UTILIZATION OF JORDANIAN OIL SHALE ASH IN ASPHALT MIX: ENVIRONMENTAL IMPACT ASSESSMENT

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ABSTRACT

The aim of this study is to conduct sustainability metrics for asphalt mix partially replaced by Jordanian Oil Shale Ash (OSA). Rapid Impact Assessment Matrix (RIAM) tool was applied to assess the environmental impact in an attempt to figure out the negative effects of using OSA in asphalt mix and to find the appropriate remediation action of these effects.

Analysis of RIAM's results indicated that using Jordanian OSA in asphalt mix will cause major positive impact resulting from Economical/Operational (EO) changes. The majority of the impacts are of class N. No negative impact on human health is expected. The Sociological/Cultural (SC) components such as the population growth and the aesthetic characteristics of the area are positively affected by the utilization of OSA-based asphalt mix. Only one negative impact is found for the Biological/Ecological (BE) category, which needs imperative attention in term of mitigation.

Keywords: oil shale ash, asphalt mix, rapid impact assessment matrix, RIAM, environmental impact assessment, sustainability metrics, industrial waste.

INTRODUCTION

In recent years, continuous and apparent deterioration has been noticed in the road network in Jordan due to the increased traffic on the roads, lack of continuous maintenance, and lack of funds. This has prompted researchers to improve the pavement performance and encouraged them to look for a pavement mixture with superior properties.

Asphalt mix has been widely used in road pavement. Estimates indicate that above 86 million tons of asphalt are combined with the aggregate annually to produce asphalt mix utilized in road pavement worldwide [1]. Unfortunately, the production of asphalt mix depletes the natural resources severely in addition to the high production cost [2].

Currently, many researchers are looking for environmentally and friendly materials to be incorporated in the asphalt mix without affecting the properties of the mixture and reduce the production cost [3, 4]. Prime example of this is the incorporation of waste material such as OSA in the asphalt mix [5].

Accumulation of solid waste such as OSA is an environmental issue of concern worldwide [6 - 8]. A safe and reliable long-term management procedure is required to avoid the negative environmental impacts of OSA. The most common practice is the direct landfilling of OSA. Unfortunately, this is not feasible from an economic point of view due to the increasing cost of landfills nowadays. This inspired the researchers towards OSA utilization instead of landfilling [9].

Several studies have investigated the possibility of incorporation of OSA in asphalt mix [10, 11]. The utilization of OSA in asphalt mix has economic and environmental benefits such as minimizing the environmental pollution, preventing the accumulation of OSA in landfills and reducing the production of new asphalt and aggregates and thus minimizing the production cost of asphalt mix. In addition, it produces high-performing asphalt mixtures.

Environmental impact assessment (EIA) of utilization OSA in asphalt mix is an essential issue from a financial and environmental engineering management perspective [12].

EIA is used to identify, predict, evaluate, and mitigate the ensuing environmental impacts of a proposed project focusing on the natural, social and economic aspects. This enables the assessor to predict the risk early in the planning and design stages and helps the decision-makers to decide whether to carry on with the project [13, 14]. The impacts could be direct or indirect, integrated or cumulative. EIA helps to manage and sustain the environment and protect both the environment and its habitants from any possible negative impact [15]. Different evaluation methods are frequently used to evaluate the potential environmental impacts, among them the checklists and RIAM.

Extensive research was carried out to exploit OSA in the engineering applications. Most of the studies focused on the technical part of the application. However, EIA studies related to OSA-based asphalt mix production are rarely investigated and assessed. In addition, evaluating the use of OSA from an ecological perspective is rarely investigated.

It is worth mentioning that the strength properties of asphalt mixes prepared from different substitution percentage of the mineral filler by OSA, concluded that the most effective percentage for substitution was 10 % OSA [5]. The goal of this study is directed toward the investigation of the environmental impacts of asphalt mix incorporated with 10 % (by weight) of Jordanian OSA to address the causes and the management of risk associated with such application, identifying the possible barriers in the using of OSA-based asphalt mix and propose a proper solution for prospective risks. RIAM tool will be employed to assess the environmental impacts.

EXPERIMENTAL

The rapid impact assessment matrix

RIAM is a powerful analytical tool used extensively for the execution and evaluation of a holistic EIA. RIAM has several advantages over the existing environmental impact evaluation methods. It provides some degree of objectivity and transparency. RIAM equips the assessors with a transparent and permanent record of analysis process as well as reducing the time needed to execute the EIA and organizing the EIA procedure [16]. Moreover, the flexibility of RIAM confers the assessors to analysis/reanalysis the selected components in depth, accurately and quickly. In addition, RIAM enables the assessors to compare different options. The graphical presentation of RIAM matrix's results greatly consolidates the clarity of the results produced [17].

According to Aiswarya and Sruthi, RIAM is idealistic mechanism where fast and clear evaluation of the main impacts is expected mainly due to the fact that all the components and parameters can easily be integrated into one platform [14]. Using RIAM, the impact of the components is scored against pre-defined criteria and the scores are then turn into ranges that describes the degree of the positive or the negative impacts.

Thus, RIAM requires identification of an important assessment criteria alongside with the necessary means to collect the semi-quantitative values for each criterion which provides an independent and accurate score for each condition. The impacts of the project activities are assessed against the environmental components. The important assessment criteria are classified into two categories [13, 15]:

(A) Criteria that are of importance (significance) to the condition, that individually can alter the resulting score, and

(B) Criteria that are of value to the situation, but individually is not capable of altering the score obtained.

A series of simple formulae are used to determine the value ascribed to each of these categories of criteria where the scores of individual components are determined on a well-defined basis and provide a measure of the impact expected from the component. The scoring system consists of simple multiplication of the score given to each of the criteria in category (A). This ensures that the weight of each score is expressed and avoids the identical results for different conditions that might be resulted from a simple summation of the scores. For Category (B), the scores attributed to each criterion are added together to end up with a single sum. This ensures the elimination of the influence of the individual value scores on the overall score but without ignoring the collective importance of all values in category (B). The result of category (A) scores is then multiplied by the sum of category (B) scores to obtain the environmental score (ES) for the condition.

The mathematical expression of the above is as follow [18]:

$$(A_1) * (A_2) = A_T \quad (1)$$
$$(B_1) + (B_2) + (B_3) = B_T \quad (2)$$
$$(A_T) * (B_T) = ES \quad (3)$$

where (A_1), (A_2) are the importance and magnitude of impact, respectively, which represent the individual criteria scores that are of importance to the condition (category (A)); (B_1), (B_2), (B_3) are the impact permanence, reversibility and cumulativity, respectively, which represent the individual criteria scores that are of value to the situation (category (B)); A_T is the result of multiplication of all (A) scores; B_T is the result of summation of all (B) scores; and ES is the environmental score for the condition. Once ES is obtained, it is then converted into a range band.

Table 1 shows the assessment criteria and the scales used in the judgment of each component. For more detailed description of the assessment criteria, readers are referred to Aiswarya and Sruthi [14].

Table 2 displays the environmental scores and the range bands used in RIAM.

The implementation of RIAM needs a special assessment of the environmental components which usually defined through a process of scoping. The environmental components are divided into four categories [13, 17]:

1. Physical/chemical components (PC)

Covering all physical and chemical aspects of the environment.

2. Biological/ecological components (BE)

Covering all biological aspects of the environment.

3. Sociological/cultural components (SC)

Covering all human aspects of the environment, including cultural aspects.

4. Economical/operational components (EO)

Quantitatively to identify the economic consequences of environmental change, both temporary and permanent.

Table 1. Assessment criteria [17].

Criteria	Scale	Description
A1. Importance of condition	4	Importance to national/international interests.
	3	Importance to regional/national interests.
	2	Importance to areas immediately outside the local condition.
	1	Importance only to the local condition.
	0	No importance.
A2. Magnitude of change/ effect.	+3	Major positive benefit.
	+2	Significant improvement in status quo.
	+1	Improvement in status quo.
	0	No change/status quo.
	-1	Negative change in status quo.
	-2	Significant negative disbenefit or change.
	-3	Major disbenefit or change.
B1. Permanence	1	No change/not applicable.
	2	Temporary.
	3	Permanent.
B2. Reversibility	1	No change/not applicable.
	2	Reversible.
	3	Irreversible.
B3. Cumulative	1	No change/not applicable.
	2	Non-cumulative/single.
	3	Cumulative/synergistic.

Table 2. Conversion of environmental scores to range bands [19].

Environmental Score (ES)	Range Bands (RB)	Range Value (RV)	Description of Range Value
+72 to +108	+E	5	Major positive change/impacts.
+36 to +71	+D	4	Significant positive change/impacts.
+19 to + 35	+C	3	Moderately positive change/impacts.
+10 to +18	+B	2	Positive change/impacts.
+1 to +9	+A	1	Slightly positive change/impacts.
0	N	0	No change/status quo/not applicable.
-1 to -9	-A	-1	Slightly negative change/impacts.
-10 to -18	-B	-2	Negative change/impacts.
-19 to -35	-C	-3	Moderately negative change/impacts.
-36 to -71	-D	-4	Significant negative change/impacts.
-71 to -108	-E	-5	Major negative change/impacts.

Fig. 1. AL-Quds Street [20].

Environmental impact assessment

EIA of incorporating the Jordanian OSA in asphalt mix is investigated in this study to assess the possible utilization of the Jordanian OSA in road pavement.

Scoping

One of the principal objectives of this project is to evaluate the OSA-based asphalt mix to provide the sustainability metrics (environment, social, economic). Another objective is to increase the national economy by reducing the imported materials, enhance the asphalt mix and decrease the maintenance costs.

The EIA study is conducted for a proposed project in which OSA-based asphalt mix is to be employed. The project is in AL-Quds Street in the AL Moqabaleen area in the south of Amman, as shown in Fig. 1.

The following are the specifications of the street:

1. Length of the street is 650 m.
2. Width of the street is 23.80 m, and there is also Bus Rapid Transit (BRT) with a width of 8.00 m.
3. Thickness of asphalt is 20 cm.

The Jordanian OSA-based asphalt mix consists of:

a. Asphalt cement: it is called asphalt blowing.
b. Aggregate: it is called dolomitic limestone.
c. Ash: it is called bottom ash from Jordanian oil shale.

The research focused on four primary environmental components of concern: Physical/Chemical (PC) component; Biological/Ecological (BE) component; Sociologic/Cultural (SC) component, and Economic/

Operational (EO) component. Issues of significance to be evaluated are identified within each environmental component of concern.

Physical impacts

Valued ecosystem components (VECs) selected for study were soil (pollution) and water resources (ground and surface water pollution and water's temperature disturbance).

Soil

The project site is located within no. 11 "Jordan Highlands Plateau" as shown in Fig. 2.

Table 3 includes a description of the soil type. This area has moderate rainfall. The thickness of the topsoil is 2 m, and the permeability of the soil is classified as slow to very slow (less than 0.2 inches of water h^{-1}). Accordingly, groundwater unlikely to be affected.

Water resources

Jordan is a semi-arid country and suffers from the scarcity of water resources. According to the Water Stress Index (Annual rainfall divided by the total population (m^3 $capita^{-1}$ $year^{-1}$), Jordan is classified in the category of "Absolute Scarcity" [21]. In addition, the population of Jordan has been recently growing due to massive influx of refugees and displaced persons and high natural growth rate.

The area of water bodies in Jordan is approximately 482 km^2. Water resources in Jordan are mainly the Gulf of Aqaba and the Dead Sea, so Jordanian people depends basically on the rainfall and groundwater. There are no surface water resources near the project site whereas groundwater resources are available with 100 m deep. The project is located in the Amman- AL-Zarqa basin, which is one of the basins exposed to excessive use.

Chemical impacts

One VEC was selected namely air quality. A change in the properties of air was considered. In general, air is considered polluted if it contains one of the polluting gases such as carbon monoxide, particles (2.5 and 10), lead, sulfur dioxide, nitrogen oxides, and volatile organic compounds. The air quality is usually monitored through the Ministry of Environment using monitoring stations located in different areas. King Abdullah II Industrial City's' station (located in Sahab region) is the closest monitoring station to the project area.

Table 4 presents the annual levels of pollutants measured at King Abdullah II Industrial City's' station and Table 5 displays Jordanian specifications for ambient air quality.

Biodiversity impacts

Two VECs, implications on plants and wildlife and impacts on habitats were nominated. Biodiversity impact is divided into impact on fauna and impact on flora. The first kind is interested in studying the animals in the project site such as reptiles (lizards, geckos and snake), wild birds, mice, sheep and wild cats. The second kind is interested in studying the plants in the project site such as trees and flowers.

Jordan is divided into four biodiversity zones as shown in Fig. 3:

1. Mediterranean: the annual rainfall is 400 - 600 mm. The typical forests are Oak, Juniper, and Pine. The project area is in this zone.

2. Irano-Turanian: the annual rainfall is 150 - 200 mm. The typical vegetation is Steppe vegetation.

3. Saharo Arabian: it is the most significant part of Jordan's land zone and an annual rainfall is 50 - 100 mm. The common plants are Artemisia herba-alba, Achillea fragrantissima, and Trigonella spicata.

4. Sudanian: the annual rainfall is 50 - 100 mm. The typical vegetation is Haloxylon persicum, Acacia sp., Calotropis procera, and Nitraria retusa.

Sociological impact

Three VECs were adopted such as population growth, the health of local populations and implications on the aesthetic characteristics of the area.

According to the latest statistics at the time of this study, the population of Jordan is 10 806 000 people of whom 5 722 000 are males and 5 084 000 are females [25]. 112 903 people live in the AL Moqabaleen area, of whom 59 936 are males and 52 967 are females. Unfortunately, there are no statistics regarding Al-Quds Street as the statistics are usually available for each city not for each street. However, the area is characterized by typical population density for Jordanian cities.

Economic impact

One VEC was chosen in this category, inflation in sales.

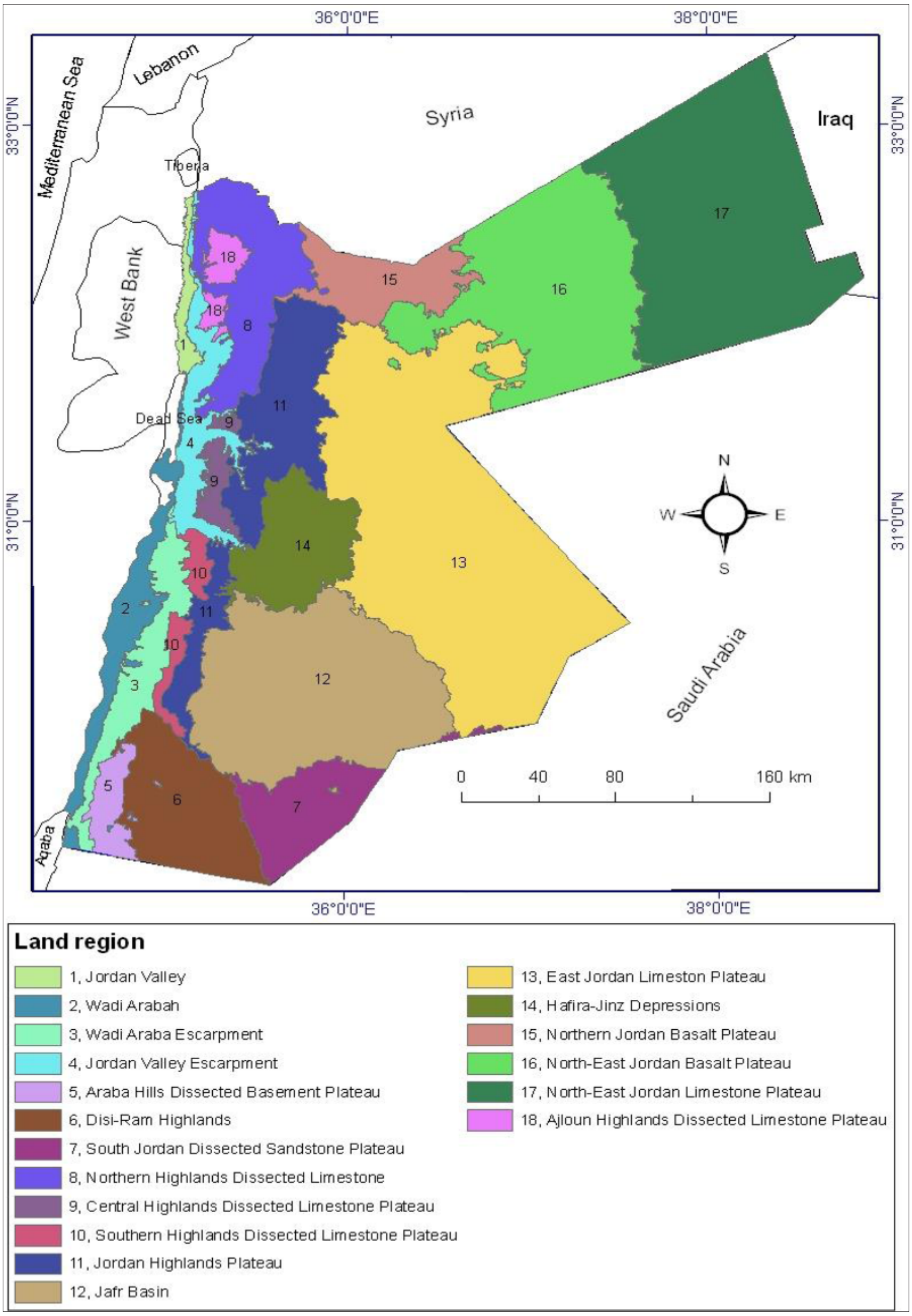

Fig. 2. Land region and soil of Jordan [22].

Table 3. Descriptions of soil type [23].

Area	Moqabaleen area (AL-Quds Street)
Land region	Jordan Highlands Plateau, (no.11).
Soil group	Inceptisols: its tendency slight, it found in arid and semi-arid regions, and it consists of Xerochreptic.
Descriptions of the soil type	Xerochreptic: 1. It is silty soil and soil fertility with light and dark brown. 2. Low organic matter and heavy metals because it contains high calcium carbonate and lime materials.

Table 4. Annual levels of pollutants [24].

	SO_2	NO_2	PM_{10}
Annual levels of pollutants	9.8 ppb	19.3 ppb	63.7 mg m^{-3}

Table 5. Jordanian specifications for ambient air quality.

	SO_2	NO_2	PM_{10}
Jordanian specifications for ambient air quality [24]	40 ppb (0.04 ppm)	50 ppb (0.05 ppm)	70 mg m^{-3}

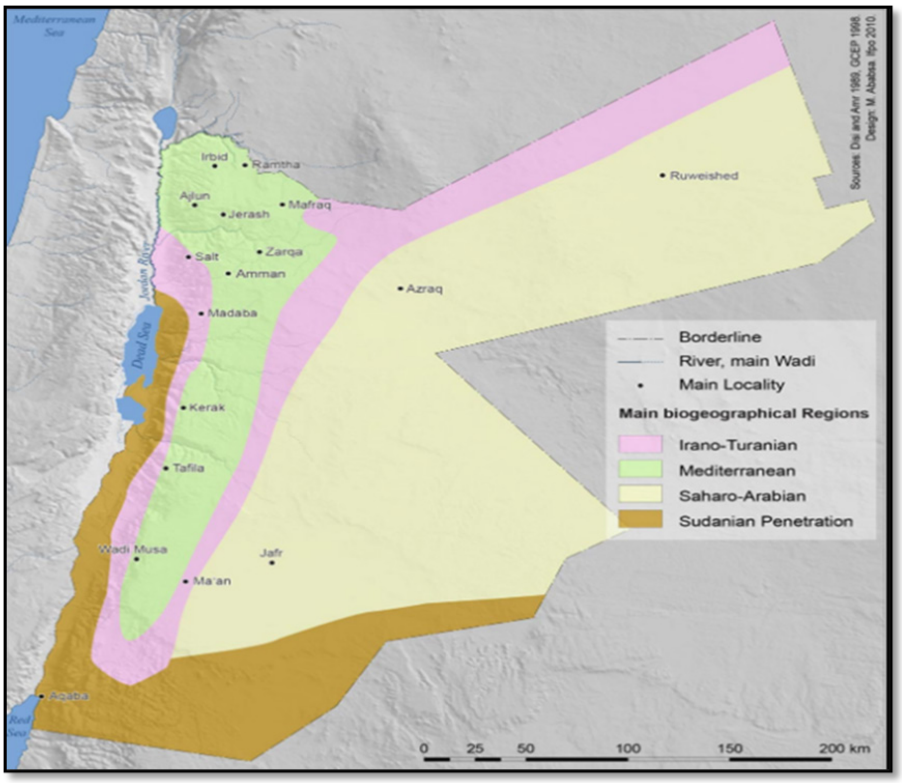

Fig. 3. Biodiversity zones in Jordan [23].

RESULTS AND DISCUSSION

RIAM matrix was produced for using Jordanian OSA in asphalt mix where the criteria used were set against defined component and each cell of the matrix showed the individual criteria scores calculated from the Eqs. 1 - 3. The individual ES scores were then banded together into ranges that facilitate the final assessment and the comparison process of the environmental components.

To minimize the element of subjectivity in the scoring process, a questionnaire was designed based on the aforementioned four environmental components and was addressed to group of experts and representatives from different disciplines, namely, solid waste management, asphalt production, oil shale and environmental issues and the scoring of RIAM matrix was performed accordingly. Notable among them were 110 experts qualified for the inclusion in this study and serve as the study sample. The distribution of the matrix was face - to - face, online, public sector, and private sector.

Results of RIAM matrix based on the responses are shown in Table 6.

The outcomes of RIAM analysis indicates that using the OSA based-asphalt mix has no effect on the physical and chemical valued ecosystem components (soil, water resources and air quality). As mentioned before, the permeability of the soil is classified as slow to very slow so it is classified as a safe layer to the groundwater. Regarding to the biodiversity impact, the results reflect that there are no implications on plants and wildlife when incorporating OSA in asphalt mix but it has negative impact on habitat as revealed by the response of ecologists.

For sociological impacts, the results show that there is no effect on the health and safety of the local population when using the OSA in asphalt mix. A slight positive impact is noticed for population growth and the aesthetic characteristics of the area. Since the purpose of adding OSA to the asphalt mix is to improve the characteristics of the asphalt mix, the area where OSA based-asphalt mix will be applied will be an attractive place for the residents to settle in. The absence of cracks and straightness in the street will have slight positive implications on the aesthetic characteristics of the area.

Table 6. Rapid Impact Assessment Matrix (RIAM).

No.	Valued Environmental Components	Standards							
		A1	A2	B1	B2	B3	AT	BT	ES
PC	Physical and Chemical Components								
PC1	Soil pollution	2	0	1	1	1	0	3	0
PC2	Ground and surface water pollution	1	0	1	1	1	0	3	0
PC3	The disturbance in the temperature of the water in the area	1	0	1	1	1	0	3	0
PC.4	A change in the properties of the air	4	0	1	1	1	0	3	0
BE	Biological and Ecological Components								
BE1	Implications on plants and wildlife	2	0	1	1	1	0	3	0
BE2	Impacts on habitat	2	-1	3	3	2	-2	8	-16
SC	Sociological and Cultural Components								
SC1	Population growth	1	+1	3	3	3	+1	9	9
SC2	Health of local populations	1	0	1	1	1	0	3	0
SC3	Implications on the aesthetic characteristics of the area	1	+1	2	2	2	+1	6	6
EO	Economical and Operational Components								
EO1	Inflation in sales	4	+3	2	2	2	+12	6	72

Table 7. Conversion of Environmental Scores to Range Bands.

Environmental score	-108 to -72	-71 to -36	-35 to -19	-18 to -10	-9 to -1	0	1 to 9	10 to 18	19 to 35	36 to 71	72 to 108
Range bands	-E	-D	-C	-B	-A	N	A	B	C	D	E
PC	0	0	0	0	0	4	0	0	0	0	0
BE	0	0	0	1	0	1	0	0	0	0	0
SC	0	0	0	0	0	1	2	0	0	0	0
EO	0	0	0	0	0	0	0	0	0	0	1
Total	0	0	0	1	0	6	2	0	0	0	1

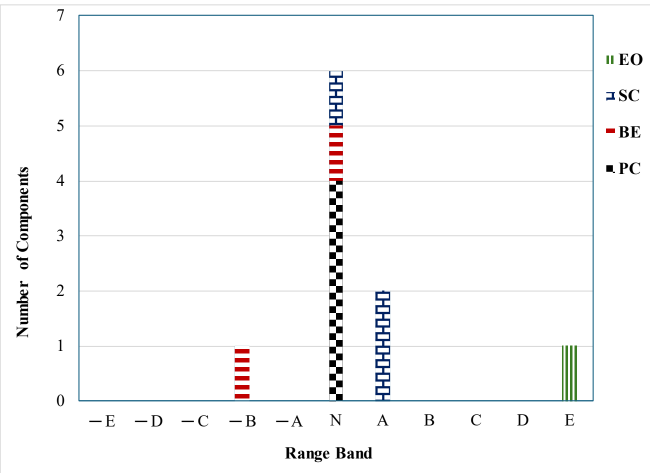

Fig. 4. Summary outcome of RIAM matrix results.

Regarding the economic impact of utilization the OSA in asphalt mix, results display a major positive impact. OSA is abundant in Jordan, and since several studies has proved the benefits of adding the OSA to the asphalt mix, this will reduce the need of importing materials that improve the properties of asphalt from outside Jordan.

Comparing the results of the environmental component score with the range bands in Table 2, the results in Table 7 were obtained. Among the ten anticipated impacts, one component is in the range band of negative impact from BE category, two components are in the range of slightly positive impact from SC category, one component from EO category is in the range of major positive impact (SE) and six components have no impact distributed between PC (4), BE (1) and SC (1) categories. Thus, most impacts are of class N.

Fig. 4 gives the results of RIAM matrix in a set of histograms with the integrated impact of the environmental components. The horizontal scale represents the range bands and vertical scale represents the number of environmental components. The further move away from the neutral point N, the more significant the impact is, either positive or negative.

CONCLUSIONS

The main intention of the study is to assess the environmental impacts of incorporating Jordanian OSA in asphalt mix using RIAM analysis tool. OSA-based asphalt mix asphalt mix was assessed in the context of environmental, social, and economic impacts.

The deduced results indicate that positive and major positive impacts arise from the SC and EO categories and one component is in the range band of negative impact from BE category and this impact should receive imperious attention and mitigation actions. As for no change/impact, the PC is the prevailing category.

With the increase call for the urgent attention and intervention towards sustainable waste management, the incorporation of Jordanian OSA in asphalt mix appears favorable.

Finally, RIAM is a powerful tool that enables the assessor to evaluate different impacts and their significance utilizing defined criteria and provides some degree of objectivity and transparency.

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