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Original Research Paper

Evaluation of the Position of Roller Compacted Concrete as a Green Material Based on Sustainable Development Criteria (Economic, Social and Environmental)

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A R T I C L E I N F O

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Abstract

Asphalt pavements are associated with severe environmental problems including energy consumption and greenhouse gas emissions. Roller compacted concrete (RCC) is one of the recently developed materials in pavement construction and can be used as an apt alternative for asphalt to tackle the mentioned problems. However, previous studies did not quantitatively calculate three pillars of sustainable development on RCC simultaneously. This study targets to investigate the sustainable development impacts of RCC and asphalt pavements to show that positive economic, social and environmental effects of RCC pavements are much higher than asphalt pavements. Questionnaire was prepared and green materials factors were identified through experts and then were ranked in order to select the most important factors for green materials in RCC, including ‘durable pavement’, ‘useful life’, ‘life cycle cost’, ‘reuse of pavement’ and ‘fossil fuels reduction’ with scores of 0.495, 0.247, 0.06, 0.12 and 0.03, respectively, using Stepwise Weight Assessment Ratio Analysis (SWARA) method. A matrix calculated through Excel was used to analyze sustainable development criteria. Also, Green Road Standard was used for both RCC and asphalt pavements. Finally, economic, social and environmental comparisons of concrete and asphalt pavements show 2 negative effects, 15 positive effects and 4.52 effects average for concrete pavement, and 8 negative effects, 10 positive effects and -0.28 effects average for asphalt pavement. The obtained results of this study prove the superiority of RCC for using in road construction projects in terms of sustainability.

Keywords: *RCC, Sustainable development, SWARA method, Asphalt pavement, Green material.*

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INTRODUCTION

Roller Compacted Concrete (RCC) is a Portland Cement product and a kind of concrete admixture, usually zero-slump, which has recently been widely used due to its low construction cost and faster performance than asphalt (Taylor, 2012; Calis & Yıldızel, 2019). RCC pavement was first introduced for a runway construction in North America (Kokubu & Anzaki, 1989). After that, pavement projects using RCC have expanded in recent years, such as parking lots, highways, roadway shoulders, etc. (Hossain, Ozyildirim, & Celik, 2016). RCC has identical strength features and basic components to conventional concrete, but with different mixture proportions and lower paste for sustainable pavement construction, which has made it a suitable material for constructing pavements that can sustain burdensome loads and bad weathers with very slight maintenance requirement and a very short construction period (Roller-Compacted Concrete Pavements, 2010; Ali & Abbas, 2022; Topli, Grdi, Risti, & Grdi, 2015; Schrader, 1987; Pavements, 2015; Khayat & Libre, 2014). Moreover, materials and gradation of Roller Compacted Concrete Pavement (RCCP) are similar to conventional concrete and hot mix asphalt pavement, respectively, and a wider variety of materials can be used by RCC as compared to conventional concrete (Keleş & Akpinar, 2022; Scanlon, Tarbox, Hess, & Hulshizer, 1999). Another feature is that due to the dryness and stiffness of RCCP mixture, the construction method of RCCP is different from conventional concrete pavements and similar to asphalt pavements, and since RCC is much stiffer than asphalt concrete (AC), tensile fatigue will not occur in AC (Hunan & Guangdong, 2014; Sok, Kim, Park, & Lee, 2022). From an economic standpoint, the primary costs of RCC pavement are much lower than asphalt pavements and conventional concrete, and since the use of asphalt pavements might lead to some inefficiencies, using RCCP may be reasonable, economically and technically, and even a long life can be achieved for the asphalt pavement on RCC base (Rezaei, Kordani, & Zarei, 2022; Moradi & Shahnoori, 2021; Liu, Wu, Li, & Xu, 2021). This benefit is mainly due to its low cement volume, which has made RCCP an economical and eco-environmentally alternative for pavements (Kalhori & Ramezanianpour, 2021). The credibility of RCCP concrete mixture for constructing the road pavement is dependent on the mechanical features of RCCP, such as compressive strength and splitting tensile strength (Zhang, Hamzehkolaei, Rashnoozadeh, Band, & Mosavi, 2022; Abbasi, Shafigh, & Baharum, 2021). However, the utilization of asphalt in concrete might be detrimental to its mechanical properties (Dareyni, Mohammadzadeh Moghaddam, & Delarami, 2018). The compressive strength and split tensile strength of RCC can be increased in a variety of ways, such as the rise of cement content (Teja & Ramesh, 2021), the need of low water with high workability and compaction (Rakesh, Maddala, Priyanka, & Barhmaiah, 2021), and using metakaolin with or without steel fiber (Abu-Bakr, Mahmood, & Mohammed, 2022). In addition, the compressive strength of RCC including Compaction is very essential in the formation of RCC structure, and RCCP applications have similar compaction to asphalt pavements (Issa & Zollinger, 2022; Selvam, NSSP, Kannan, & Singh, 2023). The implication of sustainable development is based on three dimensions namely ecological, social and economic pillars of sustainability (Klarin, 2018). Some approaches were investigated for improving the sustainability of pavements with concrete materials, and their economic, environmental and societal impacts were also considered qualitatively (Snyde et al, 2016; Siva Rama Krishna & Tadi, 2022). Sustainable development can be obtained for concrete mixtures in a number of ways, such as using recycled alternative materials (Zamora-Castro et al., 2021), the use of stone dust as an alternative to sand (Turuallo et al, 2020), using waste tyre rubber due to the cost efficiency and reduction of CO2 emissions (Ince et al, 2022), and using waste materials with the conservation of mechanical properties (Helmy et al, 2023). There are also some materials which can improve the sustainability of RCC, such as several alternative aggregates including recycled concrete aggregates (RCA), reclaimed asphalt pavement (RAP) aggregates, crumb rubber, electric-arc furnace steel slag aggregates (Selvam et al, 2022), utilization of waste materials, such as RAP (Debbarma et al, 2022), cold reuse of RAP (Boussetta et al, 2020), RAP and red mud (Ram Kumar &

Ramakrish, 2022), using coal waste (Modarres et al, 2018), coal bottom ash (Tighe, Haas, & Ningyuan, 2006), the utilization of ceramic and coal waste powders (Shamsaei et al, 2019), using fly ash as a cementitious material (Hashemi & Shafigh, 2018), a mixture of fly ash, crumb rubber and nano-silica (Adamu, Mohammed, & Liew, 2018), circulation fluidized bed combustion (CFBC) fly ash (CFA) (Lin et al., 2019), using copper slag (CS) waste fine aggregates (Sheikh, Mousavi, & Afshoon, 2022), using steel slag materials (Gallant & Asce, 2019), a mix of coconut shell ash and eggshell powder as a cement substitution (Ogbonna, 2021), using coarse RCA (Lopez-uceda et al, 2016), recycled aggregates and recycled steel fibers (Muscal et al, 2013), a natural pozzolan namely Trass (Ghahari, Mohammadi, & Ramezanianpour, 2017), the utilization of cross-linked polyethylene (XLPE) waste (Shamsaei, Aghayan, & Kazemi, 2017), using recycled tire rubbers and shredded rubber tire aggregates (Fakhri & Farshad, 2016; Meddah, Beddar, & Bali, 2014). Furthermore, sustainable RCCP mixtures would be designed in a range of ways, such as soil compaction, concrete consistency, consistency-compaction, etc (Selvam & Singh, 2022).

Some approaches were investigated for improving pavement sustainability with concrete materials production. Moreover, a literature review was conducted on sustainable pavements for roads with low volume, using sustainable materials like pervious concrete pavements, and generally their economic, environmental, and societal impacts were also considered qualitatively (Snyder et al., 2016; Krishna & Tadi, 2022). Rakesh et al. (2021) investigated that various materials can be used for RCC, including crusher dust, which is obtained from mining and quarrying with fine particles. However, environmental and social impacts of RCC were ignored. According to Hashemi et al. (n.d.) producing large amounts of RCCP for infrastructure development might lead to an increase in CO2 emissions. Fardin and Santos (2020) focused on studying the mechanical and physical characteristics of RCC utilized with RCA as an alternative for natural coarse aggregate. Marzouk et al. (2017) conducted an investigation about the application of methodology based on BIM to evaluate the environmental impacts in road construction projects. Anwer and Zena (2022) reviewed RCC according to four factors, such as environmental impact, cost, inclusion of fiber, and particular RCC utilization for the country. But the evaluation of economic and social impacts of RCC and road construction projects were not investigated and reviewed (Ali & Abbas, 2022; Hashemi et al., n.d.; Fardin & Santos, 2020; Marzouk et al., 2017). Debbarma et al. (2020) provided a set of studies relating to the utilization of RAP aggregates for RCCP. Ameli et al. (2021) investigated the application of waste materials, such as RAP and crumb rubber, into RCCP, which contributes to sustainable development while having economic and environmental advantages. Debbarma and Ransinchung (2021) reviewed that the utilization of RAP in RCCP mixtures may provide economic and environmental advantages, such as depletion in RAP stockpiles and reduction in carbon footprints, respectively. Moradi and Shahnoori (2021) studied the impacts of substituting sands acquired from mines on the properties of RCCP. Teja and Kumar (2021) conducted a literature review regarding the utilization of various sustainable materials into RCC mixes for rigid pavement construction, such as natural aggregates and red mud, which reduce CO2 emissions. However, there were no investigations and reviews about societal impacts of RCC (Moradi & Shahnoori, 2021; Teja & Kumar, 2021; Debbarma et al., 2020; Ameli et al., 2021; Debbarma & Ransinchung, 2021). Aghayan et al. (2021) studied the environmental life cycle of RCCP containing ceramic waste aggregate and coal waste powder. However, their study lacked consideration of the economic impacts of RCCP.

Although the above mentioned studies were accomplished to qualitatively investigate the sustainability of RCC based on the sustainable development dimensions, none of which quantitatively calculated three pillars of sustainable development on RCC simultaneously. The chief target of this research is to investigate the application of RCC in improving economic, social and environmental effects on roads construction. The study aims to identify and rank effective factors of selecting green materials in concrete pavements at the first stage. According to the identified factors, as well as by using the questionnaire and its distribution among the statistical population, and by using the SWARA decision criterion method, the factors of green materials are ranked, and the most important factors are selected. Moreover, ecological, social and economic factors of sustainable development are evaluated and calculated quantitatively to prove RCC as a sustainable pavement in various projects. In the third stage, sustainable development effects of RCC are calculated and compared with asphalt in which economic, users and maintenance costs of both RCC and asphalt are investigated in a certain period. Altogether, this paper targets to evaluate the position of RCC as a green material to achieve sustainable development.

Research Methodology

This part provides information concerning the specific method utilized to recognize, elicit, prepare, and analyze data about the interest phenomenon, making readers able to evaluate the reported results sufficiently. Due to the multiplicity of contents in this research, an explanation of the various tools and methods employed is given in the subsequent parts to improve transparency.

The process and stages of this study are described according to its objectives, and in Fig. 1.

1. Identification of effective factors in selecting green materials in concrete pavements: Effective factors in selecting green materials in concrete pavements are identified using the literature review of Green Road Standard and the distribution of checklists (Table 5).
2. Ranking the effective factors in selecting green materials in concrete pavements: Green materials factors are ranked according to the identified factors, as well as by using the questionnaire and its distribution among the statistical population and the SWARA decision criterion method, the most important factors for green materials in RCC are selected.
3. Evaluation of roller compacted concrete from the standpoint of sustainable development factors (economic, social and environmental impacts): Using the calculated matrix through Excel, economic, social and environmental impacts of concrete and asphalt pavement designs are evaluated.

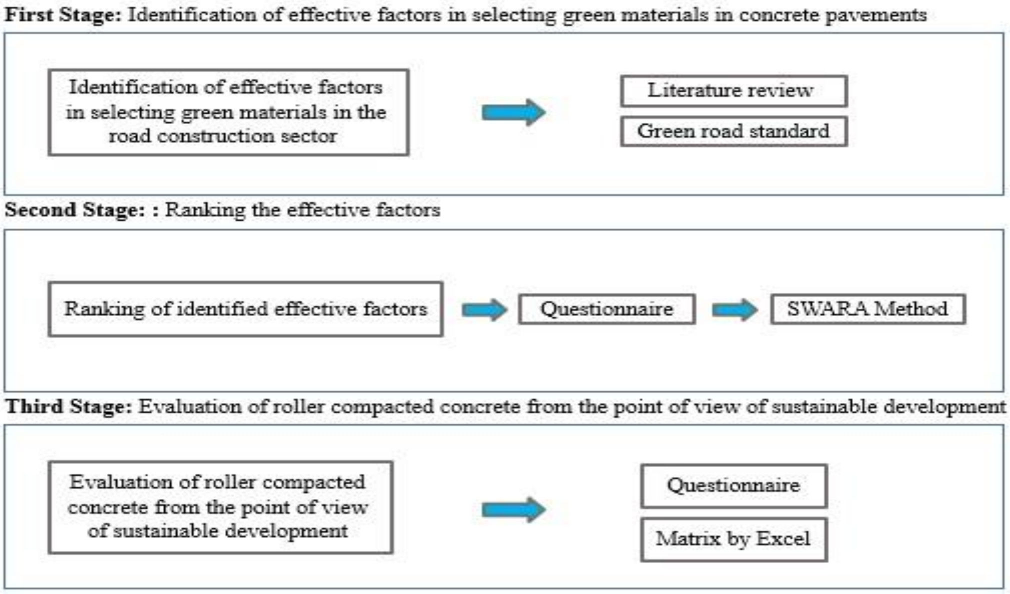

Fig 1. Steps of research

Questionnaire

In this study, a questionnaire was designed to identify effective factors in selecting green materials in concrete pavements. In this questionnaire, the respondents were asked to weigh the identifications of effective factors in selecting green materials in the identified concrete pavements according to the evaluation criteria. For this purpose, a 5-point Likert scale was utilized. In this scale, 1 and 5 were the least and the most important, respectively. The information obtained from this questionnaire was used for analysis in the SWARA method.

Identification of factors contributing to sustainability criteria

Selection criteria for the experts

In the research compiled based on the questionnaire, the selection and determination of the statistical sample is an important factor. The statistical population of this research consisted of experts working in the road construction department, totaling 120 people. Sampling from the statistical population is used when the number of individuals and geographical coverage are large (Al-Tmeemy et al., 2011). The sample size was calculated based on the following formula (Al-Tmeemy et al., 2012). The minimum number of experts required to complete the questionnaires was specified according to Equation (1), where SS, z, p, and c represent sample size, confidence level coefficient, confidence interval, and selection percentage, respectively.

$$SS = \frac{z^2 p(1-p)}{c^2} \quad (1)$$

Equations (2) and (3) were utilized to create a corrected sample size (SS), and *rr* defines the response rate:

$$Corrected\ SS = \frac{SS}{1+\left(\frac{SS-1}{pop}\right)} \quad (2)$$

In Equation (2), *pop* is the population and the corrected sample size (SS) for the response rate was measured using Equation (3), while *rr* is the response rate:

$$Corrected\ SS\ for\ rr = rr * corrected\ SS \quad (3)$$

Reliability

In this study, Cronbach's alpha test was utilized to determine the questionnaire reliability. Reliability signifies that to what extent the measurement tool gives the same results in the same conditions. In order to determine the reliability and measurement tool, there are also many different methods that one of which is estimating its internal consistency. The internal consistency of measurement tool can be measured by Cronbach's alpha coefficient. The most commonly used reliability coefficient is the Cronbach's alpha value, which ranges from 0 to 1, and higher values indicate higher reliability. Table 1 shows the domain of Cronbach's alpha coefficients and its reliability level.

Table 1. Reliability domain and Cronbach's alpha coefficients

Reliability Level	Cronbach's Alpha Coefficient
Very much	1
Much	0.8-0.99
Medium	0.6-0.79
Low	Less than 0.59

SWARA method

In numerous multi-factor decision-making problems, weighing the factors is one of the most significant steps in solving the problem (Hafezalkotob et al., 2018). Based on this, experts play an important role in evaluating the factors and their weights, and they are responsible for an unavoidable part of the decision-making process. The SWARA method is one of the most recent approaches introduced by Keršuliene et al. (2010), enabling the decision maker to select, assess, and weigh the factors. The most significant advantage of this method compared with other similar approaches is its ability to assess the precision of experts' perceptions about the weighted factors during the process. Furthermore, experts are able to consult with one another, and such consultation makes the obtained results more precise than those achieved by other decision-making criteria (Zolfani et al., 2013). This method is understandable and requires fewer pairwise comparisons than ANP and AHP methods (Hafezalkotob et al., 2018). Therefore, in the current research, using this method to calculate the weight of criteria, the steps of weighing by the SWARA method are illustrated in Fig. 2. In this method, each expert ranks the criteria first. The most significant criterion is ranked first, and the least significant is assigned the last rank. Finally, the criteria are prioritized based on the average values of respective significance. In this method, the expert plays an essential role in evaluating the calculated weights, and each expert determines the significance of each criterion based on their implicit knowledge, information, and experience. Then, according to the average value of group ranks acquired from experts, the weight of each criterion is specified.

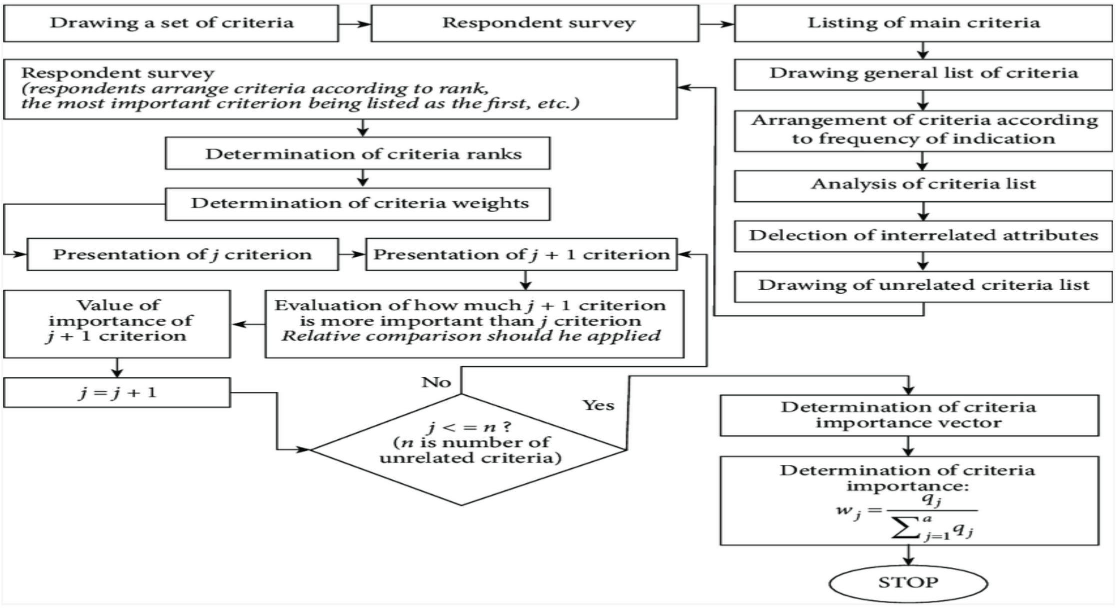

Fig2. The stages of weighing factors in the SWARA method

The calculated matrix is used to identify, investigate, predict and evaluate the effects and consequences of the activities of a plan or a project on the components and parameters of the environmental factor and policymaking and final decision-making about options. At this stage of the matrix process, the proposed different options are examined and compared, and finally, the option that has the least negative effects or its negative effects can be prevented and controlled more, and in terms of comparison, receives a higher positive score, will be selected as the best option. In the mentioned matrix calculated through Excel, rows and columns represent environmental factors and project activities, respectively. Environmental factors are classified according to physical, chemical, biological, social, economic and cultural environments, and in each environment, the impressionable micro-factors of the implementation of the project are determined according to the existing study records of the plan and field visits. Negative effects that are in the range of (-5) to (-3.1) are considered as destructive and significant effects, and should be reduced as much as possible by providing a corrective option. The point that is necessary to mention in this section is that in the implementation of projects and development plans, in addition to trying to reduce negative environmental effects and outcomes, efforts should also be made to increase and strengthen the positive effects and outcomes of the project. Then, the mutual effects of project activities and environmental factors on each other are determined and loaded as numbers in the +5 to -5 ranges. The number +5 illustrates a positive effect (high usefulness or favorability), and the number -5 illustrates negative effects (high demolition or undesirability).

Research findings

Statistical society analysis

In a research that is designed based on a questionnaire, it is necessary to determine the number of respondents from the existing statistical population in order to value the answers and results. In this study, the acceptable number of respondents was determined using Equations (1), (2) and (3). The size of the statistical population in this study was 120 people working in road construction projects, who were in the contracting and employer sectors and consultants. According to Equations (1), (2) and (3) and the statistical population, 54 valid questionnaires are sufficient to refer to the answers of the questionnaire, and in this research, 96 valid questionnaires were collected. The analysis results of the statistical population valid numbers are illustrated in Table 2.

Table 2. The number of valid responses

Safety distance (C)	0.1	0.975
Percentage of selecting an option (P)	0.5	
Safety factor (Z)	95%	1.96
Response rate (rr)	92%	
Population	250	
The number of valid responses		54

In this section, the demographic statistics and the characteristics of respondents are discussed. In a research where the results of the questionnaire are effective in determining the final result, it is necessary to select people who have sufficient experience in the field of research, therefore, the information of the respondents' career history is stated, and only the information related to valid questionnaires was analyzed. Table 3 shows the frequency and percentage of respondents based on their professional career history. The respondents were divided into four groups based on their work experience. According to the obtained statistics, about 67 people, which is equivalent to 69.8 percent of the respondents, had work experience of 10 years or more in the road construction projects field. The majority of respondents were operating engineers, contractors and designing engineers. Based on Table 3 information, 25%, 20.8% and 14.5% were operating engineers, contractors, and designing engineers, respectively.

Table 3. Frequency and percentage of the number of respondents based on job experience and responsibility

The amount of work experience	Frequency	Frequency percentage	Responsibility in the project	Frequency	Frequency percentage
1-5 years	15	15.7%	Operating engineers	24	25%
6-10 years	14	14.5%	Contractors	20	20.8%
10-15 years	48	50%	Project managers	8	8.3%
More than 15 years	19	19.8%	Consulting engineers	11	11.4%
Total	96	100	Designing engineers	14	14.5%
			Employers	10	10.4%
			Supervisor engineers	9	9.3%
			Total	96	100%

Pilot study

Pilot study is prepared before distributing the main questionnaire to evaluate the reliability of the questions. These questionnaires were distributed among a small group of experts in road construction projects, whose number was 10 people. After collecting the questionnaires and using experts' opinions, the questionnaire was modified for final distribution. Cronbach's alpha test was utilized to analyze the questionnaires reliability. The cumulative test result for the questionnaire is shown in Table 4. Cronbach's alpha coefficients for the questionnaire reliability should be higher than 0.70. After collecting the questionnaires, the necessary corrections were made in the questions. Finally, the coefficients obtained from Cronbach's alpha show that the designed questionnaire is valuable, and has acceptable sustainability for distribution. According to the number of identified statistical society, which was 96 people, in this research, 96 questionnaires were distributed among them. 75 and 21 questionnaires were distributed manually and online, respectively, and 90 questionnaires were returned. The return rate of the questionnaire was 93.75%, which is an acceptable rate. Among the completed questionnaires, 4 questionnaires were incomplete and invalid.

Table 4. Cronbach's alpha coefficients for the questionnaire

Title	Cronbach's alpha coefficient
Questionnaire for weighing sustainability factors	0.812

Identification of effective factors in selecting green materials in concrete pavements

The first step in this research is the effective factors in selecting green materials in concrete pavements. In order to obtain an encyclopedic list of factors in these projects, comprehensive studies were conducted using the literature review. At this stage, 27 factors were finally identified by using the prepared checklists (Table 5). Eventually, according to the causing factors, the factors were divided into 3 economic and technical, environmental and social groups.

At this stage, by using the Green Road Standard, the effective factors in selecting green materials are identified, and based on this standard, these criteria are scored based on the scores of this standard.

Table 5. The weight of sustainability factors in the economic and technical, environmental and social groups

Row	Group	Factors	Code
1	Economic and Technical	Durable pavement	A1
2		Safety	A2
3		Early performance and exploitation	A3
4		Materials on site	A4
5		Useful life	A5
6		Life cycle cost	A6
7	Environmental	Reuse of pavement	A7
8		Light pollution reduction	A8
9		Habitat and nesting	A9
10		Vegetation	A10
11		Surface water quantity	A11
12		The Earth shape and topography	A12
13		Residual status	A13
14		Landscape situation	A14
15		Fossil fuel reduction	A15
16		Recyclable materials	A16
17		Soil erosion	A17
18		Groundwater quality	A18
19		Air quality	A19
20		Sound status	A20
21		Energy resources consumption	A21
22	Social	Transportation and traffic	A22
23		Social welfare facilities and services	A23
24		Effect on economic activities	A24
25		Employment	A25
26		Increasing income and improving the living standard	A26
27		Development plan in the region	A27

Weighing the effective factors in selecting green materials

One of the purposes of this research was to rank the effective factors. The target of this work is to identify important factors so that the beneficiaries of this type of projects can plan to identify the effects of these factors. For this purpose, a questionnaire was first prepared and distributed among road projects experts. Respondents were asked to rank the causes of identified sustainability. The valuation scale was based on a 5-point analogy that 5 and 1 represent the greatest and the least effects, respectively. At this stage, after collecting the questionnaires, the answers average was calculated. The answers average was sorted from ascending to descending, and then, the factors were ranked based on the SWARA method stages. In Table 5, the weighing of sustainability factors is discussed. The weight of factors is classified into three economic/technical, environmental and social groups, and the most important factors of each group are determined. Table 5 shows the ranking of factors and the weight of sustainable development factors in concrete pavements. Among the factors, the 5 most important identified factors were durable pavement, useful life, life cycle cost, reuse of pavement and fossil fuel reduction.

Table 6. Ranking the sustainability factors in concrete pavements

Factors	Average	s_j	$K_j=s_j+1$	$W_j=k_j-1/k_j$	$C_i=w_j/w$	Rank
A1	7.33	-	1	1	0.495	1
A5	7.30	1	2	0.5	0.247	2

Factors	Average	s_j	$K_j=s_j+1$	$W_j=k_j-1/k_j$	$C_i=w_j/w$	Rank
A7	7.26	0.990	1.99	0.25	0.12	3
A6	7.15	0.980	1.98	0.13	0.06	4
A15	6.96	0.950	1.95	0.07	0.03	5
A3	6.93	0.947	1.947	0.03	0.02	6
A21	6.87	0.940	1.940	0.02	0.01	7
A4	6.83	0.930	1.930	0.009	0.004	8
A14	6.80	0.929	1.929	0.005	0.002	9
A2	6.74	0.920	1.920	0.002	0.001	10
A11	6.70	0.910	1.910	0.001	0.0006	11
A8	6.53	0.905	1.905	0.0007	0.0003	12
A22	6.59	0.900	1.900	0.0003	0.0002	13
A19	6.57	0.896	1.896	0.0002	0.0001	14
A18	6.48	0.880	1.880	0.0001	0.00005	15
A16	6.41	0.875	1.875	0.00005	0.00003	16
A9	6.35	0.870	1.870	0.00003	0.00001	17
A25	6.33	0.864	1.864	0.00001	0.000007	18
A24	6.30	0.861	1.861	0.000008	0.000004	19
A20	6.28	0.860	1.860	0.000004	0.000002	20
A13	6.26	0.855	1.855	0.0000023	0.0000012	21
A26	6.24	0.850	1.850	0.0000013	0.000006	22
A27	6.21	0.847	1.847	0.000007	0.0000034	23
A17	6.19	0.844	1.844	0.000004	0.0000020	24
A23	6.16	0.840	1.840	0.000002	0.0000010	25
A10	6.13	0.836	1.836	0.000001	0.0000005	26
A12	6.12	0.832	1.832	0.0000006	0.0000003	27

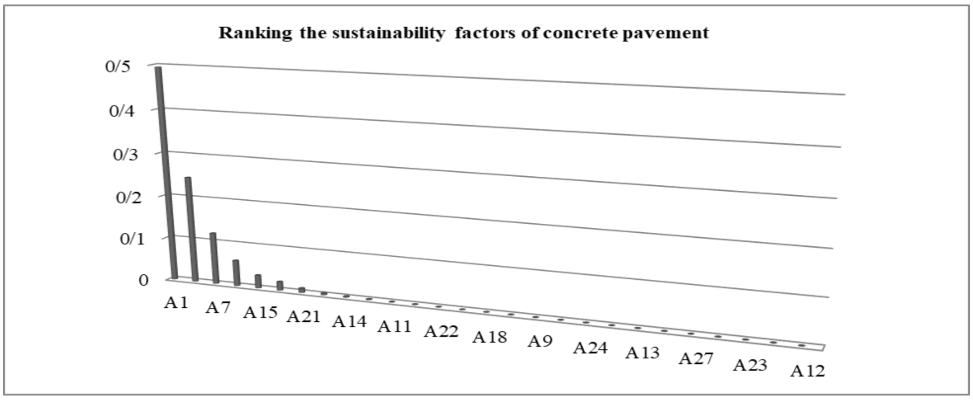

Fig 3. Ranking the sustainability factors of concrete pavement

Table 6 and Fig. 3 show the weight of sustainability factors in three economic/technical, environmental and social groups. According to the obtained results, durable pavement, reuse of pavement, and transportation and traffic factors with scores of 0.495, 0.12 and 0.0000006, respectively, were the most stable factors in these groups.

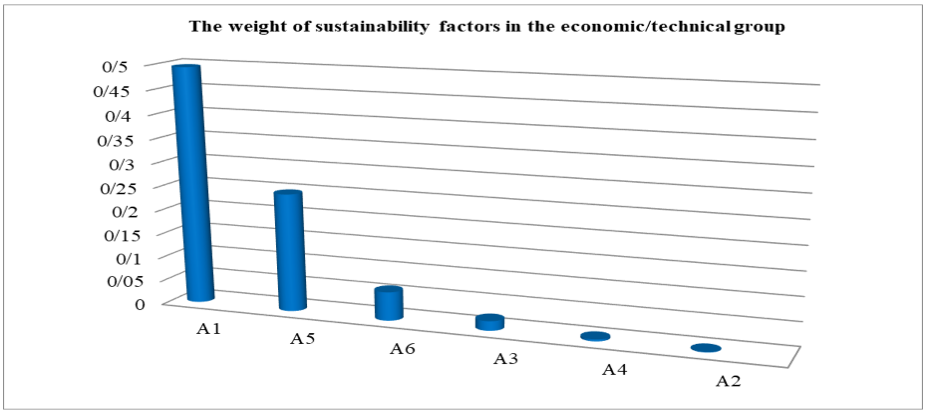

Fig 4 . The weight of sustainability factors in the economic/technical group

Fig. 4 shows the weight of sustainability factors in the economic and technical group. According to the obtained results, durable pavement, useful life and life cycle cost factors had the scores of 0.495, 0.247 and 0.06, respectively in this group.

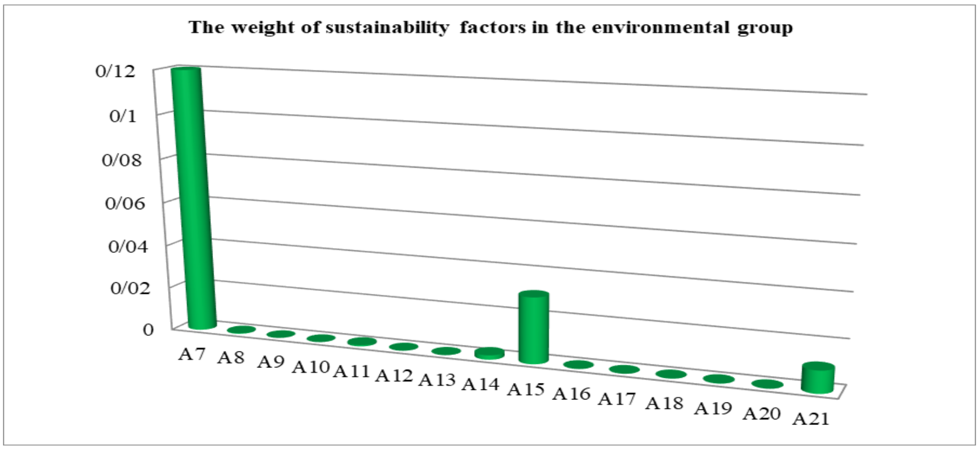

Fig 5. The weight of sustainability factors in the environmental group

Fig. 5 shows the weight of sustainability factors in the environmental group. According to the obtained results, reuse of pavement, fossil fuel reduction and energy resources consumption factors had the scores of 0.12, 0.03 and 0.01, respectively in this group.

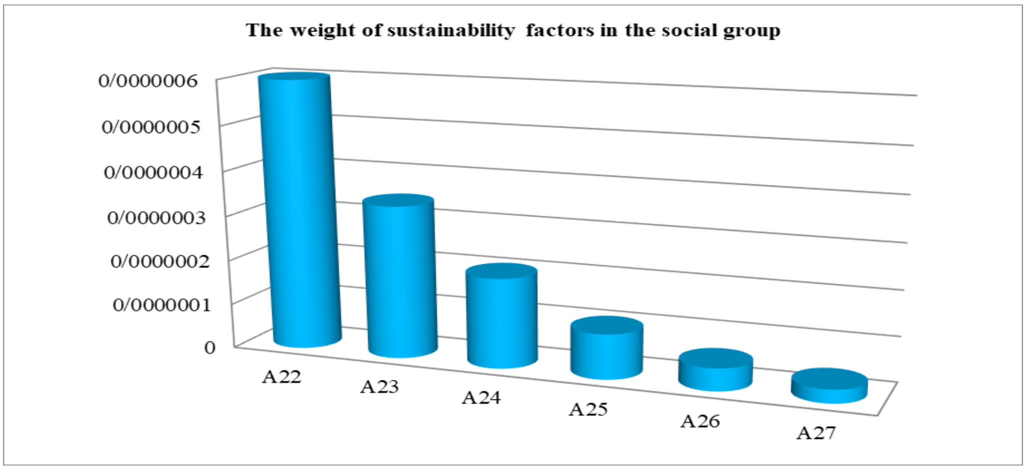

Fig 6. The weight of sustainability factors in the social group

Fig. 6 shows the weight of sustainability factors in the social group. According to the obtained results, transportation and traffic, social welfare facilities and services and effect on economic activities factors had the scores of 0.0000006, 0.00000034 and 0.0000002, respectively in this group.

3.5. Roller compacted concrete and asphalt pavements analysis using the calculated matrix by Excel

In this section, in order to draw conclusions from the studies on the evaluation of the effects of RCC and asphalt pavements, and to find out the activities positive and negative effects of these pavements during operation, based on the existing criteria, they were converted into quantitative effects, and were analyzed using the calculated matrix.

In the first stage, 27 identified criteria are categorized into economic/technical, physical/chemical, biological and social/cultural groups.

In the second stage, each of the criteria categorized based on their effects, is qualitatively evaluated with the intensity of high, medium and low effects in the form of positive or negative effects in Table 7.

In the third stage, this qualitative evaluation is converted into a numerical evaluation, which is shown in Table 7.

Table 7. Concrete pavement descriptive and numerical rating

	Environment	Sub-criterion	Operation time	Total number of results	Algebraic sum of results	Results average	Positive result numbers	Negative result numbers
1	Physicochemical	Soil quality						
2	Physicochemical	Soil stability						
3	Physicochemical	Soil erosion	2-	1	2-	2-	0	1
4	Physicochemical	Land shape and topography	2-	1	2-	2-	0	1
5	Physicochemical	Region drainage pattern						
6	Physicochemical	Natural hazards such as flood, slip and drift						
7	Physicochemical	Air quality	2-	1	2-	2-	0	1
8	Physicochemical	Groundwater quality	3	1	3	3	1	0
9	Physicochemical	Surface water quality						
10	Physicochemical	Surface water quantity	3	1	3	3	1	0
11	Physicochemical	Groundwater quantity						
12	Physicochemical	Hydrography						
13	Physicochemical	Sound status	3-	1	3-	3-	0	1
14	Physicochemical	Residual status	2-	1	2-	2-	0	1
15	Physicochemical	Fossil fuel reduction	3	1	3	3	1	0
16	Physicochemical	Landscape situation	3	1	3	3	1	0
17	Physicochemical	Light pollution reduction	3	1	3	3	1	0
18	Biological	Vegetation	2-	1	2-	2-	0	1
19	Biological	Areas under management						
20	Biological	Habitat and nesting	2-	1	2-	2-	0	1
21	Biological	Endangered plant species						
22	Biological	Endangered animal species						
23	Social/Cultural	Migration to the region						
24	Social/Cultural	Preventing migration out of the region						
25	Social/Cultural	Environmental and residents' health						
26	Social/Cultural	Development plans in the region	3	1	3	3	1	0
27	Social/Cultural	Native culture and customs						
28	Social/Cultural	Conflicts caused by water harvesting						
29	Social/Cultural	Social welfare facilities and services	3	1	3	3	1	0
30	Social/Cultural	Early performance and exploitation	4	1	4	4	1	0

	Environment	Sub-criterion	Operation time	Total number of results	Algebraic sum of results	Results average	Positive result numbers	Negative result numbers
31	Social/Cultural	Transportation and traffic	3	1	3	3	1	0
32	Economic/Technical	Useful life	4	1	4	4	1	0
33	Economic/Technical	Materials on site	3	1	3	3	1	0
34	Economic/Technical	Recyclable materials	3	1	3	3	1	0
35	Economic/Technical	Reuse of pavement	4	1	4	4	1	0
36	Economic/Technical	Energy resources consumption	3	1	3	3	1	0
37	Economic/Technical	Safety	4	1	4	4	1	0
38	Economic/Technical	Employment	3	1	3	3	1	0
39	Economic/Technical	Durable pavement	3	1	3	3	1	0
40	Economic/Technical	Increasing income and improving the living standard	3	1	3	3	1	0
41	Economic/Technical	Effect on economic activities	3	1	3	3	1	0
42	Economic/Technical	Life cycle	3	1	3	3	1	0
	Impacts	Total number	27					
	Impacts	Algebraic sum	49					
	Impacts	Average	1.8					
	Impacts	Positive effect numbers	20					
	Impacts	Negative effect numbers	7					

Operation time: it can be divided into low, medium and high impacts
Low negative impact: Soil erosion, Land shape and topography, Air quality, Residual status, Vegetation, Habitat and nesting
Medium negative impact: Sound status
Medium positive impact: Groundwater quality, Surface water quantity, Fossil fuel reduction, Landscape situation, Light pollution reduction, Development plans in the region, Social welfare facilities and services, Transportation and traffic, Materials on site, Recyclable materials, Energy resources consumption, Employment, Durable pavement, Increasing income and improving the living standard, Effect on economic activities, Life cycle
High positive impact: Early performance and exploitation, Useful life, Reuse of pavement, Safety

According to Table 7, the micro-criteria for the descriptive rating of concrete pavement are placed in the table, and the positive and negative evaluations with high, medium and low intensities are given to each of the criteria separately, and regarding the numerical ranking of the concrete pavement according to the calculated matrix, concrete pavement has been evaluated with 20 positive effects and 7 negative effects from the set of 27 effects and a positive average of 1.8, which indicates less destructive effects than the asphalt pavement.

3.6. Economic evaluation of roller compacted concrete and asphalt pavements

One of the effective factors in evaluating engineering projects is the economic parameters. Therefore, in this research, the costs of asphalt and RCC pavements are compared with each other based on the costs of construction and performance, repairs and maintenance, and users (depreciation of vehicle and tires, time spent for travel, cost spent in case of an accident due to the incomplete operation of pavement, fuel consumption cost, etc.).

The cost of road users includes the following items, which is then calculated in Table 8 and Fig. 7:

a) Vehicle operating cost: Physical characteristics and pavement conditions are effective in the speed and the amount of fuel and oil consumption and tire depreciation (vehicle operating cost). Due to the rigidity of concrete pavements, vehicle operating cost (the amount of fuel and oil consumption and tire depreciation) on these pavements is lower than on asphalt pavement.

b) Personal cost: This cost basically includes the costs of delaying users due to slowing down, stopping and blocking the road. The cost of users is mainly considered to be about one third of the construction cost in exploiting the route.

According to Table 8 and Fig. 7, RCC is 16% more economic than asphalt pavement

Table 8. Users cost on concrete and asphalt pavements

Row	Pavement	Performance cost	Increase percentage	Users cost
1	Concrete	1,719,055 IRR	30%	515,864 IRR
2	Asphalt	2,063,776 IRR	30%	619,132 IRR

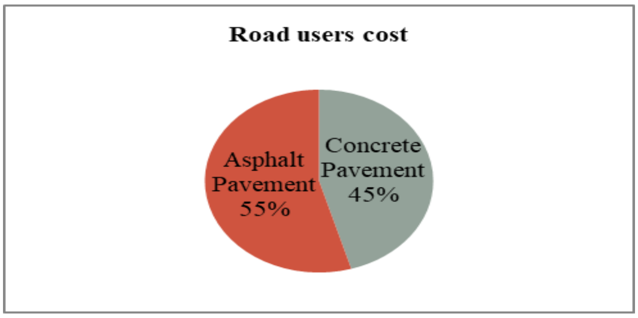

Fig 7. Users cost on concrete and asphalt pavements

Estimating the maintenance cost

In relation to the maintenance cost of roller compacted concrete pavements, no detailed study has been done so far, but it can be said that considering the concrete exposed to the weather and the passing traffic, it gradually leads to cracking during many years, and requires maintenance, as the asphalt changes drastically under the effect of temperature and traffic, and despite various damages with different intensity, it does not have the ability to have a high service life, and therefore the concrete can have a higher life according to its properties. While concrete needs maintenance after 5 years or more, asphalt usually needs maintenance after 2 to 3 years. In Table 9, the cost of the maintenance period, which is the maintenance and repair cost for the 20-year period with an annual increase rate of 15% is calculated with the cost of 5% of the performance cost for the asphalt pavement, and 2.5% of the performance cost for the concrete pavement in the first year. As it is shown in Fig. 8, the cost of asphalt pavement maintenance will be much higher than that of RCC pavement.

Table 9. The cost of asphalt and concrete pavements maintenance period

Asphalt		Concrete	
Year	Cost	Year	Cost
1	103,188 IRR	1	42,988 IRR
2	118,666 IRR	2	49,436 IRR
3	136,465 IRR	3	56,851 IRR
4	156,934 IRR	4	65,378 IRR
5	180,474 IRR	5	75,184 IRR
6	207,545 IRR	6	86,461 IRR
7	238,676 IRR	7	99,430 IRR
8	274,477 IRR	8	114,344 IRR
9	315,648 IRR	9	131,495 IRR
10	362,995 IRR	10	151,219 IRR
11	417,444 IRR	11	173,901 IRR
12	480,060 IRR	12	199,986 IRR
13	552,069 IRR	13	229,984 IRR
14	634,879 IRR	14	264,481 IRR
15	730,110 IRR	15	333,476 IRR
16	839,626 IRR	16	383,947 IRR

17	965,659 IRR	17	441,471 IRR
18	1,110,494 IRR	18	507,691 IRR
19	1,277,068 IRR	19	583,884 IRR
20	1,468,628 IRR	20	671,420 IRR
10,571,105 IRR		4,662,981 IRR	

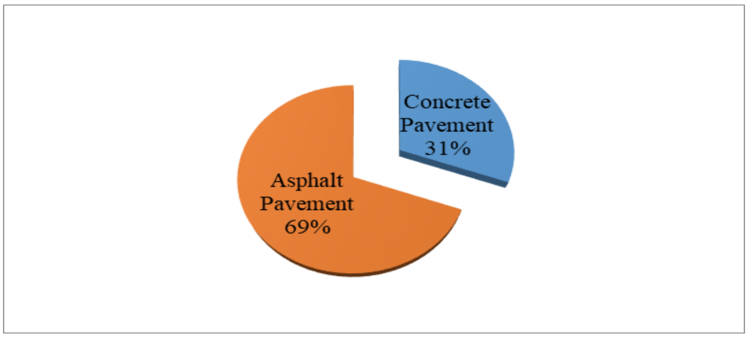

Fig 8. The cost of concrete and asphalt pavements maintenance period

Estimating the total cost

In the end, estimating the final cost of concrete and asphalt pavements, which includes the overall cost of performance, maintenance, and users is illustrated in Table 10.

Table 10. The total cost of concrete and asphalt pavements

Title	Performance cost	Users cost	Maintenance cost	Total cost
Concrete pavement	1,719,055 IRR	515,864 IRR	4,662,981 IRR	6,897,900 IRR
Asphalt pavement	2,063,776 IRR	619,132 IRR	10,571,105 IRR	13,254,013 IRR

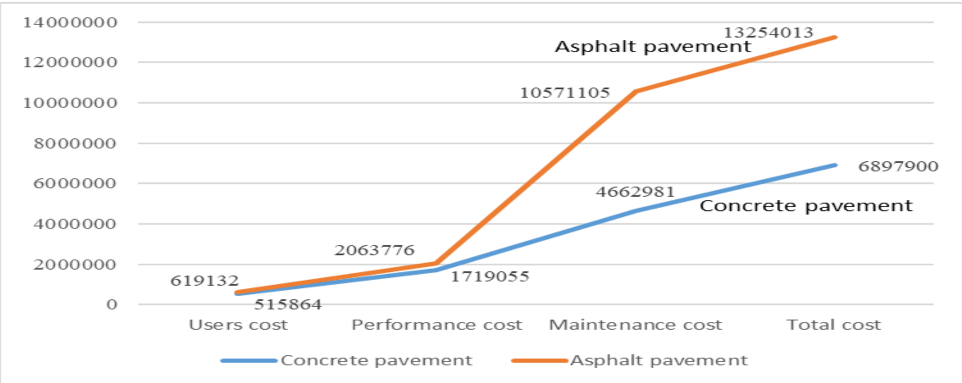

Fig 9. Economic comparison of concrete and asphalt pavements

According to Table 10 and Fig. 9, the cost of concrete construction and performance compared to asphalt, the cost of concrete users compared to asphalt, and the cost of concrete maintenance compared to asphalt reduced by 16%,16% and 55%, respectively. Therefore, according to the costs estimation in the performance, users and maintenance sections, RCC pavement can be considered as a more economical pavement than asphalt pavement.

Table 11. Biological, social and economic/technical comparisons of concrete and asphalt pavements

Title	Environmental conditions				
Pavement type	Different effects	Biological	Social	Economic/Technical	Total
Concrete pavement	Negative effect	2	0	0	2
	Positive effect	0	4	11	15
	Effects average	-2	3.25	3.27	4.52
Asphalt pavement	Negative effect	3	0	5	8
	Positive effect	0	4	6	10
	Effects average	-2.33	2.5	-0.45	-0.28

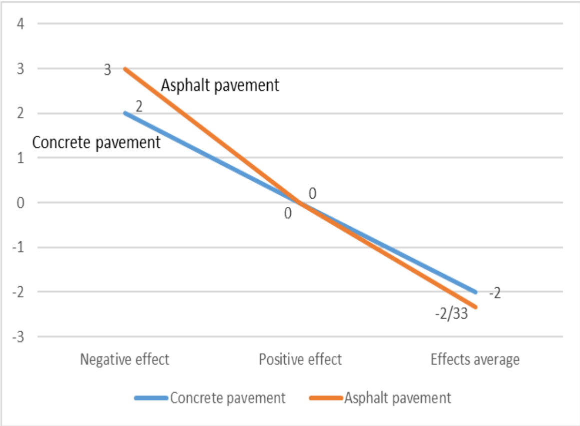

Fig 10. Biological comparison of concrete and asphalt pavements

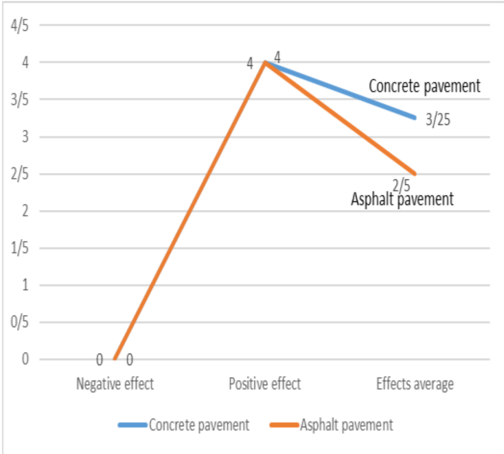

Fig 11. Social comparison of concrete and asphalt pavements

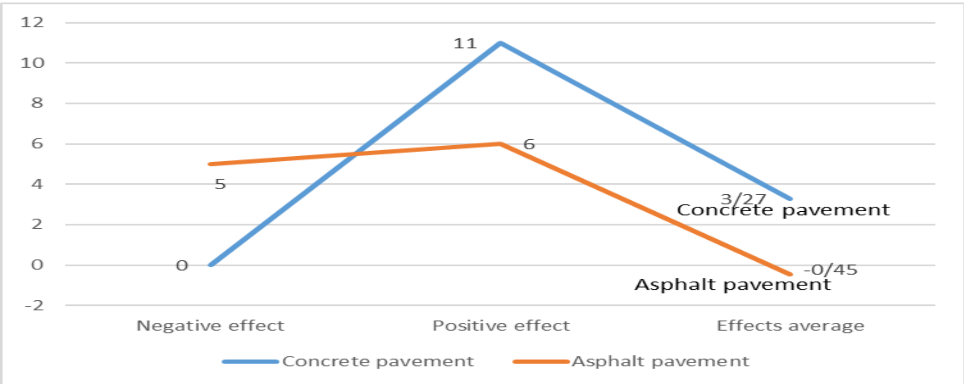

Fig 12. Economic/technical comparison of concrete and asphalt pavements

Based on Table 11, Fig. 10, Fig. 11, and Fig. 12 information, concrete and asphalt pavements are compared with each other in different environmental conditions, including biological, social and economic/technical conditions, and also negative and positive effects and effects average are calculated, which show 2 negative effects, 15 positive effects and 4.52 effects average for concrete pavement, and 8 negative effects, 10 positive effects and -0.28 effects average for asphalt pavement in biological, social and economic/technical conditions.

The hydraulic conditions of WDNs are generally evaluated by using demand-driven modeling (DDM) models as a demand function in normal operational conditions and additional pressure-driven modeling (PDM) implementations that have better responded to WDNs (WDN) analysis in operating conditions. Water distribution calculations were investigated by an under-pressure model, as it provided a better description of the system's conditions than the classical model formulas in the event of a pipe failure.

Table 12. Suitability classes of factors for dam site

Factors	Categories	Ranking	Suitability
Slope	≤ 3.1	4	High Suitable
	3.1- 7.9	3	Suitable
	7.9 – 12.9	2	Low suitable
	12.9- 19.7	1	Not Suitable
Distance from Roads	≤ 1 000 m	4	High Suitable
	1 000 m – 2 000 m	3	Suitable
	2 000 m – 3 000 m	2	Low

Factors	Categories	Ranking	Suitability
			suitable
	> 3 000 m	1	Not Suitable
Distance from Settlements and markets	< 10 km	4	High Suitable
	5-10 km	3	Suitable
	1-5 km	2	Low suitable
	> 1km	1	Not Suitable
Soil Type	Masooka rock land	4	High Suitable
	Rough mountainous land	3	Suitable
	Pirsbak	2	Low suitable
	Kamala complex	1	Not Suitable
Distance from Agricultural fields	> 500 m	4	High Suitable
	400 m – 500 m	3	Suitable
	200 m – 400 m	2	Low suitable
	> 200 m	1	Not Suitable

Results

This study had four main goals. The first goal was to identify the effective factors in selecting green materials in concrete pavements. In this step, the factors were identified utilizing the literature review, which included books, articles and Green Road Standard. In the second step, the results obtained about the factors were confirmed and proved. Finally, after collecting the results, 27 factors were identified. The factors were classified into 3 groups based on the factors of their existence, which included ‘economic and technical’, ‘social’ and ‘environmental’ groups.

The second goal of this research was to rank the effective factors in selecting green materials in concrete pavements identified in road construction projects. For this purpose, a questionnaire was first prepared and distributed among the experts of road construction projects. At this stage, after collecting the questionnaires, the answers average was calculated, and then the most important factors for selecting green materials in concrete pavements, including ‘durable pavement’, ‘useful life’, ‘life cycle cost’, ‘reuse of pavement’ and ‘fossil fuels reduction’ with scores of 0.495, 0.247, 0.06, 0.12 and 0.03, respectively were ranked based on SWARA method stages.

The third target of this study was to assess RCC from the standpoint of sustainable development factors (economic, social and environmental). At this stage, calculated matrix was used, positive and negative effects, and effects average of both concrete and asphalt pavements were analyzed, and the results have been obtained numerically in the asphalt pavement with 8 negative effects, 10 positive effects and -0.28 effects average compared to 2 negative effects, 15 positive effects and 4.52 effects average in the concrete pavement.

The final target of this research was to analyze the comparison of sustainable development effects, and using RCC than asphalt that in addition to the environmental and social effects resulting from the matrix evaluation of two pavements, economic analysis (construction, users and maintenance costs) was calculated, and presented in the form of tables and graphs, and finally, the percentages of construction and performance cost, users cost, and maintenance cost of concrete pavement compared to asphalt pavement show 16%, 16% and 55% reductions, respectively. In general, the positive economic, social and environmental effects of RCC pavements are far more than asphalt pavements, and can be used as an apt substitute in several different road construction projects.

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