Keywords: sustainable pavement; permeable pavement; pavement sustainability; porous pavement; sustainable transportation; Nablus; Westbank; Palestine

Fady M.A. HASSOUNA[1*], Reema BDAIR[2], Mohamed ALI[3], Mohannad MOSA[4], Mohammed KAYED[5], Faten DARAGHMEH[6]

ECONOMIC FEASIBILITY AND ENVIRONMENTAL IMPLICATIONS OF PERMEABLE PAVEMENT IN PALESTINE

Summary. Permeable pavement is considered one of the sustainable management options for roadway networks, which mitigates a number of problems associated with stormwater, ground water pollution, and traffic safety. In this study, the economic feasibility, vehicle operation, and environmental implications of implementing permeable pavement in Nablus, Palestine have been determined by selecting the local roadways that satisfy the permeable pavement requirement, such as low traffic volume, grade less than 5%, speed limit up to 50 km/h, and subgrade with good permeability. The total costs of construction and maintenance for both conventional asphalt and permeable pavement have also been compared based on the life cycle cost analysis (LCCA). Finally, the environmental implications such as the expected increase in the amount of ground water and the reduction in water pollutants have been investigated. The results of the analysis show that the permeable pavement is applicable for the local roadways that have satisfied the requirements, which are 61 roadways. Furthermore, it could lead to an annual significant increase in ground water by 107,404.7 m^3 and slightly reduce the cost of construction and maintenance by up to 1,912,000 ILS during its life period compared to conventional asphalt pavement. Moreover, applying porous asphalt could enhance vehicular traffic safety by improving skid resistance.

1. INTRODUCTION

Asphalt pavement has become the most common type of road pavement in the last decades due to its high performance and considerable mechanical properties such as durability, strength, safety, and acceptable cost of construction [1, 2]. Generally, asphalt pavement is composed of a thin layer of hot-mix asphalt, one or more basecourse layers, and the subgrade, which have different thicknesses based on several factors, such as layers' materials and expected traffic conditions [3].

Coupled with rapid urbanization, there is a continuous increase in the movement of goods and people through the transportation system, which requires billions of kilometers of pavements to be constructed around the world [4], and this has led to several environmental problems, such as flooding during intense

[1] An-Najah National University, Civil Engineering Department; Nablus, P.O. Box 7, Palestine; e-mail: fady.h@najah.edu; orcid.org/0000-0002-7766-3238
[2] An-Najah National University, Civil Engineering Department; Nablus, P.O. Box 7, Palestine; e-mail: rnassar@najah.edu; orcid.org/0000-0001-8403-4045
[3] An-Najah National University, Civil Engineering Department; Nablus, P.O. Box 7, Palestine; e-mail: s11642774@najah.edu; orcid.org/0009-0002-7380-3480
[4] An-Najah National University, Civil Engineering Department; Nablus, P.O. Box 7, Palestine; e-mail: s11744278@najah.edu; orcid.org/0009-0000-8540-1556
[5] An-Najah National University, Civil Engineering Department; Nablus, P.O. Box 7, Palestine; e-mail: s11524055@najah.edu; orcid.org/0009-0005-7207-8717
[6] An-Najah National University, Civil Engineering Department; Nablus, P.O. Box 7, Palestine; e-mail: s11717844@najah.edu; orcid.org/0009-0007-1545-6077
* Corresponding author. E-mail: fady.h@najah.edu

rainfall, ground water shortages, and contamination of runoff water with heavy metals. Therefore, an intense effort has been made around the world in order to develop more sustainable pavements.

One of the most promising sustainable types of pavement that have been developed in order to mitigate the environmental problems of conventional asphalt pavement is porous pavement, which has high permeability and porosity and could improve ground water recharging and reduce the risk of flooding during intense rainfall [5]. This type of asphalt could have less durability and strength than asphalt pavement due to its high permeability. Therefore, it is often used in low-traffic areas, such as local streets, parking lots, highway shoulders, and sidewalks [6].

Generally, porous pavement is composed of open-graded asphalt mixers characterized by a large content of air voids. The minimum percentage of air voids in this type of asphalt is 18%, and this percentage can reach up to 25% in Europe and Asia. The volumetric property of open-graded mixture leads to the high permeability and noise reduction ability of this pavement, which gives it advantages over conventional hot mix asphalt pavement [7].

Despite the many types of permeable pavement systems, the most used systems are pervious concrete, porous asphalt pavement, plastic grid-stabilized pavement, and permeable interlocking concrete [8]. Generally, the required type of permeable pavement is selected based on several factors, such as the place where it is intended to be constructed, the expected load, the expected rainfall intensity, and the subgrade type.

There are many advantages of permeable pavement, such as the reduced flow and volume of road runoff during rainfall events, the recharging of ground water, decreased frictional noise from tires, and improved quality of runoff water by decreasing (filtering) heavy metals and other soluble pollutants [2]. On the other hand, there are some drawbacks of using permeable pavements, such the low durability and stability due to the high percentage of air voids, rutting potential due to traffic distress, and raveling [9].

Several techniques have been developed in Europe and Japan to address the mentioned drawbacks. Adding cured carbon fiber composite materials is one of the widely used solutions [10]. Another solution was developed in Japan by using high-viscosity modified asphalt and incorporating a gab between 2.36 mm and 4.75 mm, which has enhanced the anti-aging and anti-stripping properties [11].

In Palestine, this new type of pavement has not been used yet, and the economic and environmental implications of its application are still unpredictable since they vary among regions based on several factors, such as traffic conditions, type of soil (subgrade), the availability of construction materials, the rainfall intensity, the need for ground water, and topography. However, the majority of the previous studies have focused on developing and testing additives and new materials in order to improve the quality of the pavement. In this study, the applicability and the implications of using this technology in real conditions of the road network in Palestine have been determined by assessing the economic feasibility and environmental implications of using this type of pavement. Moreover, this type of pavement could partially cover the annual water deficit in Palestine by increasing the ground water level.

The next section of this article presents the literature review, which includes the related previous studies. This is followed by the data and methodology section, which includes the applied steps and processes. Next, the design of pavement layers is presented. After that, the data are analyzed and the results are discussed. Finally, the article ends with the conclusions and recommendations.

2. LITERATURE REVIEW

Since permeable pavement is still an emerging topic, no studies have been conducted to assess the environmental and economic feasibility of applying this technique in Palestine. However, the use of this type of pavement has been investigated and applied in some regions such as Japan and Europe.

The Japanese porous pavement technique has been presented in a study by Nakanishi et al. The study investigated the effects of using high-viscosity modified asphalt on clogging and raveling, which are the main drawbacks of permeable pavements. Moreover, the study indicated that incorporating a gap between 2.36 mm and 4.75 mm aggregates will enhance resistance to clogging and permeability and in terms, which mitigates the raveling and clogging problems in permeable pavement [11].

The permeability and stability characteristics of porous asphalt pavement were investigated in a study by Akhtar et al. The behavior and the characteristics of porous asphalt under real traffic conditions were studied using Marshall and permeability tests. The study indicated that by using porous asphalt, reliable results can be provided in terms of permeability and stability of porous asphalt mixtures. Moreover, porous asphalt could reduce the possibility of floods and increase the safety of driving during intense rainfall [12].

In Brazil, a study was conducted by Ghisi and Pires in order to determine the filtering capacity of porous pavement. Three porous asphalt slabs were produced and parameters such as dissolved oxygen, pH, ammonia, nitrite, chromium, copper, iron, and zinc were determined. The study concluded that it is possible to collect higher-quality runoff water by using porous asphalt by reducing the concentration of dissolved pollutants such as ammonia [13].

A study was conducted by Zhang et al. in order to study the effects of using cured carbon fibers in porous pavement. The source of the used fibers was manufacturing scrapes wastes used in the aerospace industry. The study concluded that adding carbon fibers with 0.15%, 0.30%, and 0.45% dosages did not affect the hydraulic properties of the pavement. On the other hand, the ductility and the cracking resistance at a low temperature were improved by adding carbon fibers [10].

A study by Zhang and Kevern has been conducted to investigate the performance of porous asphalt pavement in cold weather. The study addressed the structural design considering the frost heave and frost depth of the subgrade layer, construction of porous asphalt in winter, maintenance in cold weather, and deterioration caused by other activities. The study concluded that sand and clay subgrade significantly affect the thermal and structural performance of porous asphalt in cold weather [8].

The influence of the aggregate shape on porous asphalt properties has been investigated in a study by Ksumawardani and Wong. In this study, three aggregate shapes were used (disk, blade, and cubical), and different parameters, such as roundness, sphericity, and shape were tested. The study concluded that aggregate structure is significantly affected by shape properties in terms of mechanical properties and volume. Moreover, it was concluded that the discrete element method is an appropriate method for evaluating aggregate structure [14].

In Iraq, Al-Kaissi and Mashkoor conducted a study in order to evaluate the durability of porous asphalt in terms of aging acceleration, deformation, and moisture damage. Samples were prepared with and without adding fiber and a polymer binder modifier. The study indicated that using the polymer binder modifier doubled both the permeability and the strength of the asphalt. Moreover, it was concluded that temperature significantly affects the permeability and the strength of the pavement mixture [15].

The majority of the previous studies have generally focused on developing and testing additives and new materials in order to improve the quality of pavement to address some of the drawbacks of permeable pavement and investigate the different properties of permeable pavement in specific conditions and regions. In this study, the applicability and implications of using this technology in real conditions of the road network in Palestine were determined by considering the economic aspect and the expected amount of ground water that could be saved, which is considered a very important topic due to the shortage of drinkable water in Palestine.

3. DATA AND METHODOLOGY

In this study, the required data were acquired from several sources. Data included hydrological, transportation, and geotechnical data. More specifically, data included the type of soil (subgrade layer of roadways), geometric design of the roadways, traffic volume of the roadway network, average rainfall intensity, and rainfall volume in Nablus city, Palestine.

First, Nablus city was divided into three regions (zones). Next, the type of soil (subgrade), the roadway classification, the pavement design, dimensions, and the slope of the existing roadways in each zone were investigated using the data from the Nablus municipality, previous studies, and field visits. After that, a traffic volume study was conducted for local streets in each zone. Finally, the expected rainfall intensity was determined based on the average rainfall intensity in the previous years.

Based on the collected data and by using the permeable pavement design recommendations of the American Society of Civil Engineers (ASCE), the roadways that satisfy the ASCE permeable pavement requirements were selected and the existing pavement was redesigned by using the permeable pavement as an alternative. It is worth mentioning that the standards used in actual conventional pavement design are compatible with the American standards, and the selected local roads have only occasional heavy vehicle movement. Economic feasibility was determined by comparing the cost of construction, maintenance, and lifetime of the two types of pavement. Moreover, the environmental implications of permeable pavement were quantified, as shown in Fig. 1.

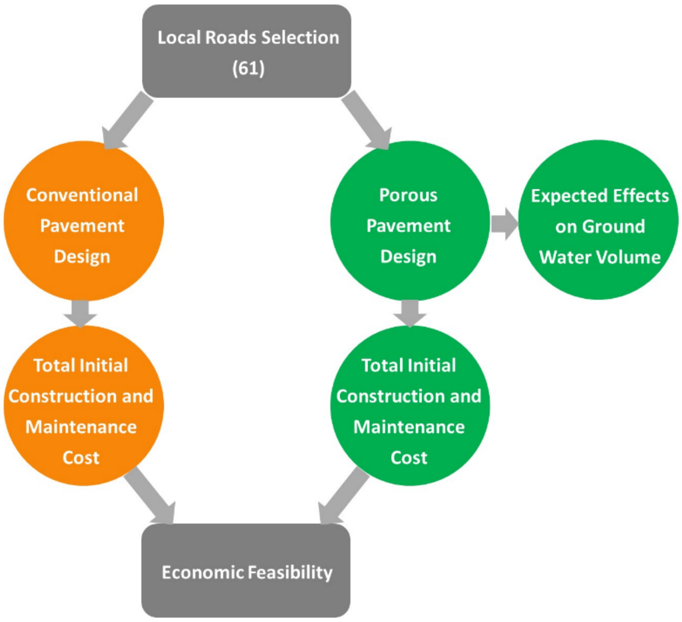

Fig. 1. Methodology Flowchart

The ASCE recommendations that were followed in this study required that the selected streets for implementing permeable pavement were local streets with speed limits up to 50 km/h, low traffic volume, and acceptable grades (less than 5%). Moreover, the use of porous asphalt as a permeable pavement without using any underdrain system required the soil (subgrade) to have a good permeability [16]. Therefore, the local streets located on permeable soil layers were selected in order to be redesigned by using the porous asphalt system.

3.1. Pavement design

Porous asphalt, pervious concrete, plastic grid-stabilized pavement, and permeable interlocking concrete are the most common surface courses of permeable pavement, which are used to allow runoff water to be drained through the pavement structure [8]. In this study, porous asphalt was used in the design, since it is suitable for local streets, whereas, the other types are more suitable for sidewalks and parking lots.

Generally, porous asphalt pavement infiltration can be classified into three types: full-infiltration, which allows all the stormwater to be infiltrated through the soil; partial-infiltration, which allows the stormwater to be infiltrated partially through the soil; and no-infiltration, which does not allow the stormwater to be infiltrated through the soil [16]. In the case of a partial or no-infiltration system, the stormwater collected in the aggregate reservoir layer should be discharged directly by a piped drainage system. On the other hand, in a full-infiltration system, there is no need for a pipe drainage system since the water can be infiltrated directly through the soil. In this study, a full-infiltration porous asphalt pavement system was used since the selected zones had soil with good permeability.

After the appropriate type of permeable pavement (porous asphalt) and the suggested infiltration system (full-infiltration) were selected, the pavement layers' materials were selected, and the pavement layers' depths were determined. More specifically, these layers usually include a porous asphalt layer, an asphalt-treated permeable base layer, a choker course layer, a reservoir course layer, and a filter course layer.

3.2. Economic feasibility and environmental implications

Based on the selected materials and layers' design of the porous asphalt pavement, the initial construction cost was determined. Next, the future maintenance and the operating costs during the design life (life cycle), which was selected to be 20 years, were determined based on the local prices and by using the present worth method.

Similarly, based on the conventional pavement design of the existing local streets, which were acquired by field visits, the initial construction cost was determined. Next, the future maintenance and operating costs during the design life were determined based on the actual prices that were acquired from the Nablus municipality.

The total expected cost of porous asphalt for the selected streets was compared to the total actual cost of the conventional pavement for the life cycle in order to determine the economic feasibility of the porous asphalt. This was done by considering all relevant variables, such as the annual increase in prices in general (i) and the annual increase in maintenance cost due to asphalt aging (g).

The expected environmental implications of the porous asphalt were determined, including the expected amount of ground water that could be obtained, by using the total area of the selected streets, average annual rainfall volume, and the expected water permeability of the pavement.

4. PAVEMENT DESIGN

Generally, the porous asphalt system that can be applied to local streets with light traffic volume consists of four layers: the porous asphalt layer, the asphalt-treated permeable base (ATPB), the reservoir course (aggregate), and the uncompacted soil subgrade. The aggregate layer's thickness depends mainly on the runoff volume and soil infiltration rate, whereas the thicknesses of the porous asphalt layer and asphalt-treated permeable base depend mainly on the traffic load.

4.1. Porous asphalt and ATPB layers

Based on the ASCE recommendations for permeable pavements [16], the minimum total thicknesses of both layers of porous asphalt and ATPB for residential streets with light to heavy truck volumes are 10 cm and 15 cm, respectively, whereas the minimum thickness for the porous asphalt layer is 3.8 cm. Therefore, due to the considerable number of trucks that use the selected local streets, a total thickness of both porous asphalt and ATPB of between 10 and 15 cm (13 cm) was selected. More specifically, 5 cm of porous asphalt and 8 cm of ATPB were used in this study.

4.2. Reservoir course layer

The reservoir course layer should contain clean, uniformly-graded aggregate with 100% passing through a 75-mm sieve and 0–5% passing through a 1.16-mm sieve with approximately 30–40% void space, which is economically available in the local market in Palestine. Moreover, the aggregate should be washed, durable, angular, and have a significant void content for water storage. The recommended thickness is typically 20 to 90 cm [16]. In this study, the thickness of this layer was selected to be 40 cm, which is close to the minimum recommended value (20 cm) instead of the average value (55 cm) since the soil has a good infiltration rate and the rainfall intensity is not high in Palestine. Fig. 2 illustrates the structural design of the pavement.

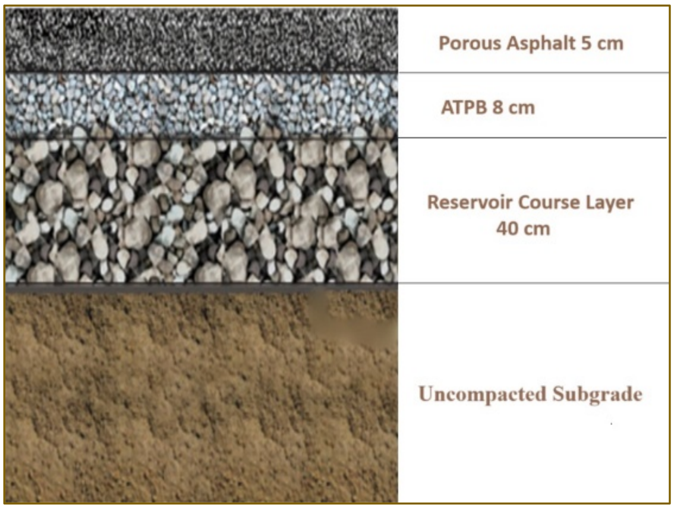

Fig. 2. Permeable Pavement Design

5. DATA ANALYSIS AND DISCUSSION

Several field studies were conducted in order to investigate the local roads that meet the selected criteria which include local streets with speed limits up to 50 km/h, low traffic volume, acceptable grades (less than 5%), and good-permeability soil (subgrade). Among all the investigated local streets in Nablus city, 61 local streets satisfied the criteria. The length, width, and grade of these streets were measured, as shown in Table 1. The total area of the selected local streets is 284,771 m^2.

After that, the economic feasibility of applying a porous pavement system was determined by comparing the cost of construction, maintenance, and lifetime with those of the conventional pavement. Moreover, the environmental implications of the permeable pavement have been quantified considering the expected extra recharge of ground water.

5.1. Economic feasibility

The economic feasibility of applying the porous asphalt system was determined by comparing the total costs of the conventional asphalt and porous asphalt pavements, which was done by considering the initial construction cost and maintenance cost and using the life cycle cost analysis (LCCA). The design life for pavements was selected to be 20 years, which is the typical design life period for transportation projects, in order to conduct this feasibility study. The annual interest rate (I), which is used to convert the future costs to present values was selected to be 2% based on the achieved construction and transportation projects in Palestine. The annual increase in maintenance cost due to the aging of pavement (g) was selected to be 1%, which is used in the majority of the transportation projects based on the interviews with several consultant companies and experts in transportation projects.

5.1.1. Initial construction cost

The materials, the water drainage, and the indirect costs were investigated by using field visits to several providers and suppliers, and the average values were determined and used in this study in order to determine the initial construction cost of the selected local roads by using conventional asphalt and porous asphalt systems. As shown in Table 2 for conventional asphalt pavement and in Table 3 for porous asphalt pavement in New Israeli Shekel (NIS), the actual conventional asphalt design was used in the selected local roads, which consists of a 7-cm asphalt layer and a 20-cm base course layer [17], whereas the selected design for porous asphalt pavement was used.

Table 1

Geometric Characteristics of the Selected Roads

Zone	Road ID	Length (m)	Width (m)	Slope	Zone	Road ID	Length (m)	Width (m)	Slope
1	63	263	12	0.03	3	86	243	10	0.01
	65	330	10	0.04		132	53	12	0
	75	132	6	0.05		301	262	10	0.02
	233	258	10	0.02		302	155	10	0.03
	244	115	10	0.01		318	398	10	0.02
	392	140	12	0.01		350	556	12	0.04
2	497	154	12	0		363	286	10	0.03
	691	1205	12	0.03		442	425	10	0.01
	692	1361	12	0.02		781	373	15	0.02
	693	473	12	0.01		792	712	15	0.03
	694	175	12	0.05		793	165	15	0.04
	695	145	16	0.04		801	142	15	0.04
	700	673	12	0.02		816	232	12	0.02
	705	1147	12	0.05		819	403	10	0.03
	743	657	12	0.02		820	306	12	0.01
	1264	102	4	0.04		821	456	12	0.02
3	4	476	12	0.05		825	355	12	0.04
	10	395	12	0.04		835	376	10	0.01
	12	690	12	0.03		836	464	12	0.04
	13	424	12	0.02		845	642	12	0.03
	15	1273	15	0.02		854	286	15	0.03
	18	433	12	0.04		855	284	15	0.04
	31	593	12	0.04		915	37	6	0.03
	32	477	12	0.01		928	244	12	0.05
	33	886	12	0.05		931	61	10	0.03
	53	162	10	0.02		932	325	12	0.03
	56	186	10	0.02		940	249	10	0.05
	58	429	10	0.02		963	64	6	0.05
	64	52	12	0		1029	87	12	0.03
	72	1049	12	0.02		1040	118	8	0.03
	83	248	10	0.01					

Table 2

Initial Construction Cost for Conventional Asphalt Pavement

Conventional asphalt material (7-cm depth) price for each m^2, with an asphalt density of 2.3 ton/m^3	30 NIS (material) + 14 NIS (wages)
Base course (20 cm) price for each m^2, with a base course density of 2.21 ton/m^3	13 NIS (material) + 4 NIS (wages)
Water drainage system	800 NIS/m

Table 3

Initial Construction Cost for Porous Asphalt Pavement

Porous asphalt material (5 cm) price for each m^2 (1.9 ton/m^3 porous asphalt density)	33 NIS (material) + 15 NIS (wages)
ATPB (8 cm) price for each m^2 (density of 1.7 ton/m^3)	30 NIS (material) + 14 NIS (wages)
Base course (40 cm) price for each m^2 (density of 1.8 ton/m^3)	26 NIS (material) + 12 NIS (wages)
Water drainage system	No Water drainage system (full infiltration)

For conventional asphalt pavement, the initial construction cost for each street was determined based on the total area of each street (the area was calculated based on the road dimensions in Table 1) and the prices of local materials (cost/m^2) from Table 2. Next, the total initial construction cost for all the selected roads was calculated (38,369,591 NIS).

Similarly, for porous asphalt pavement, the initial construction cost for each street was determined based on the total area of each street (the area was calculated based on the road dimensions in Table 1) and the prices of local materials (cost/m^2) from Table 3. Next, the total initial construction cost for each street was calculated (37,020,230 NIS).

5.1.2. Maintenance cost

For conventional asphalt pavement, regular annual maintenance includes the surface layer and drainage system maintenance. On the other hand, regular maintenance for porous asphalt includes surface layer maintenance and vacuuming (vacuum sweeping of the surface layer). Vacuum sweeping vehicles are used to clean the surface layer twice a year (once per six months) in order to keep the infiltration efficiency of the porous asphalt surface layer. The regular surface layer maintenance, the drainage maintenance, and the vacuuming costs per m^2 per year were acquired from a local study conducted by [GPR]. Finally, the total maintenance costs for conventional asphalt and porous asphalt pavements were determined by using the total area of selected local streets (m^2) as shown in Tables 4 and 5 for conventional asphalt (747,720 NIS) and porous asphalt pavement (716,255.5 NIS), respectively.

Table 4

Maintenance Cost for Conventional Pavement

Item	Cost (NIS)	Area (m^2)	Length (m)	Total Cost (NIS)
Regular maintenance and cleaning (per m^2)	2.5	284,771.0	23,862.0	711,927.0
Drainage system maintenance (per m)	1.5	284,771.0	23,862.0	35,793.0
Total				747,720.0

Table 5

Maintenance Cost For Porous Pavement

Item	Cost (NIS/m²)	Area (m²)	Total Cost (NIS)
Regular maintenance and cleaning (per m²)	2.5	284,771.0	711,927.0
Vacuuming (per 1000 m²)	0.0152	284,771.0	4,328.5
Total			716,255.5

5.1.3. Cost-benefit Analysis

An economic analysis for the pavement lifetime, which is typically considered 20 years, was conducted, and the total costs for both types of pavements were compared. Maintenance costs for the 20-year period were determined by using the present worth analysis (PWA) method while considering a 2% annual increase in prices (i) and a 1% annual increase in maintenance cost due to the aging of asphalt pavement (g). In this method, all the future cash flows were converted (discounted) to present amounts in order to determine the best alternative based on the economic advantage. Thus, the alternative with the lower present worth (PW) was selected.

For conventional pavement, the PW (38,369,591 NIS) was determined by using the total initial cost (38,369,591 NIS) and the annual maintenance cost (747,720 NIS) as well as by considering 2% and 1% values for i and g, respectively, as shown in Fig. 3.

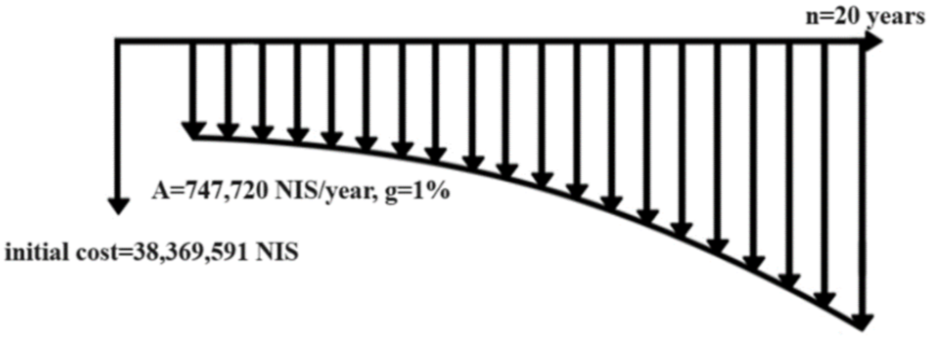

Fig. 3. Cash flow diagram for conventional pavement

Similarly, for conventional pavement, the PW (37,020,230 NIS) was determined by using the total initial cost (37,020,230 NIS) and the annual maintenance cost (716,255.5 NIS) as well as by considering 2% and 1% values for i and g, respectively, as shown in Fig. 4.

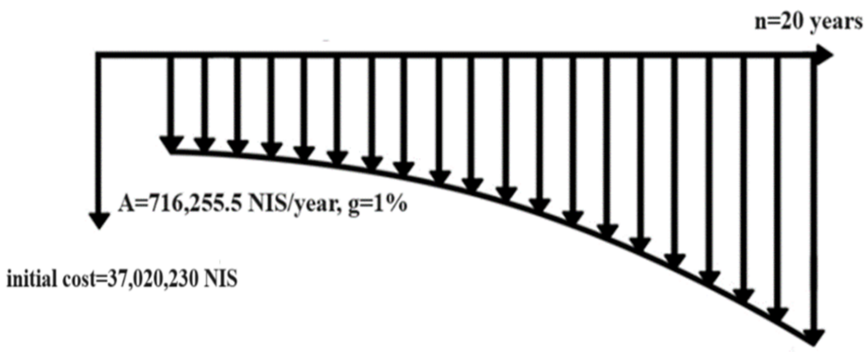

Fig. 4. Cash flow diagram for porous pavement

A comparison of PW values for conventional asphalt and porous asphalt pavements shows that implementing porous asphalt could save up to 1,912,000 ILS for the return period of the study. Therefore, the new design is a feasible alternative when considering the design life and the total construction and maintenance cost.

5.2. Environmental implications and vehicle operation

The expected annual increase in ground water volume due to porous asphalt system implementation for the selected local streets (three zones) was calculated in order to determine the environmental implications of porous asphalt. Moreover, environmental issues, such as the pollutant removal efficiency of porous asphalt have been investigated.

The total rainfall volume in Nablus city in 2019 was 4,313,400 m^3 [17]. Considering that 50% of rainwater ends on the roadway network, the volume of rainfall over the Nablus roadway network catchments (5,530,000 m^2) was determined, which is about 2,156,700 m^3. Since the total area of the selected local streets is 284,771 m^2 and the total area of the Nablus roadway network is about 5,530,000 m^2, which constitutes about 5.15%, the expected rainfall volume over the selected local roads catchments is about 111,070.1 m^3.

Generally, porous asphalt with a full-infiltration system can reduce water runoff by 96.7% due to its high permeability [18]. Thus, the annual increase in ground water volume due to implementing porous asphalt for the selected local streets is about 107,404.7 m^3.

In addition to the increase in ground water volume, other environmental benefits could be obtained from implementing a porous asphalt system, such as reducing ammonia (NH3), total Kjeldahl nitrogen (TKN), total suspended solids (TSS), cadmium (Cd), lead (Pb), and zinc (Zn) pollutants in water by 63.7%, 52.3%, 72.5%, 83.1%, 80.7%, and 71.9%, respectively [16].

In terms of vehicle operation and traffic safety, applying porous asphalt could enhance vehicular traffic safety by improving skid resistance, due to the lower fluid uplift force, better tire-pavement contact, and higher traction force [19]. Furthermore, it reduces hydroplaning risks on roadways and standing water on pedestrian walkways. Moreover, the risk of vehicle damage due to freeze/thaw conditions such as heaving and crack formation could be lowered [16]. Overall, implementing a porous asphalt system in Palestine could increase the amount of ground water and help mitigate problems related to significant water shortages, in addition to reducing pollutants in ground water and enhancing traffic safety.

6. CONCLUSIONS AND RECOMMENDATIONS

In this study, the applicability of permeable pavement in Nablus, Palestine was investigated, and economic benefits were determined by comparing the expected cost of both conventional asphalt and permeable pavement in terms of construction and maintenance. Moreover, the expected increase in the ground water level was determined. Based on the results, the following conclusions can be offered:

- Based on the topography, type of soil (subgrade), rainfall intensity, and traffic conditions in Palestine, permeable pavement is applicable in local streets that satisfy the requirements recommended by ASCE.
- Implementing porous asphalt pavement as an alternative to conventional asphalt on local roads with light traffic could increase the amount of ground water and help mitigate the problems related to significant water shortages. Moreover, it could save money during the design life of the pavement by considering the total construction and maintenance cost. For example, replacing conventional asphalt with porous asphalt for 61 local streets in Nablus city could save about 1,912,000 ILS during the design life of the pavement.
- A considerable amount of ground water could be obtained by applying a porous asphalt system in Palestine. For example, the expected annual increase in ground water volume due to implementing porous asphalt for the selected local streets in Nablus is about 107,404.7 m^3.

- In terms of traffic safety and operation, applying porous asphalt could enhance vehicular traffic safety by improving skid resistance, reducing hydroplaning risks on roadways and standing water on pedestrian walkways, and lowering the risk of vehicle damage due to freeze/thaw conditions.
- It is recommended that future works investigate the expected impacts of porous asphalt as an alternative to conventional asphalt in parking lots in Palestine since the majority of parking lots in Palestine could meet the requirements for a porous asphalt system.
- In future works, one of the local road links needs to be repaired or repaved using porous asphalt in order to compare performance-related data (before and after) and obtain practical data.

References

1. Hassouna, F.M.A. & Jung, Y.W. Developing a Higher Performance and Less Thickness Concrete Pavement: Using a Nonconventional Concrete Mixture. *Advances in Civil Engineering*. 2020. DOI: 10.1155/2020/8822994.
2. Zhao, Y. & Zhao, C. Research on the Purification Ability of Porous Asphalt Pavement to Runoff Pollution. *Adv Mat Res* [Internet]. 2012. Vol. 446-449. P. 2439-2448. Available at: https://www.scientific.net/AMR.446-449.2439.
3. Shreyas, K. & Lavanya, J. Comparison of Flexible (Dense Graded) and Porous (Open Graded) Asphalt Surface Course with Stone Dust as a Filler in Marshal Mix Design. *The Asian Review of Civil Engineering* [Internet]. 2016 Nov 5. Vol. 5(2). P. 1-6. Available at: https://ojs.trp.org.in/index.php/tarce/article/view/2232.
4. Hassouna, F.M.A. & Assad, M. & Koa, I. & Rabaya, W. & Aqhash, A. & Rahhal, A. & et al. Energy and environmental implications of using energy-harvesting speed humps in Nablus City. *Palestine. Atmosphere* (Basel). 2021 Jul 21. Vol. 12(8). P. 937.
5. Jendia, S. & AlDahdooh, Z. & AbuRahma M. & AbuJayyab, M. & ElDahdouh, A.E. Porous asphalt: a new pavement technology in Palestine. *Journal of Engineering Research and Technology*. 2018. Vol. 5(1). P. 1-6.
6. Chen, X. & Wang, H. & Najm, H. Environmental assessment and economic analysis of porous pavement at sidewalk. *Conference: Pavement Life Cycle Assessment.* 2017. Available at: https://www.researchgate.net/publication/317035506_Environmental_assessment_and_economic_analysis_of_porous_pavement_at_sidewalk.
7. Chen, J.S. & Yang, C.H. Porous asphalt concrete: A review of design, construction, performance and maintenance. *International Journal of Pavement Research and Technology*. 2020 Nov 6. Vol. 13(6). P. 601-612.
8. Zhang, K. & Kevern, J. Review of porous asphalt pavements in cold regions: the state of practice and case study repository in design, construction, and maintenance. *Journal of Infrastructure Preservation and Resilience*. 2021 Dec 8. Vol. 2(1). P. 1-17.
9. Jasni, N.E. & Masri, K.A. & Jaya, R.P. A Review of Morphological and Chemical Properties of Porous Asphalt. *Construction.* 2021 Oct 6. Vol. 1(2). P. 45-49.
10. Zhang, K. & Liu, Y. & Nassiri, S. & Li, H. & Englund, K. Performance evaluation of porous asphalt mixture enhanced with high dosages of cured carbon fiber composite materials. *Constr Build Mater.* 2021 Mar 8. Vol. 274. No. 122066.
11. Nakanishi, H. & Hamzah, M.O. & Mohd Hasan, M.R. & Karthigeyan, P. & Shaur, O. Mix design and application of porous asphalt pavement using Japanese technology. *IOP Conf Ser Mater Sci Eng*. 2019 Apr 24. Vol. 512. No. 012026.
12. Akhtar, M.N. & Al-Shamrani, A.M. & Jameel, M. & Khan, N.A. & Ibrahim, Z. & Akhtar, J.N. Stability and permeability characteristics of porous asphalt pavement: An experimental case study. *Case Studies in Construction Materials*. 2021 Dec 1. Vol. 15. No. e00591.
13. Thives, L.P. & Ghisi, E. & Brecht, D.G. & Pires, D.M. Filtering capability of porous asphalt pavements. *Water.* 2018 Feb 15. Vol. 10(206). P. 1-17. Available at: https://www.mdpi.com/2073-4441/10/2/206/htm.

14. Kusumawardani, D.M. & Wong, Y.D. The influence of aggregate shape properties on aggregate packing in porous asphalt mixture (PAM). *Constr Build Mater*. 2020 Sep 20. Vol. 255. No. 119379.
15. Al-Kaissi, Z.A. & Mashkoor, O.G. Durability of porous asphalt pavement. *Journal of Engineering and Sustainable Development*. 2016. Vol. 20(4). P. 53-70.
16. Eisenberg, B. & Lindow, K.C. & Smith, D.R. *Permeable Pavements (ASCE)*. American Society of Civil Engineers. 2015. DOI: 10.1061/9780784413784.
17. Ali, M. & Mousa, M. & Kayed, M. & Daraghmeh, F. *Economic & Environmental Impact assessment for porous asphalt applications in Nablus.* Palestine, Nablus: An-Najah National University. 2021.
18. Legret, M. & Colandini, V. Effects of a porous pavement with reservoir structure on runoff water: Water quality and fate of heavy metals. *Water Science and Technology.* 1999 Jan 1. Vol. 39(2). P. 111-117.
19. Zhang, L. & Ong, G.P. & Fwa, T.F. Developing an analysis framework to quantify and compare skid resistance performance on porous and nonporous pavements. *Transportation Research Record: Journal of the Transportation Research Board.* 2013 Jan 1. Vol. 2369(1). P. 77-86.

Received 13.12.2022; accepted in revised form 11.06.2024