ASSESSMENT OF RECLAMATION POTENTIALITY IN THE LIGNITE MINES OF NORTHERN GREECE[1]

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Abstract: Landscape reclamation at the lignite spoil heaps of Ptolemaida, Greece is complex and difficult due to adverse ecological conditions. Natural revegetation could be the first step before reclamation began, thus it was surveyed and 7 plant communities were identified, described and mapped. In order to understand the variation of some soil physical and chemical properties in an experimental block and its effect on revegetation production, graphical interpretation of those soil properties was done with the use of geostatistics in a geographic information system (GIS). Soil properties were related to natural vegetation succession and both could be indicators in assessment of reclamation potentiality on the site. Geostatistics were used to estimate soil properties and natural vegetation composition with a minimum number of samples. A geographic information system with geostatistic support helped to map with precision site quality without increasing sampling cost and facilitated solutions locally on species selection and soil amendment problems.

Additional Key Words: geostatistic, geographic information system, uncertainty, precision agriculture and phytosociology.

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Introduction

Lignite is the most important energy resource for electric power production in Greece. However, the different lignite mining activities create peculiar problems. Lignite mining changes geomorphology, underground water balance, soils and creates instability in flora and fauna. Environmental change and the abandoned spoils of lignite and fly ash create an unattractive landscape. The Public Electric Company of Greece, (the responsible utility for reclamation of that area), has done many trials to establish different forest species. The trials are not adequately planned and most of topsoil was wasted into spoils. Some of the species selected for these trials were inappropriate for the climate and soil of the area. Ashby and Kolar (1985) have pointed out that climate, type of rooting medium, drainage and herbaceous competition may limit reclamation success; most of the afforestation trials fail due to errors during the establishment and because of the extreme ecological conditions in some microenvironments.

The lignite spoils of Ptolemaida are highly variable in fertility, toxicity, and soil color depending on the percentage of marl, lignite, topsoil and fly ash in the soil. Many researchers have studied the use of natural revegetation and forest establishment on the spoils for some years before those areas are converted to agricultural lands (Alexander, 1989; Wade, 1989; Panagopoulos, 1995). Soil characteristics with similar vegetation associations were shown to be reasonable indigenous indicators of soil degradation and rehabilitation (Paniagua et al., 1999). Bioindicator-based studies have the potential to make a major contribution to optimize different reclamation systems and to influence policies governing landscape management and transformation (Paoletti, 1999). Prior to the mining of heavy minerals, the vegetation diversity has to be investigated to serve as a benchmark for the future rehabilitation of the area (De Villiers et al., 1999).

Before reclamation starts is important to provide specific biological information and incorporate it in a geographical information system; this information is used to support decision making during the design of the reclamation plan. In order to understand the variation of soil properties, a graphical interpretation of specific variables could be obtained through geostatistical techniques. Geostatistics provide inexpensive maps of a given area to decrease uncertainty (Chilès & Delfiner, 1999). The present study examines the geographical variability of some ecological conditions at the lignite spoils of Ptolemaida, Greece, and their influence to reforestation success.

Description of the Study Area

The lignite mines studied are located in Northwest Greece near the city of Ptolemaida, in a valley with 667.5 meters mean altitude, at latitude 40^{o} 30' North and longitude 22^{o} East of Greenwich (Fig. 1). The valley is rich in lignite, with six active lignite mines in the area. Fourteen electricity-generating plants, with a total of 3,683MW, produce more than 70% of Greece's electric power. Until recently, of the 12,500 has affected by mining only 400 ha were rehabilitated, and by the year 2025, it is estimated that the area affected by mining will be 20,000ha.

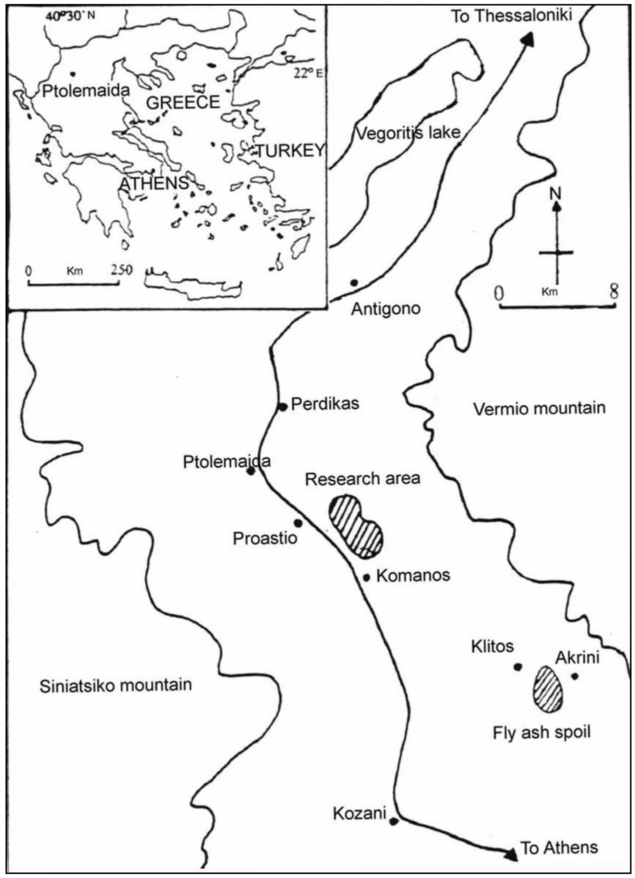

Figure 1 Location of the study area.

The climate of the area is continental Mediterranean with very hot and dry summers and mild winters. Average annual precipitation is 551.26mm (Ptolemaida meteorological station, 35 years of record) with a maximum monthly average in November (68mm) and a minimum in August (27mm). Average annual air-temperature is 12.3^{o}C with coldest month January (1.8^{o}C) and warmer July (22.5^{o}C). The absolute maximum air temperature during the research period was 41^{o}C and the absolute minimum air temperature was -21^{o}C. The dry period starts at the end of June and finishes in September, is relatively shorter than other regions of Greece and with more even precipitation.

Materials and Methods

Forty-eight geographically positioned sampling areas of 1 m2 were established on lignite spoil of the study area. For every sampling area, the Braun-Blanquet method was used and soil type, percentage of soil cover by plants and plant vitality were estimated. Phytosociological units were separated with criteria based on species physiognomy, ecology, flora and evolution. The method, based on ecology and flora, was better on achieving the purpose of the study, which was to develop ecological descriptions of separated communities that will arise from a plant-table process. The ecological description of the separated plant communities was done with the help of the ecological properties of indicator groups.

The spatial variability of spoils soil properties was estimated with 16 geographically positioned soil samples. Soil color, type of soil (lignite, peat, topsoil, fly ash, marl or mixture of the above) and percentage of vegetation cover were identified. Soil samples were transferred to the laboratory, weighted, dried and analyzed for many physicochemical properties. Soil temperature during summer, a limiting factor for revegetation success at the lignite mines of Ptolemaida, was estimated with mercury thermometers at 0.5, 2.5, 11 and 17cm depth, in three different soil colors: red topsoil (5R 4/7), light grey (10Y 7/1) dominated from marl or fly ash and black (10YR 3/1) with high lignite content. Air temperature was measured under shadow, 50cm above the soil.

Statistical analysis of the data included computation of the sample mean, variance and coefficient of variation for maximum soil temperatures measured at each depth and compared with the soil surface temperatures of a black colored soil under shadow. Comparisons of all means were examined with the Duncan's test. After conventional statistics, all data was entered into a field-scale geographic information system, and interlayer data analytical tools were utilized to quantify spatially dependent relationships (Kitanidis, 1997). A semi-variogram was produced for each soil property and several parameters from the semi-variogram were analyzed (Armstrong, 1998). Cross validation indicators and additional model parameters (nugget, sill and range) helped to choose the most appropriate model of the prediction maps for each soil property (Panagopoulos et al., 2006).

Results and Discussion

Phytosociological units were determined with the help of the indicator plant groups. After the plant-table process, 7 indicator plant groups were separated in the table of species sampling. The result of the combination of the indicator groups was the ecological description of the 6 plant groups published from Panagopoulos et al. (2001). In the following description of the phytosociological units the indicator plant group with the strongest presence was represented with capital letter while there of minor was represented with a small letter between parentheses.

Phytosociological unit E1 with indicator plant group (d): appeared in areas where topsoil exists in a depth of more than 30cm but is covered with lignite spoils. Phytosociological unit E2 with indicator plant groups A(c): could be seen in areas affected from topsoil. Phytosociological unit E3 with indicator plant groups (a)B: appeared in areas affected from topsoil mixed with marl, lignite and fly ash. Phytosociological unit E4 with indicator plant groups (a)Cd: developed in areas where all the spoil materials were well mixed, but with a higher presence of fly ash. Phytosociological unit E5 with indicator plant groups (c)Dg: developed on soil that was a mixture of all spoils materials. Phytosociological unit E6 with indicator plant group (d)F: appeared in soil similar to E5 unit but in areas with pH higher than 9 as a consequence of high fly ash content. Phytosociological unit E7 with indicator plant group E(f): appeared in areas of marl soil with loamy clay texture.

Geostatistics were used to quantify and visualize vegetation cover in areas that were not measured. Figure 2 illustrates the indicator plant groups distribution used to create the phytosociological units in the experimental area, and the vegetation soil cover after a Kriging (spherical) interpolation with lagged distance 10m. Additionally, it was possible to examine the influence of phytosociological units and the indicator plant group distribution on the soil cover. In the same figure, it can be seen that plant groups E, F and A appear generally on areas with poor soil cover, while the plant groups B, C and D develop on areas with better soil cover. Geostatistics helped to quantify the magnitude of spatial variability of vegetation cover, as well as model the spatial structure of the variability.

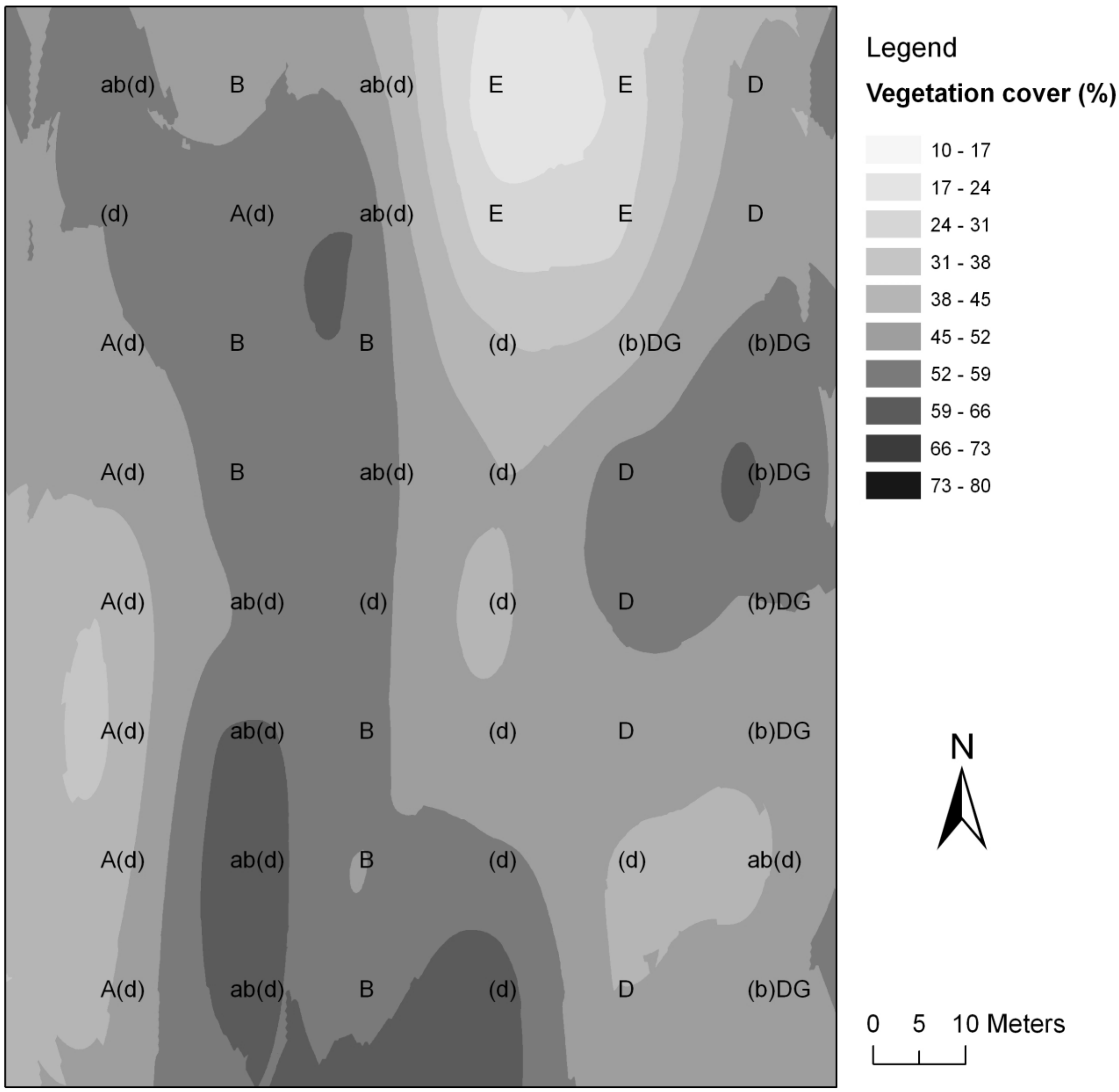

Figure 2. Vegetation soil cover and indicator plant group distribution on the spoil area (the strongest presence was represented with capital letter while there of minor was represented with a small letter between parentheses).

Exponential semivariograms were the most frequent for most factors studied. Particle size composition of the soils on the spoil heaps varied primarily because of the composition of the soil mixtures on which soil forms. Generally, they were characterized as medium-textured (Fig. 3). Topsoil had lower water holding capacity because it had less organic matter and a different texture and structure. Samples with high lignite content keep larger quantities of water available to plants. Capillary water was reaching 50.42% in samples with more lignite. However, the high amount of hygroscopic water in same samples (28.82%) decreased the available to plants water to less than 21.60%.

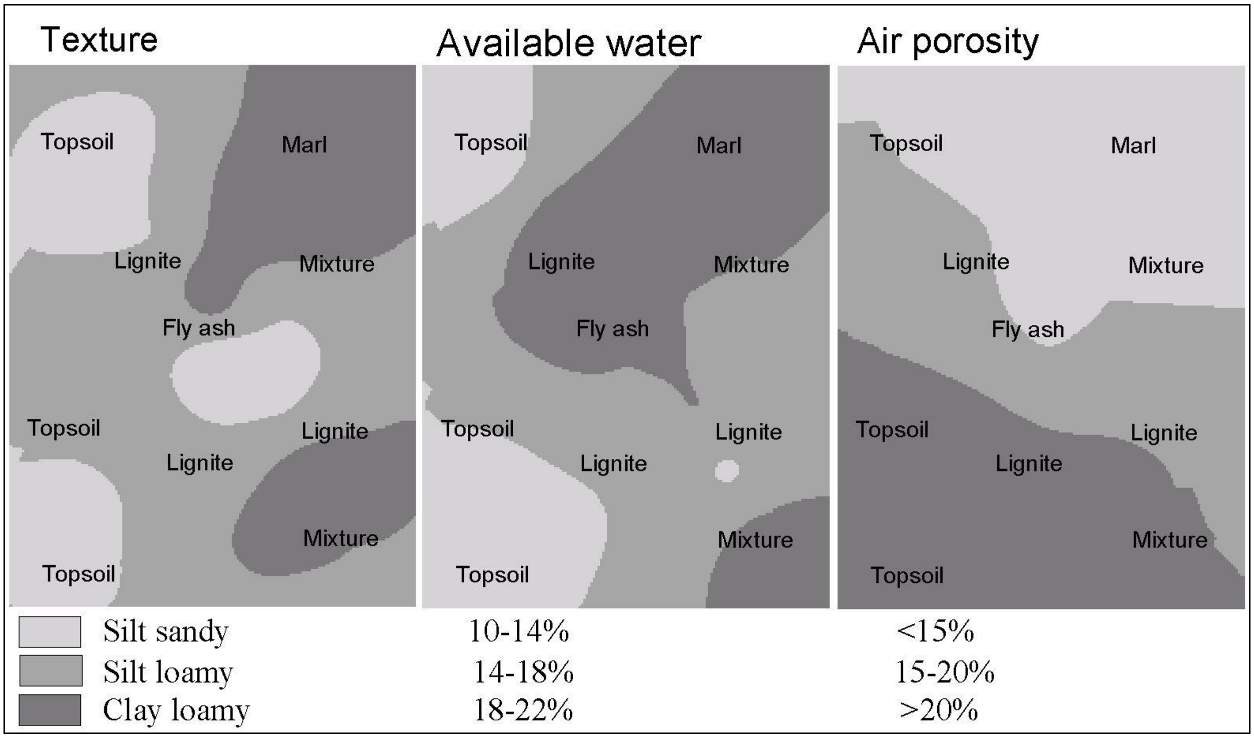

Figure 3. Distribution of spoil type materials assessed at the surface and some soil physical properties after kriging interpolation.

Bulk density and particle density were measured to calculate total porosity and air porosity. Particle density was varying between 2.41 and 2.62 g cm^{-3} and bulk density was varying between 0.77 and 1.43 g cm^{-3}, depending on soil compaction, texture, structure and organic matter in soil. Total porosity was higher than 45% in all samples, although air porosity of the heavy textured area was low with minimum value in high fly ash area (8.9%).

The average pH at the lignite spoils of Ptolemaida was 8.08; and $CaCO_3$ content was high in most samples (3 to 43%) reaching 96.8% in marl samples. Soil electric conductivity was low in most of samples except on some small areas with high fly ash content and marl where it was found to have high electric conductivity (3.85 and 7.68 ds m^{-1} respectively). Soluble Na content was also very high on the same areas (9.95 and 15.65 cmolc kg^{-1}), indicating high salinity, resulting in poor plant growth. In the first map of Fig. 3, it can be seen the estimation map provided from geostatistical interpolation of electric conductivity. This map indicated high electric conductivity areas in the Northwest part of the study area. This suggested that locally salt tolerant forest species were most appropriate and a management strategy calling for the washing of the soil of those areas for at least 2 consequent years.

Available phosphorus varied between sites and was generally low (4.23-19.78ppm) in all samples. Areas with less than 15ppm phosphorus were located on the map that came from geostatistical interpolation of soil properties (Fig. 4) and compared with the map coming from bioindicator natural revegetation species (Fig. 2). It was found that species of phytosociological groups A and F appeared in areas with less available phosphorus. To remediate the situation the use of sewage sludge as soil amendment to those areas was recommended. Using fertilizer instead of sewage sludge as soil amendment was not recommended because those areas had low organic matter and heavy texture. most physical properties needed improvement.

Soil temperatures during the two years of experiment varied between 35°C on the surface when the weather was cloudy to 62°C during clear hot days. The highest values of soil temperature were measured on black colored bare soil. The average soil temperature at 0.5cm depth, at 1500 in the black colored soil was 55°C (Table 1), while the red colored soil had 47.05°C soil temperature and the white marl soil 42.94°C. Between red and grey colored soil there were significant differences at all hours except at 1100. Surface soil temperature under shadow was on average 19.49°C lower than temperature at bare soil of the same area at the same time and type of spoil.

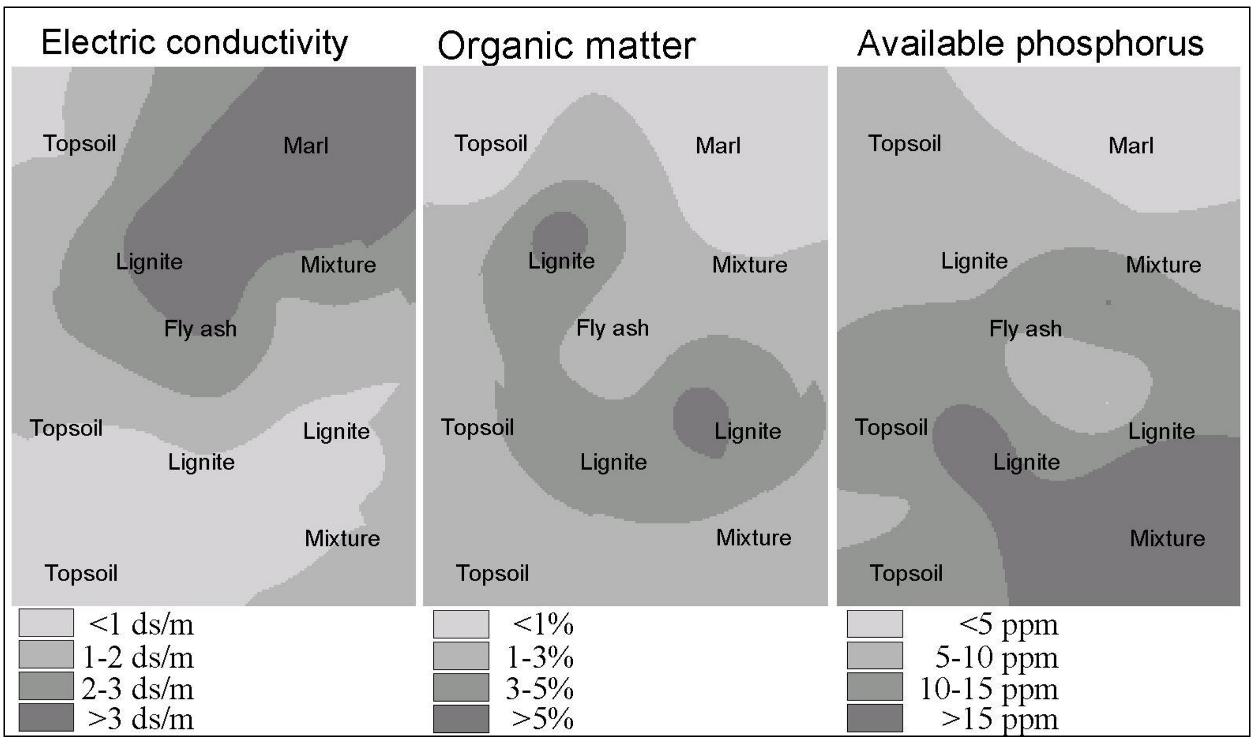

Figure 4. Distribution of soil type materials as assessed from soil color at the surface and some soil chemical properties after kriging interpolation.

Table 1. Average soil-temperature of a lignite spoil heap, in 0.5cm depth, in areas with different soil color, at different times of the day.

Color - Time	1100	1300	1500	1700
Black (10YR 3/1)	40.41[a]*	49.65[a]	55.00[a]	48.29[a]
Light grey (10Y 7/1)	35.05[b]	39.76[c]	42.94[c]	39.94[c]
Brownish red (5R 4/7)	36.29[b]	43.76[b]	47.05[b]	43.64[b]
Black with vegetation cover	32.70[c]	36.35[d]	35.41[d]	35.11[d]

* Values in the same column followed by different letters are significantly different by Duncan's multiple range test, at 0.05 level of probability.

Conclusions

Spatial heterogeneity, which is expected in mine spoil lands, has a pattern rather than being random, so surface sampling must be planned to accommodate this pattern. Soil properties were related to natural vegetation succession and both could be indicators in assessment of reclamation potentiality on the site. Geostatistics helped to map with relative precision the site quality, thereby decreasing uncertainty and minimizing the sampling cost due to number of samples needed to accurately predict soil variability. Using a geographic information system and geostatistics recommendations could be made on local soil quality problems. Soil amendments, irrigation, addition of light colored materials on the surface, or species selection could be decided for specific locations of the heterogeneous spoils. Geographic information systems that link information from prediction maps of soil properties through natural vegetation composition can be tight to database information concerning the reclamation species needs. This could be a useful decision support tool for reclamation of surface mine areas.

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