PROJECT REPORT

DPLUS206: FRESHWATER BASELINE TECHNICAL REPORT 1

PREPARED BY NYEIN KO

DPLUS206 CLIMATE IMPACTS ON FI PAST, PRESENT AND FUTURE FRESHWATER DYNAMICS

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ABOUT THE SOUTH ATLANTIC ENVIRONMENTAL RESEARCH INSTITUTE (SAERI)

The South Atlantic Environmental Research Institute (SAERI) is an academic organisation conducting research in the South Atlantic from the tropics down to the ice in Antarctica. SAERI's remit includes the natural and physical sciences. It aims to conduct world class research, teach students, and build capacity within and between the United Kingdom's South Atlantic Overseas Territories. Its mission is to advance environmental understanding in the South Atlantic through research excellence and innovative scientific leadership. SAERI was a Falkland Islands Government initiative and operated as an arm's length government department from 2012 in July 2017.

Our vision is to be an internationally recognised academic institute with its main base in the Falkland Islands, operating in the South Atlantic from the equator down to the ice in Antarctica, conducting world class natural and physical science research, teaching students, and building capacity within and between the UK South Atlantic Overseas Territories.

Strategically, SAERI aims to be a world-class research institute that teaches students and builds capacity within and between the South Atlantic Overseas Territories. In order to achieve that it must be:

1. Project optimised – by operating as a streamlined and efficient organisation through the Focal Areas;
2. Fully funded – Falklands registered limited company is able to fund SAERI overheads, ensuring SAERI ultimately becomes fully financially independent from Falkland Islands Government and by ensuring that all grant applications (where possible) contain cost of seat coverage; and
3. The holder of proprietary environmental knowledge of the South Atlantic – by continuing to provide the research expertise offered to date.

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3. INTRODUCTION

Freshwater is a finite resource that provides a diverse range of essential goods and services critical to the development and survival of human societies (1). Of the total available water on Earth's surface, freshwater, including rivers, streams, lakes, ponds, and wetlands, constitutes less than 3%, and saline water makes up more than 97% (2). However, out of the 3% of freshwater, the available freshwater which can be easily accessed is less than 1%, and the rest of the freshwater is the water stored in polar ice caps or glaciers, etc (3), (4), (5).

Climate change is expected to have a substantial impact on freshwater globally (6), however, the magnitude and extent of these impacts are still poorly understood in data-scarce regions. This lack of information makes it difficult to know how our freshwater ecosystems change over time and across different regions due to natural or human activities and to decide what management actions should be taken to adapt or mitigate undesirable conditions in the present and future. This issue is particularly acute for isolated small island territories and nations, like the Falkland Islands.

The Falkland Islands lie in the southwestern region of the South Atlantic Ocean and is an Overseas Territory of the United Kingdom (UK) with a population of approximately 4,000 people. The climate is cool temperate and oceanic, dominated by westerly winds (7). A previous study in 2008 (7) highlights that while Falkland Islands climate has become drier and warmer, both on land and at sea during the last 50 years, in the long term, the climate is likely to experience cooler, cloudier, and rainier conditions. However, Cook et al (2022) (8) reported that megadroughts are ongoing continuously in south-western North America and across Chile and Argentina, including South America, and Australia. These megadroughts have been unprecedented over the past 2000 years, have been exacerbated by anthropogenic climate change. These megadroughts might be affecting the Falkland Islands, which could be the reason why the current Falkland Islands climate is increasingly becoming dry. Lakes and ponds are now susceptible to complete desiccation which until recently, was simply unprecedented. This was demonstrated by fieldwork and landowner engagement during SAERI's DPLUS116 project (2020-2022).

Whilst the Falkland Islands marine environment has been the focus of recent climate change research (e.g., DPLUS148 and MCCIP (Marine and Climate Change Impacts Partnership), there has been comparatively little focus on Falkland Islands freshwater environments. The Terrestrial Ecosystems of the Falklands– a Climate Change Risk Assessment (TEFRA) project examined the impacts of climate on Falkland Islands plants, soils and terrestrial habitats. However, TEFRA did not focus on freshwater. Similarly, DPLUS116 took place during two exceptionally dry summers and highlighted both the vulnerability of Falkland Islands wetlands and the lack of baseline data to guide management. However, it also did not focus on freshwater dynamics. Both TEFRA and DPLUS116 provide important context to develop the proposed project, which will seek to understand the potential impacts of climate change on freshwater dynamics. This will be critical to managing, mitigating and adapting to future changes.

Falkland freshwaters cover a vast area, play a key role in maintaining aquatic and terrestrial biodiversity, in the hydrology of peatlands and the protection of their large carbon stores, and sustain Falkland water supplies and farming activities. A drying climate is a threat to Falkland Islands biodiversity, livelihoods and carbon stores. The causes of this unprecedented drying are unclear in the absence of baseline data but are likely a combination of ongoing regional drought affecting a large part of South America and now over 10 years in during (thought to the most severe of the last millennium) and likely exacerbated by climate change and land management (8). With the recognition that the Falkland climate is changing, and that this change has already impacted Falkland hydrology, focus is now on water security, adaptation and mitigation. Small Island territories and nations lack the capacity to tackle climate change at a global level but can locally mitigate and adapt by understanding risks and impacts to natural systems. Hence, there is an urgent requirement for baseline data on Falkland freshwater, with which to understand and inform current and future management.

We will assess Falkland past and present freshwater dynamics (soil moisture, surface water), and identify how freshwater dynamics are influenced by land use. We will use satellite imagery (freely available Landsat, Sentinel 1 and 2B with a resolution of 10-30 m) to identify hydrological change (soil moisture and surface water) over the last 30 years, and how spatiotemporal trends relate to climate and land use practices. The resolution of imagery has proven to be sufficient for peat condition assessment in the UK and assessment of global surface water (https://global-surface water.appspot.com/). Furthermore, the return period for Sentinel 1 data (currently 12 days) enables temporal as well as spatial assessment, which higher-resolution products may not. We will model future scenarios and identify habitats/areas prone to drying. Modelled future scenarios will provide insights into how different habitat types are influenced by drying. Finally, climate change resilience and mitigation will be mainstreamed into management through workshops.

4. FALKLAND ISLANDS

4.1. OVERVIEW

The Falkland Islands are an archipelago in the South Atlantic Ocean on the Patagonian Shelf. The principal islands are about 550 km east of the tip of South America and about 1,210 km from Cape Dubouzet at the northern tip of the Antarctic Peninsula, between latitude 51◦ S and 52◦ S and longitudes 58◦ W and 61◦ W with a cover area of 12,173 km^2 (9). They are split into two main islands, East Falkland and West Falkland, separated by the Falkland Sound (10). There are about 780 smaller islands that extend about 220 km east-west and 140 km north-south (7),(11). Approximately 510 islands are smaller than five hectares in area, of which 277 are less than one hectare. Although these islands exhibit a topographical range smaller than larger islands, they share similar habitats. Some of these small islands feature upland areas, while others are predominantly low-lying, and they support comparable ecosystems. Many of these small islands also contain numerous pools, including peat pools, coastal pools situated behind shingle barriers, and highly saline ponds.

4.2. GEOLOGY

The Falkland Islands were partially glaciated in the last ice age, with glacial features only found above 500 m, mainly around Mount Adam, Mount Usborne, and the Hornby Mountains (12). The islands tend to be a mixture of mountains and low moorland dominated by white grass (*Cortaderia pilosa*) and dwarf shrubs such as diddle dee (*Empetrum rubrum*) (10). The Falkland Islands are one of the regions with the highest peat cover in the world, with peat accounting for an estimated 38% of the total land area (13), with the remaining land area largely covered by silty mineral soils with a peaty surface layer. The highest mountains primarily comprise the most resilient rock formations (14). The oldest rocks seen are the Proterozoic granites and amphibolite facies gneisses, about 1150 to 1000 million years old, belong to the Cape Meredith Complex which is overlaying as Devonian to Carboniferous sedimentary rocks in the southernmost point of West, while most of the rest of the Islands are underlain by sedimentary rocks (15), (16). The West Falkland Group, which underlies most of the West Falkland and the northern upland areas of East Falkland, is dominated by quartzose and sandstones, with little siltstones and mudstones (16). Lafonia Group, lowland areas of the southern part of East Falkland is dominated by mostly of younger Carboniferous to Permian tillites, mudstones, sandstones and siltstones (7),(16). Most lakes formed through wind erosion, ice melt collapse, or coastal barrier beaches, while river systems originally developed during a low sea level period and later adjusted to rising sea levels, resulting in sluggish, underfit rivers (12). The geology map of Falkland Islands was developed by the Darwin Plus 116, Wetlands Project at SAERI, shown in Figure 1.

The coastlines of both East and West Falkland are highly irregular (9). East Falkland is characterized by the Wickham Heights Mountain range which extends the entire east-west span of the island with peaks ranging from 400 m to 705 m above mean sea level (Mount Usborne). The dominant landscape of the southern part is low moorland and numerous small lakes and ponds in the south (10). East Falkland is composed of two large land blocks, connected by a narrow isthmus. In the low-lying southern block, open grasslands and the plains of Lafonia are Domaine landscapes, while the northern block is dominated by more rugged and rocky with large upland areas of peat bog and numerous small permanent and ephemeral pools (9). West Falkland tends to be gently sloping with mountains with numerous broad valleys with peaks ranging from 400 m to 695 m (Mount Robinson) (10). West Falkland is also more rugged, with an undulating landscape of open plains and upland acid grasslands (9). Again, small pools are present in large numbers.

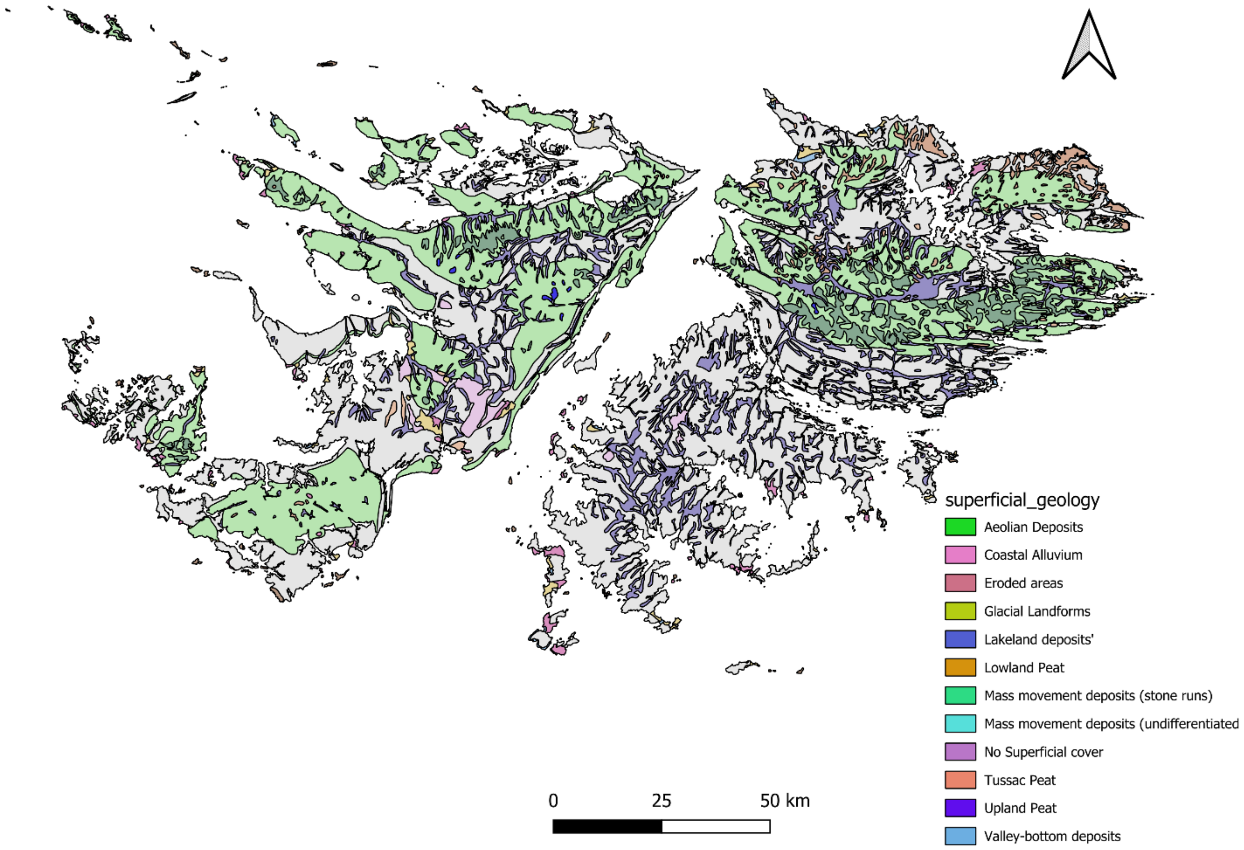

Figure 1 The supervised classification geology map developed by the Darwin Plus 116, Wetlands Project at SAERI

4.3. WEATHER

The Falkland Islands have a cool-temperate oceanic climate with an annual mean temperature of 6.6◦C (from 1987 through 2000) (17). The air temperature ranges from 9◦C (from January to June; Austral Summer) to 2◦C (from June to December; Austral Winter) (18). The cold temperatures recorded during 1951-1970 were -8◦C to 25◦C, and the annual mean temperature was 5.6◦C (14). Annual rainfall varies from 400 mm on the west Falklands to 800 mm at higher elevations on the eastern islands (19). The climate-moderating influence of the ocean produces persistent strong winds and reduces temperature extremes between winter and summer (9), (5). Freezing temperatures and heavy snow are rare, but extended periods of lying snow can occur during winter (14).

4.4. FRESHWATER HABITATS

With global warming and rising sea levels, freshwater security on islands becomes scarcer and scarcer. The ability of islands to retain freshwater varies according to the variation in topography and size (20). A range of freshwater habitats are abundant on the Falkland Islands, including coastal barrier lakes, meander ponds, glacial pools, erosion depressions, and peatland slump features (21). Inland freshwater bodies are especially abundant in the lowland peat areas, and on peat ridges, with a depth of less than 2 m (in many cases depths are less than a metre). These shallow standing water bodies tend to have high turbidity with variable and sometimes extreme pH values (21), high dissolved organic carbon (DOC) concentrations (leading to brown colouration) and high concentrations of inorganic solutes such as sodium and chloride values, leading to high electrical conductivity (EC) (7).

4.5. RIVERS AND STREAMS

Rivers and streams in the Falkland Islands are generally characterized as mature, exhibiting slow flow rates, and are considered underfit in terms of their geographical context (14) and their course is often determined by variations in the underlying geology. There are several small rivers, ranging from small brooks a metre or two wide to larger rivers (Figure 2) (14). Most rivers on the islands are relatively short because of the region's unique geography and geology. These watercourses typically terminate in creeks or large inlets. Additionally, there is a notable absence of lakes or reservoirs along the primary river channels (11). In the East, the length of the most well-known rivers/streams ranges from 5.6 km to 38.6 km, while in the West, the length of the most famous rivers ranges from less than 8 km to 28.9 km (Table 1). In addition to numerous smaller streams, there are several larger rivers with substantial drainage basins spanning vast areas such as Orqueta Arroyo, San Carlos River and Arriyo Malo in East Falkland, and Warrah River and Chartres River in West Falkland (14).

The river water quality appears to be healthy, exhibiting low turbidity (Secchi depth of 67 cm), a circumneutral pH range of 5.2 to 7.7, and generally low electrical conductivity (EC) values, ranging from 101 to 374 µS/cm (15). The primary vegetation is bryophytes which grow on rocks, and other plants, such as water milfoil (*Myriophyllum quitense*) and native pondweed (*Potamogeton linguatus*), growing in slower-flowing areas (22).

Table 1 Rivers/Streams on the East Falkland and West Falkland Islands (Source: https://www.falklands-southatlantic.com/riversandstreams.html)

Location	River/Stream	Length (km)	Flow Direction	
			From	To
East Falkland	San Carlos River	38.6	Flats of Mount Usborne	Port San Carlos
	Malo River or Arroyo Malo	20.9	North side of the Wickham Heights near No Man's Land	Malo Creek and Port Salvador
	The Murrel River		The eastern side of Mount Vernet	Eastwards: the estuary lies north of Stanley Harbour
	Fitzroy River		South side of the Wickham Heights	Port Fitzroy
	Swan Inlet River	13.6	Swan Inlet	Mare Harbour and Choiseul Sound
	Mullet Creek Stream	5.6	Between Two Sisters Mountain and Tumbledown	Mullet creek
	Moody Brook		Between Tumbledown and Two Sisters mountains	Stanley harbour
West Falkland	Warrah River	28.9	Northern slopes of Mount Maria and Mount Robinson	River Harbour
	Chartres River	25.7	Hornby Mountains	King George Bay
	Blackburn River	8	Mount Edgworth area	Byron Sound.
	Teal River	8	southern side of Mount Adam	Christmas Harbour and King George Bay.
	Doyle River	8	Mount Philomel and Mount Sulivan	Port Philomel
	Dean's River	8	Slopes of the complex of the mountains Alice	Hoste Inlet and Port Stephens.

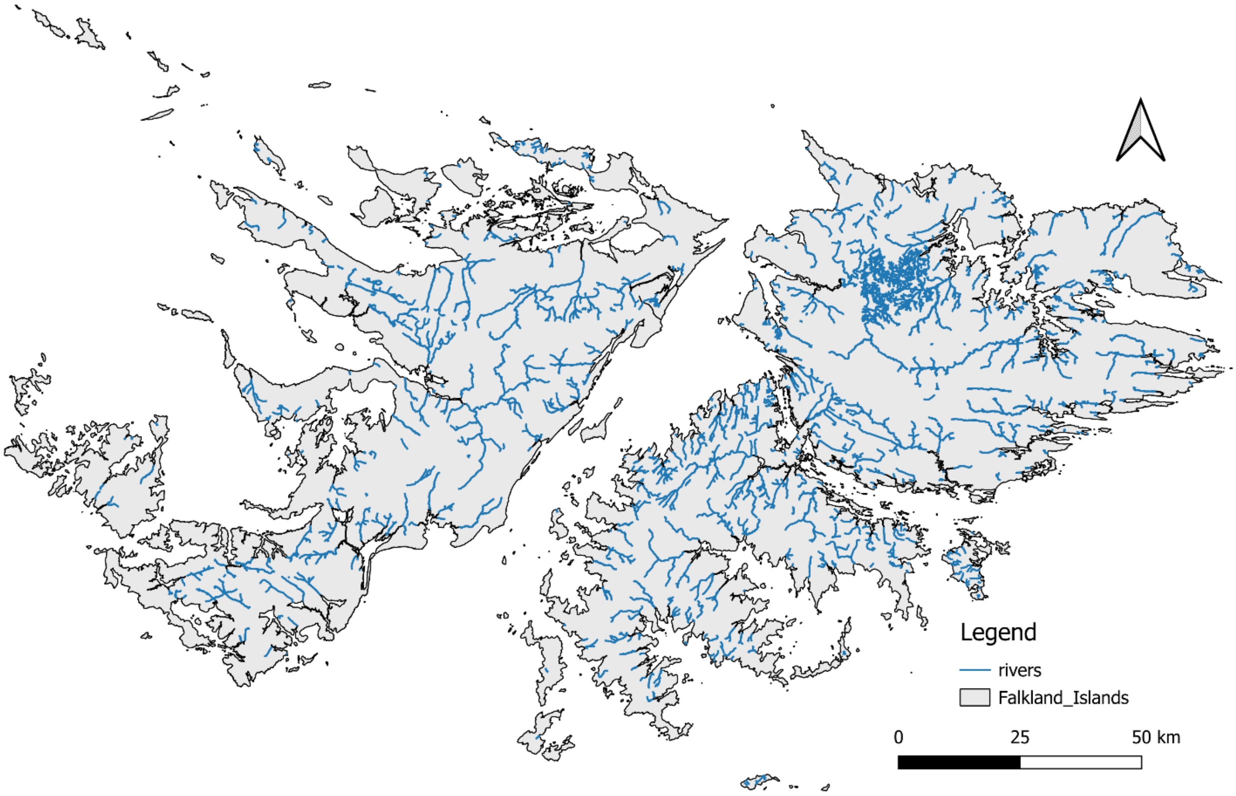

Figure 2 Map of Rivers in Falkland Islands developed by SAERI.

4.6. LAKES AND PONDS

Numerous shallow bodies of freshwater are referred to as ponds in the Falkland Islands, most of which have a depth of less than $1m$, and which range in size from a few square metres up to around 400 hectares. Ponds on areas of mineral soil tend to be larger (and many would be referred to as lakes elsewhere) but are similarly remarkably shallow in most cases. They are typically also turbid, with lower DOC concentrations and a circumneutral pH. Ponds on smaller islands can have extremely high DOC and nutrient concentrations, particularly where colonies of seabirds or waterfowl are present, and in some cases can become hypersaline (before drying out) during drought periods. Ponds with relatively stable water levels and good water quality can support emergent macrophytes, but most Falkland ponds are largely unvegetated.

Very large saline areas that are currently or recently connected to the sea by a narrow channel are termed lakes (14). The deepest freshwater bodies or lakes are Mount Adam Tarn in West Falkland and Black Tarn in East Falkland, both of which are glacial features distinct from most other water bodies (7). Numerous ponds and lakes in the Falkland Islands frequently dry up, but recent patterns indicate that more water bodies are drying out now than in the past (23) (Figure 3).

According to the field survey of 20 freshwater lakes conducted by Project DARWIN PLUS 116, the pH values ranged from 4.93 to 7.93, the salinity values ranged from 0 to 0.9 PSU, and the EC values ranged from 129 to 1772 μS/cm, Secchi depths varied between 5 to 80 cm (22). Consequently, some freshwater lakes lacked vegetation, while others supported plant species such as *Myriophyllum quitense* and California clubrush (*Schoenoplectus californicus*) (22). A variety of bed materials were observed in the freshwater lakes including sand, silt, peat, gravel, cobbles and bedrock (22).

According to the field survey of 15 freshwater ponds conducted by Project DARWIN PLUS 116, the pH values ranged from 4.81 to 8.71. Of these, eight ponds were acidic, three were near neutral, and four were alkaline. The salinity values ranged from 0 to 0.95 PSU, and the EC values ranged from 183.6 to 889.9 μS/cm. The primary bed material was sand, although silt, peat or cobbles were also present. Although most freshwater ponds did not support vegetation, plant species such as *M. quitense*, *S. californicus* and spike rush *Eleocharis melanostachys* were observed (15).

5. DATA GAPS

Scientists involved in the study and management of natural resources depend on timely and accurate data to inform decision-making processes. However, a major challenge is the significant data deficit, both spatially and temporally. In the Falkland Islands, the history of hydrological and meteorological datasets is fragmented. Observations of several meteorological elements began around 1850 at Cape Pembroke Lighthouse and ended in 1947 (17). Meteorological data have been recorded in Port Stanley since 1874, though measurements were mainly sporadic until 1923 (17), (24). Following the cessation of the military conflict between the UK and Argentina in 1982, a wide range of meteorological observations has been available at Mount Pleasant Airport (MPA), located approximately 30 miles southwest of Port Stanley, since the airport's establishment in 1986 (24).

5.1. CURRENT AVAILABLE METEOROLOGICAL AND HYDROLOGICAL DATASETS

5.1.1. Meteorological Data

Currently, the weather stations in the Falkland Islands are owned publicly and privately by governmental and non-governmental organizations, companies, and other entities (12). There are seven weather stations in the Falkland Islands, owned by the UK Ministry of Defence (MOD) (Figure 4) and their data are available online. In addition, there is one weather station in Stanley, owned by the South Atlantic Environmental Research Institute (SAERI), and four weather stations by Flux towers (Figure 4). There are also private weather stations in Stanley, Darwin, and Sea Lion Island (12).

Meteorological observation records have been recorded at Cape Pembroke Lighthouse (CPL) since 1850, continuing until 1947. However, monthly average temperature data have been available in the World Weather Records (WWR) since 1895 (17). In 1874, temperature records commenced in

Stanley by the Climate Research Unit (CRU), although these observations were sporadic until 1923 (17). A more continuous long-term temperature series has been available since 1986 from Mount Pleasant Airport (MPA), as part of the data collected by the UK Falkland Islands Trust (UKFIT) (17).

Stanley precipitation data have been available since 1986, but no such records exist for CPL, in contrast to temperature data, which are available for both locations (17). Upson, McAdam, and Clubbe (2016) (19) compiled and analysed rainfall data extending back to 1874, and one of the key outputs of their study was a map showing the total annual rainfall in the Falkland Islands.

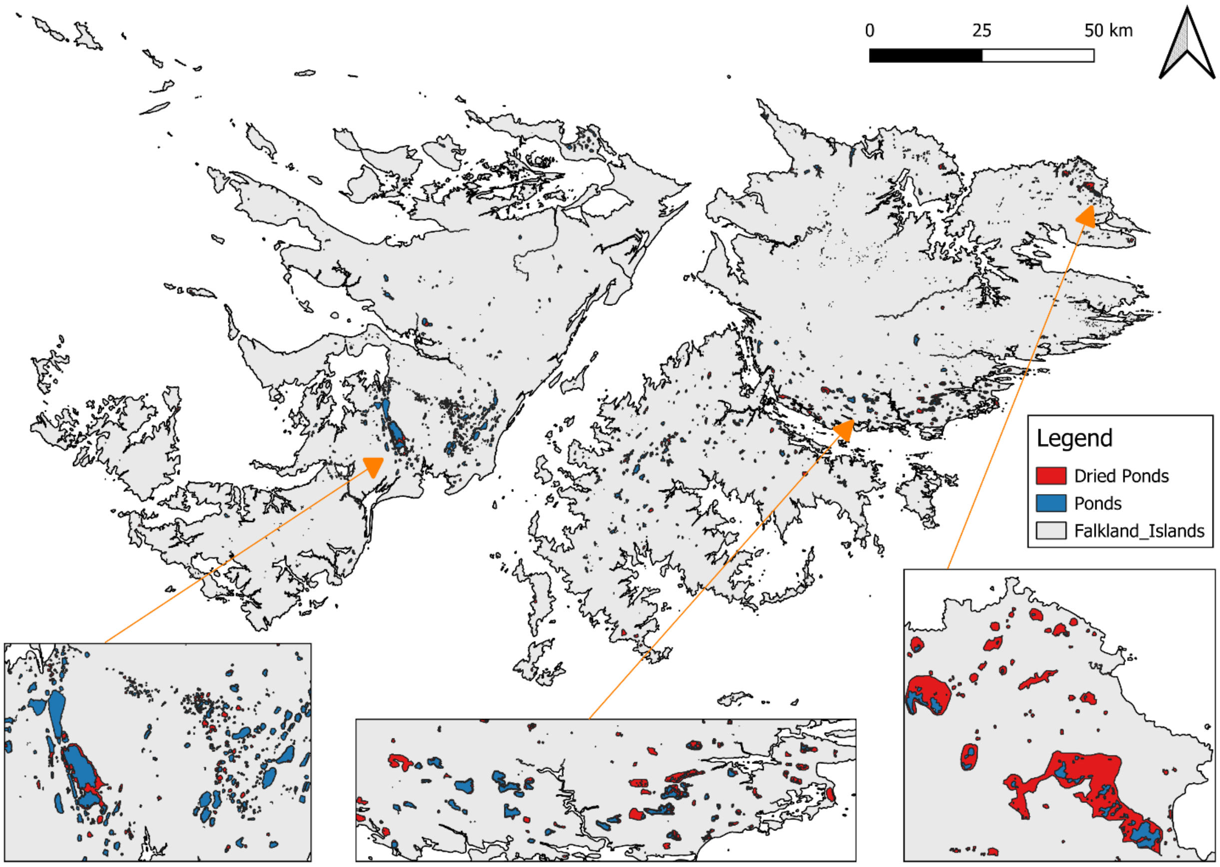

Figure 3 Map of ponds and dried ponds in Falkland Islands developed by SAERI.

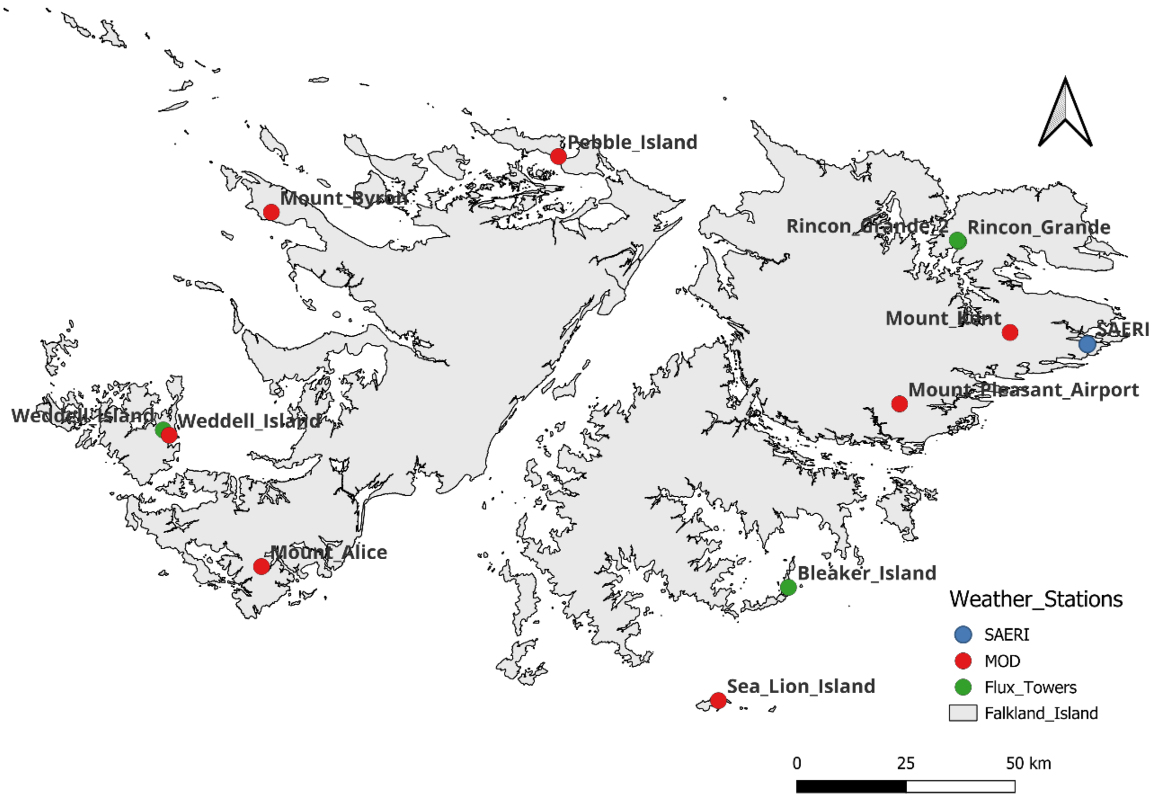

Figure 4 Map of Weather Stations in Falkland Islands by SAERI, MOD and Flux Towers

5.1.2. **Hydrological Data**

Evapotranspiration patterns for the Falkland Islands were assessed using the modified FAO Penman-Monteith equation, using weather data from 1984 to 2012 (19). Their analysis revealed that during the summer months (October to February), evapotranspiration consistently exceeds precipitation, leading to a potential soil moisture deficit.

According to Upson, McAdam and Clubbe (2016) (19), under current climate conditions, the average soil moisture deficit is 71 mm, with the most significant moisture deficit occurring between October 6 and March 12, covering 157 days. The largest deficits are observed early in the growing season, a critical phase characterized by the driest conditions and strongest winds, which raises the risk to plant health. The four eddy covariance 'flux towers' recently installed to land-atmosphere CO_2 exchange for the Defra/FIG peatland greenhouse gas project also measure water and energy fluxes, and can therefore provide direct measurements of evapotranspiration at these sites (one on Weddell Island, one on Bleaker Island, and two in the Horseshoe Bay area of East Falkland).

At present, six monitoring stations are installed across six distinct water bodies as part of the Darwin Plus 116, Wetlands Project (23), (Figure 5). These stations track various parameters, including water level, water temperature, light intensity, pH, and conductivity. However, while five of these stations primarily monitor the basic parameters, there is potential for upgrading them to also include pH and conductivity measurements, as shown in Table 2. In addition, water quality data from four rivers and their estuaries were collected between 2017 and 2019 as part of a study by Evans et al. (11) (Table 2).

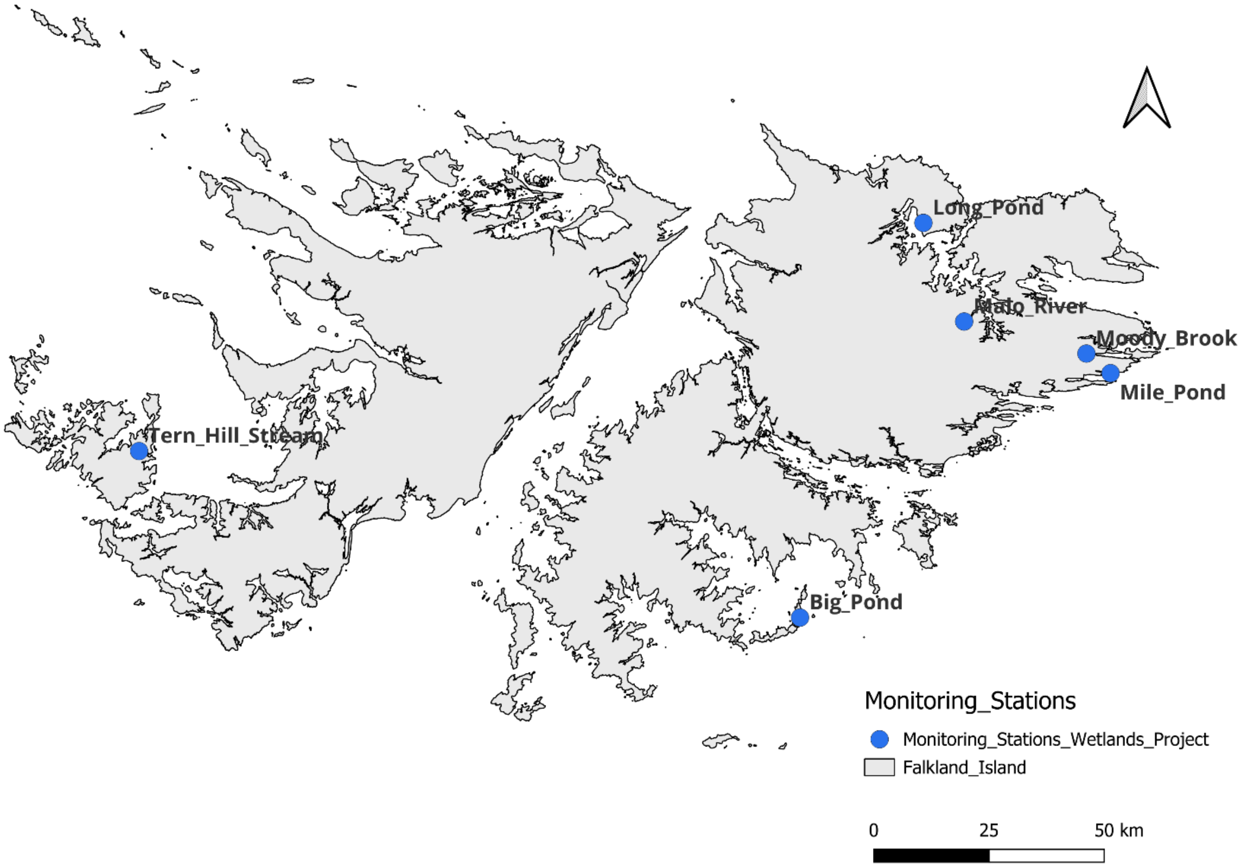

Figure 5 Map of Monitoring Stations in Falkland Islands by the Darwin Plus 116, Wetlands Project

Table 2 Lists of monitoring stations and monitoring parameter at each station by the Darwin Plus 116, Wetlands Project (23)

Name of Water Body	Farm	Location	Parameter
Moody Brook	Stanley Common	-51.6845, -57.9441	Water Level, Water Temperature, Light Level, pH, Conductivity
Mile Pond	Stanley Common	-51.7227, -57.8682	Water Level, Water Temperature, Light Level
Malo River	Riverview	-51.6219, -58.3288	Water Level, Water Temperature, Light Level
Long Pond	Salvador	-51.4287, -58.4571	Water Level, Water Temperature, Light Level
Big Pond	Bleaker Island	-51.1922, -58.8452	Water Level, Water Temperature, Light Level
Tern Hill Stream	Weddell Island	-51.8745, -60.9248	Water Level, Water Temperature, Light Level

Table 3 Lists of Water quality parameter at four freshwater bodies during 2017 and 2019, as part of a study by Evans et al. (11).

Rivers	Year	Temp [°C]	Salinity [PSU]	SiO_2 [µmol L^1]	PO_3^4 [µmol L^1]	NO_2 [µmol L^1]	DOC [molL^1]	Abs$_2$54 [m^1]	SiO_2 [µmol L^1]
Malo River	2017	-	0.06	90.9	0.11	0.00	842	0.62	6.12
	2019	16.1	2.4	10.9	0.12	0.78	2407	0.96	3.34
Swan Inlet	2017	13.3	0.09	145.8	0.15	0.14	515	0.33	5.37
	2019	15.8	2.32	14.3	0.10	0.27	1057	0.43	3.43
Murrell River	2017	8.9	0.16	95.7	0.11	0.00	1250	0.96	6.42
	2019	13.2	0.10	23.7	0.22	0.93	2132	1.38	5.4
San Carlos River	2017	12.1	0.12	133.0	0.14	0.00	1833	1.7	7.71
	2019	-	-	-	-	-	-	-	-

5.2. BATHYMETRIC MAPS

Bathymetric maps for the Falkland islands have been developed by SAERI, and are accessible through Falkland Islands Data Portal (http://dataportal.saeri.org/).

For rivers and streams, the channel network was derived from a Digital Elevation Model (DEM) with a 30-meter resolution. Although there are no specific details about accuracy or coverage on the map, the map shows that the northern part of East Falkland is more precisely mapped compared to other regions (Figure 2).

The mapping of inland water features, specifically ponds and lakes, within the Falkland Islands was carried out using a supervised classification process applied to two Landsat 8 images taken at different times: June 2014 for West Falkland and August 2013 for East Falkland, chosen for their minimal cloud cover. While not all features are captured, the dataset documents approximately 75% of these water bodies, with the results closely aligning with the official Ordnance Survey (OS) map of the Falklands at a 1:50,000 scale (http://dataportal.saeri.org/dataset/falkland-islands-inland-waters-ponds-and-lakes). In addition to mapping existing inland water features, a separate Falkland Islands Dried Ponds Map was created using Sentinel-1 data from March 2021 to identify wetland areas that underwent drying between January 1, 2014, and March 29, 2021 (Figure 3).

Several studies have contributed to the bathymetric mapping of inland water bodies in the Falkland Islands, employing different methods to measure water depth with varying levels of accuracy. Hall (2015) (25) created bathymetric maps for the tarns on Mount Adam, where point soundings were used to create detailed depth maps with an accuracy of less than 0.5 meters. The findings revealed that the South Tarn reached a maximum depth of 16 meters, while the North Tarn's deepest point was 20 meters. Similarly, in February 2018, the tarns on Mount Usborne were mapped using a geophysical depth sounder along boat transects across the lake, achieving depth accuracy of up to 1 meter. The water depths in these tarns ranged from 2.85 meters to 12.28 meters (24). All the bathymetric mapping can be accessed through the Falkland Islands Data Portal.

5.3. REMOTELY SENSED DATASETS

Innovative technologies make a better research environment, reducing both costs and time. With advances in the technology of space datasets, remote sensing techniques have become useful tools since the 1970s and continue to be widely used in water resources research around the world (26). Therefore, the use of global satellite dataset in water resources researched has received attention worldwide due to copyright-free and public accessibility, such as the U.S. Geological Survey (USGS).

A real-time observation with multi-sensor networks can provide more precise mapping capabilities using remote sensing and GIS. Although satellite datasets can provide valuable information for water resources research, the correlations between what can be directly detected from a satellite dataset versus a variety of water resource issues are limited. For example, the ability to classify surface water, the sampling depth from the surface, and current spatial and temporal resolution are limited (26). Additionally, real-time observations or ground observation data are needed to validate the space dataset. It is challenging to build a broad and wide-ranging in-situ dataset at the large river basin scale, particularly in remote locations such as some headwater areas of East and West Falkland. Despite this limitation, the use of remote sensing information appears to have great potential in monitoring and identification of water quality issues (27).

5.4. CURRENT AVAILABLE SPACE-BASED PRODUCTS FOR ESTIMATING SURFACE WATER AND SOIL MOISTURE

5.4.1. Surface Water Area

We utilize the **Global Surface Water Explorer** dataset, developed by the European Commission's Joint Research Centre (JRC) under the Copernicus Programme. This dataset provides global-scale maps of water surface location and temporal distribution over the past 32 years, offering valuable statistics on water extent and change. It is instrumental in various applications, including water resource management, climate modelling, biodiversity conservation, and food security (28). The dataset is derived from Landsat imagery, provided by USGS and NASA, specifically from 4,716,475 scenes captured by Landsat 5, 7, and 8 between March 16, 1984, and December 31, 2021 (29). The resulting mapping layers consist of seven bands, with each pixel classified as either water or non-water. This classification covers the spatial and temporal distribution of surface water, with the results compiled into a monthly history across the entire period and two distinct epochs (1984–1999 and 2000–2021) for change detection analysis (29).

The dataset includes several product types, such as yearly and monthly classifications. **The Monthly History collection (JRC Monthly History, v1.4)** presents the complete water detection history on a month-by-month basis, containing 454 images, one for each month from March 1984 to December 2021. **The Yearly Seasonality Classification collection (JRC Yearly Water Classification History, v1.4)** provides a year-by-year classification of water seasonality, based on the frequency of water occurrences detected throughout each year. Both products offer a 30-meter pixel resolution, with different water classes, including water/non-water, seasonal water, and permanent water.

Additionally, other space-based products are available for water management, such as Sentinel-2 imagery which contains 13 UINT16 spectral bands representing TOA reflectance scaled by 10000. Sentinel-2 is a wide-swath, high-resolution ranging from 10m to 20 m based on different bands, multi-spectral imaging mission supporting Copernicus Land Monitoring studies, including the monitoring of vegetation, soil and water cover, as well as observation of inland waterways and coastal areas. **Harmonized Sentinel-2 MSI: MultiSpectral Instrument, Level-1C (TOA)** product collects imagery every 5 days from June 2015 to the present (https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S2_HARMONIZED#bands).

5.4.2. Soil Moisture

Over the years, several methods have been developed using optical and thermal infrared remote sensing, where relationships are established between soil moisture (SM) and factors such as soil reflectivity, surface temperature, vegetation coverage, and soil thermal properties. Additionally, numerous techniques have been proposed in the past 35 years utilizing microwave remote sensing (30).

1) Soil Moisture and Ocean Salinity (SMOS) and Soil Moisture Active Passive Data (SMAP)

Microwave remote sensing provides many algorithms to obtain soil moisture at a large scale, such as **Soil Moisture and Ocean Salinity (SMOS)** and **Soil Moisture Active Passive Data (SMAP)** (30). The Microwave Imaging Radiometer using Aperture Synthesis (MIRAS) is a passive microwave 2-D interferometric radiometer operating at L-Band (1.4 GHz, 21 cm) aboard the **SMOS** satellite. It detects weak microwave emissions from the Earth's surface to measure various geophysical variables, including soil moisture, sea surface salinity, sea ice thickness, wind speed over oceans, and the freeze/thaw state of the soil. These data products are publicly accessible through two NASA-designated data centres: the Alaska Satellite Facility (ASF), which focuses on SAR data, and the National Snow and Ice Data Center (NSIDC), which specializes in cryosphere science and land-based microwave data. At present, these products are available with a pixel resolution of 9000 m in SMOP and 10000 m in SMAP, covering the period from March 2015 to December 2023, in the NASA/SMAP/SPL3SMP_E/006 collection. However, a previous study concluded that the pixel resolution of SMAP and SMOS is low to be able to be applied in small catchments or field scales (30).

2) USGS Landsat 8 Level 2, Collection 2, Tier 1

The Landsat 8 Level 2, Collection 2, Tier 1 product provides atmospherically corrected surface reflectance and land surface temperature data derived from the Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). The dataset includes five visible and near-infrared (VNIR) bands, two short-wave infrared (SWIR) bands, processed to orthorectified surface reflectance, and one thermal infrared (TIR) band, converted to orthorectified surface temperature. In addition, the dataset contains intermediate bands used for the calculation of Surface Temperature (ST) products, along with quality assurance (QA) bands.

Surface Reflectance (SR) products for Landsat 8 are generated using the Land Surface Reflectance Code (LaSRC). The Collection 2 ST products are derived through a single-channel algorithm, developed collaboratively by the Rochester Institute of Technology (RIT) and NASA's Jet Propulsion Laboratory (JPL). The collected data is organized into overlapping "scenes" that cover an area of approximately 170 km by 183 km, based on a standardized reference grid. Landsat 8 Level 2 products are available on the Google Earth Engine (GEE) platform, with a temporal coverage from March 2013 to the present, providing data at a 16-day revisit interval (https://developers.google.com/earth-engine/datasets/catalog/LANDSAT_LC08_C02_T1_L2#description).

3) Harmonized Sentinel-2 MSI: MultiSpectral Instrument, Level-2A (SR)

Harmonized Landsat 8/9 and Sentinel-2 (HLS) (HLSL30: HLS-2 Landsat Operational Land Imager Surface Reflectance and TOA Brightness Daily Global 30m) surface reflectance product with a spatial resolution of 30 m generated by NASA (31). The HLS produce consistent surface reflectance (SR) and top of atmosphere (TOA) brightness data from a virtual constellation of satellite sensors with a revisit interval of approximately 2–3 days. The HLS product has a combination of Operational Land Imager (OLI) with Landsat 8/9 satellites with the Multi-Spectral Instrument (MSI) with Sentinel- 2A and 2B satellites. This combined measurement enables global observations of the land of available images from all satellites. Additionally, HLS product already incorporates atmospheric correction, cloud and cloud-shadow masking, spatial co-registration and common gridding, illumination and view angle normalization, and spectral bandpass adjustment (https://doi.org/10.5067/HLS/HLSL30.002).

4) Sentinel 1 SAR GRD: C-band Synthetic Aperture Radar Ground Range Detected, log scaling

The Sentinel-1 mission offers data captured by a dual-polarized C-band Synthetic Aperture Radar (SAR) operating at a frequency of 5.405 GHz. This dataset includes S1 Ground Range Detected (GRD) scenes, which are processed with the Sentinel-1 Toolbox to produce calibrated and ortho-corrected products. The collection is refreshed daily, with new assets typically added within two days of their availability. The products are available starting from October 2014 until present and 6 days interval imagery on European Union/ESA/Copernicus dataset (https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S1_GRD#description).

This collection includes all GRD scenes, each with one of three available resolutions (10, 25, or 40 meters), four band combinations (corresponding to scene polarization), and three instrument modes. When using the collection in a mosaic context, it may be necessary to filter it to a uniform set of bands and parameters. Each scene contains one or two of the four possible polarization bands, depending on the instrument's polarization settings. The possible combinations are single band VV, single band HH, dual band VV+VH, and dual band HH+HV.

Where, VV means single co-polarization, vertical transmit/vertical receive, HH means single co-polarization, horizontal transmit/horizontal receive, VV + VH means dual-band cross-polarization, vertical transmit/horizontal receive, and HH + HV means dual-band cross-polarization, horizontal transmit/vertical receive, respectively.

6. METHODOLOGY

For the estimation on surface water areas and soil moisture on Falkland Islands, we use a cloud-based computing platform (Google Earth Engine: GEE) which uses Google's infrastructure to facilitate access to geospatial data and its processing. GEE is a free platform to facilitate geoprocessing from Landsat, Sentinel, and MODIS satellites and data on climate models, temperature, and geophysical characteristics (32). The interface of GEE has a code editor (https://code.earthengine.google.com/) which can access a registered account. It can work using JavaScript Programming language and Python and others through the Earth Engine library (32). GEE provides access to a broad range of datasets, ready-to-use image-based products, seamless data uploading, a variety of image processing algorithms, and an array of computational methods (10), (34), (35).

We applied Remote Sensing and GIS for Geospatial mapping analysis. All data processing and statistical analysis were conducted using Python libraries such as Pillow (PIL), OpenCV (cv2), and NumPy (np) and Microsoft Excel 2013.

6.1. SURFACE WATER AREA

We utilized the Google Earth Engine (GEE) platform to estimate the surface water area of the Falkland Islands, including ponds and lakes throughout the islands. Our analysis employed the Global Surface Water (GSW) Explorer datasets, specifically the JRC Yearly Water Classification History (v1.4) and the JRC Monthly History (v1.4). The processing workflow is illustrated in the flowcharts presented in Figure 6.

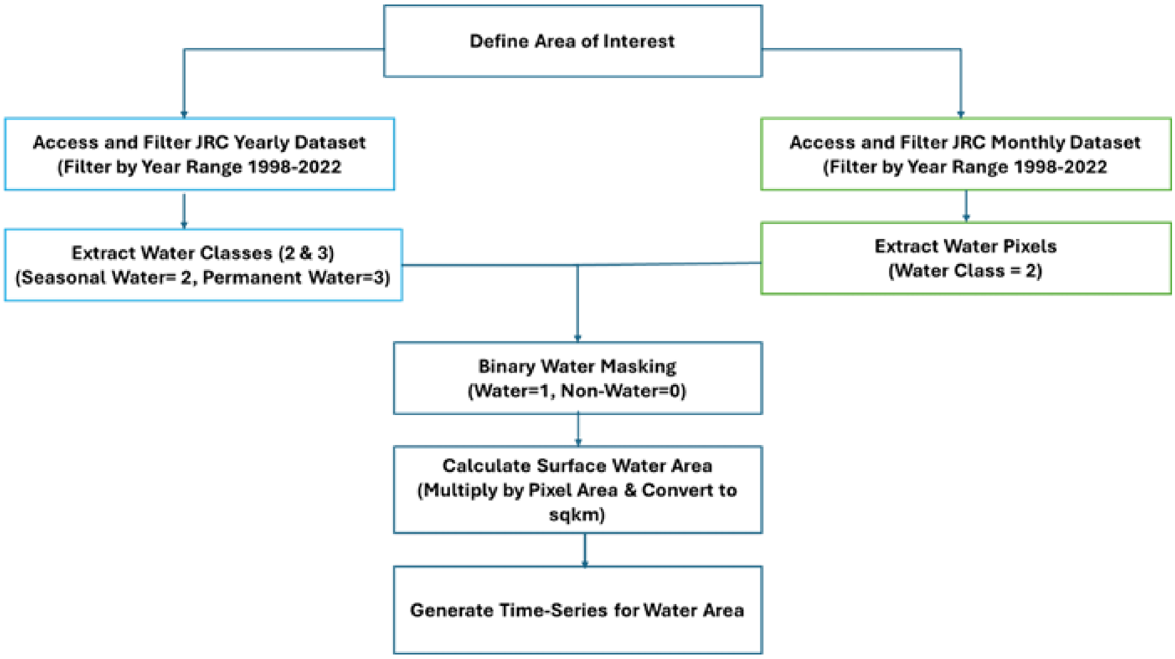

Figure 6 Flowcharts illustrating the estimation of surface water area in km^2 from JRC Yearly and Monthly water dataset.

6.2. SOIL MOISTURE ESTIMATION

To utilize NASA's SMAP and Sentinel-1 products, we implemented the following methodology on the Google Earth Engine (GEE) platform to generate time-series data of soil moisture and their corresponding geospatial maps (Figure 9). We applied The Optical Trapezoid Models for soil moisture estimation from Landsat-8 and Sentinel-2 products. We applied the traditional thermal-optical trapezoid model (TOTRAM) for soil moisture estimation from Landsat-8 images on GEE, while we applied the new optical trapezoid model (OPTRAM) for Sentinel-2 images.

1) The Traditional Thermal-Optical Trapezoid Model (TOTRAM)

we applied the Thermal-Optical TRAapezoid Model (TOTRAM) which is one of the most widely applied approaches to remote sensing of soil moisture (36). The method relies on analysing pixel distribution within the land surface temperature-vegetation index (LST-VI) space. However, TOTRAM has two key limitations: it cannot be applied to satellites that lack thermal data (such as Sentinel-2), and it necessitates the parameterization of each observation date (36). The initial index used in TOTRAM is the Normalized Difference Vegetation Index (NDVI), calculated using the equation (1).

$$NDVI = \frac{(R_{NIR}-R_{red})}{(R_{NIR}+R_{red})} \qquad \text{Eq. (1)}$$

Where; R_{NIR} is the near-infrared band reflectance and R_{red} is the red band reflectance. Soil moisture content normalized can be calculated using the local minimum dry soil moisture content $(\theta_{d)})$, and the local maximum wet soil moisture content (θ_w), given as:

$$W = \frac{(\theta-\theta_{d})}{(\theta_w-\theta_d)} = \frac{(LST_d-LST)}{(LST_d-LST_w)} \qquad \text{Eq. (2)}$$

Where LST is the land surface temperature and LST_d and LST_w are the LSTs of the dry and wet soil, respectively. The LST_d and LST_w are obtained from the LST_NDVI trapezoid, as shown in Figure 6. The dry edge and wet edge of the trapezoid can be used to estimate LST_d and LST_w at any given NDVI, using the following equations (3 & 4).

$$LST_d = i_d + s_d NDVI \qquad \text{Eq. (3)}$$

$$LST_w = i_w + s_w NDVI \qquad \text{Eq. (4)}$$

Finally, the soil moisture for each pixel can be estimated by combining equations (2, 3 & 4) as a function of LST and NDVI, given as below:

$$W = \frac{i_d+s_d NDVI-LST}{i_d-s_{dw}+(s_d-s_w)NDVI} \qquad \text{Eq. (5)}$$

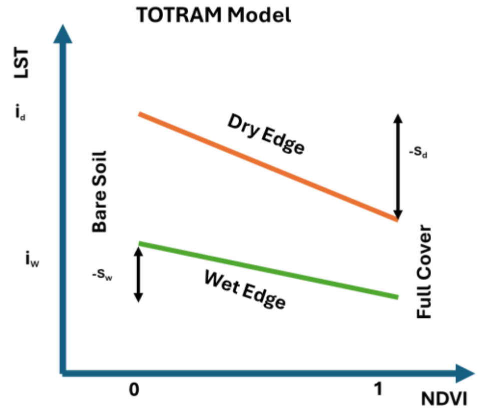

Figure 7 Sketch illustrating parameters of the traditional thermal-optical trapezoid model [Eq. (5), TOTRAM] *(36)*

2) *The New Optical Trapezoid Model (OPTRAM)*

To estimate soil moisture from Sentinel-2 data, we applied a novel model known as the Optical Trapezoid Model (OPTRAM). This model is based on the linear physical relationship between soil moisture and shortwave infrared-transformed reflectance (STR). The OPTRAM was an adaptation of the traditional trapezoid model (TOTRAM), initially developed by Sadeghi et al. (2017) (36), in which Land Surface Temperature (LST) was replaced to facilitate soil moisture estimation in the optical domain. The model is parameterized using pixel distribution within the STR-VI space. Additionally, a physical model demonstrating a linear relationship between surface moisture content and SWIR-transformed reflectance was proposed by Sadeghi et al. (2015) (37), where the two-flux radiative transfer model by Kubelka and Munk (1931) was modified for this purpose.

$$W = \frac{(\theta - \theta_d)}{(\theta_w - \theta_d)} = \frac{(STR_d - STR)}{(STR_w - STR_d)} \qquad \text{Eq. (6)}$$

Where STR means the SWIR transformed reflectance and STR_d and STR_w are the STR at θ_d and θ_w respectively. The STR can be calculated using the following equation as it is related to SWIR reflectance R_{SWIR},

$$STR = \frac{(1 - R_{SWIR})^2}{2R_{SWIR}} \qquad \text{Eq. (7)}$$

STR_d and STR_w can be obtained for a specific location from the dry and wet edges of the optical trapezoid, as shown in Figure 8.

$$STR_d = i_d + s_d NDVI \qquad \text{Eq. (8)}$$

$$STR_w = i_w + s_w NDVI \qquad \text{Eq. (9)}$$

Finally, we can combine all equations 6, 8, and 9 to estimate the soil moisture for each pixel as a function of STR and NDVI:

$$W = \frac{i_d + s_d NDVI - STR}{i_d - s_{dw} + (s_d - s_w) NDVI} \qquad \text{Eq. (10)}$$

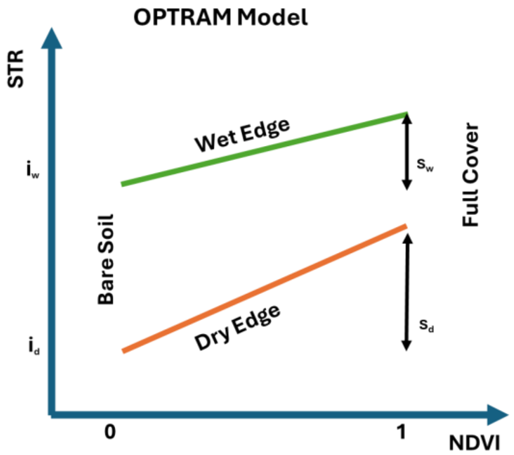

Figure 8 Sketch illustrating parameters of the new optical trapezoid model [Eq. (10), OPTRAM] *(36)*

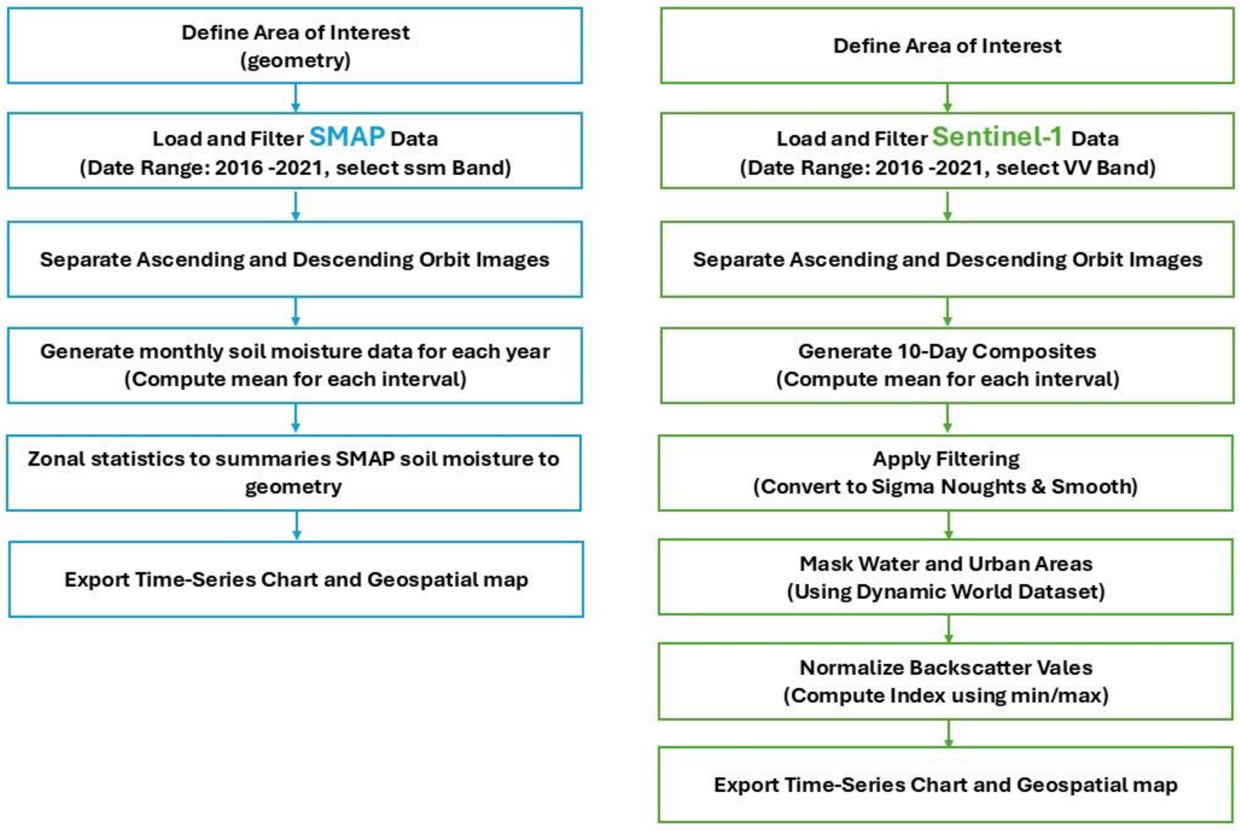

Figure 9 Flowcharts illustrating the estimation of soil moisture from SMAP and Sentinel-1 on GEE (ssm Band= Surface soil moisture in mm (0-25.39), (vv Band = single co-polarization, vertical transmit/vertical receive)

7. PRELIMINARY ANALYSIS AND RESULTS

7.1. SURFACE WATER AREA

We initially estimated the surface water area using the Yearly Product (JRC Yearly Water Classification History, v1.4) on Google Earth Engine (GEE). Figure 10 illustrates the annual surface water area (in km²) for the year 1998. Subsequently, we focused on a specific area of interest around the Falkland Islands. We then estimated the monthly surface water area (in km²) from 1998 to 2021 for lakes and ponds on both East and West Falkland Islands, with particular attention to Lake Sulivan on East Falkland, the Lakelands area of small ponds east of Lake Sulivan, lakes and ponds near the MPA (e.g., Laguna Isla and Long Pond), and Big Pond in Saladero. A key challenge in using the monthly history dataset is the lack of images for certain months, for example, there are no images for May, June and July over the Falkland Islands from 1998 to 2021. Consequently, the results show zero values, indicating a lack of data for those months.

7.1.1. Lake Sulivan and Lakelands area of small Ponds east of Lake Sulivan

We estimated the annual average surface water area for Lake Sullivan (Figures 11.a and 11.c) and for the Lakelands area of small ponds (Figures 11.b and 11.d). As shown in Figures 11.c and 11.d, the surface water areas of both Lake Sullivan and nearby ponds exhibited minimal change from 1999 to 2015. However, Figure 11.c indicates a significant reduction in the surface water area of Lake Sullivan in 2016, followed by a gradual increase from 2017 to 2020, and a second decrease in 2021. Figure 11.d reveals a sustained reduction in the annual average surface water area of the Lakelands ponds, beginning in 2016 and continuing through to 2021 (the final year of data).

Figure 12.a illustrates the monthly surface water area (in km²) of Lake Sulivan, with values ranging from 1 km² to 24 km² between June 1998 and December 2021. The minimum surface water area was typically observed in February-March (Figure 12.b), while the maximum surface water area was most frequently recorded in October over the 24 years (Figure 12.c).

Figure 13.a presents the monthly average surface water area of the Lakelands ponds from June 1998 to December 2021. The smallest surface water area occurred in February 2011 (Figure 13.b), while the largest was observed in September 1999. Notably, the overall monthly average surface water area in September, from 1999 to 2015, indicates a significant reduction of 50% after 2007. Unfortunately, data for September from 2016 to 2021 is missing (Figure 13.c).

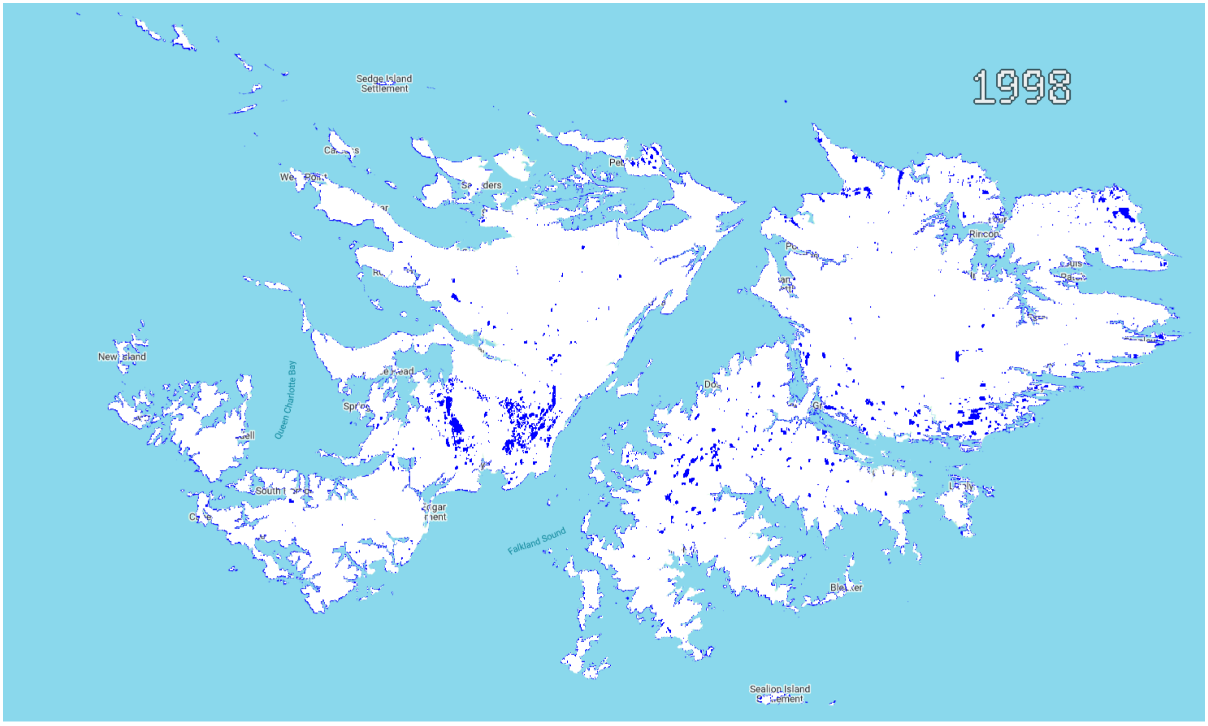

Figure 10 Map of Surface Water Bodies (1998) developed by JRC Yearly Water Classification History, v1.4

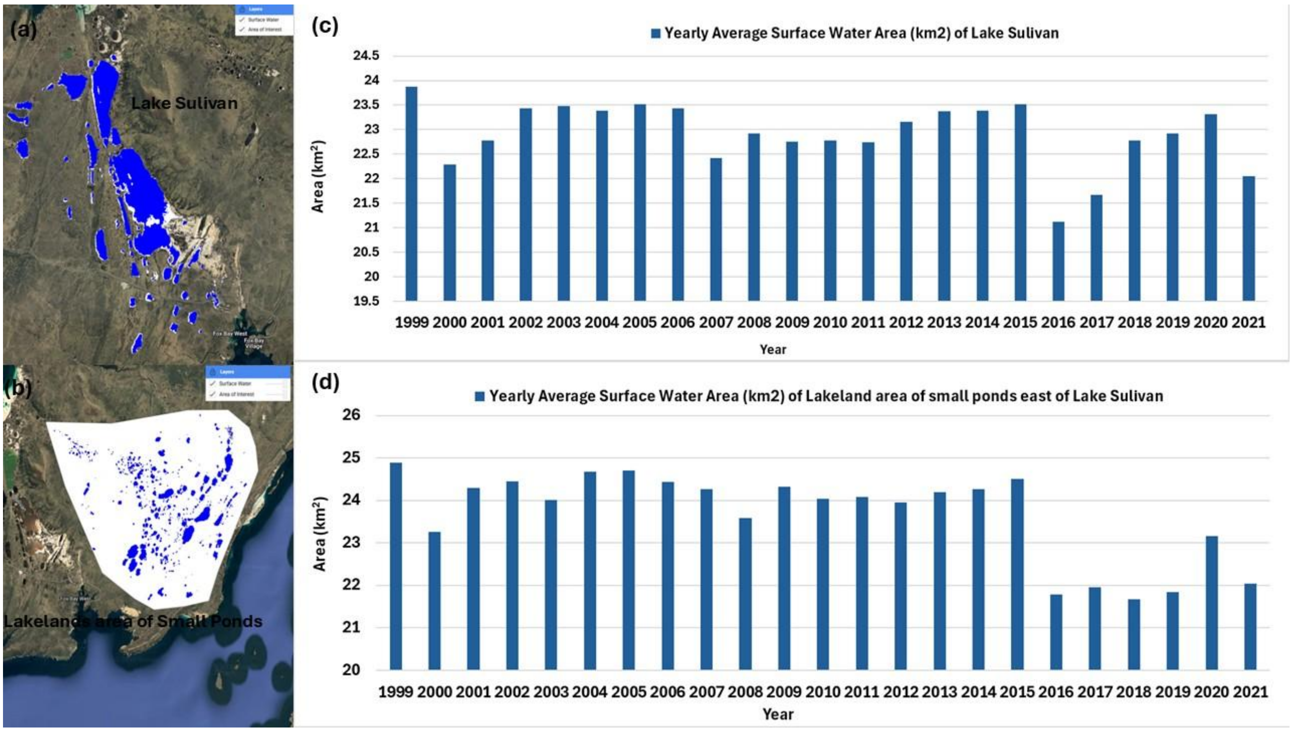

Figure 11 Map of Lake Sulivan (11.a), Map of small ponds near Lake Sulivan (11.b), Yearly average surface water area (km^2) of Sulivan Lake from 1999 to 2021 (11.c), and Yearly average surface water area (km^2) of Lakeland area of small ponds east Sulivan Lake from 1999 to 2021 (11.d)

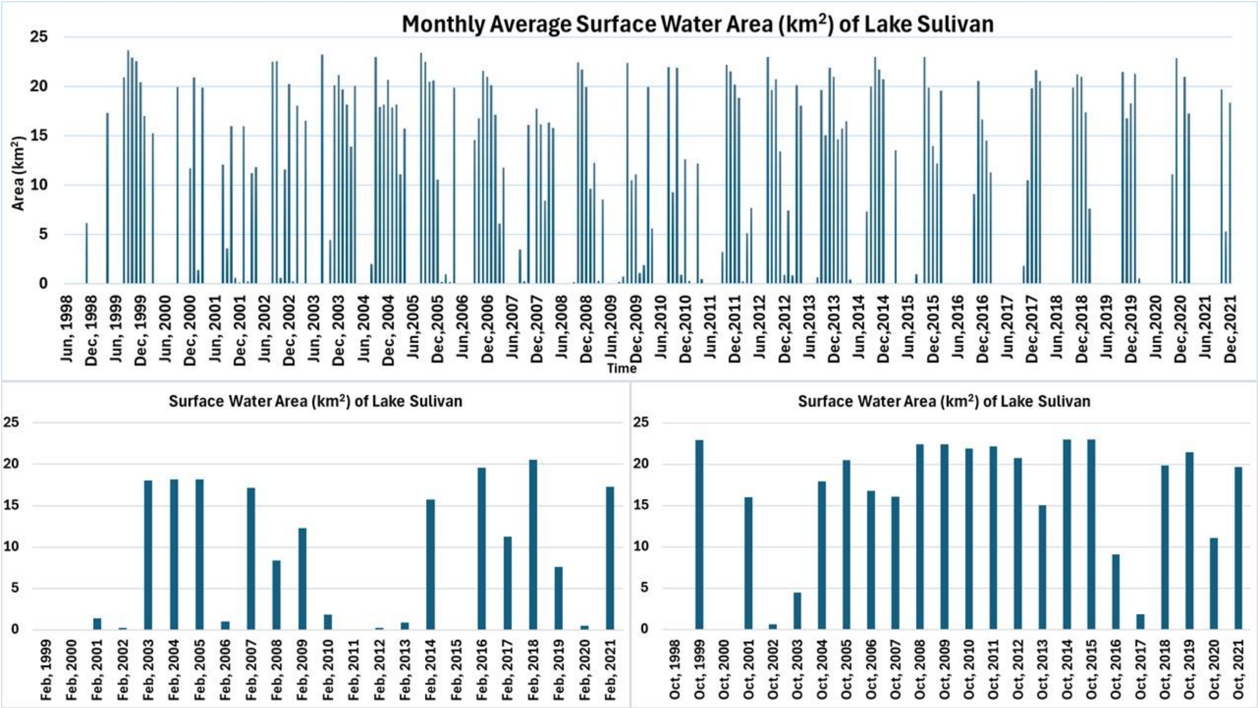

Figure 12 Monthly average surface water area of Sulivan Lake from June 1998 to December 2021 (12.a), Monthly average surface water area (km²) of February from 1999 to 2021 (12.b), and Monthly average surface water area (km²) of October from 1999 to 2021 (12.c)

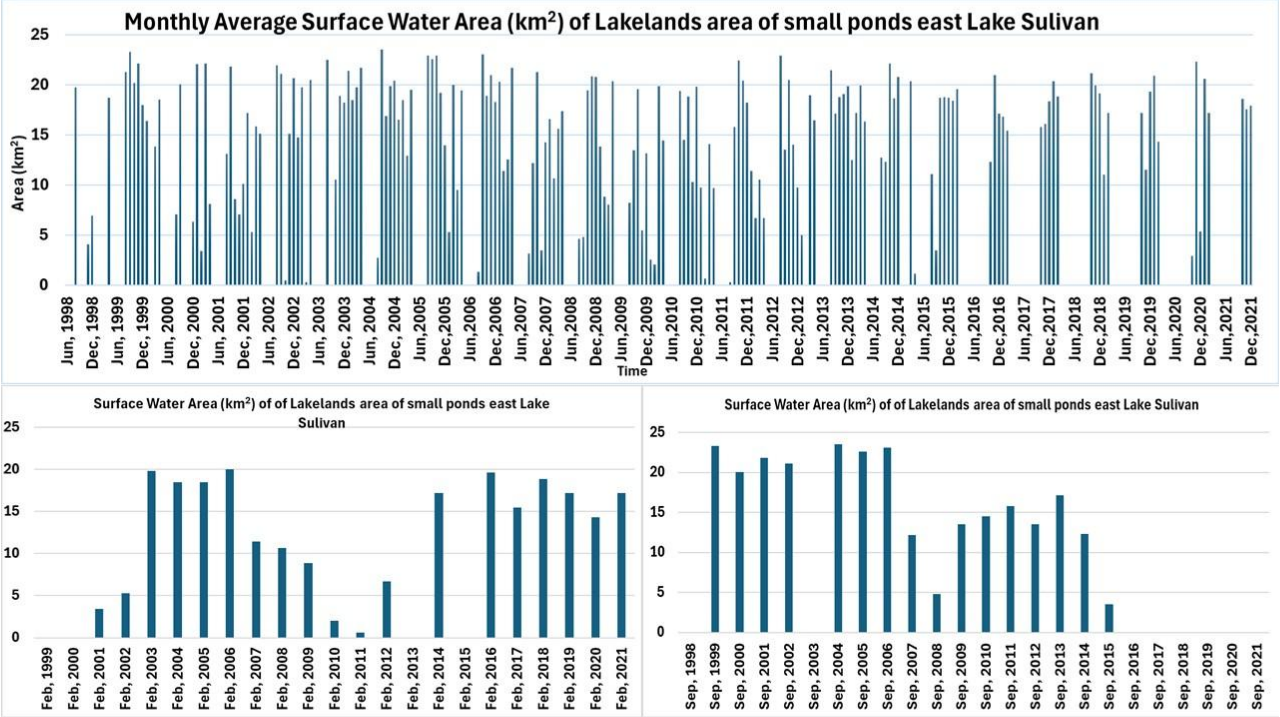

Figure 13 Monthly average surface water area (km²) of Lakelands area of small ponds east Sulivan Lake from June 1998 to December 2021 (13.a), Monthly average surface water area (km²) *of* February from 1999 to 2021 (13.b), and Monthly average surface water area of September from 1999 to 2021 (13.c)

7.1.2. Laguna Isla and Long Pond (near MPA area)

The overall yearly average surface water area of Laguna Isla and Long Pond from 1999 to 2021 shows slight variability over the 24 years, except for the surface water area of Laguna Isla in 2021 (Figures 14.c and 14.d). As shown in Figures 15.b and 15.c, there has been a clear decreasing trend in the monthly average surface water area of Laguna Isla since 2016. The maximum surface water area occurred in October, which also exhibited a declining trend after 2016 (Figure 15.c).

In contrast, data presented in Figure 9d indicate that the surface water area of Long Pond remained relatively constant over the 24 years. The minimum surface water areas were generally observed in January, while the maximum surface water areas were typically recorded in October (Figures 15.b and 15.c). Overall, the yearly average surface water area of Long Pond did not exhibit significant changes due to drying, especially when compared to the surface water area of Laguna Isla, notably in 2001 (Figures 16.c and 16.d). This does not imply that Long Pond remained full of water over this period; the method can detect the extent of water but not its depth, and (like many other Falkland ponds) water levels in Long Pond may have fallen to very low levels in recent years, even if the pond did not dry out.

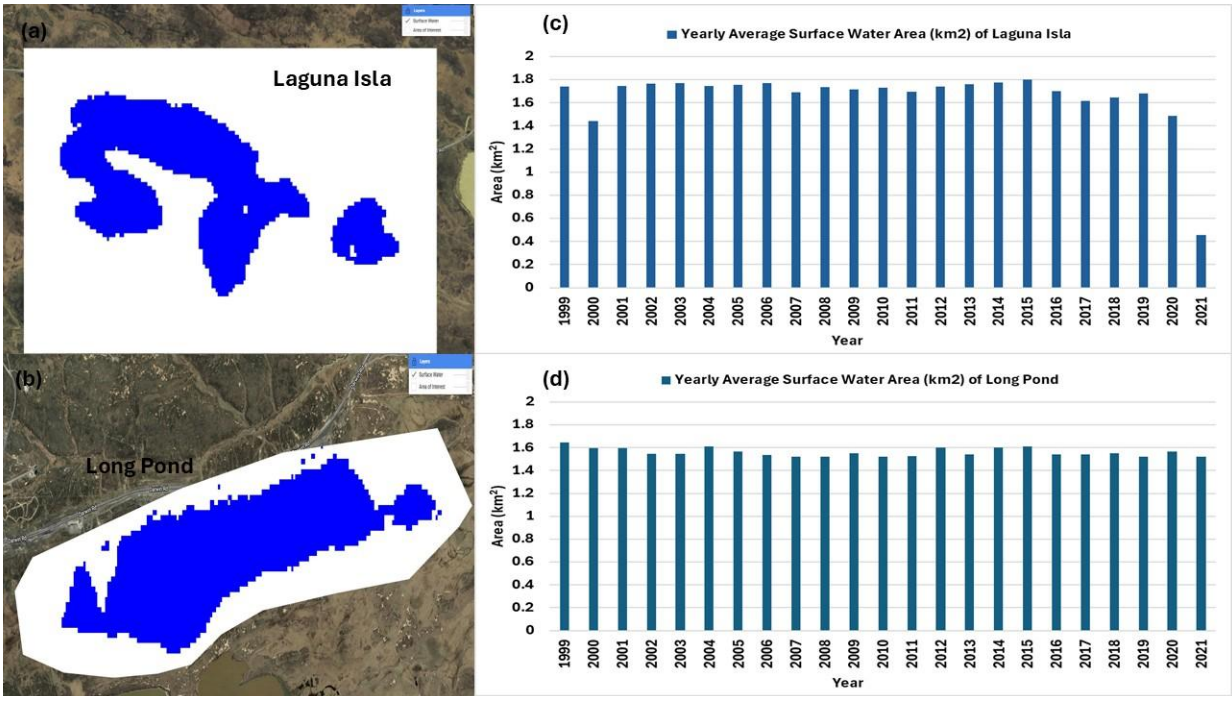

Figure 14 Map of Laguna Isla (14.a), Map of Long Pond (14.b), Yearly average surface water area (km²) of Laguna Isla from 1999 to 2021 (14.c), and Yearly average surface water area (*km²*) of Long Pond from 1999 to 2021 (14.d)

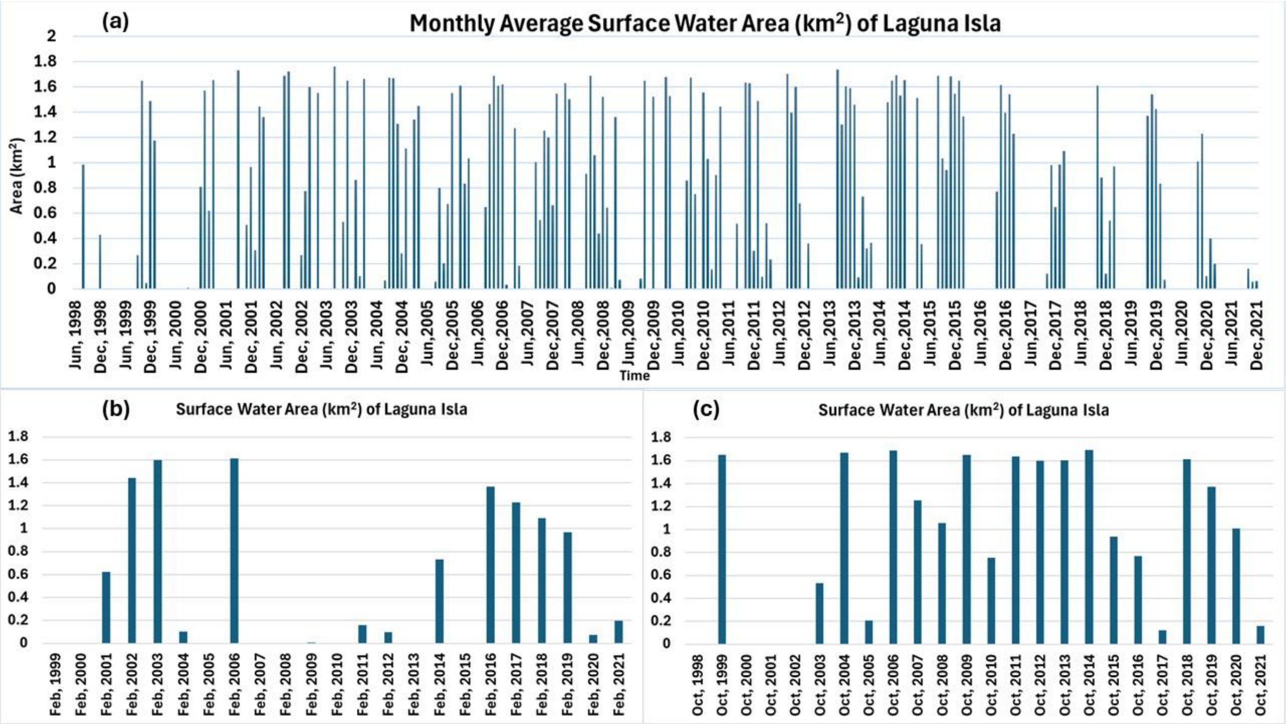

Figure 15 Monthly average surface water area (*km^2*) of Laguna Isla from June 1998 to December 2021 (15.a), Monthly average surface water area (km^2) of February from 1999 to 2021 (15.b), and Monthly average surface water area of October from 1999 to 2021 (15.c)

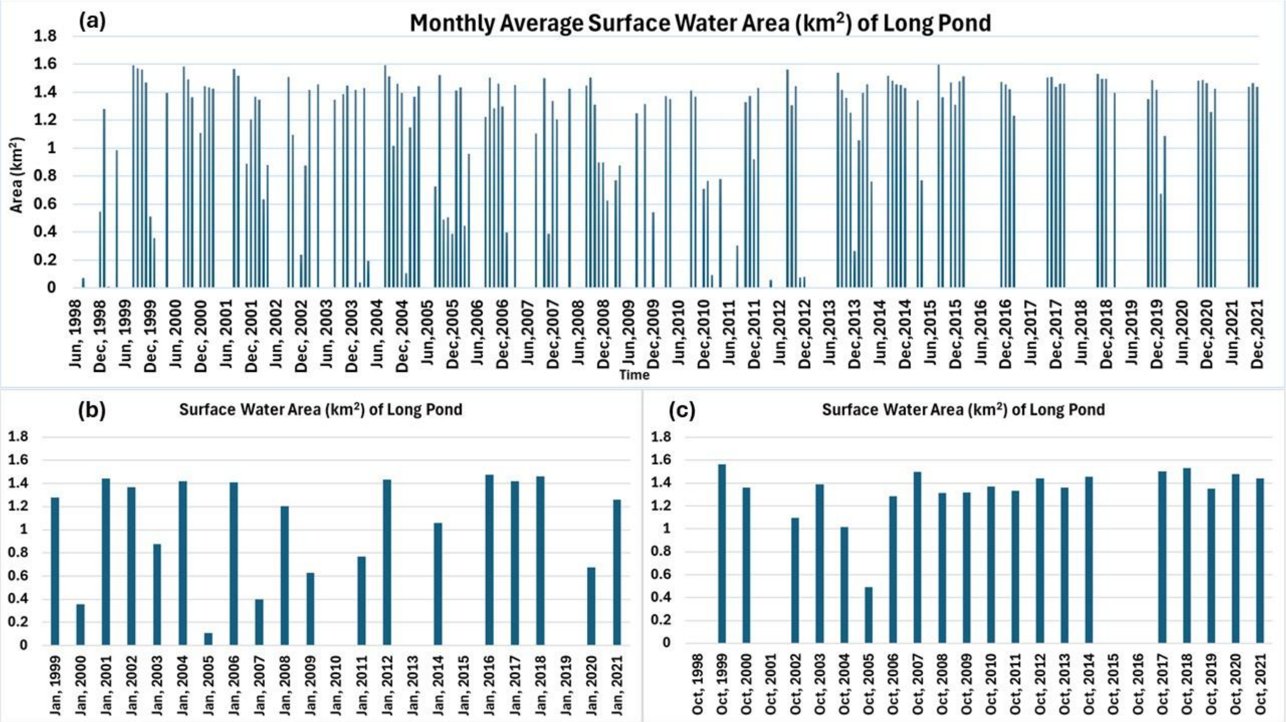

Figure 16 Figure 17 Monthly average surface water area (km^2) of Long Pond from June 1998 to December 2021 (16.a), Monthly average surface water area (km^2) of January from 1999 to 2021 (16.b), and Monthly average surface water area of October from 1999 to 2021 (16.c)

7.1.3. Big Pond in Saladero

Figure 17 presents the yearly and monthly average surface water areas of Big Pond in Saladero from 1999 to 2021. The yearly surface water area of Big Pond exhibited slight variation over the 24 years (Figure 17.a). A minor decrease in surface water area was observed in 2016, 2017, 2018, and 2019 (Figure 17.a).

In terms of the monthly average surface water area, the minimum values were recorded in December 2000, February 2007, and August 2015, while the maximum surface water area was observed in September 2014 (Figure 17.c). The results for both yearly and monthly surface water areas indicate no significant reduction in the surface water area of Big Pond from 1999 to 2021. Overall, the data suggest that Big Pond was not significantly affected by the drying trends observed in the Falkland Islands.

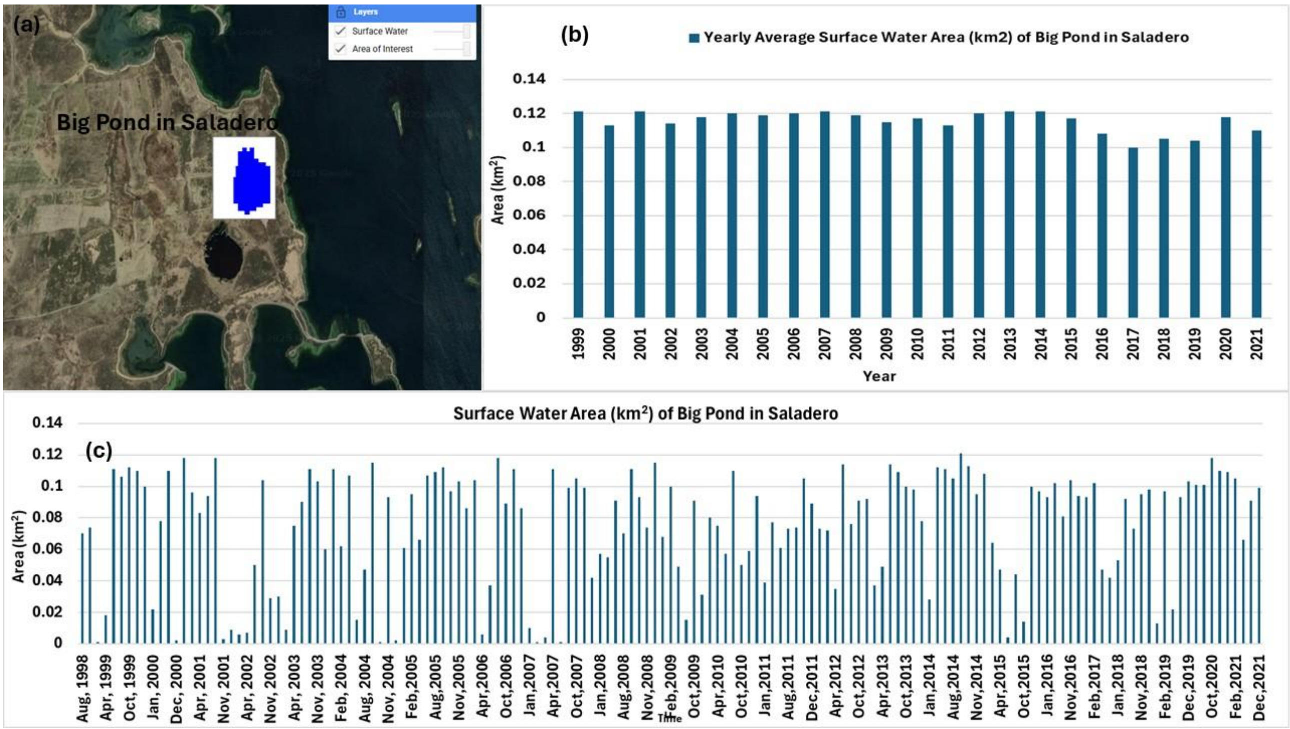

Figure 18 Map of Big Pond in Saladero (18.a), Yearly average surface water area (km^2) of Big Pond from 1999 to 2021 (18.b), and Monthly average surface water area (km^2) of Big Pond from August 1998 to December 2021 (18.c)

7.2. SOIL MOISTURE INDEX

We explored most of the available products on GEE to estimate soil moisture index for Falkland Islands, such as NASA product (Soil Moisture Active Passive Data: SMAP), USGS Landsat 8 Level 2, Harmonized Sentinel 2: MultiSpectral Instrument Level-2A, and a dual-polarized C-band Synthetic Aperture Radar (SAR) product (Sentinel 1).

7.2.1. Soil Moisture Active Passive Data (SMAP)

We initially employed the NASA Soil Moisture Active Passive (SMAP) product, which utilizes a passive microwave 2-D interferometric radiometer operating at L-band (1.4 GHz, 21 cm), to estimate soil moisture content across the Falkland Islands from 2016 to 2021, based on available imagery for the study area. SMAP measures how much water in the top 5cm of soil everywhere on Earth is not covered with water or not frozen. It also differentiates between frozen and thawed soil (13), (14). SMAP global soil moisture data provides surface and subsurface soil moisture (mm), soil moisture profiles (%), and surface and subsurface soil moisture anomalies (-) (13), (14). We applied the implementation process on the GEE platform as shown in Figure 8. Monthly mean surface soil moisture was estimated using the SMAP product, which ranges from 0 to 25.4 mm (Figure 18). The data indicate that soil moisture was lowest during the summer months (January, and February) and increased from May through July, spanning the years 2016 to 2021 (Figure 18).

Subsequently, we exported a surface soil moisture map of the Falkland Islands for 2016, created using SMAP data on Google Earth Engine and GIS (Figure 19). It is evident that the current spatial resolution of 10 km for the SMAP product is insufficient for effective application in the Falkland Islands, which aligns with the findings of Zhang et al. (2016) (30). As a result, we decided not to use the SMAP product for soil moisture estimation across the entire Falkland Islands.

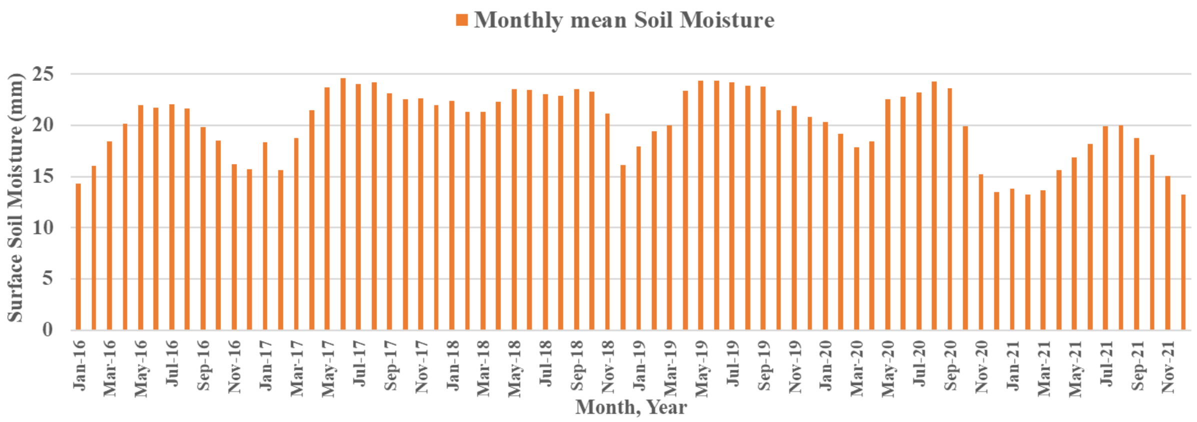

Figure 19 Monthly Mean Surface Soil Moisture of Falkland Islands from 2016 to 2021 using SMAP on GEE

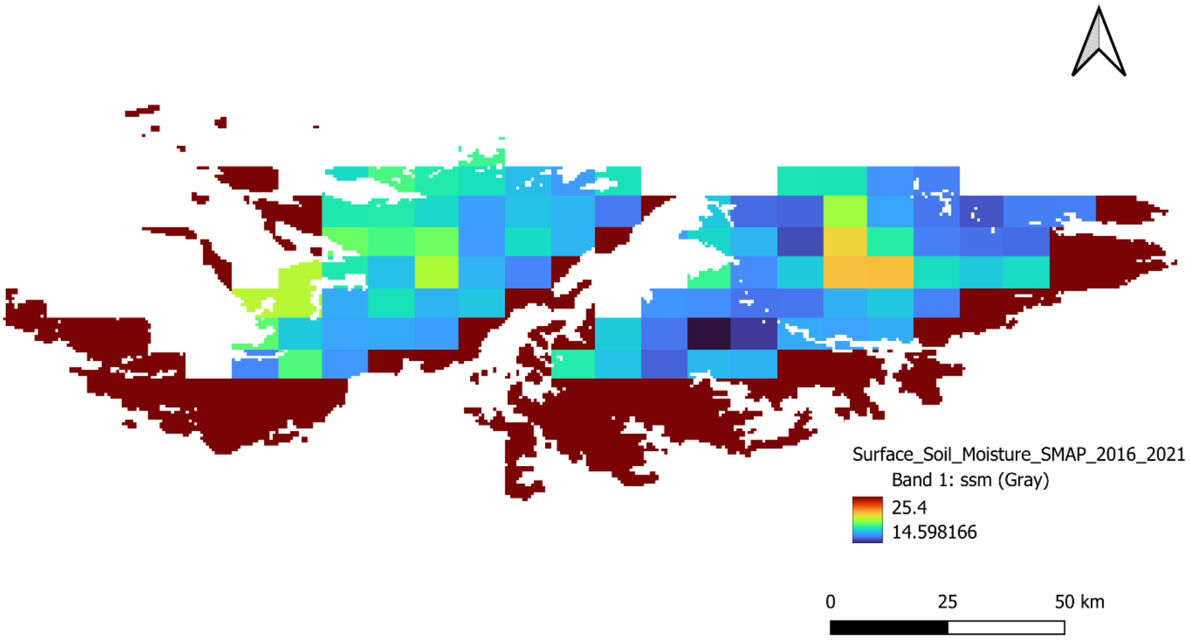

Figure 20 Map of surface soil moisture from 2016 to 2021 of Falkland Islands using SMAP, the brown areas show no data.

7.2.2. **USGS Landsat 8 Level 2, Collection 2, Tier 1**

Figure 20 presents the estimated soil moisture (cm^3 cm^{-3}) calculated using Equation 5, based on Landsat 8 imagery. A total of 20 Landsat 8 images, spanning from 2013 to 2022, were analysed. The results indicate a general decrease in soil moisture across the Falkland Islands, particularly during December, January, and February, within the period from August 2013 to November 2022 (Figure 20). However, it is important to note that the soil moisture map for the Falkland Islands does not provide complete spatial coverage. Several areas, particularly on East Falkland Island, are missing data, as highlighted in Figure 21, where these gaps are marked in black. Therefore, we opted not to use Landsat 8 imagery for soil moisture estimation on the Falkland Islands to ensure complete spatial coverage across the entire region.

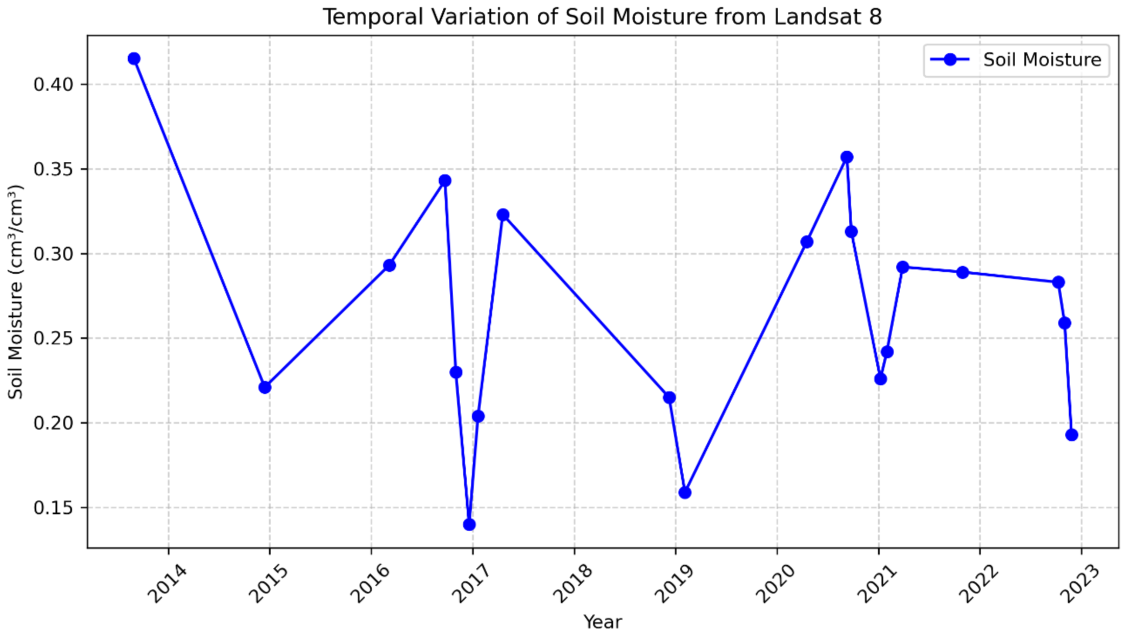

Figure 21 Estimated soil moisture of Falkland Islands using TOTRAM model on Landsat 8 images.

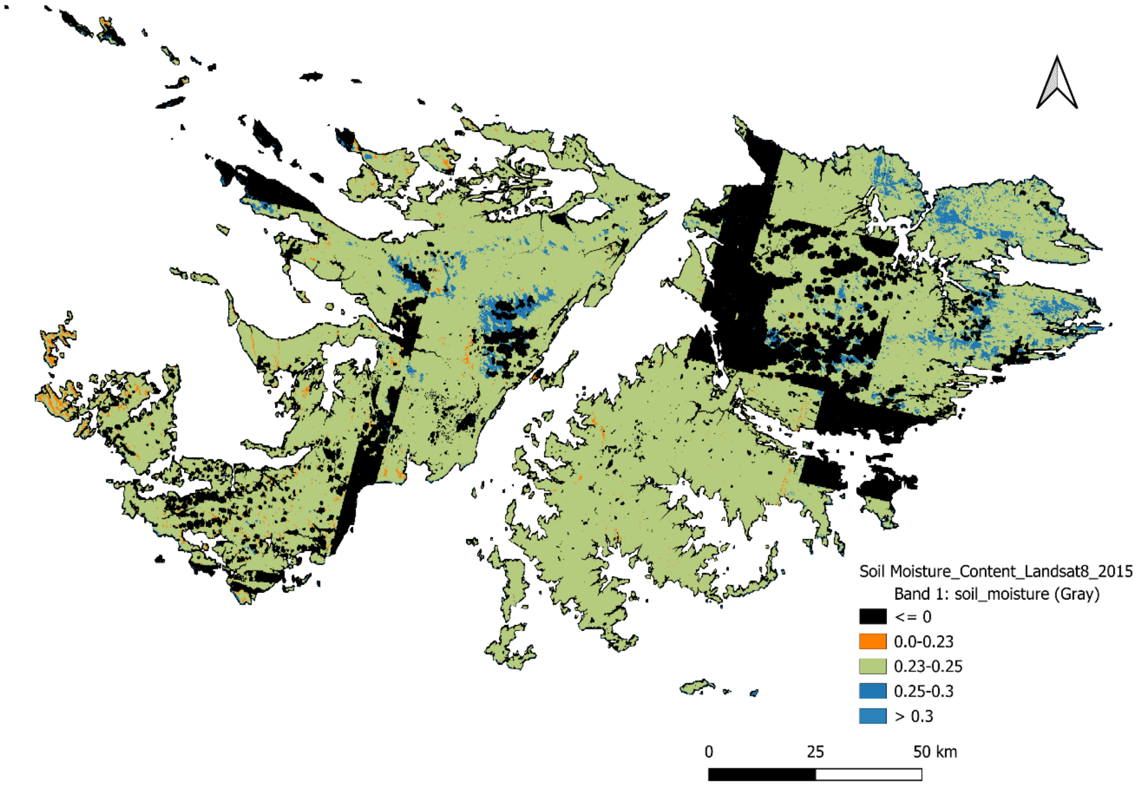

Figure 22 Map of surface soil moisture from 2016 to 2021 of Falkland Islands using Landsat 8

7.2.3. Harmonized Sentinel-2 MSI: MultiSpectral Instrument, Level-2A (SR)

We generated and exported soil moisture maps for the Falkland Islands from 2019 to 2023 using the OPTRAM model on Google Earth Engine (GEE) (Figure 22). The results indicate that Sentinel-2 data does not provide complete spatial coverage of the entire Falkland Islands (Figure 22). Therefore, it may be necessary to refine the area of interest at a smaller scale to accurately derive soil moisture using the OPTRAM model with Sentinel-2 data on GEE.

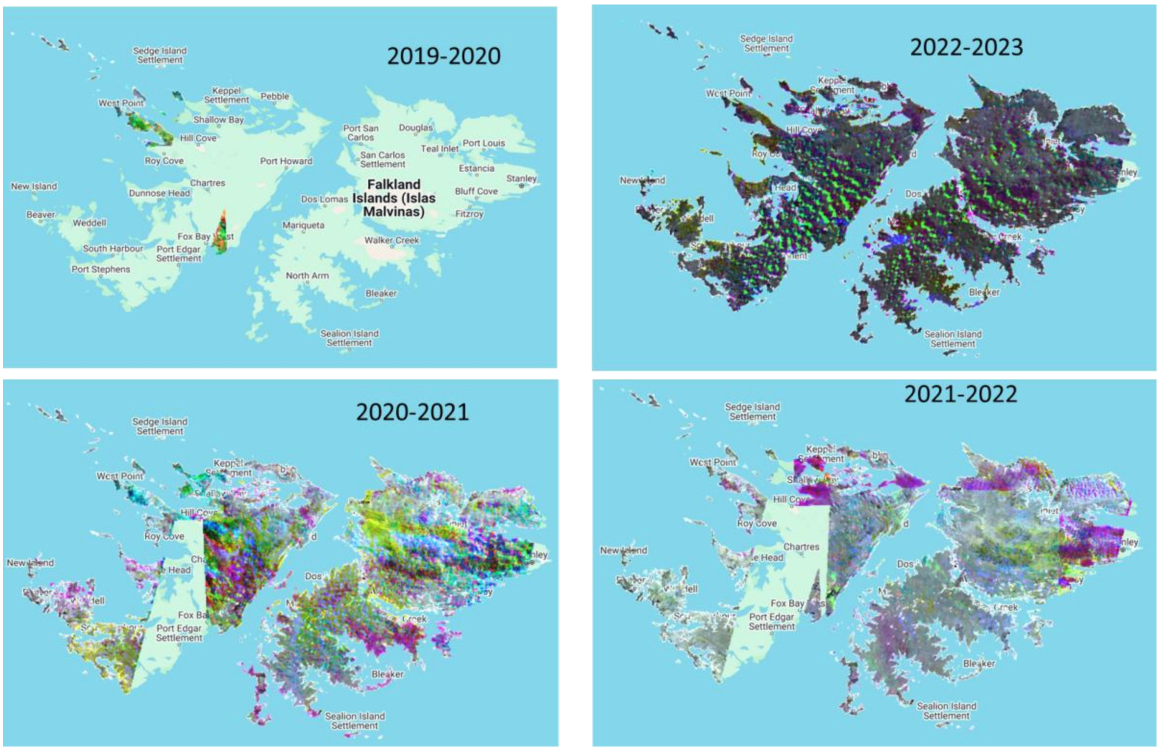

Figure 23 Maps of soil moisture from 2019 to 2023 from Sentinel-2 products on GEE platform.

7.2.4. Sentinel 1 SAR GRD: C-band Synthetic Aperture Radar Ground Range Detected, log scaling.

Finally, we utilized Sentinel-1 data to estimate soil moisture across the Falkland Islands, ensuring complete spatial coverage of the entire region. Sentinel-1 has been available since October 2014, providing imagery at six-day intervals. However, for the Falkland Islands, data is available from 2016 to 2021. The processing methodology is outlined in Figure 8, and soil moisture maps were generated for the years 2016 (Figure 23), 2017 (Figure 24), 2018 (Figure 25), 2019 (Figure 26), 2020 (Figure 27), and 2021 (Figure 28). Despite variations in data availability, the results confirm that Sentinel-1 provides comprehensive spatial coverage of the Falkland Islands (Figure 23, 24, 25, 26, 27, and 28). Therefore, Sentinel-1 data will be used for further analysis.

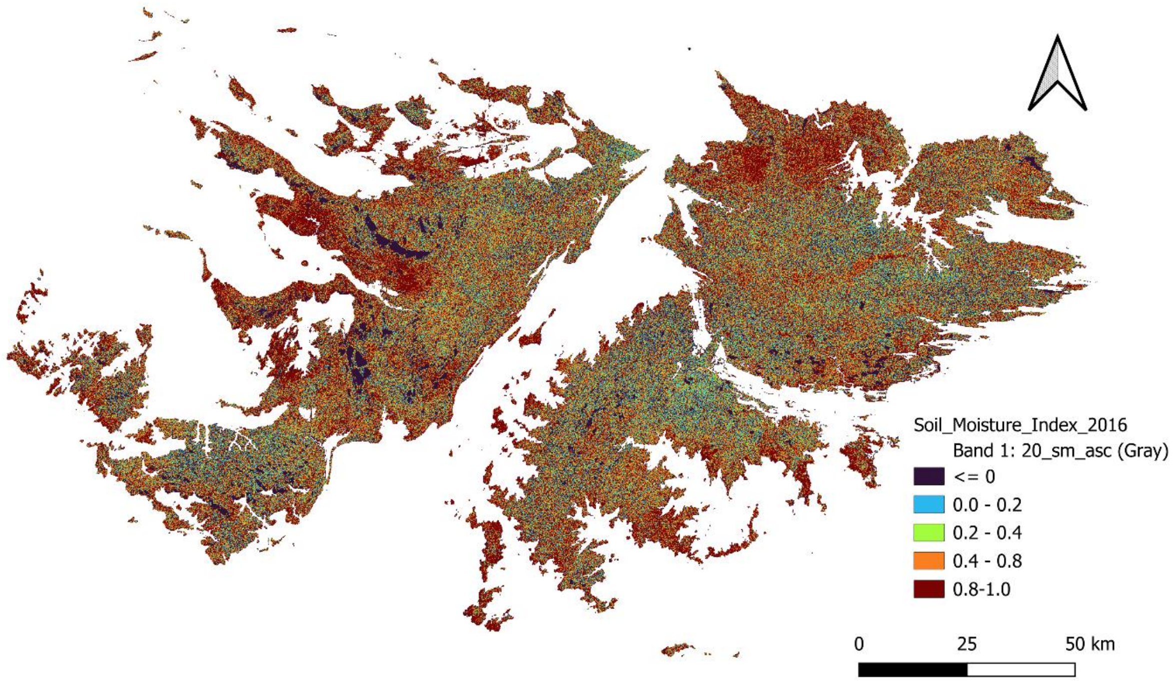

Figure 24 Map of soil moisture of 2016 using Sentinel-1 on GEE platform.

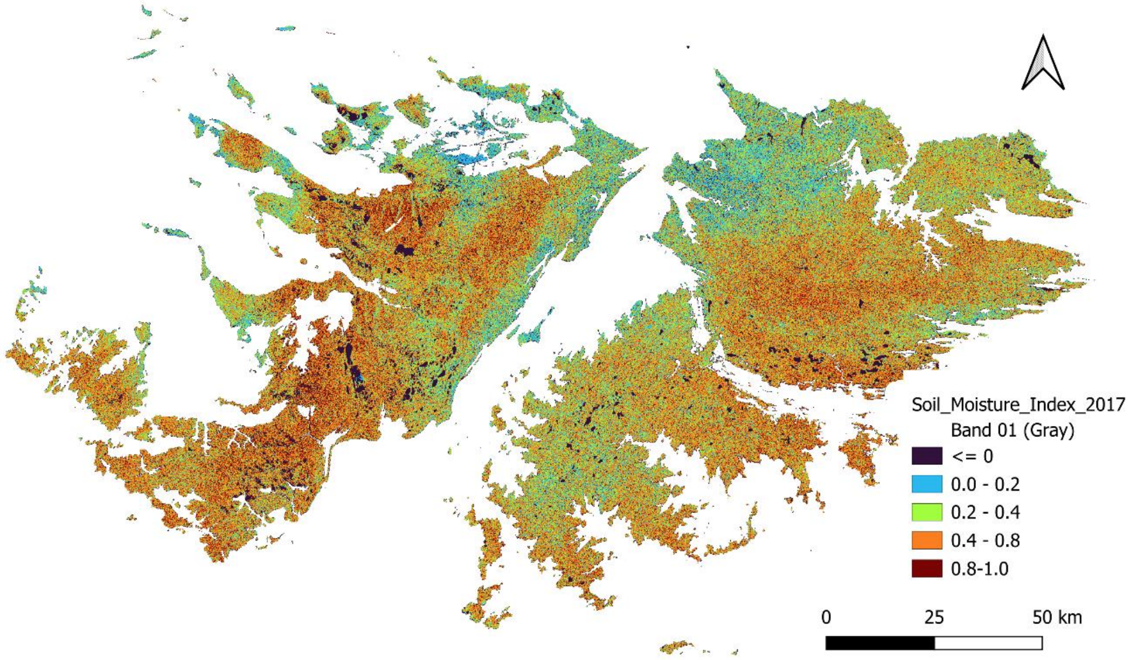

Figure 25 Map of soil moisture of 2017 using Sentinel-1 on GEE platform.

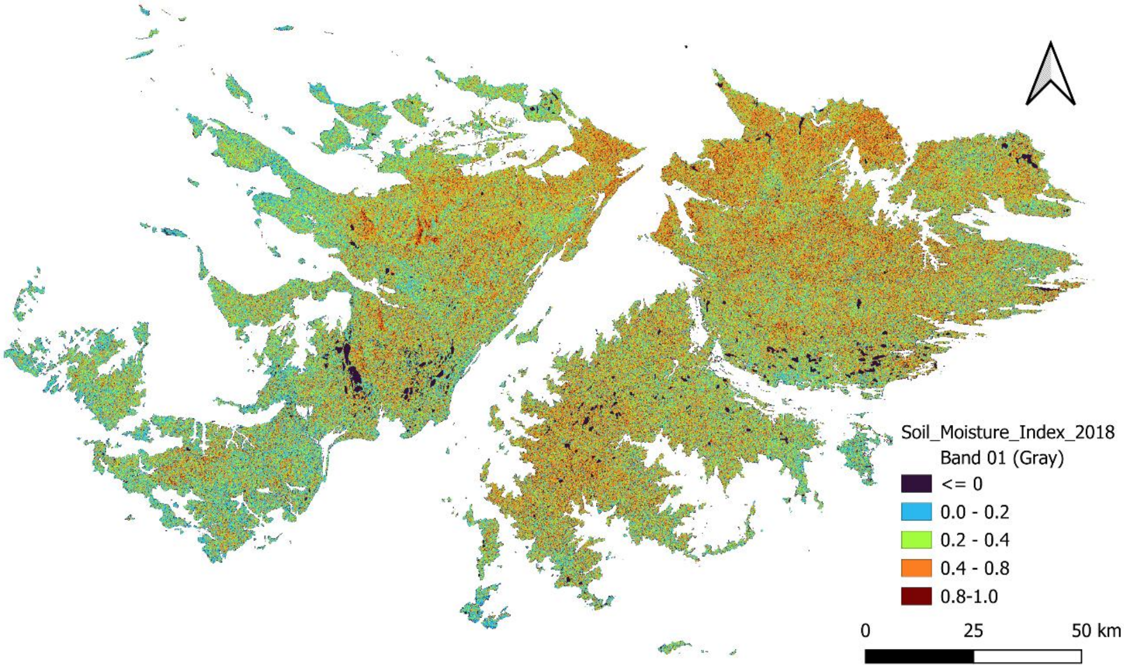

Figure 26 Map of soil moisture of 2018 using Sentinel-1 on GEE platform.

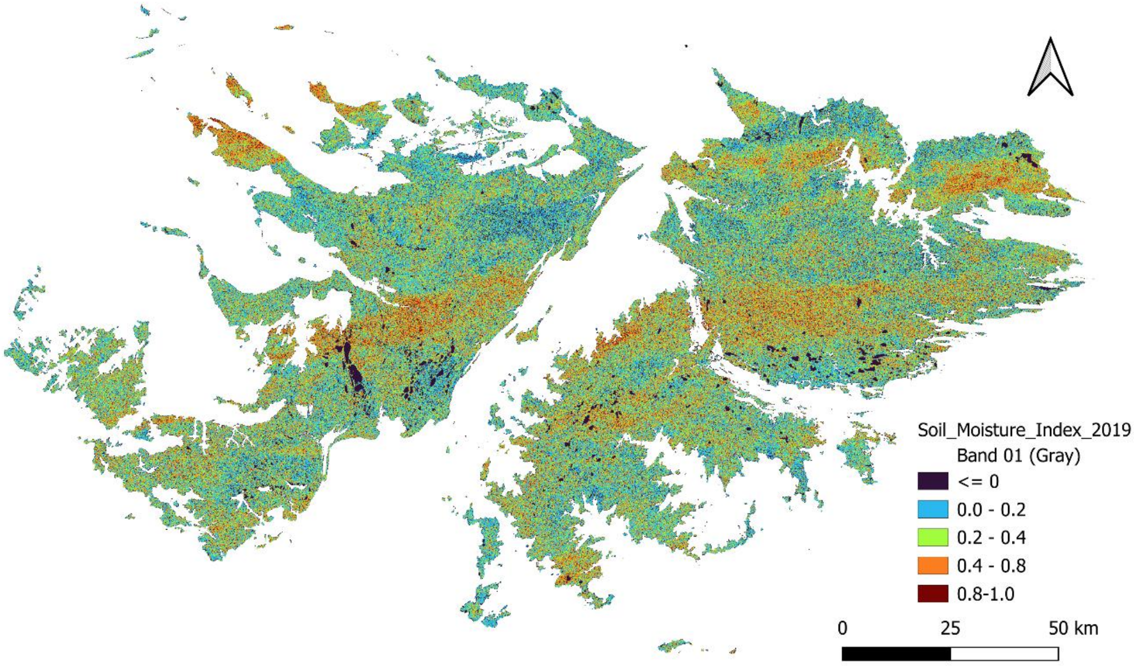

Figure 27 Map of soil moisture of 2019 using Sentinel-1 on GEE platform.

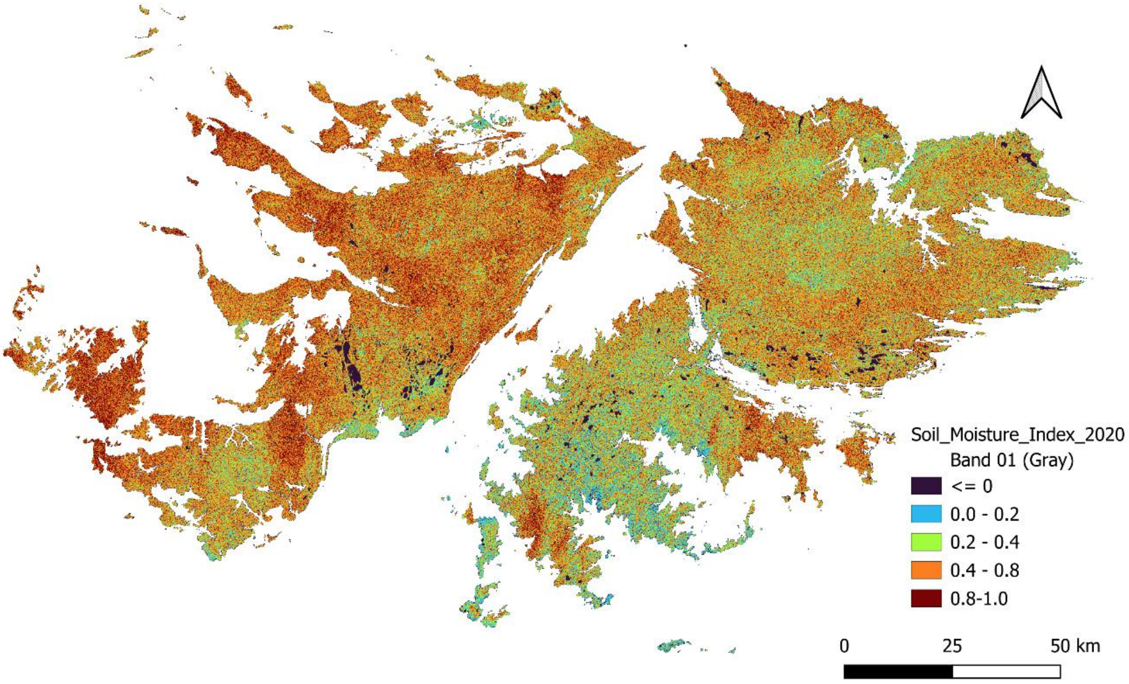

Figure 28 Map of soil moisture of 2020 using Sentinel-1 on GEE platform.

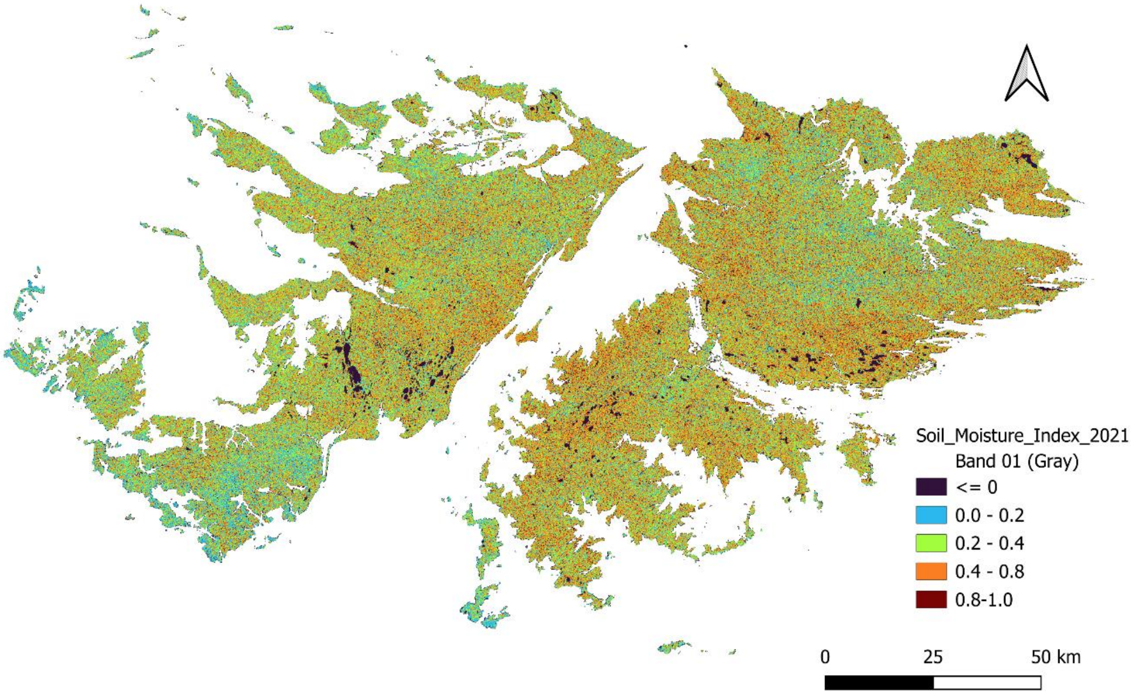

Figure 29 Map of soil moisture of 2021 using Sentinel-1 on GEE platform.

8. FUTURE WORK

8.1. FIELD VISIT

On February 14, 2025, we conducted our first field visit to Saladero. Although no formal interviews were held, we introduced the DPLUS206 project to local landowners and discussed the drying of ponds. A key observation shared by the locals, especially those involved in conservation efforts, was that Big Pond in Saladero has remained consistently full and has never experienced drying.

Our analysis of global datasets supports this observation, showing no significant change in the surface water area of Big Pond over the past 24 years (Figure 17).

In contrast, local accounts revealed that Laguna Isla experienced a significant dry period approximately two years ago. This observation aligns with our satellite imagery analysis, which indicates a clear downward trend in the surface water area of Laguna Isla since 2016 (Figures 15.b and 15.c).

While satellite datasets provide comprehensive spatial coverage of the Falkland Islands, real-time observations and ground-based measurements are crucial for validating satellite-derived data. As a next step, we plan to conduct additional field visits to collect water samples and conduct interviews. This will facilitate the calibration and validation of our remote-sensing data.

8.2. STATISTICAL ANALYSIS

We have compiled and analysed all available datasets on surface water and soil moisture in the Falkland Islands. Moving forward, we will perform statistical analyses to evaluate historical and current freshwater dynamics in key areas of interest. This assessment will provide insights into the impacts of climate change and land management on regional freshwater systems.

Meteorological variables, including precipitation, soil moisture, temperature, and water levels (or discharge) of ponds, lakes, and rivers, will be integral to these analyses. By integrating these factors, we aim to enhance our understanding of freshwater dynamics in the Falkland Islands.

9. REFERENCE

1. Tockner K. Freshwaters: Global Distribution, Biodiversity, Ecosystem Services, and Human Pressures. In: Bogardi JJ, Gupta J, Nandalal KDW, Salamé L, van Nooijen RRP, Kumar N, et al., editors. Handbook of Water Resources Management: Discourses, Concepts and Examples [Internet]. Cham: Springer International Publishing; 2021 [cited 2025 Mar 10]. p. 489–501. Available from: https://doi.org/10.1007/978-3-030-60147-8_16

2. Qadri H, Bhat RA. (PDF) The Concerns for Global Sustainability of Freshwater Ecosystems [Internet]. [cited 2025 Mar 10]. Available from: https://www.researchgate.net/publication/334546308_The_Concerns_for_Global_Sustainability_of_Freshwater_Ecosystems

3. Ahuja S. Handbook of water purity and quality. Academic press; 2021.

4. Rijsberman FR. Water scarcity: Fact or fiction? Agricultural Water Management. 2006 Feb 24;80(1):5–22.

5. Musie W, Gonfa G. Fresh water resource, scarcity, water salinity challenges and possible remedies: A review. Heliyon. 2023 Aug 1;9(8):e18685.

6. Kernan M, Battarbee RW, Moss BR. Climate Change Impacts on Freshwater Ecosystems. John Wiley & Sons; 2011. 470 p.

7. Otley H, Munro G, Clausen A, Ingham B. Falkland Islands state of the environment report 2008. Falkland Islands Government and Falklands Conservation, Stanley. 2008;288.

8. Cook BI, Smerdon JE, Cook ER, Williams AP, Anchukaitis KJ, Mankin JS, et al. Megadroughts in the Common Era and the Anthropocene. Nature Reviews Earth & Environment. 2022;3(11):741–57.

9. Woods R, Ingham R, Brown A, Black-browed A. Falkland islands. Important bird areas in the United Kingdom Overseas Territories Sandy: Royal Society for the Protection of Birds. 2006;99–162.

10. Turner J, Pendlebury S. The international Antarctic weather forecasting handbook [Internet]. British Antarctic Survey; 2004 [cited 2025 Mar 10]. Available from: https://nora.nerc.ac.uk/id/eprint/17324/1/handbook_16june04.pdf

11. Evans CD, Felgate SL, Carter S, Stinchcombe M, Mawji E, Rees AP, et al. Marine nutrient subsidies promote biogeochemical hotspots in undisturbed, highly humic estuaries. Limnology & Oceanography. 2023 Aug;68(8):1802–20.

12. Carter S, Stroud DA. Falklands wetlands and aquatic habitats: baselines for monitoring future change. Report under Darwin Plus Project 116 by the South Atlantic Environmental Research Institute [Internet]. 2021; Available from: https://nora.nerc.ac.uk/id/eprint/532710

13. Carter S, Aitkenhead M, Evans C, Jungblut A, McAdam J, McNee M. Soil map and online database as climate change mitigation tools. Darwin Plus [Internet]. 2020 [cited 2025 Mar 10];83. Available from: https://www.south-atlantic-research.org/wp-content/uploads/2022/09/Presentation_DPLUS-083-Soil-Mapping_Project-Overview_Steffi-Carter.pdf

14. Weller MW. Ecological studies of Falkland Islands' waterfowl. Wildfowl. 1972;23(23):25–44.

15. Stone P. The geology of the Falkland Islands. Deposits magazine. 2010;(23):38–43.

16. Aldiss DT, Edwards EJ. The geology of the Falkland Islands [Internet]. British Geological Survey; 1999 [cited 2025 Apr 2]. Available from: https://nora.nerc.ac.uk/id/eprint/507542/

17. Jones PD, Harpham C, Lister D. Long-term trends in gale days and storminess for the Falkland Islands. International Journal of Climatology. 2015;36(3):1413–27.

18. Cheung WWL, Pitcher TJ. A mass-balance model of the Falkland Islands fisheries and ecosystems. Fisheries Centre Research Reports. 2005;13(7):65–84.

19. Upson R, McAdam J, Clubbe C. Climate change risk assessment for plants and soils of the Falkland Islands and the services they provide. Royal Botanic Gardens Kew and UK Falkland Islands Trust https://doi org/1013140/RG [Internet]. 2016 [cited 2025 Mar 10];2(15660.67203). Available from: https://www.researchgate.net/profile/Colin-Clubbe/publication/308416318_Climate_Change_Risk_Assessment_for_Plants_and_Soils_of_the_Falkland_Islands_and_the_Services_they_provide/links/57e3c4b308ae847401683d2f/Climate-Change-Risk-Assessment-for-Plants-and-Soils-of-the-Falkland-Islands-and-the-Services-they-provide.pdf

20. Scalley TH. Freshwater resources in the insular Caribbean: an environmental perspective. Caribbean Studies. 2012;40(2):63–93.

21. Pelembe T, Cooper G. UK overseas territories and crown dependencies: 2011 biodiversity snapshot [Internet]. Joint Nat. Conserv. Comm., Peterborough, UK; 2011 [cited 2025 Mar 10]. Available from: https://www.researchgate.net/profile/Tara-Pelembe-2/publication/282647578_UK_Overseas_Territories_and_Crown_Dependencies_2011_Biodiversity_snapshot/links/5615363208ae983c1b41ee6f/UK-Overseas-Territories-and-Crown-Dependencies-2011-Biodiversity-snapshot.pdf

22. Carter S, Evans CD, Flower RJ, Stroud DA, Thompson JR. Falklands wetlands and aquatic habitats: baselines for monitoring future change. action plan recommendations. 2022 [cited 2025 Mar 10]; Available from: https://www.researchgate.net/profile/David-Stroud-2/publication/372629340_Darwin_Plus_116_Falklands_wetlands_and_aquatic_habitats_Baseli

nes_for_monitoring_future_change_Action_Plan_recommendations/links/64c0f8868de7ed28bac3f477/Darwin-Plus-116-Falklands-wetlands-and-aquatic-habitats-Baselines-for-monitoring-future-change-Action-Plan-recommendations.pdf

23. Carter S, Evans CD, Flower RJ, Stroud DA, Thompson JR. Falklands wetlands and aquatic habitats: baselines for monitoring future change. Indicator monitoring report. 2022 [cited 2025 Mar 10]; Available from: https://nora.nerc.ac.uk/id/eprint/532710

24. Jones PD, Harpham C, Lister DH. Construction of high spatial resolution climate scenarios for the Falkland Islands and southern Patagonia. United Kingdom Falkland Islands Trust [Internet]. 2013 [cited 2025 Mar 10]; Available from: http://www.ukfit.org/wp-content/uploads/2015/03/Falklands_Patagonia_report_08-10-2013.pdf

25. Hall B. Bathymetric data of mount adam's ponds in the falkland islands 2015 [Internet]. South Atlantic Environmental Research Institute (SAERI); 2015. Available from: http://dataportal.saeri.org/dataset/ bathymetric-data-of-mount-adams-ponds-in-the-falkland-islands-2015

26. Hellweger FL, Schlosser P, Lall U, Weissel JK. Use of satellite imagery for water quality studies in New York Harbor. Estuarine, Coastal and Shelf Science. 2004;61(3):437–48.

27. Zheng G, DiGiacomo PM. Uncertainties and applications of satellite-derived coastal water quality products. Progress in oceanography. 2017;159:45–72.

28. Pekel JF, Cottam A, Gorelick N, Belward A. Global surface water explorer dataset. European Commission, Joint Research Centre (JRC). 2017;

29. Pekel JF, Cottam A, Gorelick N, Belward AS. High-resolution mapping of global surface water and its long-term changes. Nature. 2016;540(7633):418–22.

30. Zhang D, Zhou G. Estimation of soil moisture from optical and thermal remote sensing: A review. Sensors. 2016;16(8):1308.

31. Claverie M, Ju J, Masek JG, Dungan JL, Vermote EF, Roger JC, et al. The Harmonized Landsat and Sentinel-2 surface reflectance data set. Remote sensing of environment. 2018;219:145–61.

32. Velastegui-Montoya A, Montalván-Burbano N, Carrión-Mero P, Rivera-Torres H, Sadeck L, Adami M. Google Earth Engine: a global analysis and future trends. Remote Sensing. 2023;15(14):3675.

33. Chen F, Crow WT, Bindlish R, Colliander A, Burgin MS, Asanuma J, et al. Global-scale evaluation of SMAP, SMOS and ASCAT soil moisture products using triple collocation. Remote Sensing of Environment. 2018;214:1–13.

34. Chan SK, Bindlish R, O'Neill PE, Njoku E, Jackson T, Colliander A, et al. Assessment of the SMAP passive soil moisture product. IEEE Transactions on Geoscience and Remote Sensing. 2016;54(8):4994–5007.

35. Mohseni F, Ahrari A, Haunert JH, Montzka C. The synergies of SMAP enhanced and MODIS products in a random forest regression for estimating 1 km soil moisture over Africa using Google Earth Engine. Big Earth Data. 2024 Jan 2;8(1):33–57.

36. Sadeghi M, Babaeian E, Tuller M, Jones SB. The optical trapezoid model: A novel approach to remote sensing of soil moisture applied to Sentinel-2 and Landsat-8 observations. Remote sensing of environment. 2017;198:52–68.

37. Sadeghi M, Jones SB, Philpot WD. A linear physically-based model for remote sensing of soil moisture using short wave infrared bands. Remote Sensing of Environment. 2015;164:66–76.

38. Bolten JD, Crow WT, Zhan X, Jackson TJ, Reynolds CA. Evaluating the utility of remotely sensed soil moisture retrievals for operational agricultural drought monitoring. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. 2009;3(1):57–66.

39. Sazib N, Bolten JD, Mladenova IE. Leveraging NASA soil moisture active passive for assessing fire susceptibility and potential impacts over Australia and California. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. 2021;15:779–87.

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