

Balancing Food Costs and Women's Health through Nutrition: A Journey of Mathematical Modeling

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Abstract:

This article aims to investigate how a Linear Programming (LP), issue might be defined with an emphasis on women's health management. Next, we'll create a mathematical model that minimizes the expense of a healthy meal throughout the day by optimizing the diet program relying on the no. of calories required for daily intake (during menstruation), diet budget and the healthiest meal distribution throughout a day. After that, we'll solve the problem using the R program to get optimized results.

Keywords: Formulation of LPP, Integer LPP, R Programming,

Introduction

LPP is a mathematical approach for optimizing a conclusion relying on a set of constraints expressed in the form of linear equalities or inequalities and formulating them as an LPP model.

A procedure was required during the Second World War to resolve the allocation problem of military resources. Then, the American Scientist "George Dantzig" tried to overcome this issue and, in 1947, developed a theory and practice using the "Simplex Method".

LPP has established various applications in distinct fields, i.e., resource allocations, production planning, transportation planning, marketing optimization, financial management, etc.

The Simplex Method is a popular algorithm or methodology for solving Linear Programming Problem that requires multiple decision variables, constraints and restrictions, making graphical methods impractical. It is an iterative process used to find the optimal solution by either maximizing or minimizing the objective function.

During the menstrual cycle, a woman's body undergoes hormonal fluctuations that can significantly impact energy levels, metabolism, and cravings. Eating the right balance of calories and nutrients can help manage these changes and alleviate symptoms like fatigue, mood swings, and cravings.

Maintaining a balanced diet during the whole cycle is the most important thing for a woman's body. Not getting the right calories and nutrients can greatly impact women's health and even lead to weakness.

R is a programming language that is largely used for statistical computation, data analysis, and graphical representation, and solving optimization problems. It was developed by statisticians Ross Ihaka and Robert Gentleman in 1993; it has since lengthened into one of the most widely used tools for data scientists, statisticians, and researchers across many fields because it has extensive capabilities in data manipulation, statistical modelling, and visualization.

R software is also used for solving Linear Programming Problems (LPP) using various packages, with lpSolve and ROI (R Optimization Infrastructure) being the packages that are commonly used for optimization problems. These packages provide easy-to-use functions that allow users to solve linear programming problems.

This research paper focuses on Women's Healthcare Management, which is one of its applications, and by comparing the nutrient requirements by using available ingredients, linear programming can help us to determine a balanced diet for women during the menstrual cycle that meets these requirements at the lowest possible cost.

Women's bodies undergo a number of physiological changes during menstruation, which raises their energy needs. The rise in energy needs can be credited to the body's efforts to regulate hormonal changes, manage discomfort, and replenish nutrients lost during the menstrual cycle.

In 1954, C. E. Lemke discussed the dual method of solving the linear programming problem. In that paper he developed a new computational method of solving general linear programming problems [see, 1].

In 1983, Anderson, A.M, et al., discussed Diet planning in the third world by linear and goal programming. In this study, goal programming significantly improved the nutritional balance of the raw materials chosen compared to linear programming [see, 2].

In 1991, Henson et al., discussed linear programming analysis of constraints upon human diets. This study applies linear programming cost-minimization approaches to the analysis of human meals. The models consider both nutritional and non-nutritional elements in food selection to assess how following dietary guidelines impacts the price of both nutritious and delicious diets. This research uses dual pricing to estimate the cost of meeting nutrient requirements for different demographic groupings. In this study, marginal cost curves for variations in the supply of nutrients specified in the dietary guidelines were computed using by sensitivity analysis [see, 3].

In 1992, Soden, P. M. and co-authors described modifying diets to satisfy nutritional requirements using linear programming. In this paper they discussed a computational technique for creating individually acceptable meals by changing a predetermined diet to fulfil nutritional needs is given. The impacts on food quantities of imposing varied nutrient requirements on a sample meal are presented, as well as measures for ensuring the modified diet's acceptability to the individual. The starting point for the computation is the individual's current dietary consumption. This is updated utilizing LP (Linear Programming) approaches, which make the tiniest modifications to meal quantities in order to reach particular goals. Sequential modification can be used to determine what modifications are acceptable to the individual. The computer tool was created in conjunction with practicing dietitians and is used in several prominent UK hospitals [see, 4].

In 2004 Drewnowski, A. was addressed Dietary Energy Density and Diet Costs in Obesity and the Food Environment. In this work, he demonstrated how diet cost serves as the primary mediating variable and how the present energy-cost method offers an economic explanation for the observed relationships between obesity and the food environment. The main cause of obesity in America is economic. If rising food prices are a perceived and real obstacle to dietary change, especially for low-income families, then adopting better diets may be more dependent on family economic resources and the food environment than on psychosocial variables, self-efficacy, or motivation to change. If pricey diets are still being promoted to low-income families as a public health campaign, the poor and ignorant will simply get more irate and feel guilty [see, 5].

In 2006, Nicole Darmon et al. discussed the influence of cost constraints on food choices for French women to provide them with a nutritionally adequate diet [see, 6].

In 2010, Lisa Quintiliani et al. did research on healthy eating strategies in the workplace, which stated that there is a link between dietary behaviour and a range of chronic diseases and worksite is the central venue for influencing diet behaviour, so this research provides an overview of healthy eating strategies during work [see, 7].

In 2014, Katz, D. L. and co-workers discussed the best diet for health [see, 8].

In 2015, Corne Van Dooren et al. wrote an article to find diets with low prices and climate impact yet fulfil all nutritional requirements using linear programming. The fundamental goal of this research is to create diets that are both inexpensive and environmentally friendly while meeting all nutritional requirements. Linear programming is used as the method of optimization. The program restricts 33 elements to meet Dutch dietary standards. In a second cycle, the top limit for climate impact from Greenhouse Gas Emissions (GHGE) is set at 1.6 kg CO₂eq/day. In the third cycle, the costs are fixed to €2.50 as a limit. The optimization's objective function aimed to maximize the most eaten food products ($n = 206$) for male and female individuals (ages 31-50) [see, 9].

In 2015, Okubo, H. et al. were designed the optimal food intake patterns for Japanese individuals to achieve their nutrition objectives by using linear programming optimization models. In order to accomplish a set of 28 nutrient recommendations listed in the DRIs for Japanese people, the authors of this paper utilized the Linear-Programming (LP) model to mathematically develop optimized food intake patterns that were particular to age and sex. This study revealed how nutrient-based

recommendations can be transformed into nutritionally sufficient food intake patterns among Japanese people with minimum changes to their present dietary habits [see, 10].

In 2016 Alexander Parlesak et al. proposed an article in which they developed a problem that minimized the cost range for a nutritionally healthy diet to promote a food basket that helps prevent micronutrient inadequacy and non-communicable diseases [see, 11].

In 2019, Alaini, R. et al. conducted research on diet optimization in Kuala Lumpur, Malaysia, utilizing linear programming to create an inexpensive cancer preventive eating plan for a subset of adults. Thus, the goal of this project is to use linear-programming to create a low-cost, balanced, and healthful menu that can be tailored to each person's needs and may help prevent cancer. One hundred adults from a nearby university in Kuala Lumpur participated in a three-phase cross-sectional study. The subjects' sociodemographic, anthropometric, and dietary recall data were collected in the first phase. The development of a balanced diet model at the lowest possible cost was the second stage. The completion of the cancer prevention menu was the third and last stage. Based on the World Cancer Research Fund/American Institute for Cancer Research (WCRF/AICR) 2007 guidelines, the Malaysian Dietary Guidelines (2010), and the Recommended Nutrient Intake (RNI) (2017), the best and most balanced menus were created at the lowest possible cost. A healthy, well-balanced menu for cancer prevention can be achieved at a low cost by using linear programming to translate nutritional requirements based on specific Dietary Guidelines. Additionally, the models could influence the dietary choices of consumers in order to avoid cancer, particularly for those in the low-income group, where the primary barrier to good eating has been the high cost of health foods [see, 12]

In 2020 Nilu, T.Y., and associates conducted research on the use of linear programming to analyze dietary choices in order to create a healthy nutrition plan. The basic and comprehensive methods for creating LPs models in a variety of real-world decision-making situations, decisions, works, etc. were covered in this study. Numerous diseases linked to nutrition can be brought on by an improper diet. A healthy diet can occasionally be too expensive, which influences our ability to create a diet-based, cost-effective nutrition model. Our objective is to reduce the overall expense while taking the necessary quantity of nutritional values into account. We calculated the cost-effective values by using certain standard nutrition ingredient values to build the study [see, 13].

In 2021 Chungchunlam, S. M., and co-authors conducted a study on the use of linear programming to determine the Role of Plant- and Animal-Sourced Foods in Least-Cost, Nutritionally Adequate Diets for Adults. This study employed linear programming (LP) to identify the components of cost-effective, nutritionally sound food patterns. Foods derived from animals would be included in least-cost diets because of their high density of certain critical elements, according to the hypothesis tested [see, 14].

In 2022, Sultana, J. and co-authors used Linear Programming to create a method for optimizing diet cost for various age groups. In this paper they studied employs Linear Programming optimization to determine the minimum price and amount of food products for selecting a proper diet comprising sufficient nutrition elements over a week for three different age groups. To do this, a LP (Linear Programming) optimization model is first chosen, followed by the creation of three data files detailing the various food items and their respective cost and nutrition factors for three unique age groups. Finally, the model files and data files are combined to determine the output cost and number of food

items to be purchased. The optimum solution exhibits distinct food costs and quantities for different age groups [see, 15].

In 2022 Chaudhary, A. et al published a descriptive cross-sectional study on alcoholic liver disease in patients hospitalized to a tertiary care centre's Internal Medicine Department. In this research with ethical approval from the hospital's Institutional Review Committee, a descriptive cross-sectional study involving 538 patients admitted to the Department of Internal Medicine of a tertiary care centre in Nepal between November 3, 2021, and February 22, 2022 was carried out (Reference number: 006-078/079). They used convenience sampling. The Statistical Package for the Social Sciences, version 24.0, was used to analyze the data after it had been gathered and entered into Microsoft Excel. 95% point estimate for binary data, the confidence interval was computed along with the frequency and percentage; for continuous data, the mean and standard deviation were computed [see, 16].

In 2022 Dev, B. associates conducted a descriptive cross-sectional study on Lumbar Disc Degenerative Disorder in Patients Receiving Magnetic Resonance Imaging in a Tertiary Care Facility. From May 24, 2021, to December 31, 2021, a descriptive cross-sectional study was carried out at the Department of Radio diagnosis and Interventional Radiology of a tertiary care centre among patients who complained of low back pain. The Institutional Review Committee granted ethical approval (Reference number: 134/2077-78). Convenience sampling was used with a sample size of 899. Version 22.0 of the Statistical Package for the Social Sciences was used to enter and analyze the collected data. 95% point estimate for binary data, the Confidence Interval was computed along with the frequency and percentage; for continuous data, the mean and standard deviation were computed [see, 17].

In 2023, Vipin Bihari Yadav and Rajveer Dhabas discussed the student diet problem using Linear Programming approach. In this research a survey was done. Forty respondent- all students-were given a survey to complete information regarding their daily eating habits for breakfast, lunch and dinner. The food menus are provided by the cafeteria at the various Indian institutes and universities where these 40 students reside. Now using this information, they formulate the Linear programming problem and find the lowest cost that meets the daily recommended nutrients including in breakfast, lunch and dinner. After that they run this model by Tora application and Excel solver and result was compared [see, 18].

In 2024 Ayoob, F. et al. was created an optimization tool for formulating diets in a supplementary nutrition program for children. This study's goal is to develop a linear programming (LP) model that maximizes a variety of meal options for an SNP to satisfy program requirements while utilizing locally accessible foods and economic constraints. In this article, they employed an LP algorithm with proper constraints to develop an ideal THR based on raw foods, or an optimal weekly HCM menu consisting of a midday meal with mid-morning snacks, based on user food and recipe preferences. The database of foods used was generated through a prospective survey done throughout all Indian states for this reason, confirming that the recipe and food optimization were diversified and tailored to the guidelines for each beneficiary group [see, 19].

In 2024 Deo, K. K. et al. Deo, K. K. et al. conducted a descriptive cross-sectional study on hydrocele in patients receiving surgery in the surgery department of a tertiary care centre. A tertiary care facility served as the site of this descriptive cross-sectional investigation. All of the patients having surgery in

the general surgery department were included in the retrospective data collection, which was done using medical records spanning a year (2021 July to 2022 June). The same institute's Institutional Review Committee granted ethical approval (Reference number: 820/2080/81). A systematic proforma was used to identify hydrocele surgery cases and retrieve pertinent data. Microsoft Excel 2016 was used for descriptive analysis [see, 20].

These are the findings on health management yet, and in this problem, we are minimizing the cost of a daily nutritious diet for women in middle-class families.

Objectives: Our objective is to emphasis on women's health management with minimizes the expense of a healthy meal throughout the day by optimizing the diet program also concern with calories required for daily intake (during mensuration), diet budget and the healthiest meal distribution.

Methods: First we have converted the given data into information that is LPP then followed by R software i.e. a programming language used for statistical computing and data analysis. Statistical analysis provides various statistical techniques, including linear and non-linear modelling, time series analysis, and classic statistical tests. R software helps manage large datasets and performs complex data manipulation in data analysis. R is a powerful tool in Operations Research (OR) due to its flexibility, statistical capabilities, and extensive libraries for optimization, simulation, data analysis, and modelling.

Results & Discussion:

Data for Optimizing Food Balance Diet

#	Food (100g)	Carbs (g)	Proteins (g)	Fat (g)	Price
X_1	Brown bread	51	8.4	1.6	10
X_2	Butter	0.1	0.9	81	48
X_3	Fruits	27	1.3	0.4	3
X_4	Vegetables	13	2.9	0.2	5
X_5	Flour	76	10	1	5
X_6	Rice	28	2.7	0.4	2
X_7	Pulses	14	5	0.4	21.8
X_8	Milk	5	3.4	1	5
	Total	214.1	34.6	86	

Problem Formulation

The food ingredients of breakfast, lunch and dinner are defined on the basis of no. of calories required by a woman per day. These are selected according to the carbs, proteins and fats required throughout the day. We ought to minimize the cost of daily intake by a woman.

The data mentioned in the table has been accumulated from different resources and may vary according to the different situations:

Price of brown bread from a shop has been determined as Rs. 40 to 55 for 400gm packet

While considering for fruits, the price of seasonal fruits may vary so taking banana into consideration which is available in all seasons and which is Rs. 30 to 45 per kg

While considering vegetables price of vegetables which are available in all seasons is considered.

The minimum price of 1kg long grain rice is Rs. 20 to 80. The price increases depending on its type, quality, brand, packaging type, shelf life, etc.

In same way the prices of other products are also considered which is for butter, flour and pulses.

A woman requires a Maximum of 2000-2500 calories throughout the day, which is 100-300 extra during mensuration in comparison to other days.

$$\text{Minimize } Z = 10x_1 + 48x_2 + 3x_3 + 5x_4 + 5x_5 + 2x_6 + 21.8x_7 + 5x_8$$

Subject to constraints:

$$51x_1 + 0.1x_2 + 27x_3 + 13x_4 + 76x_5 + 28x_6 + 14x_7 + 5x_8 \geq 138.1$$

$$8.4x_1 + 0.9x_2 + 1.3x_3 + 2.9x_4 + 10x_5 + 2.7x_6 + 5x_7 + 3.4x_8 \geq 24.6$$

$$1.6x_1 + 81x_2 + 0.4x_3 + 0.2x_4 + x_5 + 0.4x_6 + 0.4x_7 + x_8 \geq 85$$

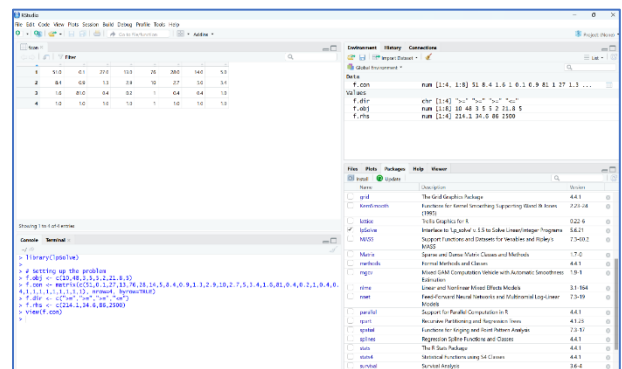
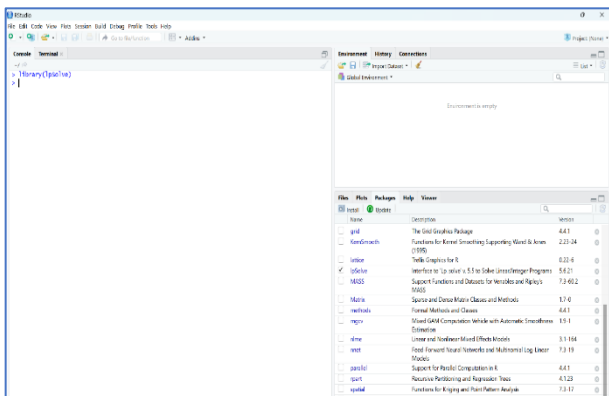
$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 \leq 2500$$

Non negative constraints: $x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8 \geq 0$

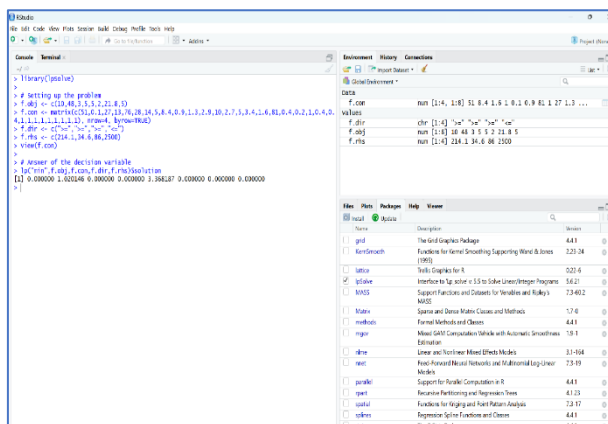
Let us now interpret how we can get the solution using step-by-step R programming.

Step 1: Activate the lpSolve package.

Step 2: Setting up the problem or defining the problem in R.



Step 3: Getting the answers of the decision variables using lp function.



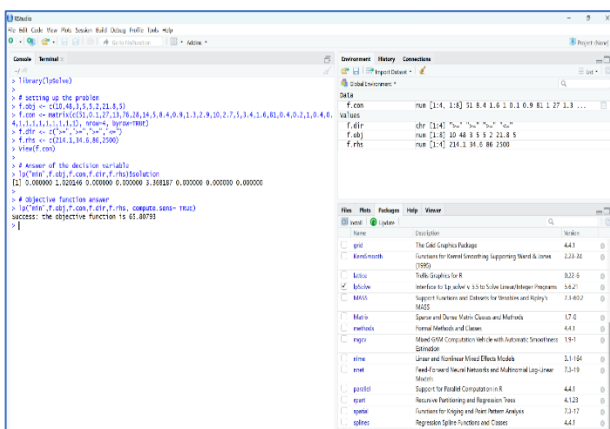
In this step we get the values to the decision variable that is

$$x_1 = 0, x_2 = 1.020, x_3 = 0, x_4 = 0, x_5 = 3.368, x_6 = 0, x_7 = 0, x_8 = 0$$

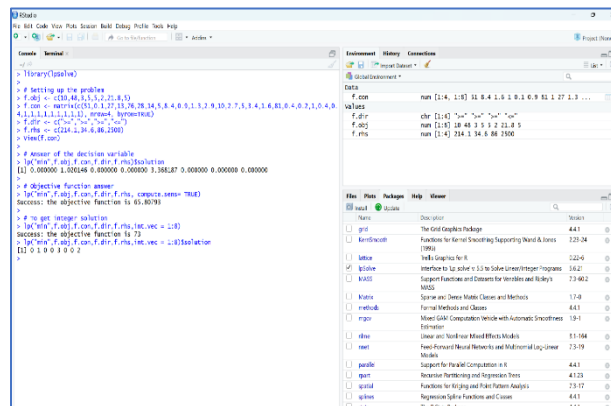
Step 4: Next we'll compute the answer to the objective function.

In this after performing the program we'll get the minimized price as required.

Since the decision variables we are getting here are non-integer so we will have the optimized value of objective function as non-integer value.



Step 5: To get integer solution



Value of objective function is: 65.80793

So, the integer value of objective function is: 73

And integer value of decision variables comes out to be

$$x_1 = 0, x_2 = 1, x_3 = 0, x_4 = 0, x_5 = 3, x_6 = 0, x_7 = 0, x_8 = 2$$

Now, after getting the integral values of objective function and decision variables we can even get the sensitive analysis of the function using R software.

Sensitive analysis of function

Also, after calculation of optimized price the sensitive analysis of variables is done. So that an individual can get an idea that in what variation in price range may not affect the optimized solution.

However, we urge that any diet plan must be implemented only after consulting a qualified medical professional and should be taken into account the individual's unique health conditions.

References:

- [1] Lemke, C. E. (1954). The dual method of solving the linear programming problem. *Naval Research Logistics Quarterly*, 1(1), 36-47.
- [2] Anderson, A. M., & Earle, M. D. (1983). Diet planning in the third world by linear and goal programming. *Journal of the Operational Research Society*, 34(1), 9-16.
- [3] Henson, S. (1991). Linear programming analysis of constraints upon human diets. *Journal of Agricultural Economics*, 42(3), 380-393.
- [4] Soden, P. M., & Fletcher, L. R. (1992). Modifying diets to satisfy nutritional requirements using linear programming. *British Journal of Nutrition*, 68(3), 565-572.
- [5] Drewnowski, A. (2004). Obesity and the food environment: dietary energy density and diet costs. *American journal of preventive medicine*, 27(3), 154-162.
- [6] Darmon, N., Ferguson, E. L., & Briend, A. (2006). Impact of a cost constraint on nutritionally adequate food choices for French women: an analysis by linear programming. *Journal of nutrition education and behavior*, 38(2), 82-90.
- [7] Quintiliani, L., Poulsen, S., & Sorensen, G. (2010). Healthy eating strategies in the workplace. *International journal of workplace health management*, 3(3), 182-196.
- [8] Katz, D. L., & Meller, S. (2014). Can we say what diet is best for health? *Annual review of public health*, 35, 83-103.
- [9] Van Dooren, C., Tyszler, M., Kramer, G. F., & Aiking, H. (2015). Combining low price, low climate impact and high nutritional value in one shopping basket through diet optimization by linear programming. *Sustainability*, 7(9), 12837-12855.
- [10] Okubo, H., Sasaki, S., Murakami, K., Yokoyama, T., Hirota, N., Notsu, A., ... & Date, C. (2015). Designing optimal food intake patterns to achieve nutritional goals for Japanese adults through the use of linear programming optimization models. *Nutrition journal*, 14, 1-10.
- [11] Parlesak, A., Tetens, I., Dejgard Jensen, J., Smed, S., Gabrijelcic Blenkus, M., Rayner & Robertson, A. (2016). Use of linear programming to develop cost-minimized nutritionally adequate health promoting food baskets. *PLoS one*, 11(10), e0163411.
- [12] Alaini, R., Rajikan, R., & Elias, S. M. (2019). Diet optimization using linear programming to develop low cost cancer prevention food plan for selected adults in Kuala Lumpur, Malaysia. *BMC public health*, 19, 1-8.
- [13] Nilu, T. Y., Ahmed, S., & Ahmed, H. (2020). Analysis of diet choice towards a proper nutrition plan by linear programming. *Medicine*, 7(8), 26.
- [14] Chungchunlam, S. M., Garrick, D. P., & Moughan, P. J. (2021). Using Linear Programming to determine the role of plant-and animal-sourced foods in least-cost, nutritionally adequate diets for adults. *Current Developments in Nutrition*, 5(11), nzab132.
- [15] Sultana, J., Hasan, M. M., Tanni, S. I., Ruman, U., & Islam, S. (2022). An Approach to Diet Cost Optimization for Different Age Groups Using Linear Programming. *Open Access Library Journal*, 9(1), 1-11.
- [16] Chaudhary, A., Chaudhary, A. K., Chaudhary, A., Bhandari, A., Dahal, S., & Bhusal, S. (2022). Alcoholic liver disease among patients admitted to the Department of Internal Medicine of a Tertiary Care Centre: a descriptive cross-sectional study. *JNMA: Journal of the Nepal Medical Association*, 60(248), 340.
- [17] Dev, B., Shah, A., Chaudhary, A., Yadav, A. K., Jha, S. C., & Chaudhary, A. K. (2022). Lumbar Disc Degenerative Disorder among Patients Undergoing Magnetic Resonance Imaging in a Tertiary Care Centre: A Descriptive Cross-sectional Study. *JNMA: Journal of the Nepal Medical Association*, 60(249), 430.
- [18] Yadav, V.P., and Dhabas, R. (2023). Student Diet Problem using Linear Programming Approach. *International Research Journal of Management Science & Technology*, 14(12), ISSN: 2250-1959 (online), 2348-9367 (print).
- [19] Ayoob, F., Manivannan, J. R., Ahamed, A., Murikkanchery, A. K., Mondal, A., Bhatnagar, G., & Thomas, T. (2024). An Optimization Tool to Formulate Diets within a Supplementary Nutrition Program for Children. *Current Developments in Nutrition*, 8(7), 104409.
- [20] Deo, K. K., Chaudhary, A. K., Shrestha, R., Chaudhary, A., Adhikari, B., Bista, A., ... & Sutihar, A. (2024). Hydrocele among Patients undergoing Surgery in the Department of Surgery in a Tertiary Care Center: A Descriptive Cross-sectional Study. *JNMA: Journal of the Nepal Medical Association*, 62(275), 458.