The natural heritage of the Island of Gozo, Malta

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The name ‘Gozo’, meaning ‘joy’ in Castilian, was given to this small island by the Aragonese who took over the Maltese Islands in 1282. Over the years the island has inspired many names. In 700 BC the Phoenicians called it “Gwl” or ‘Gaulos’, meaning round ship, a name that was retained by the Greeks and translated by the Romans as ‘Gaudos’ or ‘Gaulum’. The Moors, who ruled the Maltese islands around a thousand years ago, and who strongly influenced its Semitic language, referred to it as ‘Gaudoich’ preceding the current name ‘*Għawdex’* (pronounced Aw-desh), which is used today by the local inhabitants. In a legendary context it is often called the ‘Island of Calypso’ referring to the Greek mythological location of Ogygia, home of the beautiful nymph Calypso. In Homer’s epic poem, The Odyssey, Calypso keeps the Greek hero Odysseus as a prisoner of love for 7 long years.

Introduction

Fig. 1 Colour composite of the Maltese Islands based on Landsat 7 ETM image, 9 January 1989

The Maltese Archipelago, located at the centre of the Mediterranean Sea, consists of the islands of Malta, Gozo and Comino as well as a few other uninhabited islets. Gozo is the second largest island with a coastline of 47 km, and a surface area of 66 square kilometres. The Islands have a typical Mediterranean climate, with mild, wet winters and long, dry summers. The average annual rainfall amounts to around 530 millimetres and follows a clearly marked seasonal rhythm.

With a population of just over 31,000 inhabitants, Gozo is much less urbanized and greener than its sister island, Malta. One finds a more varied geology and larger relief contrasts, with typical flat-topped hills and fertile valleys. It boasts an impressive coastline with its sandy beaches, magnificent cliffs and unique karst features such as the Dwejra Inland Sea, the Azure Window and Calypso's Grotto.

Fig. 2 Wied San Blas, one of Gozo's many picturesque valleys

Fig. 3 Inside the Old Citadel

The history of Gozo goes back to prehistoric times. The first settlers are believed to have crossed from Sicily around the 5th millennium BC as witnessed by the oldest freestanding megalithic structures at Ġgantija and the Xagħra Stone Circle. Throughout the years, Gozo has been vastly influenced by the cultures and history of its various dominators including the Phoenicians, Romans, Arabs, Normans, Spanish, The Knights of St. John, the French and the British, who have all left their mark on the local culture and folklore. The Old Citadel is one of the most beautiful architectural complexes on the island. Upon the arrival of the Order of St. John in 1530, the Citadel was only a small, fortified medieval town. In 1551, the Turks invaded Gozo and besieged the 'Castello'. After a brief and heroic resistance the 5000 inhabitants sheltering within the Citadel surrendered. With the castle destroyed all those found within its walls were taken away into slavery and it took almost 50 years to repopulate the island and rebuild the Citadel to its present layout with its austere bastions. The Citadel now hosts various important buildings, most notably the Cathedral built during 1697-1703 by Lorenzo Gafa. The Cathedral is also the annual pilgrimage site of the Grand Priory of the Mediterranean of the Hospitaller Order of Saint Lazarus of Jerusalem.

Fig. 4 Boat houses in Xlendi

The main source of income on this small island comes from agriculture, fishing and tourism. Traditional farming and animal husbandry practices are very widespread and the island is still home to several cottage industries, including lace making, glass blowing and local *ġbejniet* (goat cheese) making. Gozo welcomes thousands of tourists each year, including the hundreds that cross from the mainland to visit the island for some peace or revelry. All these attributes make Gozo into a unique destination full of culture, history and charm.

Administratively, the island is divided into fourteen local councils. i.e. municipalities. The road network follows a star-shaped pattern with all roads connecting to Rabat (Victoria), Gozo's capital city. One of the most important archaeological sites, from the temple period in the Maltese Islands, the Ġgantija Temple Complex, is found in Xagħra Local Council, which also hosts Gozo's most famous beach with its beautiful golden-reddish sand Ramla l-Ħamra. The lighthouse at Ta' Ġurdan offers a 360 degree panorama experience of the island.

Map 1. Administrative divisions and main places of interest in Gozo

Geological Setting

"Northwest of the Gozo Great Fault the topography becomes increasingly dominated by the Globigerina Limestone series. The large dissected Upper Coralline Limestone plateaux of Nadur and Xagħra give way to the smaller remnant hills of Żebbuġ and Rabat, then to roughly conical hills like Ġiordan. Strong valleys between, which break abruptly through the Greensands in cliffs, give way to valleys cut almost entirely in the Globigerina rock. In the east, the karst tops are strongly dissected and further west broad valleys still cut through the complete sequence."

D.M. Lang, Soils of Malta and Gozo, 1960

Origin

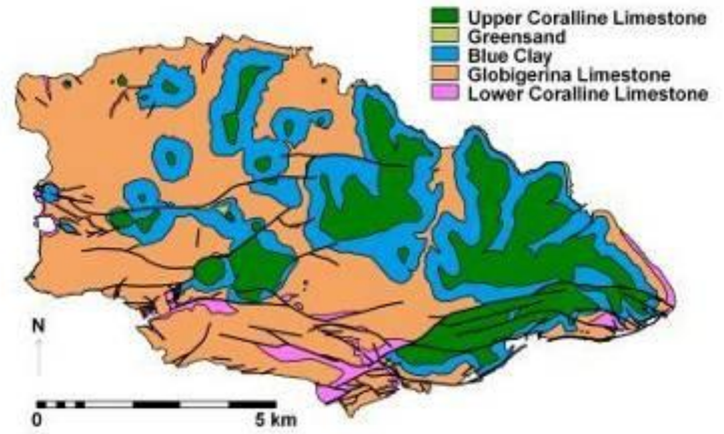
The Mediterranean basin has been dated to the Late Triassic and Early Jurassic formed during the rifting of the African and Eurasian plates. The Maltese islands lie on what is called the Malta-Hyblean Platform that is found on the topmost margin of the African Plate. This sedimentary platform is the result of the accumulation of carbonate sediments deposited in a relatively shallow marine environment at a time when the eustatic level of the Mediterranean was higher than today. The Islands expose an Oligo-Miocene succession that is underlain by at least 3000m of late Oligocene to early Cretaceous (or Jurassic) shallow water carbonates.

The original strictly horizontal layers of the depositional platform were subjected to frequent 'extensional tectonics' and subsequent folding, tilting, faulting, up- and over-thrusting. This finds the whole block of islands itself tilted eastwards, raising the cliffs to the west to about 240 metres above sea level and drowning the valleys on the eastern and south-eastern coast. This tilting is also visible on the island of Gozo. From the south-west to the north-east, the coast consists entirely of cliffs, whilst the southern part of the island facing Malta is low lying.

Fig. 5 & 6 Spectacular sheer cliffs mark the south-west to north-eastern coastline of Gozo

Geological Formations

The Maltese Islands are made up almost entirely of marine tertiary limestone with subsidiary clays and marls. All exposed rocks were deposited in shallow waters during the Oligocene and Miocene periods. Quaternary deposits represent the other type of rock formation found on the islands and are sediments that were deposited in a terrestrial environment following the emergence of the Maltese Islands above sea level.



Map 2. Geological Map of Gozo

The sequence of Tertiary rocks, starting from the uppermost and hence 'most recent' formation, is shown in Table 1.

Table 1. Geological Formations: Thickness and Lithological Characteristics

Era	Formation	Thickness (m)	Lithology
Quaternary		2 - 10	Alluvial valley fillings, cave deposits
Miocene	Upper Coralline Limestone	30 - 100	Cross-bedded limestone with reef formation patches
	Greensand	0 - 12	Sand with phosphorite material
	Blue Clay	0 - 75	Kaolinite rich clay and marly clay
	Globigerina	30 - 230	Pale yellow massive limestone beds
Oligocene	Lower Coralline Limestone	> 450 m	Coarse grained with extensive cross-bedding and reef patches

Lower Coralline Limestone is the oldest exposed rock in the Maltese islands and is responsible for forming magnificent cliffs, some reaching 150 metres in height. These characteristic vertical cliffs are found around most of Malta, south of Fomm ir-Riħ, and also in western Gozo. The Lower Coralline is hard and intractable and when found inland usually gives rise to a barren, grey limestone-pavement topography.

Fig. 7 Lower Coralline Outcrop at Ta' Ċenċ

At the top of this formation is a characteristic band, a few metres thick, with frequent fossil occurrence, referred to as the *Scutella* bed. The widespread *Scutella* graveyard, found among other locations at the Dwejra Inland Sea, suggests that during the formation of the uppermost part of the Lower Coralline Limestone the sea floor was nearly flat.

Fig. 8 Scutella bed in the Lower Coralline Limestone

Globigerina Limestone represents the second oldest rock and is the most widespread outcropping formation on the Maltese Islands. Softer, compared to the underlying Lower Coralline Limestone, Globigerina produces rather meagre soils, and a gentle, rolling landscape. The latter characteristic has lent itself to terraced slopes which are intensively cultivated.

The Lower Globigerina provides the golden brown building stone, 'franka', which is a very easily cut freestone which is worked in large, vertical sided quarries and is used for most of the buildings on the islands.

Fig. 9 Lower Globigerina Limestone quarry in San Lawrenz

Fig. 10 Blue Clay 'talus' in Ramla

Blue Clay is a series of blue and yellow clays and marls which overlie the Globigerina Limestone. Aided by the spring flows above it, Blue Clay forms the most fertile outcrop on the islands. The outcrop is usually narrow and the slopes steep, and is carefully terraced and tilled, except in places where it forms a classical 'talus'.

Blue Clay is of considerable importance to the fresh water resources on the Islands, as the formation acts as a seal to the water which infiltrates from the surface and is stored in the Upper Coralline Limestone and Greensand aquifers.

Greensand is a coarse orange-brown, thick-bedded fragmental limestone, which usually forms the base to the Upper Coralline Limestone cliffs. An abundance of glauconite gives the rock a green colour.

The formation has yielded a very rich echinoid fauna together with shark teeth and the remains of dugongs, manatees, dolphins and whales, indicating that the Blue Clay was deposited under warm shallow marine conditions.

Upper Coralline Limestone is the youngest Tertiary formation on the islands but resembles the oldest and lowest formation both in its chemical and palaeontological characteristics. Usually the Upper Coralline Limestone caps the highest hills which are typically barren limestone plateaux. In Gozo, these take the form of conical hills that are found in a uniform distribution across the island.

Fig. 11 Upper Coralline Plateau behind Ta' Pinu Church

Pleistocene Quaternary Deposits are found in the form of palaeosols, fluvial gravels, coastal conglomerates and breccias, and bone deposits in caves and fissures.

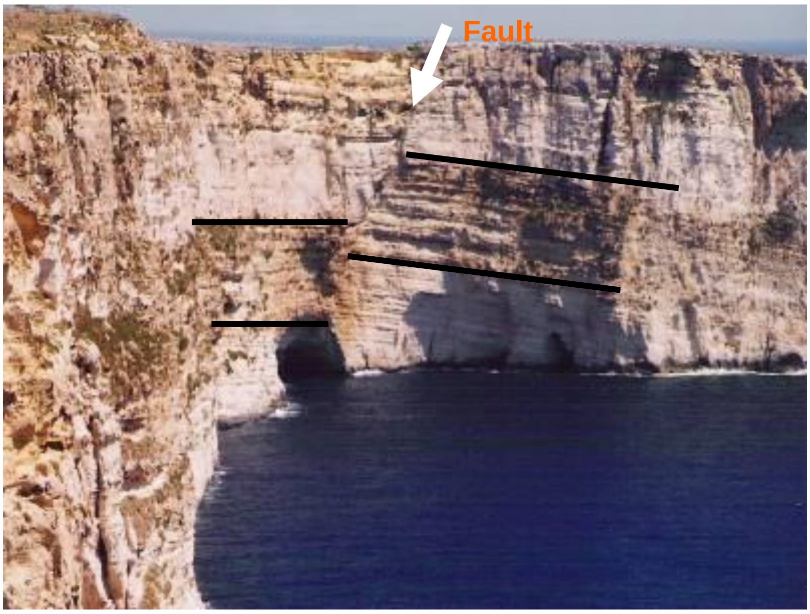


Fig. 12 Transverse faulting below Ta' Ċenċ

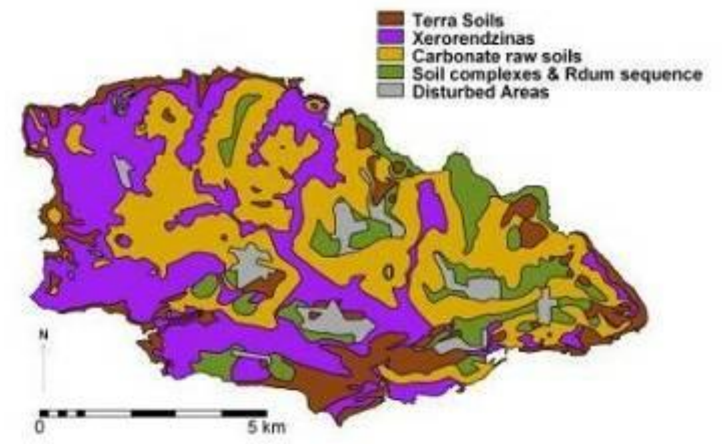
Geological Faults: As in Malta, the island of Gozo is cut by a system of normal faults most of which follow a north eastern - south western (NE-SW) trend. A particularly dense sequence of such faults is found in the south eastern part of Gozo, around the Mġarr harbour. A second system of faults follows a north western - south eastern (NW-SE) trend and is particularly dense in the central, southern part of Gozo. These geological faults play an important role in the replenishing of the aquifers.

Soils

The original, natural pattern of soils distribution in the Maltese Islands is largely determined by the parent material (in most cases the underlying rock), climate (both present and past under which rock weathering and soil formation took place), time and topography. The different kind of soils in Malta and Gozo are almost entirely due to the differences in the chemical composition, as well as in the physical constitution of the parent rock. The soils have in common that they are very calcareous because the parent rock is limestone. Since the processes of soil formation on calcareous material is very slow in a semi-humid country, the soils on the islands are considered to be young or immature soils.

Fig. 13 The fertile Lunzjata valley

On the ridges, plateaux and plains, the soils are usually very shallow ranging in depth from less than 20 to about 60cm. In valleys the soils are much deeper, often exceeding 150cm, while on the gentler slopes of the Globigerina Limestone, the soils are moderately deep ranging from 60 to 120cm.



Map 3. Soil Map reproduced from Lang, 1960

The soils of Malta and Gozo were first classified by Lang (1960) following Kubiena's system into three groups: the Terra Rossa, Xerorendzina and Carbonate Raw soils. It should be noted that today, the distribution of soils in Malta and Gozo appears to follow a rather random pattern. The Fertile Soil Act, particularly during the rapid urbanization witnessed throughout the 1980's, resulted in large quantities of soil being moved from one location to another as required for its preservation. Thus, the distribution of soils today no longer maintains the very close relationship to the underlying bedrock as at the time when Lang produced the Islands' Soil Map in 1960.

In recent years a national soil inventory of the soils of the Maltese Islands was undertaken within the framework of the project MALSIS, A **MAL**tese **S**oil **I**nformation **S**ystem. Information on soils is now found at the National Soil Unit (NSU), in a soils geo-database that includes soil classification information, and data on soil characteristics and soil contamination for more than 350 geo-referenced sites.

Water Resources

"Sir, I have inspected the Malta Water Works and I find that they are in a highly satisfactory condition."

correspondence from Mr. Osbert Chadwick, dated 10th January 1896, reporting to Count. G. Strickland, Chief Secretary to Government

A Brief History

In the absence of perennial streams, the scarcity of fresh water has been an acute problem for many centuries. This scarcity is more apparent during the summer period, when the water availability has traditionally depended on the efficient collection and storage of rainfall during the rainy season.

Several tanks for the storage of fresh water have been discovered dating back as long ago as Punic and Roman times. The delegation of the Knights of St. John which was sent to report on the existing conditions on the Islands in 1530, described the water resources as being "salty and sedimentary". The delegation observed that "the local population stored water in cisterns and even in ditches". After the founding of Valletta by the Knights in 1566, several measures were taken to conserve water resources. The provision of fresh water was considered to be of paramount importance to the inhabitants of Valletta since the lack of it could have drastic consequences especially during a siege. Thus regulations were set up to prohibit gardens in the city and to enforce the construction of a well (*bir*) in every house. These measures were, however, insufficient and several attempts by various grandmasters followed to further secure the water supply in the city.

Between 1883 and 1897 engineer Osbert Chadwick devised several programmes which were aimed at addressing the islands' chronic water supply problems. The loss of surface water runoff into the sea led Chadwick to propose that "small masonry dams be constructed at suitable points in all '*widien*' with an adequate catchment to appropriate the surface run-off during winter rains". True to his life-long motto: "the first duty of an engineer is to make a measurement, his second to make a better one", Chadwick went on to advise that "the ultimate height of each dam was to be determined experimentally, commencing with a low dam, and increasing its height according to the actual results observed from year to year" (Morris, 1952).

Water Catchments

The term '*wied*' refers to the valley (plural '*widien*'). The largest water catchment, Wied Marsalforn includes the central part of Gozo which drains into the sea to the north. Table 2 lists the 'larger' of around 40 distinct catchment areas that are found on the island in descending order of their surface area.

Table 2. Main Water Catchments In Gozo

Main Catchments	Surface Area (Km2)	Main Catchments	Surface Area (Km2)
Marsalforn	11.5	Mġarr	1.8
Ramla	6.3	Daħlet Qorrot	1.8
Xlendi	5.3	Wilga	1.5
Mġarr ix-Xini	5	Biljun	1.1
Ilma	4.5	Raħeb	1
Mielaħ	3.9	Sabbar	1
Għasri	3.3	Pergla	0.9
Qliegħa	2.8	Xilep	0.3
San Blas	2		

Fig. 14 Wied Marsalforn, Marsalforn Valley

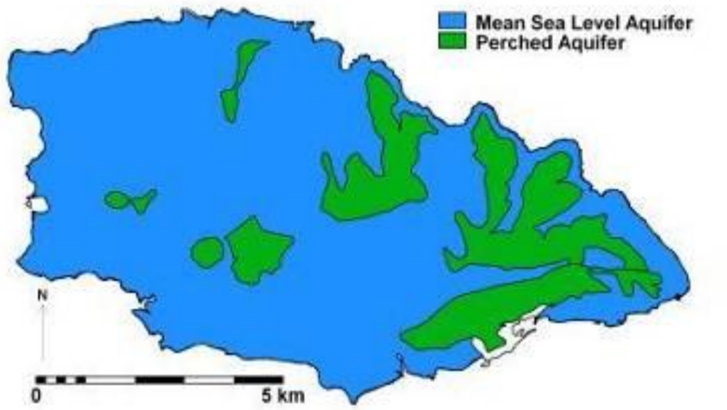
Fig. 15 Small dams are built to increase infiltration

As far back as the 1880s, many small dams have been built across watercourses and are aimed at retarding the flow and thus to retain the water within the valleys '*widien*' for longer periods to allow increased infiltration and percolation into the limestone. The latter processes are responsible for recharging the aquifers from where the water either seeps out naturally or is extracted. Studies carried out by Morris (1952), Newbury (1968), and Chetcuti (1988) have consistently shown that only an estimated 16 to 25 percent of the annual rainfall percolates through the porous limestone rock to recharge the islands' aquifers.

Aquifers

Owing to the islands' geology, all aquifers are limestone aquifers. As in Malta, the two main categories of aquifers that are found in Gozo are the so-called 'mean sea level' and 'perched' aquifers respectively. As its description suggest, the former type of aquifer is found at sea level. Owing to its lesser density, the fresh water body within the rock formation finds itself "floating" on seawater. The Gheyben-Herzberg principle, which is based on the difference in density between fresh water and seawater, advises that for every one meter of fresh water above sea level, it can be expected to find up to 36 meter of fresh water within the rock formation below sea level. The natural drainage of this aquifer occurs all around the coastline, and hence this aquifer takes the form of a lens-shaped body.

As shown in Map 4, the Mean Sea Level Aquifer extends over the whole island with the exception of a small area in the south-eastern part of the island around the Mġarr harbour.



Map 4. Aerial extent of main aquifers in Gozo

The perched aquifers on their part owe their existence to the presence of the Blue Clay formation. The latter acts as a seal to the deeper infiltration of water from the land surface. The overlying, porous and fissured Upper Coralline Limestone allows for substantial amounts of water to be retained in the Upper Coralline and (where present) Greensand aquifers. Thus, these aquifers are literally 'perched' on the top of the Blue Clay.

Table 3 provides an overview of the perched aquifers in Gozo, their aerial extent, the names of the major springs as well as the means of extraction and main use of the water.

Table 3. Overview of the Perched Aquifers in Gozo

Perched Aquifers	Surface area (km2)	Major Springs	Means of extraction (*)	Main use
Għajn Abdul	0.12	Għajn Abdul		Agriculture
Għajnsielem	2.88		224 private wells 1 borehole for public supply	Agriculture
Għar Ilma	0.10	Għar Ilma		Agriculture
Kerċem	0.29		old wells and a number of galleries	Domestic
Nadur	4.88		427 private wells and 37 springs	Agriculture
Victoria and Fontana	1.05	Għajn il-Kbira	old wells and a number of galleries	Domestic
Xaghra	3.02		475 private wells and 15 springs	Agriculture
Żebbuġ	0.38		82 old wells (*spejjer*)	Domestic

(*) Figures obtained from MRA (Malta Resources Authority), 2005, *Initial Characterisation of Groundwater Bodies*

Public Water Supply

With regard to the extraction of groundwater for public water supply purposes, Morris (1952) lists two main civil engineering works: 'an older line of galleries, of total length 4610 feet along *Wied Imġarr ix-Xini* (Mġarr ix-Xini Valley) on the southern side of the island, and a newer line, of total length, 6020 feet, much of which was constructed during the war years, along *Wied ta' Marsalforn* (Marsalforn Valley) on the northern side of the Island'. These galleries refer to underground tunnels cut into the rock just above the mean sea level datum. The excavation proceeded from a vertical shaft and the underground tunnel was then excavated away from this shaft while maintaining a slight, upward gradient. This technique assures that the water collected in the tunnel flows by gravity towards the shaft from where it is pumped to the surface. In Gozo, these underground galleries were dug along the natural course of the valleys.

The 1970s saw the advent of a large-scale programme of borehole drillings across the Maltese Islands. While the underground galleries supplied only what was being collected by gravity, the boreholes could (at least in theory) supply water at a constant rate all year round. In reality, this 'new' method quickly led to increased levels of salinity in the water extracted. The mode of operation compromises the 'natural equilibrium' between the fresh water body and the seawater below, thus leading to increased levels of sea-water intrusion in the Mean Sea Level Aquifer.

The National Statistics Office (2004) reported that extraction from boreholes in Gozo accounted for as much as 91% of the total water abstraction for drinking water supply purposes, with only 9% being produced by underground galleries. The Malta State of the Environment Report (SOER, 2005) confirms that major groundwater bodies in the Islands are being over-abstracted or are dangerously close to being over-abstracted.

Karst Heritage

"*The importance of conserving representative karst areas for science and recreation has been recognized in many countries by the designation of national parks and reserves.*"

(Ford et al., 1989)

"*Some of the best examples of normal faulting, karstification and solution subsidence, cliff recession, cave formation as a result of marine erosion, and incision of steep-sided valleys to be found in the Maltese Islands occur here.*"

(Cassar et al, 2004) on the Qawra/Dwejra area in Gozo

Karst Landscapes

Karst landscapes or terrains represent a distinctive topography in which the landscape is largely shaped by the dissolving action of water on carbonate bedrock. This geological process, occurring over many thousands of years, results in dramatic landscapes with unusual surface and subsurface features ranging from sinkholes, dolines, vertical shafts, disappearing streams and springs, to complex underground drainage systems and caves.

Karst in the Maltese Islands

The Maltese Islands are characterised by well-developed karst phenomena which result in truly dramatic landforms. Several dolines as well as many caves (Calypso's cave in Gozo being the most legendary) can be found in the uppermost geological layer, the Upper Coralline limestone. The Lower Coralline hosts archaeologically important caves, sinkholes (il-Maqluba, Malta) as well as some spectacular natural arches (Azure Window in Gozo, Blue Grotto in Malta). Inland, this rock type forms barren, karstified limestone platforms (Ta' Ċenċ, Gozo). Far less karstified compared to the previous limestone formations, karstic channeling and cavities are found mostly where the Globigerina outcrops.

Caves

The better known caves in Gozo include Calypso's Cave, Xerri's Grotto, Ninu's Cave and Għar Ilma. The former three caves are situated within the boundaries of the Xagħra Local Council. Calypso's Cave may not be considered an impressive cave in terms of karst features, but its association with Homer's epic "The Odyssey" always manages to generate curiosity among visitors to the island. Xerri's Grotto and Ninu's Cave, on the other hand, provide some remarkable natural speleothems, of both stalactite and stalagmite formations. In Xerri's Grotto there are also some interesting formations, which have developed as the result of calcification of tree roots. In Ninu's Cave, the calcification of water dripping from the cave ceiling formed numerous magnificent columns standing side by side. Għar Ilma provides an example of an important archaeological site due to the deposits that were found suggesting its use as a dwelling during Neolithic times.

Fig. 16 Seacaves are found all along the western coastline of Gozo

The Gozo coastline is also dotted with a large number of seacaves. It is quite likely that some of these caves started as inland karst forms, i.e. underground caves which were later invaded by seawater. From this point onwards, the wave action became the dominant agent for the continued erosion. The mechanical action of seawaves and the receding cliffs have at times provoked the collapse of the ceiling of the caves of karstic origin.

An impressive example is the spectacular limestone archway found at Dwejra Point, referred to as the Azure Window. This is a natural arch rather than a window and was formed by the enlargement of an initial cave that developed along a line of rock weakness, which has cut through the limestone, resulting in the arch being formed. The long ledge of rock forming the upper arch is in danger of collapsing and ultimately the roof will fall down and the westerly remnant will form a stack, similar to Fungus Rock.

Fig. 17 Azure Window at Dwejra

Solution Subsidence Structures

Subsidence structure is the general term used for the different types of natural depressions occurring in karst environments, which are also referred to as dolines and sinkholes. The formation of these structures can be varied, but it is mainly associated with the solution of limestone by percolating acidified ground water which eventually leads to roof collapse of the enlarged underground caverns or caves. These structures can range from a few metres to a few hundreds of metres in diameter and in depth, and they may occur as isolated features (as for example the Maqluba sinkhole in Malta), or in groups as for example in the Qawra area in Gozo. Here, both the Inland Sea and Dwejra Bay provide excellent examples of large-scale circular subsidence structures that were formed during the Miocene period.

Fig. 18 Dwejra Bay

Fig. 19 Inland Sea

Fig. 20 Fungus Rock

Fungus Rock or *il-Ġebla tal-Ġeneral* as it is locally known, is another karst feature of note in the Qawra area. It is found several metres away from the shore and is the surviving seaward edge of a collapsed subsidence structure. This outcrop, or stack, is surrounded by spectacular sheer vertical cliffs and is home to the rare phallic-shaped Fungus Melitensis, *(cynomorium coccineum).* Despite its many given names referring to it as a fungus, the plant is neither a fungus nor is it found only in Malta or Gozo. The Knights of St. John believed this plant to possess medicinal powers and went to great extremes to guard the Fungus Rock and protect the much-prized plant. Anyone caught stealing the plant was sentenced to death or put to the galleys.

Other Karst Features

Other features in the karst landscape of Gozo include grikes and clints, as well as a dense development of solution pits and solution pans.

Grike-and-clint topographies are common in karst landscapes and are an assemblage of irregular, deep, narrow grooves present at the rock surface, also known as 'limestone pavement'. These forms are referred to as 'Karren' (German) or 'Lapies' (French).

Fig. 21 Typical grike and clint topography

Solution pits are round-bottomed erosion holes that are usually circular, elliptical or irregular. Solution pans, on the other hand, display a flat or nearly flat bottom that is usually horizontal. In the past, these solution pans were sculpted into a more regular arrangement by man and used as salt pans. An example of such salt pans, which are still in use to date, can be seen at Marsalforn.

Fig. 22 Solution pits at Dwejra

Fig. 23 Salt pans at Marsalforn

The Special Vulnerability of Karst Environments

All over the world, karst landscapes are arguably among the most vulnerable environments because of the close interconnectedness between the geological, geomorphological, biological, and most importantly, hydrological processes affecting these landscapes. The underground solution channels and conduits commonly provide a direct hydraulic link between the surface and the underground aquifers. This causes the hydraulic behaviour of karst areas to be very complex. This can be illustrated by the fact that it is common in karst environments for the impact of an accidental spillage to be transmitted through underground path flows to a point which may be far removed from the initial point of impact. This is a distinctive characteristic of a karst environment, with its hydrological processes that operate underground and, unfortunately, out of sight of many policy makers (Urich, 2002). Quite literally, a karstified drainage system may lead to the development of blind or disappearing streams. A typical example of a blind valley is found at Ħondoq ir-Rummien, in the south-eastern part of Gozo.

Fig. 24 Blind valley at Ħondoq ir-Rummien

Production of a Water Resources Vulnerability Map for Gozo

The production of a water resources vulnerability map for the island of Gozo featured as one of the innovative outputs achieved from our research carried out under the EU-sponsored International Cooperation (INCO) Project entitled *ResManMed:* Resource Management in Karstic Areas of the Coastal Regions of the Mediterranean. The SCI (Surficial Cover

Infiltration) map provides a qualitative assessment of the relative ability for contaminants at the surface to infiltrate down to the underlying aquifer.

The methodology which is used to produce the SCI map considers the combined appraisal of four hydrogeological factors: surface lithology, faults, karst features and surface drainage density. Developed by the authors in partnership with the International Research and Application Centre for Karst Water Resources at Hacettepe University in Ankara, Turkey and the National Centre for Remote Sensing in Beirut, Lebanon, the methodology consists of first rating the effect of each of the hydrological factors individually. Subsequently, by assigning weighting coefficients to the factors, their combined effect is represented by the so-called SCI Index. The latter index is calculated for each cell of a grid that has been placed over the area under investigation. For the Island of Gozo, the SCI Indices have been calculated according a grid made up of 200 by 200m square elements.

Calculation of the SCI Index

In each cell of the grid, the SCI Index is calculated on the basis of the ratings obtained for each of the individual factors. The four factors have been assigned with a ‘weight’ which represents their relative importance on the infiltration phenomenon.

Table 4. Relative weights assigned to the factors considered in the SCI Method

Factor	Weight (%)
1- Surface Lithology	35
2- Faults	20
3- Karst Features	30
4- Surface Drainage Density	15

The SCI Index in any given cell of the grid is obtained as follows:

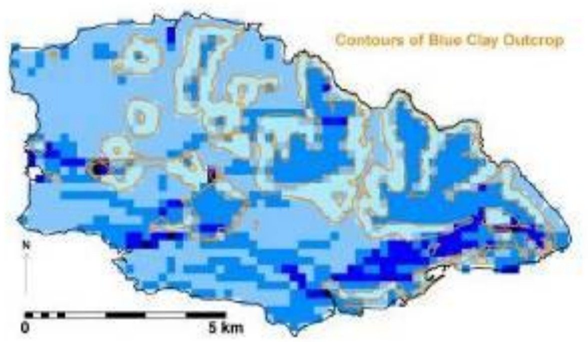
SCI Index = 0.35x(Surface Lithology rating) + 0.20x(Faults rating)
+ 0.30x(Karst Features rating) + 0.15x(Surface Drainage Density rating)

Finally, the SCI Index values are interpreted according to the colour legend shown below.

Table 5. Classification and colour legend of SCI Index values

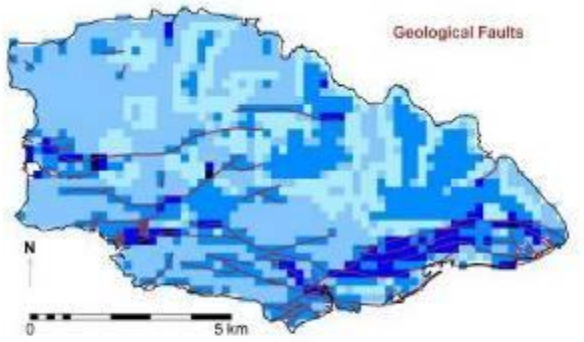
SCI Index value	Colour code	Interpretation
<0.40		No infiltration
0.41-0.85		Very low infiltration ability
0.86-1.30		Low infilration ability
1.31-1.75		Moderate infilration ability
1.76-2.20		High infilration ability
> 2.20		Very high infitration ability

In the maps provided below, the effect of the hydrogeological factors on the final SCI map is examined in more detail.



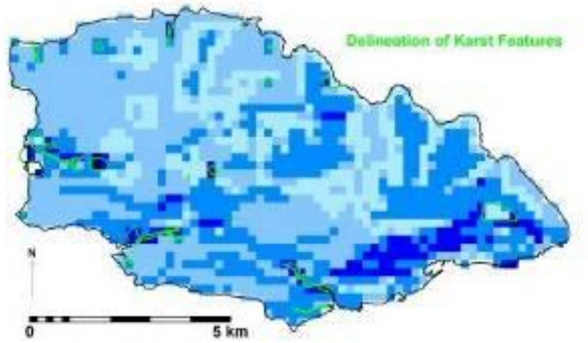
Map 5. Effect of Blue Clay Outcrops

The SCI method considers that the surface lithology is divided into three distinct classes: pervious, semipervious and impervious, which are assigned with a rating of 2, 1 and 0. The infiltration ability is reduced in those areas where the Blue Clay forms the outcropping formation (delineated by the contours shown in orange). These areas are shown to have a 'Very low infiltration ability' in the SCI map.



Map 6. Effect of Geological Faults

Fault lines play an important role in the infiltration process. The SCI method measures the length of the faults in each cell of the grid, leading to a fault density value. The density values thus obtained are divided into 3 categories: high, medium and low and are assigned with ratings of 3, 2 and 1. Areas with a high fault density are clearly increasing the infiltration ability on the SCI map.



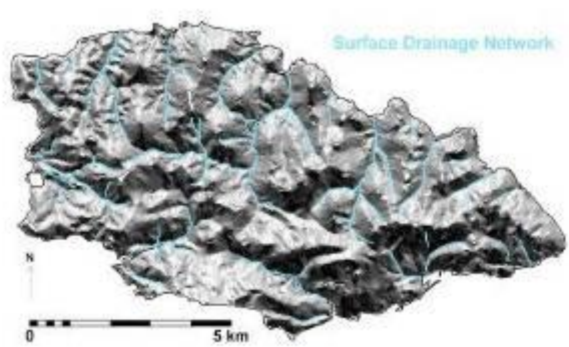
Map 7. Effect of Karst Features

According to the SCI method, the cells that contain depression features of karstic origin are assigned with a higher infiltration rating. Their surface area is measured in each cell of the grid and assigned with a rating of 3 (high), 2 (medium) or 1 (low density). However, in areas where the surface lithology is impervious, a 0 rating is assigned, i.e. in this instance the SCI method considers that the karst feature does not have any effect on the infiltration.

One of the largest dolines is found in the south-eastern part of the island, however its location coincides with a Blue Clay outcrop. The latter represents an impervious surface lithology. Thus, in agreement with the method, this particular doline is considered to have no effect on the infiltration ability. Apart from dolines, the karst features which affect the relative infiltration ability for the island of Gozo include a series of gorge shaped valleys, which appear as deep incisions into the landscape.

Fig. 25 Wied ix-Xini, a gorge shaped valley

The final, fourth factor considered in the SCI method is the surface drainage density. The study of the drainage (stream) network on a topographical map can provide useful hints about the hydrogeological conditions. For example, areas that show a very dense drainage network can typically be associated with the existence of impervious formations beneath the surface cover. Thus, a higher Surface Drainage Density is linked to lower infiltration ability.



Map 8. Surface Drainage Network

In Gozo, the Surface Drainage Network is quite uniformly distributed across the whole island. Moreover, the Surface Drainage Density values are consistently 'low'. This led to the understanding that the Surface Drainage Density factor should not be used to further 'fine tune' the SCI Index. The SCI map considers the Surface Drainage Density to be uniform and low, and thus with a maximum rating of 3 for the whole island.

Human Impact

"For over 5,000 years people have lived here, and have changed and shaped the land, the wild plants and animals, the crops and the constructions and buildings on it. All that speaks of the past and the traditions of the Islands, of the natural world too, is heritage."

Haslam, S. M. & Borg, J., 2002. 'Let's Go and Look After our Nature, our Heritage!'. Ministry of Agriculture & Fisheries - Socjeta Agraria, Malta.

From an infrastructural and urban development point of view, Gozo is generally still less developed than the main island, Malta. However, its environmental resources are acknowledged to be under constantly increasing pressure from human activities. Urban development, quarrying, waste disposal, overexploitation of groundwater, down slope ploughing and arable land abandonment have intensified the pressures on the island's natural resources.

Limestone quarrying

The increased urbanization in Gozo over the past few decades has intensified quarrying practices on the island, wearing away stretches of the already limited natural and agricultural land. Quarries are mostly concentrated in the north western part of Gozo, mainly in San Lawrenz, but also in Kerċem and Għarb Local Councils. The majority are so-called softstone quarries, quarrying the Globigerina Limestone, the lower part of which produces the highly sought after building stone called 'franka'.

The environmental impact associated with the quarrying of limestone needs to be analysed carefully in relation to the protection and conservation of the ground water resources. Indeed, the quarrying of limestone represents the removal of the natural 'protective cover' overlying the aquifers. Abandoned quarries often become utilized as waste sites. Unless the necessary precautions are taken, this practice can dramatically increase the likelihood of pollution.

Fig. 26 Quarrying at Dwejra

Groundwater exploitation and pollution

According to the Malta State of the Environment Report 2005, a 'preliminary risk assessment carried out by the Malta Resources Authority indicates that, with the exception of the Comino Mean Sea Level aquifer system, all Malta's groundwater bodies are at risk or probably at risk of failing to meet the objectives of the (European) Water Framework Directive: 'Malta's groundwaters are seriously at risk from overexploitation and pollution, risking the loss of Malta's only renewable freshwater resource'.

The highly fissured limestone makes the possibility of sea water intrusion into the Mean Sea Level aquifer a permanent problem, yet the over-abstraction of the aquifer has clearly exacerbated the problem to an alarming level.

The dumping of waste is a major source of concern. Derek Ford (1989) alerts that 'Unfortunately, in all inhabited karsts (around the world), dolines and sinkholes are perceived as being particularly suited for the dumping of solid or liquid waste, because it disappears underground and 'out of sight is out of mind!' As elsewhere in the Mediterranean, besides dolines and sinkholes, it is often whole valleys that are the 'preferred' target for the illegal dumping of waste!

Evidently without adequate and rigorously enforced protection measures, even regulated landfills present a major problem. A heritage conservation area, which appears to be under particular threat, is found in Dwejra. This major tourist attraction is in close proximity to a landfill, which is growing at an alarming rate. Besides damaging the aesthetic beauty of the area, it also threatens to pollute the marine environment from leachates reaching the sea.

As has already been mentioned, a major threat to the quality of ground water, is derived from quarrying activity, and worse, when a disused quarry becomes the object of landfilling that is not strictly monitored to receive inert waste only.

Agricultural practices

Agriculture has always been an important pillar of Gozo's agrarian economy. Over time, in an effort to conserve and exploit the barely adequate soil and water resources, human activity has literally re-sculptured the land surface by cutting terraces through the soft rock, building stone embankments and walls, and redistributing the stones and soil material on the terraces. Traditionally, the slopes of valleys are terraced to allow agricultural cultivation. Every cultivable piece of land with soil has been terraced and is used to grow some crop at some time or other.

Agriculture has had a great effect in shaping the island's environment by providing such characteristic landscape elements as rubble walls, terraced fields and wind pumps. However, increasing intensification of agriculture can also have a negative impact on the quality of the landscape.

Fig. 27 Traditional farming

Today because of a high level of economic development, off-farm resources such as feed, fertilizers, pesticides, fuel and machinery are being used as substitutes for traditional farm inputs. From a resource-management point of view, despite this increase in mechanisation, management of arable land still has its shortfalls. Maintenance of the traditional rubble walls appears to be a dying practice and tillage of fields is not always done in parallel to the contours, thus facilitating erosion.

Fig. 28 Agriculture in Wied Ilma

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