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The Influence of Hydrogeological Conditions on Salt Quality Standards in Ambal District Kebumen Regency Central Java Indonesia

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ABSTRACT

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Salt (NaCl) also known as halite, has a vital role as an essential ingredient in human life and industry. Kebumen Regency in Central Java, especially along the south coast area of Ambal District, is one of the area in Indonesia that produces salt, originating from elongated dome-shaped salt ponds, which are the primary source of salt production in the region. Salt quality standards are regulated by SNI 3556:2016, which provides limits for metal contamination such as cadmium (Cd) <0.5 mg/kg, lead (Pb) <10 mg/kg, mercury (Hg) <0.1 mg/kg, and arsenic (As) <0.1 mg/kg. This research aims to: understanding and mitigating groundwater impact, monitoring and managing heavy metal contamination in salt ponds, and enhancing salt production quality standards. The conditions of seawater and groundwater used in the salt production process have a significant impact on the quality of the salt produced, which can be determined from hydrogeological studies.The results of measuring residents' wells at 43 points show that the depth of the groundwater level ranges from 4.4 to 14.75 meter below sea level. The results of salt analysis from 2 different salt ponds showed Cd levels ranging between 0.0949-0.1001 mg/kg, Pb between 0.5163-0,755 mg/kg, Hg between 0.01198-0.06203 mg/kg, and negative As levels; with water content ranging from 14.43-14.92% w/w and NaCl content between 72.3-85.8%. The analysis of well water and seawater from 3 samples showed Cd <0.0009 mg/kg, Pb <0.0011-0.0098 mg/kg, Hg <0.0001 mg/kg, and As <0.001 mg/kg. The results of groundwater level mapping show that hydrogeological conditions influence the quality standards for salt on the southern coast of Kebumen, especially by the significant grain size factor that carries groundwater and the elements dissolved in it. Meanwhile, salt produced from 2 salt ponds in Ambal District did not meets quality standards based on SNI 3556:2016.

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1. INTRODUCTION

Halite, commonly referred to as salt and chemically represented as NaCl, manifests as cubic or isometric crystals, constituting a vital component for both human sustenance and industrial applications (Lowenstein & Hardy, 1985). Kebumen Regency in Central Java, particularly along the southern coastline within Ambal District, stands out as one of Indonesia's major salt-producing regions. The predominant structures facilitating salt production in this area are elongated dome-shaped salt ponds. Upholding the quality and safety of the yielded salt products is paramount, and to achieve this, stringent salt quality standards are in place. These standards, as outlined in Indonesian National Standard (SNI) 3556:2016, set specific criteria for permissible metal contamination levels in salt. According to the standards, concentrations of cadmium (Cd) should be less than 0.5 mg/kg, lead (Pb) less than 10 mg/kg, mercury (Hg) less than 0.1 mg/kg, and arsenic (As) less than 0.1 mg/kg.

In a study by Wen et al. (2019), the research delves into the influence of salinization in coastal groundwater on the distribution and potential risks associated with heavy metals. The findings underscore the profound impact of coastal groundwater quality on regional sustainable development, aligning with the core focus of this investigation on adhering to salt quality standards within the coastal vicinity. Wang et al. (2022) have explored the repercussions of changes in land use on groundwater hydrochemistry in an oasis-desert region. Their investigation reveals that prolonged agricultural irrigation can alter the distribution patterns of soil moisture and salt, thereby potentially influencing adherence to salt quality standards. The quality of seawater, serving as the principal source in the salt production process, plays a pivotal role in shaping the ultimate quality of the produced salt. Hydrogeology, a scientific discipline centered on the study of groundwater distribution and movement within the earth's crust, particularly in aquifers, exhibits interconnectedness with various surface waters, including seawater a primary component in the salt production process.

The primary objective of this study is to scrutinize the quality standards applicable to salt ponds situated along the south coast of Kebumen Regency, Central Java, and to explore their correlation with the prevailing hydrogeological conditions. In more detail, the objective of this study is to highlighting a significant aspect of the research findings related to salt quality standards and hydrogeological conditions in the Ambal sub-district, Kebumen district, e.g.:

1.1. Understanding and Mitigating Groundwater Impact

The primary goal is to comprehend the hydrogeological conditions in the research area, specifically focusing on the groundwater level variation and its impact on drainage patterns. This understanding is crucial for developing targeted mitigation strategies, mainly where drainage patterns influence the flow towards rivers and seas.

1.2. Monitoring and Managing Heavy Metal Contamination

A key objective is to establish comprehensive monitoring systems for heavy metal contamination in salt ponds. The study reveals varying levels of Cd, Pb, Hg, and As in different salt ponds, emphasizing the need for ongoing monitoring programs. The aim is to ensure that heavy metal concentrations remain within safe limits, protecting both environmental and human health.

1.3. Enhancing Salt Production Quality Standards

Focused on improving the quality standards of salt production, this objective aims to address the discrepancies identified in the salt produced from salt ponds in Ambal District. By aligning salt production practices with national standards (SNI 3556:2016), the goal is to enhance the overall quality of salt, ensuring it meets safety and regulatory requirements. This includes considering factors such as grain size distribution and adherence to permissible levels of heavy metals.

The research methodology involves comprehensive hydrogeological mapping conducted in the field, alongside water chemical analysis and salt chemical analysis. The overarching goal is to fulfill the main objectives of the research, with the anticipated outcome being the assurance that salt products derived from the south coast salt ponds in Kebumen adhere to established quality standards. Additionally, the study aims to contribute meaningful insights that ensure both the quality and safety of salt products, thereby benefiting the local community and industry.

2. METHOD

This research method is based on the objectives to be achieved. Understanding and mitigating groundwater impacts is carried out using the hydrogeological mapping method in the field by regularly measuring the depth of 43 residents' wells at a distance (grid) of approximately 500 meters. The result of this hydrogeological mapping is a map that describes the conditions and patterns of groundwater flow below the surface, which aims to detect whether there is the possibility of seawater intrusion in the research area or the possibility of specific flow patterns carrying heavy metal elements in the groundwater. The map was created by processing groundwater depth data from measurements in the field, interpolating the processed data using the Kriging method to create a groundwater contour map, and determining the direction of groundwater movement based on high to low contours. Monitoring and managing heavy metal

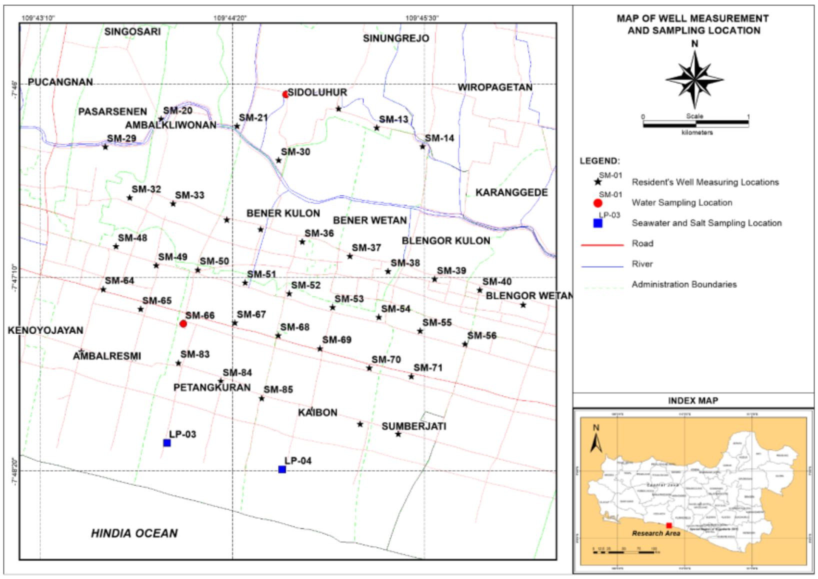

Figure 1. Map of the Well Measurement and Sampling Location

contamination is carried out by taking water samples from residents' wells around the salt ponds of two samples, taking seawater samples used as raw material for the salt of one sample, salt sampling in salt ponds of two samples, and chemical analysis of these samples (water and salt) to determine the levels of elements listed in SNI: cadmium (Cd), lead (Pb), mercury (Hg), and arsenic (As) using gravimetric, conductometric, and AAS (Atomic Absorption Spectrophotometry), and for mercury (Hg) analysis using a mercury analyzer. Chemical analysis to determine levels of salt quality and heavy metal elements is carried out at the Integrated Research and Testing Laboratory, Gadjah Mada University, Yogyakarta (LPPT-UGM), the Health Laboratory and Calibration Center for the DIY Provincial Health Service (Labkes-DIY), and the DIY Provincial Center for Environmental Health Engineering and Disease Control (BBTKLPP-DIY). Enhancing salt production quality standards in the research area can be determined by integrating data obtained from the results of chemical analysis of water and salt, which are matched with SNI 3556:2016 for salt quality standards, then looking for links if there are chemical data anomalies (for example, an increase in heavy metal elements) from contour maps and groundwater flow patterns from the results of hydrogeological mapping. A map of the research and sampling location is presented in Figure 1. The photos of data and sample collection in the research area is shown in Figure 2.

Figure 2. Collecting Field Data in the Research Area. **a**. Measuring the depth of residents' wells using a tape. **b**. Taking samples of residents' well water. **c**. Taking sea water samples from one of the tunnels, which is used as raw material for making salt. **d**. Taking salt samples

3. RESULTS AND DISCUSSION

3.1. Understanding and Mitigating Groundwater Impact

This can be known from the results of hydrogeological mapping to determine the contours and patterns of groundwater flow. Research conducted by Ashilah et al. (2022) showed that hydrological factors greatly influence salt production in one area in Rembang Regency. This research area covers 11 villages in Ambal District: Ambalresmi, Petangkuran, Kaibon, Sumberjati, Blengor Wetan, Blengor Kulon, Bener Wetan, Bener Kulon, Ambalkliwonan, Sidoluhur, and Karanggede (see Figure 1). There are 43 resident's wells in the research area, which are taken at a distance (grid) of approximately 500 meters. To measure groundwater level elevation, calculations are carried out by calculating the difference in height between the ground surface and the depth of the groundwater table using the following equation (Amah & Agbebia, 2015):

$$\mathrm{GWL.El} = \mathrm{G.El} + \mathrm{h} - \mathrm{SWL} \quad (1)$$

Where: GWL.El is the groundwater level elevation (meters under sea level); G.El is the ground elevation (meters above sea level); h is the height of well casing (meters); and SWL is the depth of the wells (meters).

Information regarding the coordinates of the research location and calculation of the depth of the groundwater level at the research location can be found in Table 1. From this data, it was then processed using the Kriging interpolation method to create a groundwater contour map in the research area which can be seen in Figure 3.

Table 1. Location of Well Measurements and Depth of Ground Water Level at the Research Location

Well ID	Coordinate Systems: UTM WGS84, zone 49S			h (m)	SWL (m)	GWL.El (m)
	Longitude	Latitude	G.El(m)			
SM-11	361537	9141173	9	0,4	3,4	6
SM-12	362126	9141018	11	0,75	2,9	8,85
SM-13	362554	9140810	12	0,55	2,5	10,05
SM-14	363066	9140602	10	0,75	3,4	7,35
SM-20	360143	9140900	8	0,9	4,5	4,4
SM-21	360988	9140824	11	0,7	2,6	9,1
SM-29	359518	9140588	12	0,75	4,9	7,85
SM-30	361457	9140444	11	0,75	4,05	7,7
SM-32	359794	9140023	17	0,8	3,8	14
SM-33	360278	9139961	19	0,9	3,9	16
SM-34	360877	9139782	15	0,7	3,4	12,3
SM-35	361257	9139675	16	0,6	3,2	13,4
SM-36	361725	9139540	18	0,75	4,3	14,45
SM-37	362254	9139381	15	0,8	3,25	12,55
SM-38	362685	9139214	14	0,6	3,2	11,4
SM-39	363202	9139128	16	0,65	3,6	13,05
SM-40	363709	9139010	14	0,7	3,8	10,9
SM-41	364193	9138848	17	0,5	3,5	14
SM-48	359641	9139484	18	0,95	4,2	14,75
SM-49	360092	9139273	15	0,8	3,3	12,5
SM-50	360555	9139225	12	0,75	4	8,75
SM-51	361086	9139085	17	0,9	4,4	13,5
SM-52	361578	9138965	18	0,8	4,2	14,6

Well ID	Coordinate Systems: UTM WGS84, zone 49S			h (m)	SWL (m)	GWL.El (m)
	Longitude	Latitude	G.El(m)			
SM-53	362063	9138811	14	0,8	4,3	10,5
SM-54	362582	9138703	16	0,6	4,1	12,5
SM-55	363042	9138552	14	0,75	4,5	10,25
SM-56	363545	9138409	14	0,8	3,7	11,1
SM-64	359499	9139006	17	0,9	3,9	14
SM-65	359917	9138786	17	0,85	3,2	14,65
SM-66	360397	9138622	16	0,8	3,9	12,9
SM-67	360973	9138637	16	0,8	4,1	12,7
SM-68	361457	9138498	15	0,7	4	11,7
SM-69	361926	9138356	14	0,85	3,9	10,95
SM-70	362476	9138140	17	0,75	3,5	14,25
SM-71	362946	9138048	18	0,8	3,6	15,2
SM-81	359259	9138310	15	0,8	4,4	11,4
SM-82	359845	9138242	17	0,9	4,2	13,7
SM-83	360343	9138190	18	0,8	4,4	14,4
SM-84	360818	9137989	17	0,8	4,8	13
SM-85	361274	9137801	17	0,9	4,2	13,7
SM-86	361841	9137676	14	0,85	4,5	10,35
SM-87	362374	9137517	17	0,75	5	12,75
SM-88	362803	9137409	16	0,9	4,4	12,5

It can be seen from Table 1 that the ground surface height in the study area varies between +8 masl and +19 masl. Meanwhile, the depth of the groundwater level at the research location ranges from -4.4 meters above sea level to -15.2 meters above sea level. The lowest relative groundwater level is in the western part of the research area, at Ambalkliwonan Village in SM-20. Meanwhile, the highest relative groundwater level is also at Ambalkliwonan Village on SM-33 in the southern part (see Figure 3). Information about groundwater flow patterns is obtained through creating groundwater flow contour maps. When groundwater flows, it forms a flow pattern that matches the contour of the groundwater table. Groundwater flow patterns always start from areas with the highest elevation and move towards areas with lower elevation; this is influenced by gravitational attraction (Saldanela et al., 2015). Figure 3 shows the results of groundwater level data interpolation using the Kriging method, presented in a groundwater level contour map and groundwater drainage patterns in the research area.

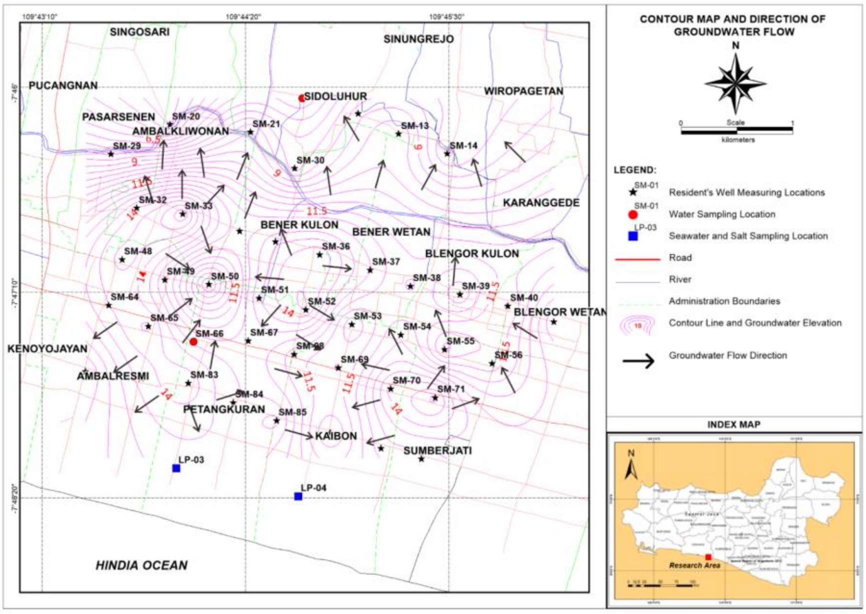

Figure 3. Groundwater Contour Map and Flow Patterns in the Research Area

3.2. Monitoring and Managing Heavy Metal Contamination

This can be known from the results of chemical analysis for salt and sea water. The results of chemical analysis on salt and water samples to determine heavy metal levels are shown in Table 2 and Table 3.

Table 2. Salt Sample Analysis Results

Sample ID	Water content (% b/b)	NaCl (%)	Hg (mg/kg)	As (mg/kg)	Pb (mg/kg)	Cd (mg/kg)
LP-03	14,43	72,3	0,01198	Negative	0,755	0,1001
LP-04	14,92	85,8	0,06203	Negative	0,5163	0,0949

Table 3. Water Sample Analysis Results

Sample ID	As (mg/L)	Cd (mg/L)	Hg (mg/L)	Pb (mg/L)
LP-03 (seawater)	<0,001	<0,0008	<0,0001	0,0102
SM-11 (well-water)	<0,001	<0,0009	<0,0001	<0,0011
SM-66 (well-water)	<0,001	<0,0009	<0,0001	<0,0011

3.3. Enhancing Salt Production Quality Standards

This aims to determine the relationship between hydrogeological conditions and results of chemical analysis of salt and water by integrating the data and results of the analysis. The hydrogeological situation in the study area, as seen in Figure 4, shows that the groundwater flow pattern generally consists of two parts: a flow pattern that dominates in the north, with a relatively south-north flow direction originating from rivers that stretch from west to east; and a flow pattern in the south, with a relative north-south flow direction towards the sea and a south-north flow pattern towards the river. From the drainage pattern, the seawater samples taken at point LP-03 were influenced by the groundwater drainage pattern, which leads to the south. The salt quality standards set by SNI 3556:2016 are as follows:

Table 4. Quality requirements for iodized consumption salt (SNI 3556:2016)

ID	Test Parameters	Unit	Requirements
1	Water content	Mass fraction %*	Maximum 7
2	NaCl content dmb**	Mass fraction %*	Minimum 94
3	Metal contamination:	mg/kg	
3.1	Cadmium (Cd)	mg/kg	Maximum 0.5
3.2	Lead (Pb)	mg/kg	Maximum 10
3.3	Mercury (Hg)	mg/kg	Maximum 0.1
4	Arsenic (As)	mg/kg	Maximum 0.1

* Mass fraction is weight/weight

** Dmb is on a dry matter basis

After examining Table 2 and Table 4, it becomes apparent that concerning quality standards, the salt extracted from the salt tunnels in the Ambal area falls short of meeting SNI requirements, particularly in terms of water content and NaCl concentration. Despite this, the contamination of heavy metals such as Cd, Pb, Hg, and As remains below the permissible pollution threshold. Notably, there exists a noticeable upward trend in the levels of heavy metals, including Cd, Pb, and Hg, in the groundwater from upstream to downstream, specifically in the water samples SM-66 to LP-03, with a substantial escalation observed in Pb levels (refer to Table 3). This upward trend is further echoed by the elevated levels of Cd, Pb, and Hg in both salt samples, as depicted in Table 2.

Speranza et al. (2013) and Moroni et al. (2019) explained that the presence of the main elements in halite fluid inclusions, together with the presence of certain minerals shows that the main constituent components of salt mostly come from seawater, one of which is formed through the evaporation system. This is closely related to the research of Moller et al. (2017), who discussed how halite brines and igneous/metamorphic rocks interact chemically and highlighted that halite plays a crucial role in influencing the composition of the fluids that form the salt. In a study conducted by Li et al. (2019), they performed a numerical simulation focusing on the release of salt at the interface between sediment and water within a low-permeability region. Their research findings highlight how the properties of the sediment, particularly particle size, play a crucial role in both salt release and water quality. These findings support the assertion that the notable increase in heavy metals within the study area correlates closely with the smaller particle size of the constituent rocks. The content of heavy metals in water may decrease due to the resuspension process, as highlighted by Maslukah (2013). Consequently, the heavy metals present in the sediment tend to be released into the water column. The prevalence of quartz minerals (SiO_2) in sediments, especially in the grain composition forming the Alluvium (Qa) structure upstream (comprising clay, silt, sand, gravel, and pebble) (Asikin et al., 1992), possesses larger grains and lower levels of adsorption capacity, thereby contributing to the release of heavy metals from the sediments (Roussiez et al., 2005).

On the other hand, the existence of fine grains and clay minerals, possessing extensive surface areas, leads to the powerful absorption of heavy metals, consequently binding them to the sediment under downstream geological conditions, exemplified by the Beach Deposits (Qac) identified in the downstream section characterized by well-sorted loose sand-medium (Asikin et al., 1992). The smooth surface of a particle, as observed by Suarsa (2017), directly impacts its surface area and subsequent collision reactions with compounds within the sediment. Sand-sized particles lack the ability to interlock, resulting in the formation of macropores that serve as pathways for water and air, facilitating rapid water drainage (Hakim et al., 1986; Soniari, 2016), especially within the study area with unconsolidated material conditions. Coarser soil or sediment textures exhibit a more extensive distribution of macropores, rendering them more porous with a relatively lower water-holding capacity. Waterborne heavy metals such as Cadmium (Cd^{+}), Mercury (Hg^{2+}), Lead (Pb^{2+}), and Arsenic (As^{2+}) can traverse easily through larger particles but are more likely to be entrapped in finer particles (Soniari, 2016). Fine sediment, typically classified as <0.0063 mm or 63 µm, falls into the silt or clay category, acting as efficient filters for both inorganic and organic pollutants.

The absorption of pollutants by fine sediment (63 µm) proves effective across various water pH conditions, encompassing neutral or acidic pH levels, and is influenced by factors including organic matter content, Fe, Mn-Oxide, and clay minerals (Kraklik, 1998). The expansive surface area of particles significantly aids in adsorbing molecules and cations, leading the molecules to envelop the surfaces of smooth or clay-sized sediments. Generally, clay carries a negative charge, facilitating the binding of positive cations to the sediment (Soniari, 2016). The contribution or distribution of sediment particle sizes in the escalation of heavy metal concentrations can exceed 80%, with heavy metals often concentrating or becoming trapped in exceedingly fine sediment (<63 µm) (Ridha et al., 2019). Therefore, despite still falling within safe limits, there might be an elevation in heavy metal elements within the study area due to the comparatively smaller size of sediment grains from upstream to downstream, acting as the path through which groundwater flows, thus influencing the increase in heavy metal concentrations.

Another potential explanation is provided by Nawab et al. (2015), who conducted a quantification of heavy metals in soil affected by mining activities, and their subsequent bioaccumulation in indigenous plant species. Additionally, the work of Talabi (2022) delves into the distribution of groundwater within urban settlements, offering valuable insights into the hydrogeological conditions present in the study area. Their collective research emphasizes the potential for heavy metal contamination in regions impacted by agricultural and urban practices, a consideration that may hold relevance for the Ambal District. To bolster this interpretation, it is imperative to undertake further research exploring the interconnectedness between land use, hydrogeology, and the pollution of heavy metals within the designated research area. Such investigations will provide a comprehensive understanding of the complex dynamics governing heavy metal distribution and its correlation with specific land-use patterns and hydrogeological factors in the study area.

4. CONCLUSIONS

Based on the results of research and discussion, the following conclusions can be drawn bellow.

- The hydrogeological conditions in the research area have a groundwater level ranging from -4.4 to -15.2 m below sea level, with a groundwater drainage pattern that is divided into two: in the northern part with a drainage pattern towards the river and in the southern part of the research area with a drainage pattern towards the sea.
- The results of salt analysis from 2 different salt ponds show Cd levels ranging between 0.0949-0.1001 mg/kg, Pb between 0.5163-0,755 mg/kg, Hg between 0.01198-0.06203 mg/kg, and negative As levels; with water content ranging from 14.43-14.92% w/w and NaCl content between 72.3-85.8%. The analysis of well water and seawater from 3 samples showed Cd <0.0009 mg/kg, Pb <0.0011-0.0098 mg/kg, Hg <0.0001 mg/kg, and As <0.001 mg/kg.
- Hydrogeological conditions influence salt quality standards in the Ambal sub-district, Kebumen district, especially in terms of groundwater drainage patterns and grain size distribution, which are closely related to increasing heavy metal concentrations, although they are still within safe limits. Meanwhile, salt produced from 2 salt ponds in Ambal District did not meets quality standards based on SNI 3556:2016.

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