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Optimal planning of wastewater reuse using the suitability approach: A conceptual framework for the West Bank, Palestine

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Abstract

Recently, wastewater reuse is receiving a great deal of focus and interest among planners and decision makers in the West Bank, Palestine. This interest in wastewater reuse is motivated by the shortage in water resources accessibility due to the unstable political situation in the region. Much of the recent dispute that took place at the national level and among the stakeholders and planners revolved around issues related to the priorities of wastewater reuse in terms of location implementation of reuse schemes. The paper illustrates the conceptual framework for developing such a map and elaborates on the factors that dictate map development. Examples of such factors are discussed. The paper's outcomes show that the development of the map requires a multidisciplinary expertise and the work necessitates the collaboration among experts from different fields.

Keywords: Wastewater reuse; Agriculture; Suitability map; Optimal; Planning; Palestine

1. Introduction

Agriculture is an important and vital sector in the West Bank where agriculture accounts for 25% of the national income and consumes approximately 70% of the available water resources. However, the scarcity and fragility of the water resources have constrained the agricultural development in the West Bank. The rapid population growth and the socio-economic development have aggravated water shortages. This in turn has raised serious debate on the need to consider unconventional water sources and shed light on the importance of the reuse of wastewater in agriculture, especially considering the inability to develop new groundwater resources due to the political restrictions and Israeli occupation. The need for the disposal of wastewater in an environmentally sound manner compels the construction of wastewater treatment plants

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and motivates considering the reuse of treated wastewater in agriculture. Much dispute is taking place at the national level where the focus is on the spatial, social, religious, topographic, environmental, and hydrologic appropriateness of wastewater reuse in the West Bank. This dispute is on going, and while many advantages and disadvantages regarding the potential reuse of wastewater have been raised, no concrete consensus has been reached. This has obliged the need to devise tools for assessing the suitability of wastewater reuse across the West Bank. Such tools can aid in the decision-making process, provide realistic estimates of potential treated wastewater quantities, give reasonable expectations of economic revenues, and facilitate the assessment of the potential reuse alternatives and corresponding schemes.

This paper focuses on the importance of considering the development of a suitability map for wastewater reuse in the West Bank. The paper illustrates the conceptual framework for developing such a map and elaborates on the factors that dictate map development. Examples of such factors are discussed. The paper's outcomes show that the development of the map requires a multidisciplinary expertise and the work necessitates the collaboration among experts from different fields. In addition, the development of the map requires the utilization of different tools and techniques such as Geographic Information Systems (GIS).

2. Description of the study area

Fig. 1 shows the geographic location of the West Bank. The West Bank has an area of 5800 km^2, a 130 km length from north to south and between 40 and 65 km in width from east to west [1]. The West Bank is mostly composed of limestone hills that are between 700 and 900 m in high. The lowest point of the West Bank is the Dead Sea at 400 m below the sea level. Fertile soils are found in the plains. Soil cover is generally thin and rainfall is erratic. The West Bank formations are comprised of limestone, dolomite, chalk, marl, chert, shale, and clays. The West Bank is divided into eleven districts (see Fig. 1) and each district is divided into municipalities and local councils [1].

Approximately 2.5 million Palestinians live in the West Bank. Around 65% of the populations live in urban areas. Annual population growth is estimated at 4.8%. The climate in the West Bank can be characterized as hot and dry during the summer and cool and wet in winter. The climate becomes more arid to the east and south. The mean summer temperatures range from 30°C at Jericho to 22°C at Hebron which is 850 m above sea level. The annual average relative humidity is about 52% at Jericho. Annual rainfall on the Central Highlands averages 700 mm and becomes less than 100 mm at the Dead Sea. However, great variations in rainfall amount and distribution exist. It is common for only half the average to fall in any one year. The West Bank is composed of four main climatic regions: hyper-arid; arid, semi-arid, and sub-humid [1].

The principal available water resources include groundwater, springs, and harvested rainwater. There is little surface water and thus groundwater is the principal source of water in the West Bank. The West Bank lies over the Mountain aquifer. The Mountain aquifer is divided into the eastern aquifer, the northeastern aquifer, and the western aquifer. The eastern aquifer and part of the northeastern aquifer flow east towards the Jordan River. The western aquifer and part of the northeastern aquifer flow westerly towards the Mediterranean Sea [1].

3. Wastewater treatment and reuse in the West Bank

There are five wastewater treatment plants in the West Bank located in Jenin, Tulkarem, Ramallah, Al-Bireh, and Hebron [1]. The treatment plant in Jenin is not functioning. The same applies on that in Hebron. The remainder of the cities do not have such plants though master plans do exist for that. The Israeli occupation has blocked all the efforts to construct such treatment plants and impeded the rehabilitation actions for these plants due to the continuous incursions. Except for the recently-constructed treatment plant in Al-Bireh, the remainder treatment plants efficiencies are low [1]. The percentage of population in the West Bank connected to sewer networks is 34.6% while almost all the villages do not have sewerage systems and thus use cesspits. This indeed limits the options for the reuse of wastewater. The total collected wastewater in the West Bank for the year 2006 is approximately 12 millions cubic meters (mcm) and distributed across the

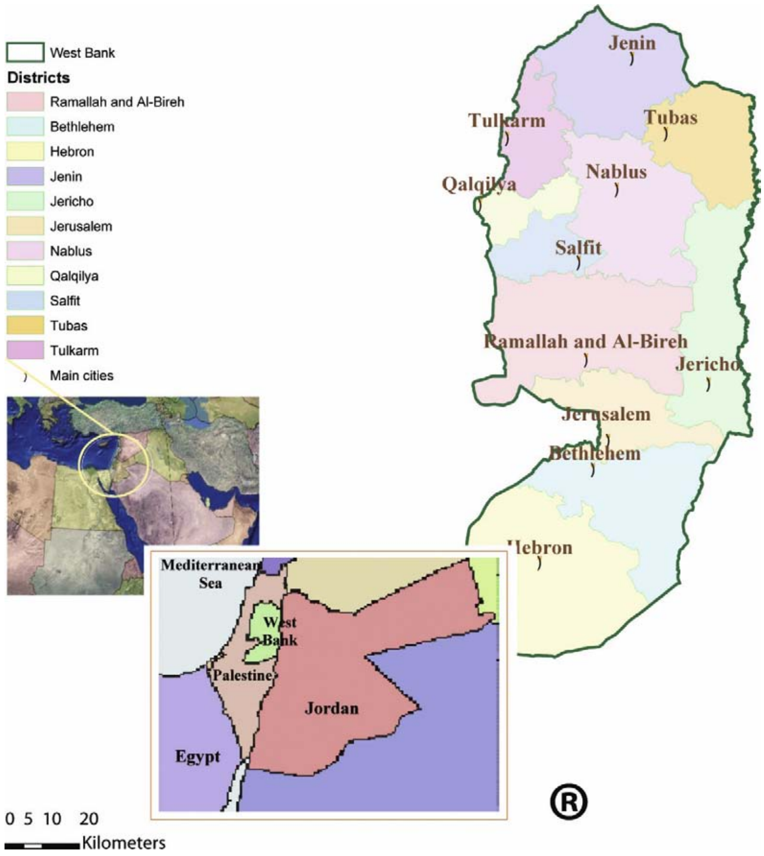

Fig. 1. The regional setting of the West Bank, the districts, and the main cities.

districts as shown in Fig. 2. However, these estimates would increase based on an increase in the per capita water consumption and the sewerage coverage. Wastewater reuse is currently practiced at small scale levels as the case of the experimental wastewater treatment plant of Birzeit University where restricted irrigation is practiced.

4. The scope of strategic wastewater reuse planning

The Palestinian Water Authority (PWA) as the key regulator of the Palestinian water resources has developed a set of strategies for reuse of treated wastewater. These strategies are [1]: reuse of treated wastewater must be considered in all treatment schemes; co-operation must be established with different relevant bodies; for every reuse project, beneficiaries must be involved in all project phases; flexible reuse plans should be developed to be able to utilize treated wastewater in winter seasons and when the effluent quality drops below the demands; establish planning tools (regulations, standards, guidelines, etc.) for reuse and recharge; discharge to surface water may be considered as an interim action, or if reuse is not feasible; do not allow irrigation of crops eaten raw by treated effluent and adopt appropriate enforcement means; for better water quality and reuse efficiency, consider (1) mixing of treated effluent with urban and surface runoff, (2) artificial recharge of groundwater with treated effluent wherever possible, and (3) establish surface storage for treated effluent with or without harvested runoff; allow

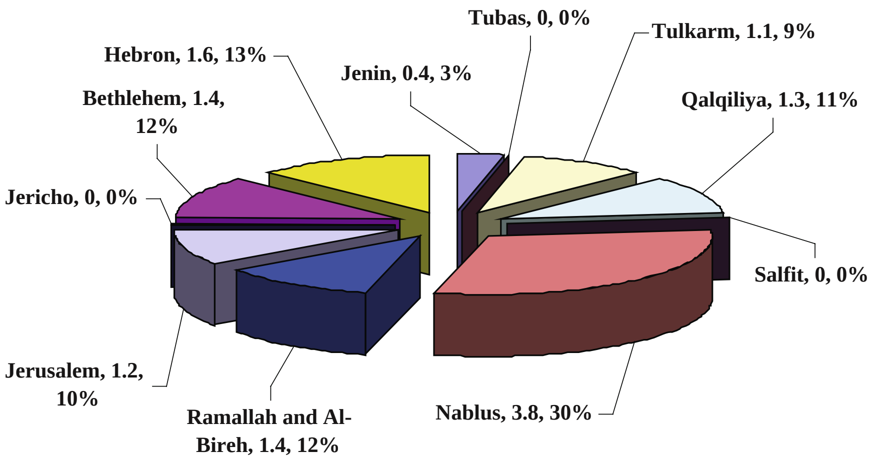

Fig. 2. Total annual wastewater collected by sewer networks (mcm) for each district and the percentage of sewerage coverage.

private sector and/or public to manage or share the management of wastewater reuse projects (contract private companies or public associations and co-operative to manage wastewater reuse); and develop a program for modifying water use habits to include reuse of treated effluent in urban centers (greening, fountains, urban parks and landscape irrigation forestation, and other areas).

Despite the presence of such strategies at the national level to regulate and promote the reuse of wastewater, no clear-cut approach or work plan do exist in this regard. Apparently, a successful wastewater reuse project does not just depend on the effectiveness and suitability of the technology, but also on the presence of a set of factors that ought to be considered collectively. Fig. 3 depicts such factors. Fig. 3 suggests that for an efficient reuse of wastewater in an area, different parameters ought to be taken into consideration.

These parameters differ in their very nature. For instance, there are factors that address environmental issues such as vulnerability of groundwater to contamination while others may just measure the social willingness of people to accept the very principle of wastewater reuse. The existing of this multitude of factors necessitates the development of a conceptual methodology that accounts for these factors to arrive at the spatial prioritization for the implementation of wastewater reuse schemes. In other words, when considering these factors, we can assess the suitability of a specific site for the development of a reuse scheme.

5. The suitability approach

The very premise of proposing the suitability approach is to designate for each area an index that takes into account the factors shown in Fig. 3. One major issue to consider is the spatial extent of the analysis. Since the objective is to decide on the reuse of *collected* and treated wastewater, then the analysis will be carried out at the watershed level. This resolution level is motivated by the fact that wastewater collection and conveyance from the served communities can be achieved by gravity. Therefore, for each watershed the different factors (where applicable) should be assessed. Once these factors are assessed, then it is possible to use a multi-criteria decision analysis to prioritize the watershed for potential wastewater reuse schemes. In the following sections, selected factors (shown in Fig. 3) are discussed. Fig. 4(i) shows the watersheds of the West Bank.

The proposed concept of the suitability approach relies on superposing (overlaying) the different factors for each watershed as shown in Fig. 4(ii). There are different methods to account for these factors compositely. The issue here is the factors are different in nature. For instance, environmental factors are easy and straightforward to quantify unlike factors related to culture and religion.

A multi-criteria decision analysis is proposed to account for the different factors in order to arrive at a composite suitability index for each watershed. In a

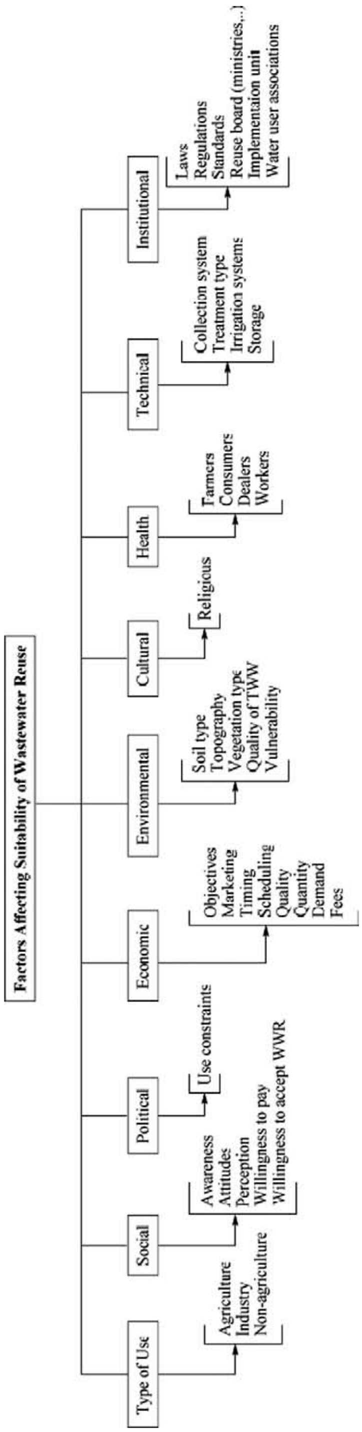

Fig. 3. The factors affecting the suitability for wastewater reuse.

more decision-making context, each watershed can be viewed as an alternative and each alternative represents a set of decision criteria (the factors and sub-factors depicted in Fig. 3). The whole assignment afterward becomes a task of ranking these alternatives according to their overall suitability index.

The choice of an alternative from a set of alternatives is difficult if these alternatives are non-dominated regarding a set of decision criteria. For an alternative to be dominant, it should be the best in terms of all the decision criteria. Since the decision criteria related to the reuse of treated wastewater reflect a diversity of parameters, it is anticipated that no alternative will be dominant. The ranking of the alternatives (watersheds) necessitates the use of a multi-criteria decision analysis.

In general, multi-criteria decision analysis evaluates a utility that expresses a decision maker's outcome preference in terms of multiple criteria. Multi-criteria decision analysis decomposes the complex problem of assessing a multi-attribute utility function into one of assessing a series of unidimensional utility functions [2]. A criterion is a characteristic of the alternatives (watersheds) that are considered important. There are several methods of multi-criteria decision analysis. However, a multi-criteria decision analysis methodology that is based on the importance order of criteria (IOC) is adopted, in this work, to find the dominating alternative out of the set of alternatives.

The IOC methodology is developed by Yakowitz et al. in 1993 (see [3]) and is conceptually simple and provides the decision maker with clear graphical evidence if one alternative is strongly dominant over another. The IOC method is simple and easy to program (using an Excel spreadsheet) and provide rational results. It relies on defining the best and worst total utilities of the alternatives through the ranking of the decision criteria of each alternative. Best total utility of an alternative is computed via maximizing the expected utility function, U_j, as in the following:

$$U_j = \sum_{i=1}^{m} w_i v_{ij} \qquad (1)$$

where m is the number of criteria of alternative j; v_{ij} is the value of jth alternative with respect to the ith criterion; and w_i is the weight assigned to criterion i.

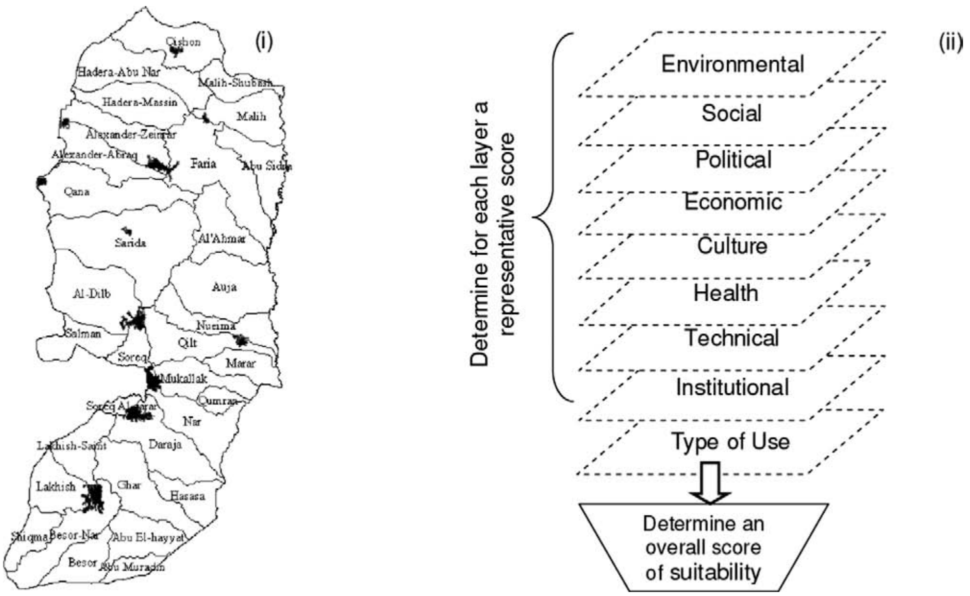

Fig. 4. (i) Watersheds and main cities in the West Bank and (ii) the suitability approach for the assessment of wastewater reuse.

The maximization of the objective function in (1) is subject to the following constraints

$$w_1 \geq w_2 \geq \cdots \geq w_m \quad (2)$$

$$\sum_{i=1}^{m} w_i = 1 \quad (3)$$

$$w_m \geq 0 \quad (4)$$

The first constraint defines the ranking of the importance of the criteria so that the criteria can be ordered where the constraint expresses the allowable weight vectors. The second and third constraints are the scaling and the weight non-negativity constraints. Likewise, the lowest total utility is found by minimizing the objective function in the above linear program instead of maximizing it.

The solutions of the minimum and maximum objective functions determine the minimum and maximum total utility possible for any weight combinations as far as the constraints are met. The two linear programs must be solved for each alternative under consideration. However, it was shown (see [3]) that these linear programs could be solved in a closed form as follows. Let $k = 1, \ldots, m$, then S_{kj} can be defined such that

$$S_{kj} = \frac{1}{k}\sum_{i=1}^{k} v_{ij} \quad (5)$$

Let BU_j and WU_j indicate the values of the objective function at the optimal solutions to the best and worst total utilities, respectively, then

$$BU_j = \max\{S_{kj}\} \quad (6)$$

and

$$WU_j = \min\{S_{kj}\} \quad (7)$$

An alternative k dominates alternative j with respect to a given IOC if $WU_k \geq BU_j$. However, if the computation of the best and worst total utilities did not yield a complete ranking of the alternatives, then the best and worst total utilities for each alternative are averaged out and the alternatives are ranked in descending order of these averages. For instance, $\frac{BU_k+WU_k}{2} \geq \frac{BU_j+WU_j}{2}$. In general, the criterion values

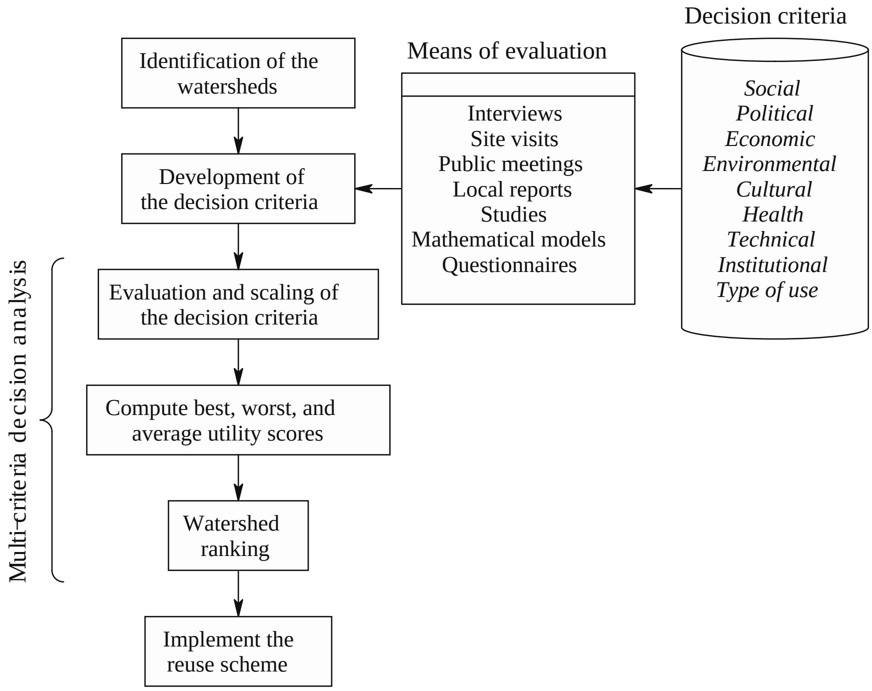

Fig. 5. Pictorial representation of the multi-criteria decision analysis approach as based on the method of the importance order of criteria for ranking the watersheds.

are scaled to remove the computational difficulties caused by the incommensurable units. The scaling aims at obtaining comparable quantities that facilitate alternative comparisons. Linear scaling between 0 and 1 is common in the IOC approach where the maximum value of a decision criterion corresponds to 1. As such, the normalized value of v_{ij} is given as (Hope, 1996)

$$v_{ij}^{N} = \frac{v_{ij} - \min\{v_{ij}\}}{\max\{v_{ij}\} - \min\{v_{ij}\}} \tag{8}$$

where v_{ij}^{N} is the normalized value of v_{ij} and $\min\{v_{ij}\}$ and $\max\{v_{ij}\}$ are the minimum and the maximum values of the ith decision criterion of the alternatives, respectively. The overall multi-criteria decision analysis approach of the IOC method as applied to ranking the watersheds for wastewater reuse is depicted in Fig. 5.

Once the decision alternatives and their respective criteria are defined and identified quantitatively (for example as shown in Table 1), a multi-criteria decision analysis can be conducted and the watersheds are ranked. Yet, it is important to bear in mind that the transpired ranking does reflect the preference of the decision maker in terms of the order of the decision criteria. Table 1 summarizes the scaled values of the criteria to be utilized in the analysis. The fundamental equation in the IOC method is Eq. (5) which enables us to compute the value of S_{kj} where k is the ID of the criteria (as in Table 1). If the social criterion is to be given the highest weight then it should be listed at the beginning as in Table 1 and thus $k = 1$. Implementation of Eq. (5) yields the set of S_{ij} values. For instance, $S_{11} = \frac{1}{1} v_{11}$ and $S_{52} = \frac{1}{5} \sum_{i=1}^{k} v_{ij} = \frac{1}{5} \times (v_{12} + v_{22} + v_{32} + v_{42} + v_{52})$. Once all S_{ij} values are computed, the minimum and maximum values are determined (BU_j and WU_j, respectively) using Eqs. (6) and (7). The watersheds are compared for WU_j values and accordingly watershed ranking is performed.

Table 1
General outlook of the alternative/criteria table for the suitability analysis. The symbol "*n*" represents the number of watersheds

		Watershed					
ID	Criteria	Alt. 1	Alt. 2	. ….	Alt. j	. ….	Alt. n
1	Social	v11	v12	.	v1j	.	v1n
2	Political	v21	v22	.	v2j	.	v2n
3	Economic	.	.	.	.	.	.
.	. . .. . .	.	.	.	.	.	.
i	Environmental	vi1	v52	.	vij	.	vin
.	Health	.	.	.	.	.	.
.	Technical	.	.	.	.	.	.
.	Institutional	.	.	.	.	.	.
m	. . .. . .	vm1	vm2	.	vmj	.	vmn

6. Conclusions

This paper presents a method for prioritizing watersheds for potential wastewater reuse schemes. The method relies on multi-criteria decision analysis using the IOC in order to figure out the suitability of watersheds for the wastewater reuse. Although the paper is based on a conceptual illustration of the suitability index, however, the method needs to be implemented on a real case study to verify its practicality. One of the challenges in utilizing the suitability concept is its reliance on a multitude of parameters (criteria). Many of these parameters are difficult to quantify because of the very nature of these parameters. For example, it might be difficult to quantify numerically the social criterion or to find a geographic variability in the religious criterion.

The IOC method in multi-criteria decision analysis is a straightforward and efficient method for decision analysis and allows for ranking the watersheds based on the preference order of the decision criteria.

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