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Extended Goal Programming DASH Diet Plan for Stroke Patients

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Abstract: *Goal Programming (GP) optimizes decisions in diet planning by computing efficient solutions that minimize deviations from the recommended nutrient goals target levels. Extended Goal Programming (EGP) enhances the flexibility of the GP model by using additional maximal deviation parameters that create a balance between efficiency and equity in the model. This work presents an EGP 2000-calorie daily Dietary Approaches to Stop Hypertension (DASH) diet plan for stroke patients. The proposed diet plan minimizes deviations from daily recommended nutrient targets, addressing the dual role of diet in stroke prevention and recovery. Data from the recommended food chart and nutrient levels were collected from the Nutritional Epidemiology Institute and DASH diet plan bulletins while the food samples and weights were obtained from Abia State, Nigeria. This study achieves three objectives: formulating an EGP diet model, presenting an efficient diet plan, and comparing results with those of other GP model variants. LINGO software is used in the analysis. The diet plan obtained showed six goals targets out of nine were achieved. A comparison of the EGP diet plan with the Chebyshev GP diet plan highlights the EGP's flexibility and efficiency than the latter.*

***Keywords**: Extended Goal Programming, Goal Programming Variants, Stroke Diet, DASH eating plan, Diet Optimization.*

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1.0 Introduction

Goal programming (GP) presents a technique for solving multi-objective problems in various fields of study. The GP method has been extended and enhanced by researchers most notably Ijiri (1965), Ignizio (1976), Romero (1991), and Tamiz and Jones (1996). Extended Goal Programming (EGP) is a flexible GP optimization model for multi-objective decision-making problems. It gives efficient and balanced solutions to multi-objective problems through the inclusion of additional maximal deviation terms that create a balance between efficiency and equity in the model (Jones *et al*. 2016). In the context of diet planning, the GP model has been applied several times to obtain diet plans that minimize deviation from set nutrient targets (Gerdessen and De-Veris 2015). EGP on the other hand has not been applied to the diet plan problems. Meanwhile, the EGP model is an extension of the GP model which has additional parameters of balance and equity that enhance flexibility in obtaining a more balanced diet plan with equiTable nutrient content at the desired cost. Stroke, a condition associated with poor blood flow resulting in cell death, underscores the significance of dietary choices (Lin 2021).

Larsson (2017) emphasized that stroke is a significant contributor to mortality and long-term disability, with irreversible consequences. Stroke survivors often face mental and physical impairments, necessitating assistance in daily activities. Foods can either shield against or heighten the risk of stroke, with nutrient-based recommendations like Dietary Reference Intakes (DRIs) guiding dietary intake. To operationalize DRIs effectively, a food intake pattern must be designed. Here, Extended Goal Programming (EGP) proves invaluable for the stroke patient. As the decision maker, EGP empowers them to formulate a diet plan that not only meets diverse nutrient intake levels but also adheres to recommended daily food servings while minimizing costs. This strategic optimization technique offers a systematic and efficient approach to decision-making in stroke prevention through nutrition.

Past studies suggested that diet optimization methods are useful in achieving diet plan goals, especially for health conditions that require a particular diet plan for better recovery or prevention. However, the selection of the consumed foods is usually done intuitively and most times it is subject to a trade-off between the available household budget for foods and the micronutrient and macronutrient needs. The main challenge in this diet plan problem is meeting the recommended nutrient level or minimizing deviation from the specific nutrient levels amidst the conflicting nutrient levels (Sinha and Sen, 2011). GP and EGP models have been applied in the diet plan problem as well as other areas by several researchers. Koenen *et al*. (2022) proposed a bi-objective goal programming algorithm in diet optimization in which on one hand all nutrient intakes except energy are allowed to deviate from their prescription which is considered beneficial in situations with restrictive budget or when a nutritionally adequate diet is either unaffordable or unattainable. Also, the exact energy intake is relaxed, with the other nutrients kept within their requirements, to investigate how the energy intake acts on the cost of a diet. Alam (2022) utilized goal programming to assess the financial planning of Saudi Basic Industries Corporation (SABIC). Oliveira *et al*. (2021) presented an extended goal programming model for the integrated lot-sizing and cutting stock problem in manufacturing. The formulation enabled balancing conflicting goals and optimizing cost efficiency. Iwuji and Agwu (2017) Proposed a weighted Goal Programming DASH diet model that minimizes the daily cost of the DASH eating plan as well as deviations of the diet's nutrient content from the DASH diet's tolerable intake levels for persons with hypertension. Abdallah and Kapelan (2017) introduced Iterative Extended Lexicographic Goal Programming (iELGP) as an effective and efficient optimization method for addressing pump scheduling challenges in water distribution networks. Jones *et al*. (2016) proposed an Extended Goal Programming methodology for balanced decision-making in a hierarchical network, emphasizing efficiency across objectives and stakeholders. The model demonstrated in the context of regional renewable energy generation, is controlled by three key parameters governing non-compensation and centralization. Jones and Wall (2015) applied extended goal programming in offshore wind farm site selection, emphasizing the strategic significance of using the United Kingdom's proposed round three sites as an example. Gerdessen and De-Veris (2015) demonstrated the use of the EGP achievement function in allowing flexibility in choosing between Minsum and minimax functions in a diet problem. Muhammad *et al* (2015) used extended lexicographic goal programming to address a multi-objective non-linear integer allocation problem in multivariate stratified random sampling with a linear regression estimator. The proposed approach introduces a new Gamma cost function for achieving optimum allocation. In this study, we apply the extended goal programming model to obtain an efficient daily diet plan for persons with stroke that minimizes deviation from the recommended nutrient intake level in the DASH diet plan for persons with stroke.

2. Methodology

2.1 Goal programming variants.

One of the GP variants used in solving multi-objective problems is the Chebyshev GP model.

2.1.1 Chebyshev GP Variant

Chebyshev goal programming is used to minimize the unwanted deviation, rather than the sum of deviation, in multi-objective problems. It's called Chebyshev GP because it uses the underlying Chebyshev means of measuring distance. It is presented by Hillier (2010) as follows;

$$Minimize\ D = \lambda \quad (1)$$

Subject to

$$\mathrm{F_q(x)} + n_q - p_q = b_q \qquad ,q = 1, \dots, Q \quad (2)$$

$$\frac{u_q n_q}{k_q} + \frac{v_q P_q}{k_q} \leq \lambda \quad (3)$$

$$x \in F \quad (4)$$

$$n_q, p_q \geq 0$$

where

D is the objective function

n_q and p_q are the underachievement and overachievement in goal q

u_q and v_q are the weights associated with minimization variables (negative and positive) from the target value

$f_i(x)$ is the function of decision variables

k_q is a normalization constant associated with the qth goal.

2.1.3 Extended goal programming model

The EGP model allows a parametric analysis of the trade-off between efficiency and balance between the goal target values' achievement levels. Given α as the parameter that balances optimization (efficiency) and equity between the conflicting goals, the EGP model presented by Hillier (2010) is given by

$$\text{Min D} = \alpha\lambda + \beta \sum_{q=1}^{Q} \left(\frac{u_q n_q}{k_q} + \frac{v_q p_q}{k_q} \right) \quad (5)$$

Subject to

$$\sum_{j=1}^{n} a_{jq} x_j + n_q - p_q = b_q \qquad j=1,2,...,n \quad (6)$$

$$\sum_{i=1}^{n} c_{ij} x_j \ (\leq, =, \geq) g_j \qquad i= 1,2, \dots, m \quad (7)$$

$$\frac{U_q n_q}{K_q} \leq \lambda \quad , q \in Q_1 \quad (8)$$

$$\frac{V_q P_q}{K_q} \leq \lambda \quad , q \in Q_2 \quad (9)$$

$$x_j \leq s_j\ , \beta = 1 - \alpha\ , n_q \geq 0, p_q \geq 0, x_i \geq 0, n_q\, p_q = 0, Q_1, Q_2 \varepsilon Q\ ,$$

where $k_q$is the normalization constant associated with the qth goal, a_{jq} is the quantity of ith nutrient in one serving of food in goal q, i= 1,...,m. C_{ij} is the quantity of ith nutrient in calorie i, j = 1,...,m.

$u_q$and v_q are the weights associated with per unit minimization of the positive and negative deviational variable from the qth target value. Q_1 and Q_2 is an ordered set of the indices of unwanted positive and negative deviational variables, b_q is the estimated target level for qth goal, S_j is recommended daily servings of food j, α is the relative importance of the minimization of the maximum unwanted deviations from the set of goals, β is the relative importance of the minimization of the normalized weighted sum of unwanted deviations from the set of goals.

2.2 Diet and Stroke

Diet will influence stroke development through multiple pathways and mechanisms, including effects on blood pressure, blood lipids, thrombosis and coagulation, oxidative stress, systemic inflammable, endothelial function, glucose and insulin homeostasis, gut microbiome, and body weight. There are many dietary approaches each one targets a different contribution to reducing stroke. For an overall eating plan, we consider the DASH (Dietary Approach to Stop Hypertension) plan which has been proven to be effective in lowering the risk of stroke.

2.2.1 The DASH eating plan

The DASH diet is rich in fruits, vegeTables, and low-fat dairy products and is reduced in saturated and total fat. In an RCT involving 459 adults, the DASH diet significantly reduced systolic and diastolic blood pressure by 5.5 and 3.0mmHg, respectively, more than a control diet. Prospective studies have also shown an inverse association between the DASH dietary pattern and the risk of stroke. DASH eating plan is a healthy way of eating designed to be flexible enough to meet the lifestyle and food preferences of most people since it requires no special foods and instead provides daily and weekly nutritional goals. The number of servings depends on the number of calories you are allowed each day. There are calorie levels in the DASH Plan; 1600, 1800, 2000, 2200, 2400, 2600, 2800 and 3000 calories. This work will focus on 2000 calories serving. One's calorie levels depend on age and especially how active one is. The activity level is made up of;

(i) **Sedentary:** When you do only light physical activity that is part of your physical day-to-day routine.
(ii **Moderately Active:** When you do physical activity equal to walking about 1.5-3miles a day at 3-4 miles per hour, plus light physical activity.
(iii) **Active:** When you do physical activity equal to walking more than 3 miles per day at 3-4 miles per hour plus light physical activity.

2.3 Extended goal programming model for the DASH Diet problem for stroke patients

The decision variables for the weighted Goal Programming DASH diet model are $x_1, x_2, \ldots, x_8$ which represents the daily number of servings of foods 1,2,3,…, 8 in the diet plan.

The target goals to be achieved include:

- Goal 1(Cost goal): Minimize the overachievement of the daily budget cost (C_q) of the diet plan in naira (₦).
- Goal 2(Sodium nutrient goal): Minimize the overachievement of the maximum tolerable intake level of sodium, S in milligrams (mg).
- Goal 3(Saturated fat goal): Minimize the overachievement of the maximum tolerable intake level of saturated fat, SF in milligrams (mg)
- Goal 4 (Total fat goal)**:** Minimize the overachievement of the maximum tolerable intake level of total fat F in grams (g)
- Goal 5 (Calorie goal): Attain a daily calorie level of CAL
- Goal 6(Protein goal): Minimize the underachievement of the minimum tolerable intake level of protein in grams (g)
- Goal 7(Magnesium goal): Minimize the underachievement of the minimum tolerable intake level of magnesium MAG in milligrams (mg)
- Goal 8(Fibre goal): Minimize the underachievement of the minimum tolerable intake level of fibre FIB in grams (g)
- Goal 9(Potassium goal): Minimize the underachievement of the minimum tolerable intake level of potassium PO in milligrams (mg)
- Goal 10(Calcium goal): Minimize the underachievement of the minimum tolerable intake level of calcium CAC in milligrams (mg).
- Goal 11(Carbohydrate goal): Minimize the overachievement of the

maximum tolerable intake level of carbohydrate CAR in grams (g)

- Goal 12(Cholesterol goal): Minimize the overachievement of the maximum tolerable intake level of cholesterol, COL in milligrams (mg)

The extended goal programming model for the diet plan is presented as follows:

$$\text{Min } D = \alpha\lambda + \beta\left(\frac{v_1p_1}{k_1}+\frac{v_2p_2}{k_2}+\frac{v_3p_3}{k_3}+\frac{v_4p_4}{k_4}+\frac{v_5p_5}{k_5}+\frac{u_6n_6}{k_6}+\frac{u_7n_7}{k_7}+\frac{u_8n_8}{k_8}+\frac{u_9n_9}{k_9}+\frac{u_{10}n_{10}}{k_{10}}+\frac{v_{11}p_{11}}{k_{11}}+\frac{v_{12}p_{12}}{k_{12}}\right) \quad (10)$$

Subject to

(cost goal constraint)

$$a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + a_{14}x_4 + a_{15}x_5 + a_{16}x_6 + a_{17}x_7 + a_{18}x_8 + n_1 - p_1 = C_N \quad (11)$$

(Sodium goal constraint)

$$a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + a_{24}x_4 + a_{25}x_5 + a_{26}x_6 + a_{27}x_7 + a_{28}x_8 + n_2 - p_2 = S_{(mg)} \quad (12)$$

(Saturated fat goal constraint)

$$a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + a_{34}x_4 + a_{35}x_5 + a_{36}x_6 + a_{37}x_7 + a_{38}x_8 + n_3 - p_3 = SF_{(mg)} \quad (13)$$

(Total fat goal constraint)

$$a_{41}x_1 + a_{42}x_2 + a_{43}x_3 + a_{44}x_4 + a_{45}x_5 + a_{46}x_6 + a_{47}x_7 + a_{48}x_8 + n_4 - p_4 = F_{(g)} \quad (14)$$

(Calorie goal constraint)

$$a_{51}x_1 + a_{52}x_2 + a_{53}x_3 + a_{54}x_4 + a_{55}x_5 + a_{56}x_6 + a_{57}x_7 + a_{58}x_8 + n_5 - p_5 = CAL \quad (15)$$

(Protein goal constraint)

$$a_{61}x_1 + a_{62}x_2 + a_{63}x_3 + a_{64}x_4 + a_{65}x_5 + a_{66}x_6 + a_{67}x_7 + a_{68}x_8 + n_6 - p_6 = PT_{(g)} \quad (16)$$

(Magnesium goal constraint)

$$a_{71}x_1 + a_{72}x_2 + a_{73}x_3 + a_{74}x_4 + a_{75}x_5 + a_{76}x_6 + a_{77}x_7 + a_{78}x_8 + n_7 - p_7 = MAG_{(mg)} \quad (17)$$

(Fibre goal constraint)

$$a_{81}x_1 + a_{82}x_2 + a_{83}x_3 + a_{84}x_4 + a_{85}x_5 + a_{86}x_6 + a_{87}x_7 + a_{88}x_8 + n_8 - p_8 = FIB_{(g)} \quad (18)$$

(Potassium goal constraint)

$$a_{91}x_1 + a_{92}x_2 + a_{93}x_3 + a_{94}x_4 + a_{95}x_5 + a_{96}x_6 + a_{97}x_7 + a_{98}x_8 + n_9 - p_9 = K_{(mg)} \quad (19)$$

(Calcium goal constraint)

$$a_{10,1}x_1 + a_{10,2}x_2 + a_{10,3}x_3 + a_{10,4}x_4 + a_{10,5}x_5 + a_{10,6}x_6 + a_{10,7}x_7 + a_{10,8}x_8 + n_{10} - p_{10} = CAC_{(mg)} \quad (20)$$

(Carbohydrate goal constraint)

$$a_{11,1}x_1 + a_{11,2}x_2 + a_{11,3}x_3 + a_{11,4}x_4 + a_{11,5}x_5 + a_{11,6}x_6 + a_{11,7}x_7 + a_{11,8}x_8 + n_{11} - p_{11} = CAB_{(mg)} \quad (21)$$

(Cholesterol goal constraint)

$a_{12,1}x_1 + a_{12,2}x_2 + a_{12,3}x_3 + a_{12,4}x_4 + a_{12,5}x_5 + a_{12,6}x_6 + a_{12,7}x_7 + a_{12,8}x_8 + n_{12} - p_{12} = CH_{(mg)}$ (22)

where $x_{1,2,\dots,n} \leq s_j$

s_j is the number of servings of foods j, j=1,2,..8

$\frac{u_q n_q}{k_q} \leq \lambda$ q ε Q_1 (23)

$\frac{v_q p_q}{k_q} \leq \lambda$ q ε Q_2 (24)

where: $x_1, x_2, \dots, x_8 \geq 0, n_q p_q = 0, Q_1 Q_2 \varepsilon Q, \lambda \geq 0, \alpha + \beta = 1$

n_1, and p_1 are the underachievement and overachievement of budgeted daily cost of diet

$n_2, n_3, n_4, n_5, n_6, n_7, n_8, n_9, n_{10}, n_{11}, n_{12}$ represents the underachievement of maximum tolerable intake of foods.

$p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10}, p_{11}, p_{12}$ are the overachievement of maximum tolerable foods

$u_1, u_2, u_3, u_4, u_5, u_6, u_7, u_8, u_9, u_{10}, u_{11}, u_{12}$, represent the weights associated with the minimization of the negative deviational variable for the food target value

$v_1, v_2, v_3, v_4, v_5, v_6, v_7, v_8, v_9, v_{10}, v_{11}, v_{12}$, are the weights associated with the minimization of positive deviational variable for the food target value.

$k_1, k_2, k_3, k_4, k_5, k_6, k_7, k_8, k_9, k_{10}, k_{11}, k_{12}$, represents the normalized constant associated with food

g is the percentage of nutrients in the calorie level

λ is the maximum deviation from the goal target

Q_1 and Q_2 are the ordered set of the indices of unwanted negative and positive deviational variables.

$$\text{Min } D = \lambda + \left(\frac{(1)p_1}{1500} + \frac{(1)p_2}{1500} + \frac{(1)p_3}{16} + \frac{(1)p_4}{68} + \frac{(1)p_5}{2000} + \frac{(1)n_6}{115} + \frac{(1)n_7}{542} + \frac{(1)n_8}{34} + \frac{(1)n_9}{4721} + \frac{(1)n_{10}}{1334} + \frac{(1)p_{11}}{284} + \frac{(1)p_{12}}{129}\right) \quad (25)$$

Subject to:

(cost goal constraint)

$100x_1 + 70x_2 + 100x_3 + 100x_4 + 200x_5 + 100x_6 + 70x_7 + 300x_8 + n_1 - p_1 = ₦1500$ (26)

(Sodium goal constraint)

$2x_1 + 20x_2 + 16x_3 + 8x_4 + 6x_5 + 3x_6 + 60.75x_7 + 59x_8 + n_2 - p_2 = 1500_{mg}$ (27)

(Saturated fat goal constraint)

$0.05x_1 + 0.04x_2 + 0.07x_3 + 0x_4 + 0.1x_5 + 0x_6 + 1.63x_7 + 0.8x_8 + n_3 - p_3 = 16_{mg}$ (28)

Total fat goal constraint

$0.4x_1 + 0.2x_2 + 0.2x_3 + 2x_4 + 0.6x_5 + 1.6x_6 + 4.28x_7 + 5.1x_8 + n_4 - p_4 = 68_g$ (29)

(Calorie goal constraint)

$106x_1 + 30x_2 + 115x_3 + 137x_4 + 118x_5 + 134x_6 + 62.55x_7 + 141x_8 + n_5 - p_5 = 2000_g$ (30)

(Protein goal constraint)

$0.6x_1 + 1.4x_2 + 1.5x_3 + 7.7x_4 + 7.9x_5 + 3.5x_6 + 5.67x_7 + 23.6x_8 + n_6 - p_6 = 115_g$ (31)

(Magnesium goal constraint)

$10x_1 + 24x_2 + 14x_3 + 62x_4 + 114x_5 + 31x_6 + 4.95x_7 + 39x_8 + n_7 - p_7 = 542_g$ (32)

(Fibre goal constraint)

$4.8x_1 + 1.4x_2 + 3x_3 + 1.4x_4 + 5.3x_5 + 3.7x_6 + 0x_7 + 0x_8 + n_8 - p_8 = 36_g$ (33)

(Potassium goal constraint)

$214x_1 + 268x_2 + 366x_3 + 326x_4 + 312x_5 + 93x_6 + 58.95x_7 + 375x_8 + n_9 - p_9 = 4721_g$ (34)

(Calcium goal constraint)

$$72x_1 + 26x_2 + 26x_3 + 20x_4 + 24x_5 + 7x_6 + 23.85x_7 + 55x_8 + n_{10} - p_{10} = 1334_g \quad (35)$$

(Carbohydrate goal constraint)

$$22.8x_1 + 5x_2 + 25.3x_3 + 21.2x_4 + 17.5x_5 + 24.6x_6 + 0.32x_7 + 0x_8 + n_{11} - p_{11} = 248_g \quad (36)$$

(Cholesterol goal constraint)

$$0x_1 + 0x_2 + 0x_3 + 0x_4 + 0x_5 + 0x_6 + 165x_7 + 52x_8 + n_8 - p_8 = 129_g \quad (37)$$

3.1 Results and interpretation

The EGP model for the daily diet plan of persons with stroke is analysed using the LINGO optimization software. The efficient solutions for deviations from recommended nutrient intake levels and daily serving sizes are presented in Tables 1 and 2. Table 1**:** Summary of the EGP diet plan nutrient deviation. From Table 1, we can say that the extended goal programming model gave an efficient solution since out of 12 goals, 9 goals were achieved with 3 goals not achieved, and also the maximum unwanted deviation given was not exceeded. From the goals in which the overachievement of the tolerable limits is being minimized (i.e. cost, sodium, calorie level, saturated fat, protein, carbohydrate, cholesterol, and total fat goals), 6 goals were achieved while 2 were not achieved. On the other hand, From the goals in which the underachievement of the tolerable limits is being minimized (i.e. magnesium, calcium, potassium, and fibre nutrient goals), 3 goals were achieved while the goal was not achieved**.** Also, Table 2, presents information on the number of food servings of the EGP diet plan solution, it is seen that the achieved diet plan from the EGP model does not include apples and maize. This might be because of their high price in the season of data collection as the model minimizes cost. Nevertheless, other cheaper sources of fruits and food items like cucumber, Bambara cake, and cowpea with high levels of potassium, calcium, magnesium, and fibre are in the diet plan.

Table 1: Summary of EGP diet plan nutrients deviation from the target level

Goals	Target val	Negative Deviation	Positive deviation	%deviation from Target	Goal achievement
Cost	1500	0	371.50	24.77	Not achieved
Sodium	1500	1132.73	0	75.52	Achieved
Saturated fat	16	0	0	0	Achieved
Total fat	68	45.09	0	66.31	Achieved
Calorie	2000	250.13	0	12.51	Achieved
Protein	115	32.22	0	28.02	Achieved
Magnesium	542	0	147.53	27.22	Achieved
Fibre	34	0	2.83	8.32	Achieved
Potassium	4721	0	765.40	16.21	Achieved
Calcium	1334	875.08	0	65.60	Not achieved
Carbohydrate	284	0	0	0	Achieved
Cholesterol	129	0	61.13	47.39	Not achieved
		λ= 0.6559785			

Table 2: Summary of the EGP solution showing the deviation of the servings from the recommended no. of servings

Foods	Recommended no. of Servings	Achieved no. of servings	Deviation from the Recommended Servings
Apple	5	0	5
Cucumber	5	5.00	0
Sweet potatoes	5	5.00	0
Bambara cake	5	5.00	0
Cowpea	5	1.47	3.53
Maize	8	0	8
Egg	2	2.00	0
Fish	2	0.28	1.72

Table 3 presents the comparison between EGP and Chebyshev GP models in their achievement of the goal which is to minimize unwanted deviations from the recommended nutrient's target levels.

Table 3 Comparison of deviations from goals between EGP and Chebyshev GP models

Goals	Target value	Extended GP model			Chebyshev GP model		
		Deviation	% deviation	Achiev	deviation	% deviation	Achiev
Cost	₦1500	371.5(+ve)	24.77	NA	905.93(+ve)	60.40	NA
Sodium	1500mg	1132.73(-ve)	75.52	A	1102.82(-ve)	73.52	A
S.fat	16mg	0	0	A	9.66(+ve)	60.38	NA
T.fat	68g	45.09 (-ve)	66.31	A	42.32(-ve)	62.24	A
Calorie	2000	250.13(-ve)	12.51	A	55.19(+ve)	2.76	NA
Protein	115g	32.22(-ve)	28.02	A	7.85(-ve)	6.83	A
Magnesium	542g	147.53(+ve)	27.22	A	415.52(+ve)	76.66	A
Fibre	34g	2.83(+ve)	8.32	A	14.79(+ve)	43.5	A
Potassium	4721mg	765.4(+ve)	16.21	A	1573.28(+ve)	33.33	A
Calcium	1334g	875.08(-ve)	65.60	NA	805.67(-ve)	60.40	NA
Carbohydrates	284g	0	0	A	39.48(+ve)	13.90	NA
cholesterol	129mg	61.13(+ve)	47.39	NA	61.21(+ve)	47.45	NA
Max. unwanted deviation		65.60			60.40		

****Achiev - Achievement**

From the results in Table 3, the EGP model achieved 9 out of 12 goals while the Chebyshev GP model on the other hand achieved 6 out of the 12 goals. This shows the EGP model achieves a more efficient diet plan that minimizes unwanted deviations from the recommended nutrient target in the daily diet plan.

Meanwhile, from Table 4, which presents the number of servings of the foods in the diet plan, the servings of cucumber, sweet potatoes, Bambara cake, egg, and maize were exactly achieved while those of fish and cowpea had minimal deviations.

From the information provided in the Table, the maximum unwanted deviation of the solution obtained using the extended goal programming model was 65.60, while those of weighted and Chebyshev were 69.83 and 60.40 respectively, the deviation from the target and number of achievements in the extended goal programming model is observed to give the best optimal solution than those of the weighted and Chebyshev goal programming model.

Table 4: Deviation from recommended serving

Foods	**Recommended No. of servings**	**EGP**		**Chebyshev GP**	
		No. of Servings	Deviation From recommen servings	No. of servings	Deviation From Recommended Servings
Apple	5	0	5	0	5
Cucumber	5	5.00	0	5.00	0
Sweet potatoe	5	5.00	0	5.00	0
Bambara Cake	5	5.00	0	5.00	0
Cowpea	5	1.48	3.52	3.73	1.27
Maize	8	0	8	0.33	7.67
Egg	2	2.00	0	2.00	0
Fish	2	0.29	1.71	0.56	1.44

4.0 Conclusion

This study presented an extended GP model that minimizes deviations from recommended nutrient intake levels that reduce the systolic blood pressures in moderately stroke patients as evident in tests carried out. The extended GP model was used to minimize the budgeted daily diet cost, minimizing the overachievement of the recommended daily requirement for sodium, saturated fat, total fat, carbohydrate, protein, and cholesterol while also minimizing the underachievement of the recommended daily requirement for magnesium, fibre, potassium, calcium and also maintaining the daily calorie level. The efficient daily diet plan obtained using the EGP model was compared with the Chebyshev GP model diet plan. The results obtained showed that the EGP model achieves minimized deviations from the nutrient's target levels than the Chebyshev GP model. This is so as more of the nutrient's target goals were achieved for the EGP model than the Chebyshev GP model. So it can be concluded that the EGP model produces a more efficient daily diet plan for people with stroke that balances equiTable daily food servings and minimises deviation from recommended nutrient intake levels than the Chebyshev GP model.

5.0 References

Abdallah, M., & Kapelan, Z. (2017). Iterative extended lexicographic goal programming method for fast and optimal pump scheduling in water distribution networks. *Journal of Water Resources Planning and Management*, 143, 11 https://doi.org/10.1061/(ASCE)WR.1943-5452.0000843.

Alam, T. (2022). Modeling and analyzing a multi-objective financial planning model using goal programming. *Appl. Syst. Innov*, 5, 128 https://doi.org/10.3390/asi5060128

Gerdessen, J. C., & De Vries, J. H. (2015), Diet models with linear goal programming: impact of achievement functions. *European Journal of Clinical Nutrition*, 69, 11, pp. 1272-1278. DOI: 10.1038/ejcn.2015.56.

Ignizio, J. P. (1978). A Review of Goal Programming: A Tool for

Multiobjective Analysis. *The Journal of the Operational Research Society*, 29, 11, pp. 1109-1119.

Ijiri, Y.(1965) Management Goals and Accounting for Control. Rand-McNally, Chicago.

Iwuji, A. C., & Agwu, E. U. (2017). A weighted goal programming model for the Dash diet problem: comparison with the linear programming DASH diet model. *American Journals of Operations Research*, 7,. Pp. 307-322.10. DOI;4236/ajor.2017.75023

Jones, D. F., Florentino, H., Cantane, D., & Oliveira, R. (2016). An extended goal programming methodology for analysis of a network encompassing multiple objectives and stakeholders. *European Journal of Operational Research*, 225, 3, pp. 845-855.

Jones, D. F., And Wall, G. (2016) An extended goal programming model for site selection in the offshore wind farm sector. *Annals of Operations Research* 245, 1, pp. 121-135.

Koenen, M.F.,Balvert, M. & Fleuren, H. (2022). Bi-objective goal programming for balancing cost vs nutritional adequacy. *Frontiers in Nutrition*, 1-22. 9:1056205. doi: 10.3389/fnut.2022.1056205

Larsson S.C. (2017). Dietary Approaches for Stroke Prevention. *Stroke*, 48, 10, pp. 2905-2911. Doi: 10.1161/STROKEAHA.117.017383.

Lin, C.-L. (2021). Stroke and diets – A review. *Tzu Chi Medical Journal*, *33*(3), 238. https://doi.org/10.4103/tcmj.tcmj_168_20

Muhammad *et al*. (2015). Multi-objective Compromise Allocation in Multivariate Stratified Sampling Using Extended Lexicographic Goal Programming with Gamma Cost Function. *J Math Model Algor*, 14, 2, pp. 255–265. https://doi.org/10.1007/s10852-014-9270

Oliveira, W. A., Fiorotto, D. J., Song, X., & Jones, D. F. (2021). An extended goal programming model for the multiobjective integrated lot-sizing and cutting stock problem. *European Journal of Operational Research*, 295, 3, pp. 996-1007.

Romero, C. (1991). On Misconceptions in Goal Programming. *The Journal of the Operational Research Society*, 42, pp. 927-928.

Sinha, B., & Sen, N. (2011). Goal programming approach to the tea industry of Barak Valley of Assam. *Applied Mathematical Sciences*, 5, 29, pp. 1409-1419.

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The authors declare that they have no conflict of interest.

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All data used in this study will be readily available to the public.

Consent for publication

Not Applicable.

Availability of data and materials

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