions for further improvement (whenever applicable).
- emphasizes the importance or applicability of our research.