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Geobotanical prospecting for underwater deposits in desert and semi arid region. Patagonia Argentina by remote sensing studies

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ABSTRACT

The relationship between natural vegetation and the presence of groundwater, particularly in arid regions, is a well known fact. The distribution of certain vegetable species in different environments, the topographic position and the sanitary state of the vegetation can indicate those areas have possibilities of carrying potable water in the grounds and rocks.
This study was carried out in the vicinities of Puerto Deseado in the Argentine Patagonia. This region, with warm climate and high pluvial precipitations millions of years ago, is undergoing a constant severe desertification due to the formation of the Andes mountain range. At present, the annual rain is not over 250 mm and dry West-Southwest winds are constant.
The study, a combination of geobotanical observation techniques performed on satellite images, together with a field survey, allowed the identification of several potable water springs (about 50). Reddish spots were detected through the visual analysis of various Landsat 4 images, infrared 7, 5, 4 (RGB) version, which in infrared combination indicate vegetation. They are located on the surface of Tehuelches formation in defined topographic positions, from which the presence of water in the subsurface could be deduced. The Rodados Tehuelches formation constitute the most accessible rainwater and nival reservoir.

KEYWORDS

Underground water; Patagonia; Vegetation; Desert; Remote sensing.

INTRODUCTION

The studied area has suffered a deep climate change along its geologic history. In the vicinities of Jaramillo, 256 km west from Puerto Deseado, the remains of a petrified forest can be found, in which a species of araucaria apparently related to one existing nowadays in Australia (*A bidwillii*) stands out. Specimens of big size trees can be observed, as well as enormous fallen tree trunks 35 to 40 m long and 3 m diameter. There are still lots of scattered petrified/fossilized pieces indicating that a more humid climate boosted the development of such a lush flora in the past[5].

When the Andes mountain range emerged in the Paleozoic or Tertiary Era, about 70 million years ago, the winds of the Pacific Ocean lost their humidity to the west of the mountains and hit the region arid and furious, which added to the numerous volcanic eruptions after

that geological accommodation, he finished with that orchard.

If compared to the present conditions in which rain is not over 150/250 annual mm in this steppe or semi desert area, the idea of a rigorous climate change, still evolving and which has lead the area into a severe desertification.

For more than a century, several explorers have carried out studies to diminish the aridity of the region Oneto, A (1882) carried out one of the first known hydrogeological studies in the Río Deseado valley, mentioning the existence of seven springs in the floodplain with a 330 litres flow per second. Raymond (1887) describes several indicative plants useful for the exploration of deposits or ores. Beck, R.(1906). mentions for Arizona the relationship of certain plants with the presence of silicious, slate and calcareous rocks. Meinzer (1923/1927) refers to different plants associated to certain environmental factors such as underground waters (*Freatophytes*), draught conditions (*xeròphytes*), salinity, (*halophytes*). Tharp, B (1952) observed different types of plants when there is an important difference between the parental material and its residual soils. Frenguelli, J (1954) relates the existence of Talas *(Celtis tala)* on the sandy cords of the marine coast of province of Buenos Aires to the presence of calcareous material/marine fossils in the profile. Shvyriayayeva and Stankova (1961) observed that plants indicating high salinity (*halophytes*) allowed to find buried salt domes which resulted very useful in the oil search in Russia. Ulibarrena et al. (1964) observed, in the vicinities of Pergamino, province of Buenos Aires, Argentina, the close relationship between the *sunflowers* presenting a bigger size in caliche soils than those without this material in their profile. Cannon, H[2] made a significant contribution to this subject in a work where he refers to indicative plants in the search for underground water, geologic mapping and mineral prospecting, and makes an excellent compilation of works by other authors from different parts of the world. Ulibarrena, J and Rojo, A (1980), highlight the importance of the presence of *phreatophytes* plants as a useful tool for indicating the existence of potable water in arid and semi arid regions as is the case with the Argentine Patagonia.

MATERIALS AND METHODS

The study focused on the idea of detecting the vegetation by means of the colours present in those images specially prepared in the NIR infrared colour combination. These reddish spots clearly express the presence of terrestrial vegetation in good sanitary state, whereas certain variations such as green, yellow and orange indicate vegetation stress. This occurs when the vegetation is in contact with salt water or brackish water or any other polluting material.

A basic planimetry was prepared on the basis of an image obtained by the Multispectral Scanner MMS LANDSAT Series vehicle 4, recorded on January 15th 1976, corresponding to Path 227 and Row 093 of the World Reference System (WRS). The following segments were selected for the combination: MSS 7 0,800 to 1,100; MSS 5 0,600 to 0,700 and MSS 4 0,500 to 0,600 nanometers of the electromagnetic spectrum, with which a combination 7, 5, 4 infrared NIR was prepared. (Figure 1)

A hard copy scale 1:250.000 was used for the analysis. Paths, prints, human settlements, drainage network, gaps, salines, saltpeters, gullies and rills were drawn. Special attention was given to the humidity of the soil and to the small spots of associated vegetation.

For the second stage an image of the same sensor satellite system recorded on December 1st 1980 was used, and a IR and combination (NIR) was prepared with identical channel selection. This image was excellent in quality with a good radiometric resolution, which allowed to adjust and complete the photomorphic unities map.

For this purpose we have a positive and transparent film copy in a 1:1,000.000 scale which was digitalized. Special sections were amplified to a scale of approximately 1:200.000. Over them a visual analysis was performed, paying special attention to the position and distributions of the reddish spots representing the vegetation.

At the same time a geological sketch was prepared, in which the outcrop units of regional expression outstand, according to the YPF map[11], which was improved with all kinds of information taken from the images.

Once this was done it was relatively easy to prepare the base planimetry and geological sketch necessary to perform future campaigns tasks/ terrestrial-aerial correlation. (Figure 2a, b, c, d)

The working zone was visited in order to carry out a terrestrial/aerial correlation, with the purpose of adjusting and checking the laboratory observations performed in the lab.

Some vegetable species were observed, preferably taking into account the topographic position of their different spots, and at the same time the state of development related to the degree of humidity of the soils.

The plants, despite being randomly distributed in a uniform landscape, show a marked similarity and a high degree of association to the variations of micro relief, adjusting to well defined topographic positions. (Figure 3a, b)

The terrestrial aerial correlation confirmed the expressed as a work hypothesis in the preliminary phases of the study. Google Earth Pro images and terrestrial photographs were also used for the regional characterization.

LOCATION AND LIMITS OF THE STUDY AREA

The study area is delimited on the coastal Argentine Patagonia, Northeast of Santa Cruz province, 47º 20' and 47º 56' South latitude and 65º 41' and 66º 42' West Longitude, covering a surface of approximately 11.000 km2. (Figure 4). The study area is delimited by the Río Deseado on the South, route No. 3 on theWest and the Atlantic Ocean on the East and North. Within this region, topography is between is 0 m.a.s.l on the maritime coast and 160 m.a.s.l on Meseta Central on the West border.

Puerto Deseado, located in coordinates S 47º 45' 00" and / W 65º 52'30" on the left bank of Estuary Deseado is the closest most important city, although Tellier is the closest locality to Puerto Deseado, S 47º

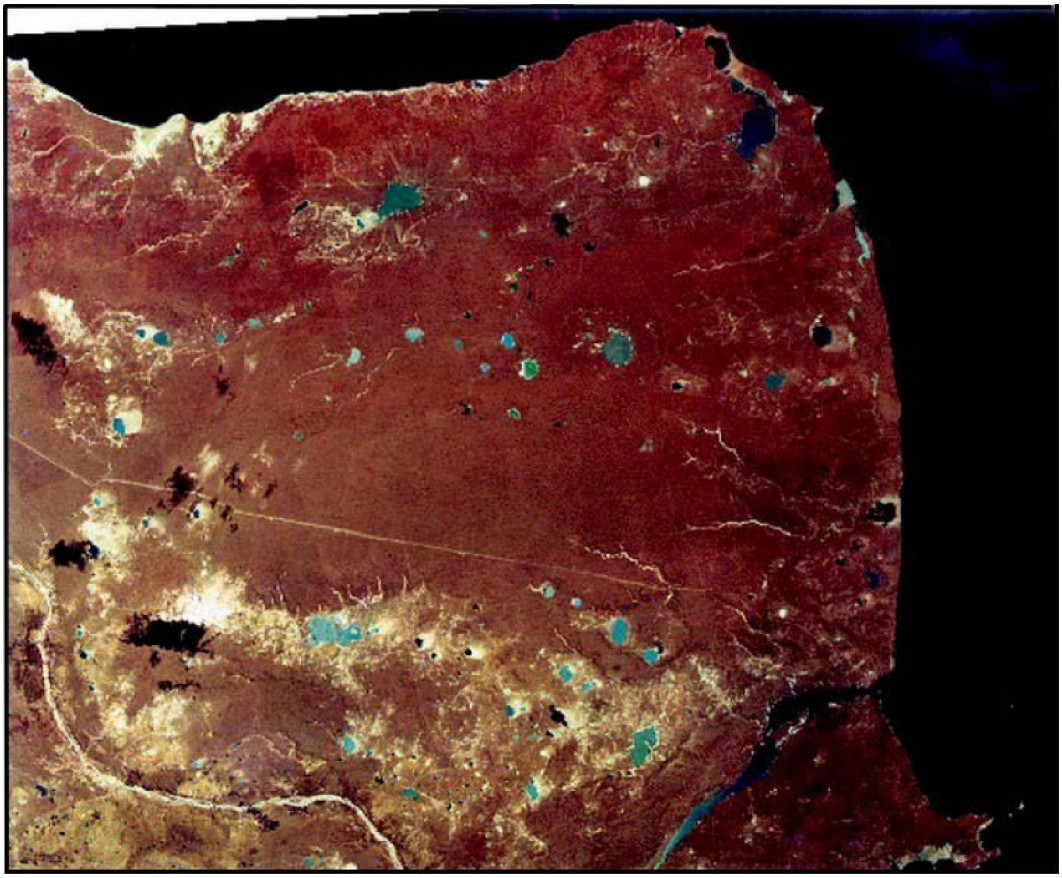

Figure 1: Landsat satellite image; Show the area which covers the study zone, prepared by the CONAE (National Commission of Spatial Activities) of Argentina registered on 1st December, 1980. It was later re digitalized in parts to 1,200 dpi and printed in paper (Hard copy) to an approximate scale of 1:200.000 in order to complete the study of details.

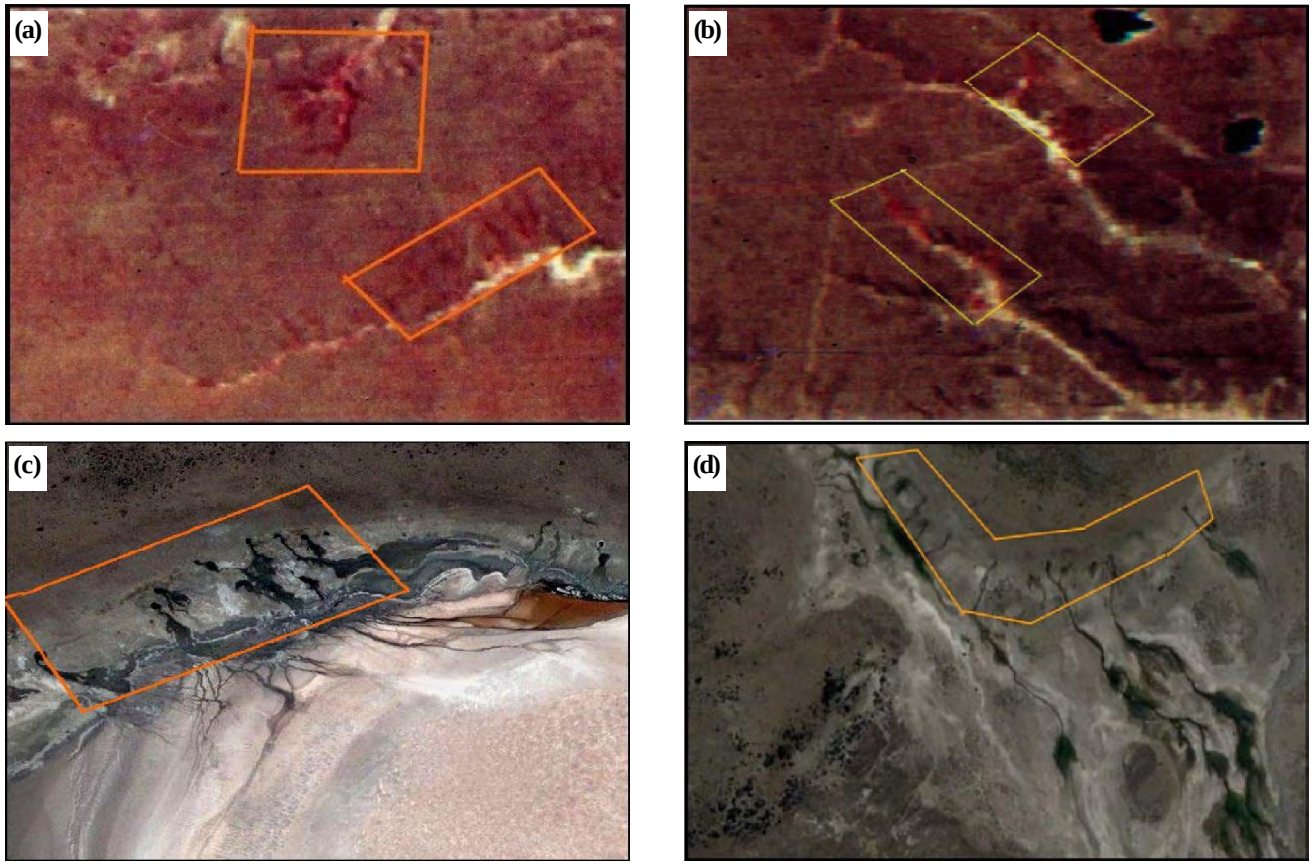

Figure 2: Springs in the High Plateau; (a, b) The two upper images show the presence of many areas with springs in the higher part of the Plateau, marked by reddish spots in the vegetation, in a NIR infrared colour version. This indicates the high spectral reflectance of the vegetation due to good sanitary state. Google Earth Image; (c, d) The two images on the bottom show the flow of potable water can be seen, which falls in salinated extensions, thus generating gullies. Google Earth Image In both cases a considerable volume of the scarce resource is lost due to the lack of conduction works and reservoirs for proper storage for its best use

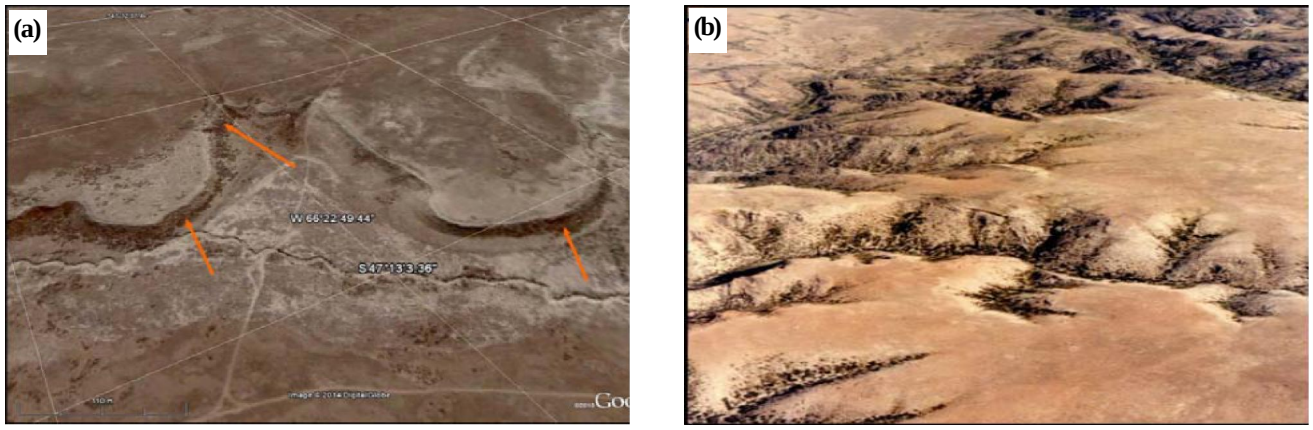

Figure 3: Aerial details; (a) The imagen on the left shows the compressed disposition of the vegetation in the area, where the spree breaks the slope, created by the presence of the Rodados Tehuelches. The upper layer is made up by porous/permeable material in the uplands it is less permeable.and have a very finite edge, and its scree is almost vertical due to the presence of caliche in the profile. The Patagonic formation which constitutes the impervious material under layer is seen in the lower zone and presents a softer and slightly concave slope; (b) Photography/aerial view. The higher concentration of the vegetation in the depressions and gullies of the higher part can be observed, where the permeable material is found. The caliche acts as a limit/floor which favours the retention of humidity, blocking or delaying the flow of water towards the salinated Patagonic Formation under layer. Google Earth Image.

38' 45''/W 66º 02' 18'', on route 281 approximately 19 km West of the mentioned locality. Jaramillo is located 256 km. Northwest S 47º11' 02''/ W67º 08' 40, 20'') on the Meseta Alta/ High Plateau.

Population growth has constantly varied in the last years in Puerto Deseado. Due to this situation, the municipal government requested a study to the Hydrogeology Department of the Facultad de Ciencias Naturales (Faculty of Natural Sciences), Universidad Nacional de la Plata (National University of La Plata) in order to adequate the water provision of the city to the new conditions.

GEOLOGICAL SETTING

On the surface it is constituted by large accumulations of gravel and sand deposits with 8 to 10 meters thickness variable, from the upper tertiary-quaternary the denominated Rodados Tehuelches formation is found. It might be present as a loose surface or cemented by calcareous material (caliche). Cortelezzi et al 1968. This hardpan usually has a thickness between 40 and 50 cm which waterproofs the profile and delays deep percolation.

The under layer is a transgressive marine sediments from the upper Miocene - lower Oligocene known as "Patagonian Formation". It has a thickness that reaches 50 or 60 meters of lime sandy clay and plastic tertiary clays. highly salinized.

The base of the system of aquifuge conditions is formed by porphyritic rocks from the middle Jurassic times, known as "Bahia Laura" Formation. (Figure 5)

DESCRIPTION OF THE AREA

Within the studied area, two well defined geomorphological environments are found: A) Grassy steppe of Golfo San Jorge and B) Central district or Meseta Central. They share roughly the same geological structure.

The limit between both landscapes is a winding border East of the route Nª 14. On the West, near route No.14, the landscapes are interrelated and the last expressions of the Meseta Central are found, markedly eroded and with a sharp slope. (Figure 6)

Grassy steppe of Golfo San Jorge

The geomorphological district of Golfo San Jorge is located in the central East region of the province of Santa Cruz in the Argentine Patagonia. Its eastern limit is the Atlantic Ocean and the western is marked approximately by the aforementioned route No. 14, its limit being sinuous or digitated.

It reaches approximately from route No. 14 to the East, where the Rodados Tehuelches Formation and Patagonia formation begin to decrease. In the eastern section next to the seaside dispersed outcrops from Bahía Laura Formation may be observed, which are covered by a thin layer of unconsolidated materials.

Closer to the coastal zone, the ground is formed by unconsolidated sediments, not differentiated, of fine to median texture from the erosion and later depositing. On the coastal zone there are only sandy marine deposits, constituting a group of beach ridges and relatively recent sandy sea beaches.

The landscape is slightly wavy in the western section while the eastern portion of the area shows brooks and

Figure 4: Location of the area

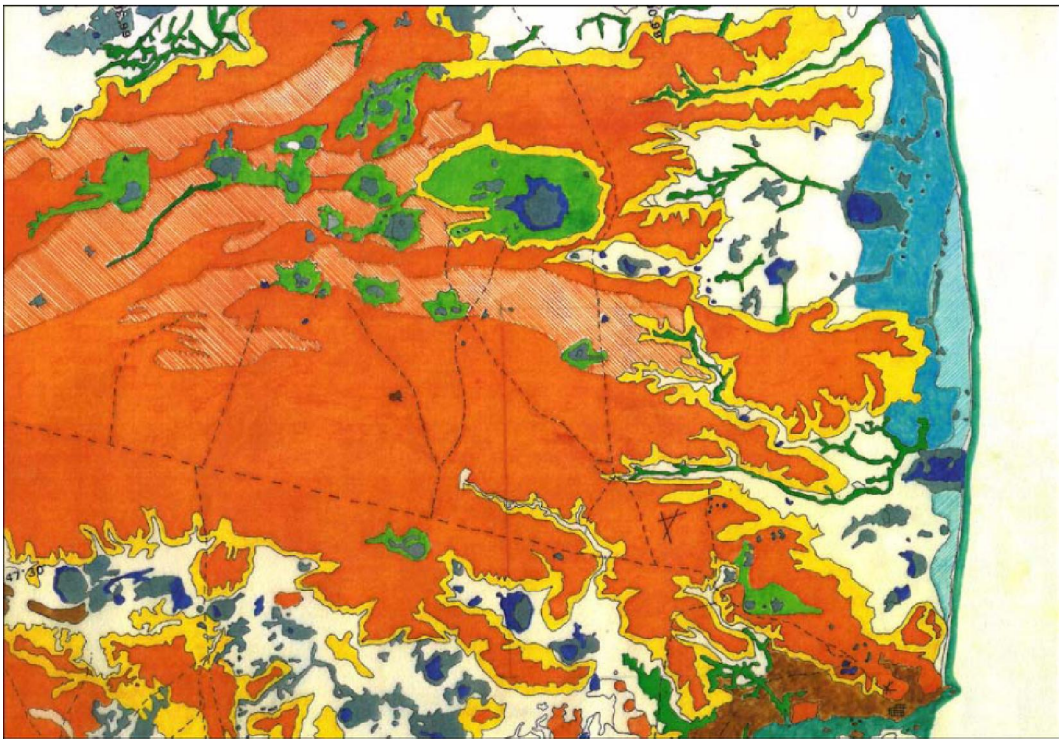

Figure 5: Geologic Map; The lithostratigraphic units of regional extension are presented. In orange the Rodados Tehuelches Formation which acts as pluvial and nival water reservoir is shown. In the shaded areas the highest concentration of vegetation is found. In yellow the Patagonia marine formation. In white Porphyric complex little covered and in celestial (blue) Sandy sea beachest[11]

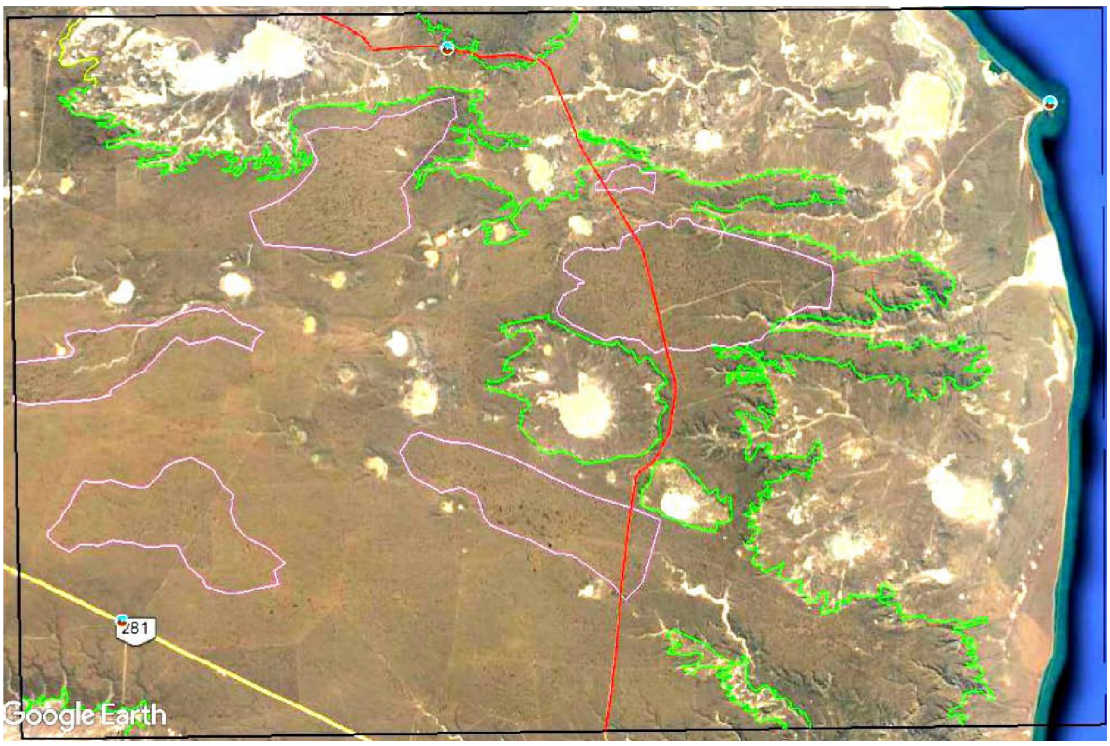

Figure 6: Geomorphological units; Two completely different landscapes can be observed, Unit Grassy steppe of Golfo San Jorge (Right) and Unit known as Meseta Central (Meseta Central) (left). The vertical red line represents the approximate limit of the two units (Provincial Route 14). The green lines mark the edge of the Rodados Tehuelches formation. The pink areas are zones of higher aligned vegetation concentration and the blank areas are saline depressions. Google Earth Image.

rills. These brooks, cut on the porphiritic complex Bahia Laura Formation.

The drainage network is very singular, made up by little streams. It presents a dendritic model, with short, straight affluents and it is almost perpendicular to the main course. The typical dendritic model beginning at the scree of Rodados Tehuelches Formation. Most of them are covered by bushes on the edges or slopes.

The main courses are generally ample. They may be over 200 meters wide, they present a great quantity of meanders at the lower areas next to the sea. They lack vegetation but they have traits of strong salinization. They all discharge into coastal lagoons. (Figure 7a)

The herbaceous stratum at the bottom of the canyons is dominated by diverse types of Coirons (*Festuca gracillina*) as dominant species. At the head and median courses of the canyons the vegetation is similar to that of the mallines (wetlands). The areas with permanent humidity are mainly covered with rushes.

Central district or Meseta Central

The region of the Central Table Land, from extra Andean Patagonia known as District or Central Table Land, is located West of route No. 14. For the purpose of this work its western limit was located on the vicinities of Jaramillo. The relief is formed by a series of ascending step plateaus towards the West, showing a flat to gently wavy morphology.

Other topographic landforms interrupting this monotonous table land are those of negative relief, constituted by canyons and small brooks, rills or ponds with endorheic surface drainage of varied forms and sizes generally with some saline material

The plateau is almost totally covered by a layer of relatively thick, non cohesive material, gravel and sand known as Rodados Tehuelches Formation. The exterior side of the scree is dissected by retrograde erosion occasioned by transverse rills. This results in a very characteristic winding border with marked notches and sharp slopes from where the Rodados Tehuelches Formation waters surging are the only aquifer of the area of study.

This layer of sand and gravel constitutes the main goal of this work, representing an important reservoir of potable water. The permeable texture is deduced from the shape of the gully heads, which allow a significant volume of infiltration and good water storage. The non existence of visible superficial water courses in unit B indicates the high degree of permeability of the

Figure 7a: Dendritic model drainage; (a) The image shows the dendritic model predominating on the East of route 14, district Golfo San Jorge. Typical model of the areas constituted by cohesive material, relatively impervious material of fine sand and silt which lay over the Patagonia formation. Google Earth Image.

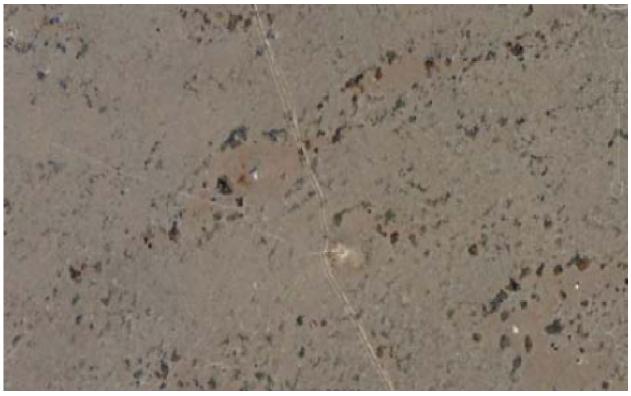

Figure 7b: Braided model drainage; (b) On these images the old dendritic drainage web marked by dark spots can be inferred. It looks less pronounced and silted by sand, constituting a braided model. The dark spots are grouped vegetation, partly aligned occupying the old riverbeds (channels). The model corresponds to the Meseta Central. Google Earth Image.

Rodados Tehuelches Formation, and the scarce water volume during droughts in the low water channel allows the growth of vegetation, aligned and compressed, in search for the vital element due to the greater water availability. (Figure 7a, b).

This river system is formed by those less important rivers which flow mainly on the scarcely consolidated top unit of the Rodados Tehuelches Formation. These rivers, which were dendritic in ancient times, are at present filled with non consolidated sediments constituted mainly by sands and gravel.

Vegetation includes formations of mixed grass steppe, with abundance of generally short bushes. Predominant vegetation in the plateau are Xerophyte hard pastures, grassy steppe and short semiround bushes in the form of cushions which might reach a height of 20 to 100cm.

La Mata Negra (*Junellia tridens*) is exclusively seen on the soil of the brooks and the surroundings of the runoff lines. They mark the drainage or ways of underground water. The subordinate herbaceous vegetation is preferably composed of Coirons, rushes and grass.

HYDROGEOLOGICAL MECHANISM

The Rodados Tehuelches Formation located at the top of the stratigraphic column constitute the sediment package which stores the rainwater, the snowmelt and the water originated by the snows. The infiltration of this waters is fast in the first centimetres but is later retarded by the presence of a less permeable lower layer zone formed by the presence of caliche material in its profile.

After infiltration water runs on the roof of the irregular calcareous horizon towards the tableland scree, thanks to the pre-existing relief and the slight inclination to the East of the whole sediment package, generating a lot of springs.

Sala, J. et al.[6] and Sala, J and Rojo, A. (1982) report the following characteristics of the aquifer of the formation Rodados Tehuelches: "free acuifer", mean satured width 2.50 m., the flow volume varies from 3.5 to 5.00 m3/h and this water is chemically fit for human consumption. (Verbal communication)

DISCUSSION

After an intense search/review in both satellite images from the Landsat series, the presence of reddish spots could be confirmed. They were very small, located at the head of the brooks, preferably in the mid/high part of the gullies or slope of these characteristics. Only in a few extreme cases they were found in the ground of the brooks.

Undoubtedly it was vegetation which, though meagre, it was in good sanitary state, and because of this fact presented a high reflectance in the NIR colour image expressed in red.

In general, an area with a finely dotted/spotted texture can be observed, more than a line, located inside of the main brooks, which keep this disposition for several hundred meters upwaters, advancing towards the high terrace, beyond its beginning in the initial of these brooks.

Due to the geological/geomorphological features of the zone, the first case, the one of the reddish spots located in the slopes of the brooks, they represented springs or areas where the surface lithologic unit runs its waters, known as Rodados Tehuelches. It specifically had to be the geological contact between the first layer of sedimentary package, temporary receptor of the water and caliche, less permeable.

In the second observation, the one where vegetation is aligned/concentrated over the high terrace, is about depressed areas where rivers ran, today silted, where the phreatic zone is found closer. This is how the presence of 50 new springs was found. (Figure 8)

On the other hand, chromatic differences were confirmed among these stains according to their position inside the profile/slope. The data was later verified with the chemical analysis given byte Municipality of Puerto Deseado, in order to link these variations in colour to the quality of the waters. Obras Sanitarias de la Nación. (1974).

The experience was positive, due to the fact that a coincidence between the good quality of the water and the reddish spots seen in the NIR colour image was observed. As the waters descend the quality worsens and the colour of the vegetation spots turns yellower until they reach a brownish colour in the lower part.

This change in colour can be explained if we take into account the fact that when the waters descend from the high terrace towards the lower lands circulate over the roof of the marine formation, the Patagonian, which presents a high saline content, stressing the vegetation and diminishing the infrared reflectance.

VEGETATION/MORPHOLOGY RELATION

The working zone was visited in order to carry out a terrestrial/aerial correlation, with the purpose of adjusting and checking the laboratory observations performed in the lab. (Figure 9a, b, c, d)

Some vegetable species were observed, preferably taking into account the topographic position of their different spots, and at the same time the state of development related to the degree of humidity of the soils.

The terrestrial aerial correlation confirmed the expressed as a work hypothesis in the preliminary phases of the study.

Artificial oases

In spite of the poor volume of water available in the area, there are some concrete examples which indicate that certain areas where the water concentrates might be adapted with rational and adequate management of the existing resource.

As a matter of fact artificial oases have been created, where prosperous farms exist and blossom, apparently profitable farming and livestock operations located in a desert area. (Figure 10a, b).

These artificial oases can be built through the capture and storage of the underground water running into the sea. These farms are generally emplaced under the plateau screes, in relatively depressed areas where several canyons or water streams simultaneously converge.

The capture might be done through small buried impervious screens transversally cutting the current flux, causing the concentration of water which is forced to ascend to the surface of the buried canyon. Another possibility is the establishment of small windmills or

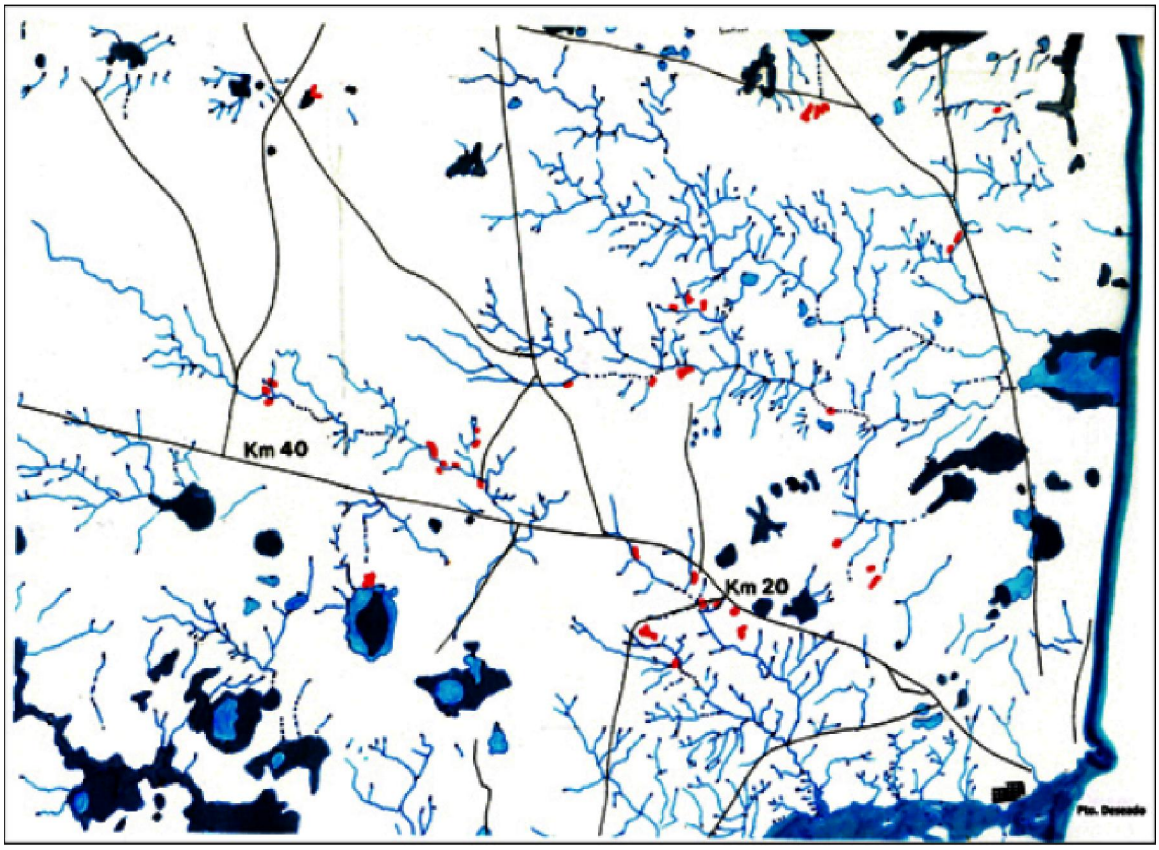

Figure 8: Map of location of springs; The small red stains show the existence and location of some well known/found springs and located/displayed in the right geographical position.

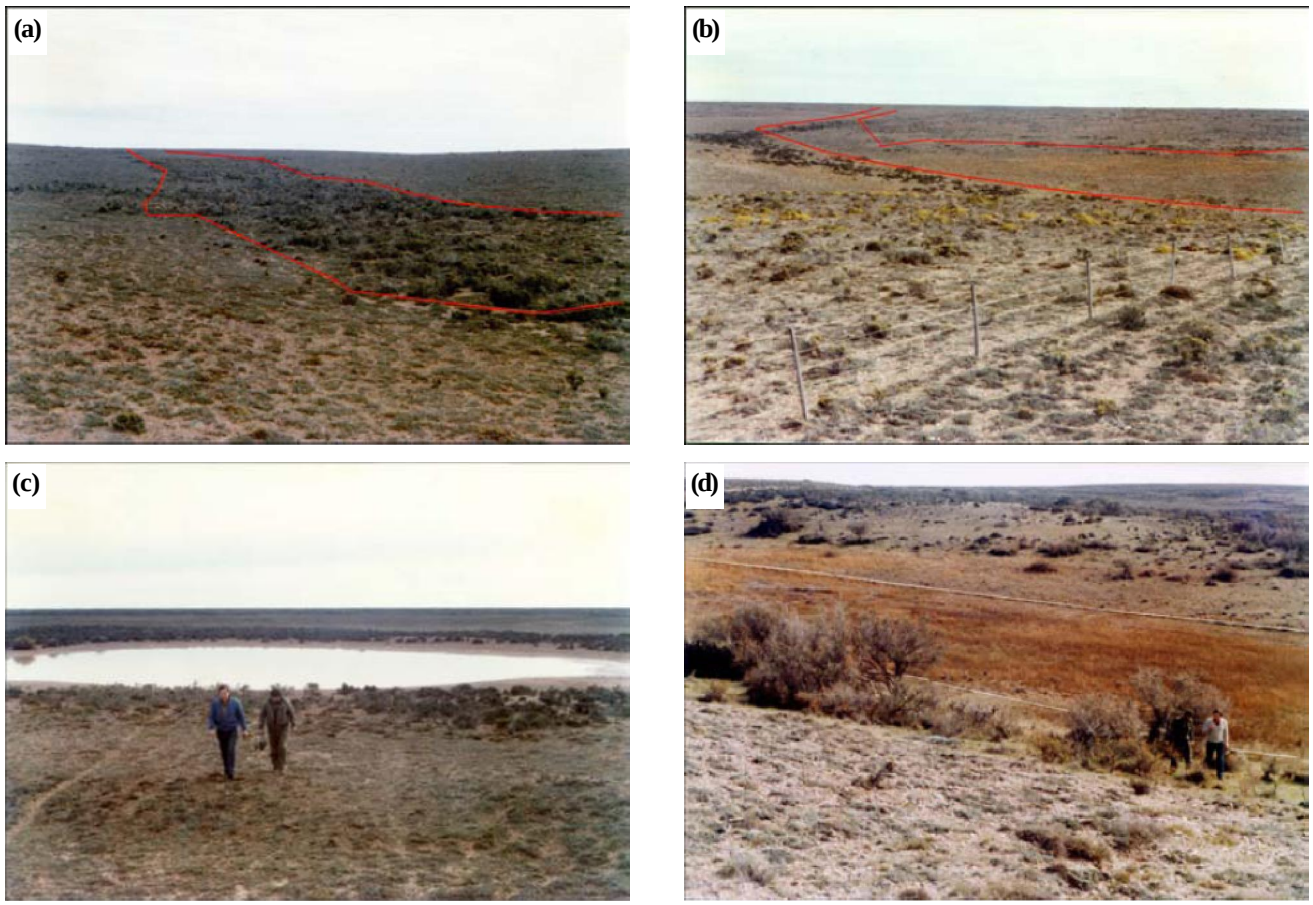

Figure 9: Terrestrial photographs with different details; (a) The presence of aligned and grouped vegetation of bigger dimension and greener in colour, can be observed along the brook; (b) Aligned herbaceous vegetation, usually located in more humid areas, can be observed in the depressed zone; (c) The concentric distribution of the vegetation, mainly shrubby/ cushions, around a small waterbody, can be observed; (d) The presence of shrubbly at the edge of the high plains and herbaceous vegetation at the bottom of the depression can be observed

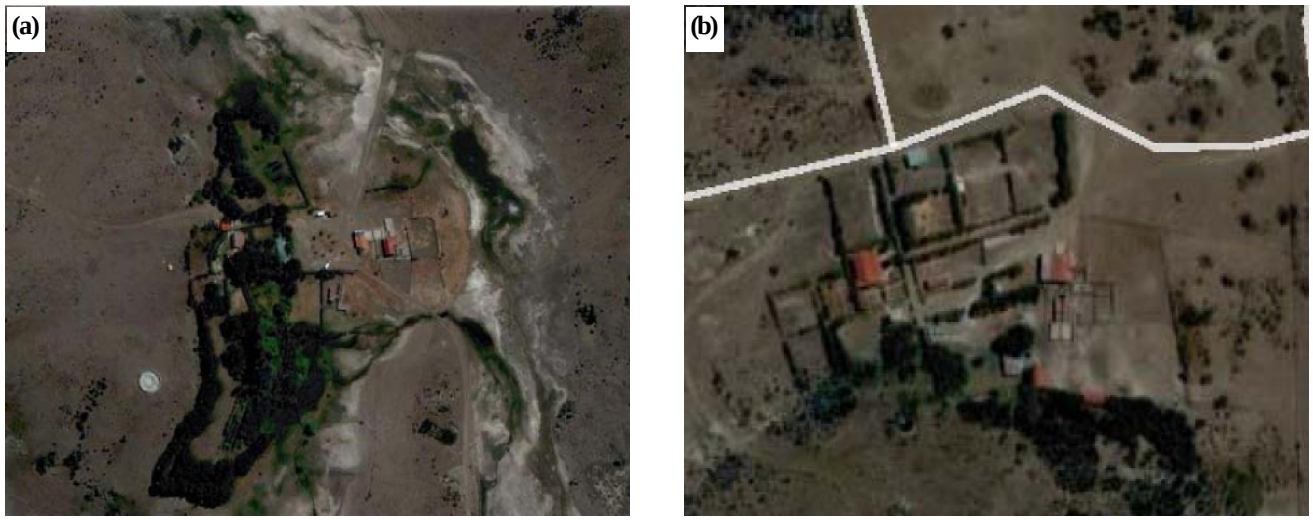

Figure 10: Agricultural farms on a desert area; (a) The image on the left correspond to an establishment located S 47º 19' 9"/W 65º 57' 13", with good development of implanted arboreal vegetation. It is located on the edge of the depression; (b) The image on the right correspond to a farm located S. S47º 31' 01.18"/W 65º 48' 43.32". The existence of many constructions and well-developed implanted arboreal vegetation may be observed. It is found in a depression where many gullies converge. Elevation 86 MASL. Google Earth Image.

stirrup pump to extract the water. Finally, it would be convenient to build reservoirs for local consumption under a strict program for its rational and sustainable use.

For this purpose it is fundamental that once emerged to the surface, the waters are sent through pumps to the storage zone in order to avoid the saline pollution as they run through the Patagonia formation.

CONCLUSIONS

The studied area has been subject to severe climatic changes, going from being a zone of important forest cover to a semi-desert zone. The city of Puerto Deseado lacks a stable source for the provision of drinking water to cover its basic needs.

Given the success of the investigation, these observations, though obvious, are extremely interesting, since this hybrid mechanism combining the analysis of geology, botany and remote sensing could be extrapolated to different regions of the Patagonian Desert with the purpose of searching for good quality water for local use in field establishments as well as small towns.

Without a shadow of a doubt, in order to extend this experience to any area of the Patagonia, it will be necessary to carry out new research work on the subject in order to prove\substantiate this idea.

ACKNOWLEDGEMENTS

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