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# The Hydrogeological Significance of Karst Systems in Myanmar and its Impact on Groundwater Conservation


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# The Hydrogeological Significance of Karst Systems in Myanmar and its Impact on Groundwater Conservation

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**Abstract**

Based on stratigraphy, there are eleven different types of aquifers in Myanmar, depending on their lithology and depositional environment, groundwater from those aquifers varies in quality and quantity. The Cambrian-Silurian aquifer and plateau limestone aquifers, associated with karst topography, are critical sources of drinking water despite not being the most ideal for this purpose. Myanmar's karst covers about 80,000 km², roughly 12% of the national territory, making it the second-largest karst region in Southeast Asia. In the Plateau Limestone and associated aquifers, very high recharge rates are expected, particularly in areas where intense weathering and karst features are observed. An overlay analysis was performed using the karst area map, groundwater type map, and map or groundwater use for drinking and a Karst Groundwater Vulnerability Index (KGVI) was constructed and calculated. The results of the analysis indicate that karst areas in Myanmar include many locations that are heavily dependent on groundwater, and these water resources are facing significant long-term sustainability risks due to high permeability, rapid flow pathways, and anthropogenic pressures. Based on this study, it is recommended that comprehensive groundwater conservation strategies be developed, karst-specific groundwater protection zones be established, and regionally differentiated policies be implemented in karst-associated areas. The present study supports the management of Myanmar's karst groundwater resources and provides essential information for sustainable groundwater use.

**Keywords:** *Aquifer, Karst, Karst Groundwater Vulnerability Index, Protection Zone*

# မြန်မာနိုင်ငံရှိ ထုံးကျောက်လွှာစနစ်များ၏ ရေဘူမိဗေဒဆိုင်ရာ အရေးပါမှု နှင့် မြေအောက်ရေထိန်းသိမ်းရေးအပေါ် သက်ရောက်မှု

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အောင်မင်း[၁]
[၁] ဘူမိဗေဒလေ့လာရေးနှင့် ဓာတ်သတ္တုရှာဖွေရေးဦးစီးဌာန

## စာတမ်းအကျဉ်း

မြန်မာနိုင်ငံရှိ အောက်ခံကျောက်သားအမျိုးအစားနှင့် အနည်ကျသည့် ပတ်ဝန်းကျင်အရ မြန်မာနိုင်ငံတွင် မြေအောက်ရေလွှာ (aquifer) အမျိုးအစား (၁၁) မျိုးခွဲခြားနိုင်ပြီး ၎င်းမြေအောက်ရေလွှာအပေါ်မူတည်၍မြေအောက်ရေ၏ အရည်အသွေးနှင့်အရေအတွက်ကွဲပြားခြားနားမှုရှိနိုင်သည်။ ကမ်ဘရီးယန်း-ဆိုင်လူရီးယန်း သက်တမ်းကျောက်လွှာရှိ မြေ အောက်ရေလွှာများနှင့် ကာ့စ် (karst) မြေမျက်နှာပြင်နှင့်ဆက်စပ်နေသော အစဉ်လိုက်တည် ရှိသည့် ကုန်းပြင်မြင့်ထုံးကျောက် ရေလွှာများသည် သောက်သုံးရန်အတွက် အကောင်းဆုံး မဟုတ်သော်လည်း အရေးပါသော သောက်သုံးရေ အရင်းအမြစ်များဖြစ်သည်။ မြန်မာနိုင်ငံရှိ ကာ့စ်မြေဧရိယာသည် စတုရန်းကီလို မီတာ ၈၀,၀၀၀ ခန့် (နိုင်ငံနယ်နိမိတ်၏ ၁၂% ခန့်) ကျယ် ဝန်းပြီး အရှေ့တောင်အာရှတွင် ဒုတိယအကြီးဆုံးကာ့စ်ဒေသဖြစ်သည်။ ကုန်းပြင်မြင့်ထုံး ကျောက်ရေလွှာများတွင် ရာသီဥတုဒဏ်ခံနိုင်မှုနှင့် ကာ့စ်ဒေသများတွင် မြေအောက်ရေ ပြန်လည်ဖြည့်တင်းနှုန်းအလွန်မြင့်မားမည်ဟု မျှော်မှန်းရပါသည်။ ကာ့စ်ပြန့်နှံ့တည်ရှိမှုမြေပုံ၊ မြေအောက်ရေ အမျိုးအစားမြေပုံနှင့် သောက်သုံးရန်အတွက် မြေအောက်ရေ အသုံးပြုမှု မြေပုံများကို အသုံးပြု၍ အလွှာဆက်စပ်ဆန်းစစ်မှု ပြုလုပ်ခဲ့ပြီး ကာ့စ်မြေအောက်ရေ ထိခိုက်လွယ်မှု ညွှန်းကိန်းကို တွက်ယူခဲ့သည်။ မြန်မာနိုင်ငံရှိ ကာ့စ်ဒေသများတွင် မြေအောက်ရေအပေါ် အလွန်အမင်းမှီခိုအားထားရသည့် နေရာများစွာပါဝင်ပြီး ၎င်းရေအရင်းအမြစ်များသည် စိမ့်ဝင်နှုန်း မြင့်မားခြင်း၊ ရေစီးကြောင်းလမ်းကြောင်း မြန်ဆန်ခြင်းနှင့် လူအများတို့၏ အသုံးချမှုများကြောင့် ရေရှည်တည်တံ့မှု စိုးရိမ်ရသည့် အန္တရာယ်များကို ရင်ဆိုင်နေရသည်။ မြေအောက်ရေ ထိန်းသိမ်းရေးစီမံချက်များကို စနစ်တကျရေးဆွဲခြင်း၊ ကာ့စ်ဒေသများအတွက်အထူးမြေ အောက်ရေကာကွယ်ရေးဇုန်များသတ်မှတ်ခြင်းနှင့် ကာ့စ်ဒေသများတွင် ဒေသအလိုက် ကွဲပြားသည့် မြေအောက်ရေမူဝါဒများ အကောင်အထည်ဖော်ခြင်းတို့ကို အကြံပြုထားပါသည်။ လက်ရှိ လေ့လာမှုသည် မြန်မာနိုင်ငံ၏ ကာ့စ်မြေအောက်ရေ အရင်းအမြစ်များစီမံခန့်ခွဲရေးကို ပံ့ပိုးပေးပြီး ရေရှည်တည်တံ့သော မြေအောက်ရေအသုံးပြုမှုအတွက် အရေးပါသော အချက်အလက်များကို ပေးစွမ်းနိုင်ပါသည်။

# The Hydrogeological Significance of Karst Systems in Myanmar and its Impact on Groundwater Conservation

## 1. Introduction

Myanmar's karst covers about 80,000 km², roughly 12% of the national territory, making it the second-largest karst region in Southeast Asia (Day & Urich, 2000). Myanmar's karst mainly develops in Ordovician–Triassic strata, with Permian–Triassic, Devonian, Silurian, and Ordovician limestones and dolomites up to several hundred to 5,000 m thick, with $CaCO_3$ content of 80–96% (Wei et al.,2023). Karst systems play a crucial role in groundwater storage and transmission due to their unique geological characteristics, including dissolution features such as fractures, conduits, and caves (Ford & Williams (2007)). In Myanmar, karst terrains are widely distributed and form an essential component of the country's groundwater resources, particularly in rural and mountainous regions. By combining information on karst geology, aquifer types and drinking water usage based on population density within a GIS-based system, this research will create a clear and scientific assessment of groundwater vulnerability in Myanmar's karst regions. This study meant to help decision-makers and water managers protect drinking water sources and ensure long-term water security in these areas.

## 2. Study Objectives

To map and assess the vulnerability of karst groundwater resources in Myanmar using a constructed Karst Groundwater Vulnerability Index (KGVI). Based on this assessment, the research will provide scientifically grounded recommendations to support policymakers and water resource managers. These recommendations are intended to guide sustainable management practices, protect critical drinking water supplies, and enhance long-term water security in Myanmar's karst-dominated regions.

## 3. Material and Methods

### 3.1. Geographic and Demographic Context

Myanmar is geographically located in Southeast Asia between 9° 32' and 28° 31' north latitude and 92° 10' and 101° 10' east longitude, and it has a total land area of 676 557 km2. Major river systems, such as the Ayeyarwady, Chindwin, Sittaung and Thanlwin provide surface water, yet groundwater remains a critical and often primary source for domestic, agricultural, and industrial use in many regions due to seasonal variability, pollution, and inadequate piped water infrastructure (World Bank, 2019). The population of Myanmar in 2014 was estimated at 51.316 million (Fig-01) (DOP (2024)). Nationally, with nearly 70% of the population living in rural areas, groundwater is the cornerstone of water security for most villages, supporting drinking water, kitchen gardens, and livestock. In urban areas, inadequate municipal water supply systems and polluted river sources further drive groundwater dependency for both domestic and commercial use (MoALI, 2016).

### 3.2 Stratigraphy and Aquifer Systems

There are eleven different types of aquifers in Myanmar based on stratigraphy (Fig-02) (Table-1). Myanmar's aquifer systems reflect diverse lithological and depositional histories. Groundwater from alluvial and Irrawaddian aquifers is estimated to be potable for both irrigation and domestic uses. Groundwater extracted from the Peguan, Eocene and Plateau limestone aquifers are used for the domestic water supply in water scarce areas, although these aquifers are not suitable for drinking purposes (Than Zaw & Maung Maung Than, 2016).

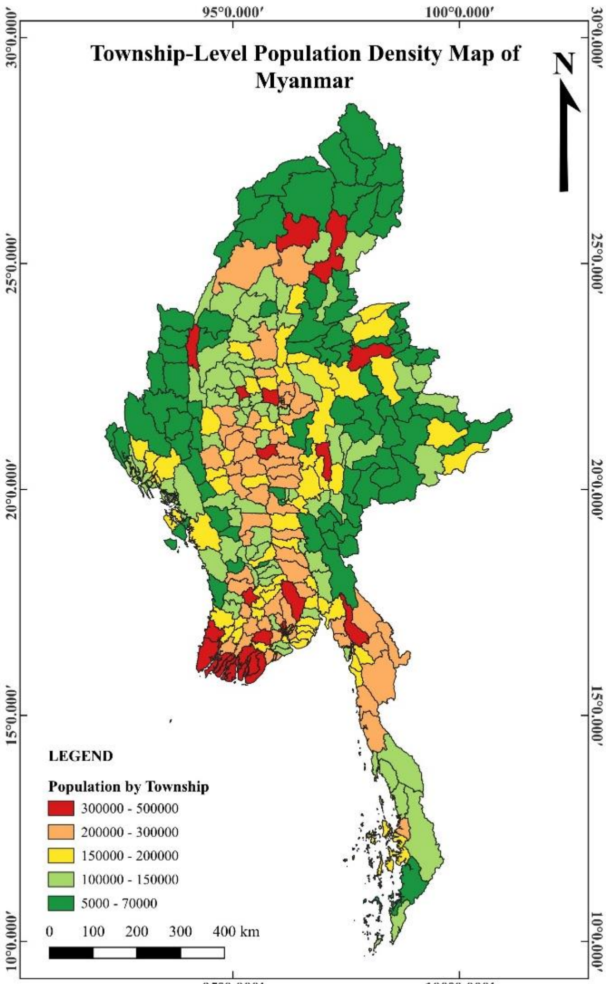


Fig (1) Population Density Map of Myanmar (DOP-2024)

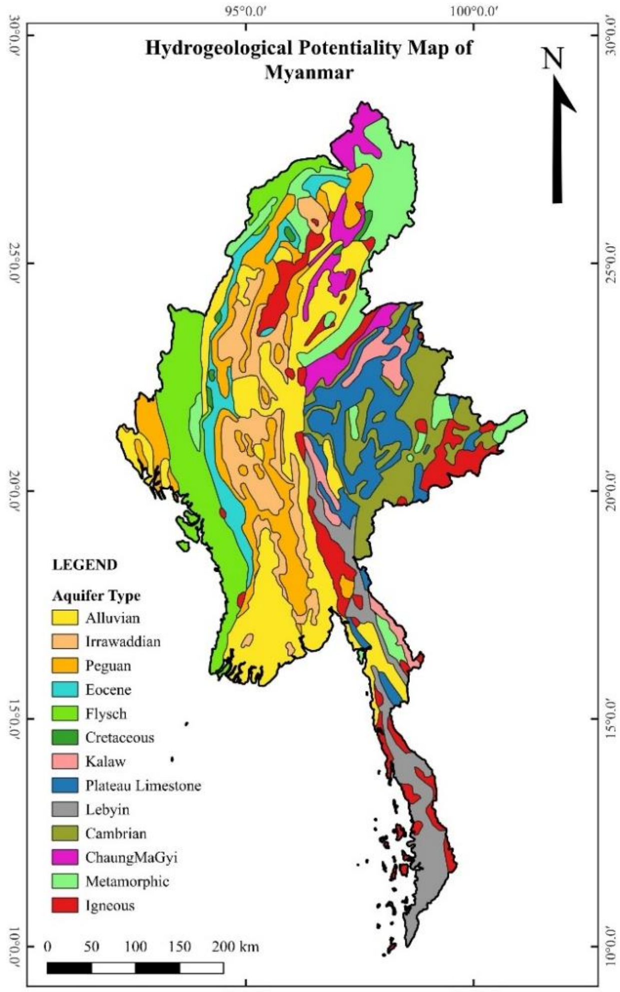


Fig (2) Hydrogeological Potential Map of Myanmar (IWUMD)

### 3.3 Karst Distribution and Characteristics and Groundwater Recharge

Karst regions in Myanmar are concentrated in Shan, Kayah, and Kayin States (DGSE,2008) (Fig-03). These areas are characterized by sinkholes, conduits, and large springs, which facilitate rapid groundwater flow. Recharge rates vary: high (>300 mm/year) in fractured limestone zones with heavy rainfall, moderate (100–300 mm/year) in vegetated karst plateaus, and low (<100 mm/year) in isolated pockets. Recharge occurs through direct infiltration via sinkholes, diffuse infiltration through epikarst zones, and focused recharge along fault-controlled conduits (Than Zaw & Maung Maung Than, 2016). It is important to note that groundwater recharge is highly dependent on rainfall patterns, with seasonal and regional variations influencing the rate and distribution of recharge across the country (Fig-04). Based on other areas in Myanmar, recharge coefficients in alluvium are expected to be 10% to 15% of annual rainfall. With rainfall varying from 1,600 to 1,900 mm over the alluvial areas, recharge estimates of 160 mm up to 285 mm per annum could be expected (World Bank, 2017).

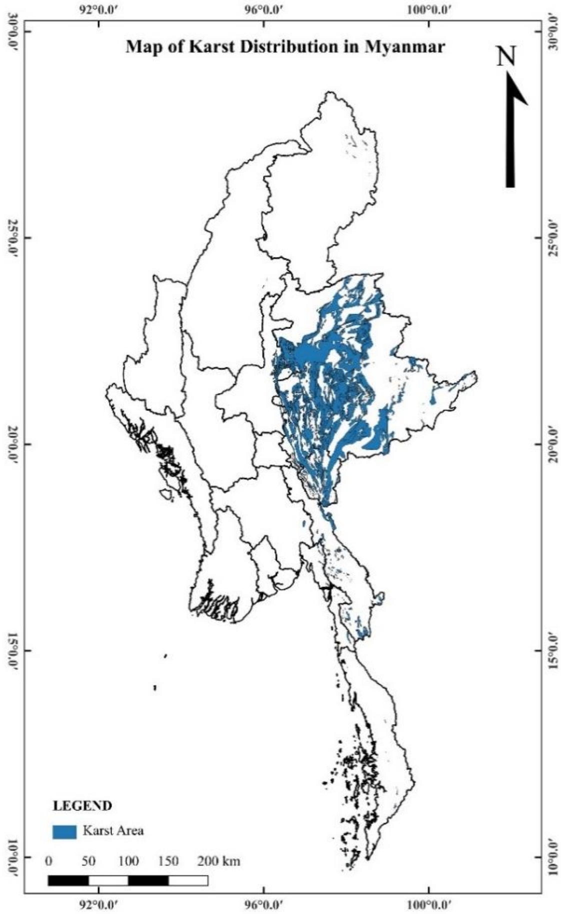


Fig (3) Karst Distribution Map of Myanmar (DGSE-2008)

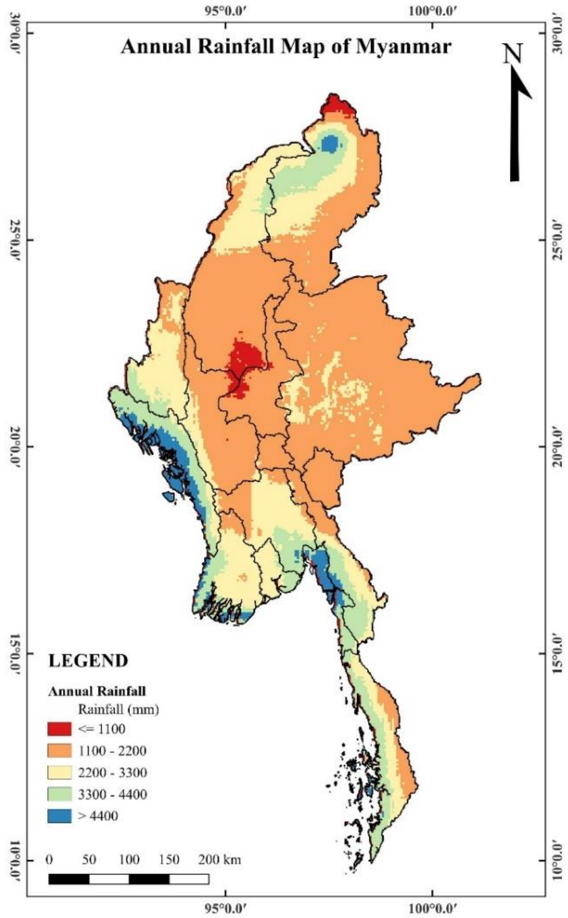


Fig (4) Annual Rainfall Map of Myanmar(https://climateengine.org/)

Tabel (01) Eleven different types of aquifers in Myanmar (Than Zaw & Maung Maung Than, 2016)

| No | Name of the Aquifer | Major Rock Units | Topographic Region | Occurrence of Groundwater |
|---|---|---|---|---|
| 1. | Alluvial | Sands, gravels, and muds | Major river basins and its tributaries, base of mountains and ranges | Fresh Groundwater, seasonal water table changes |
| 2. | Irrawaddian | Mainly sands, Sandstones with gravels, grits, siltstones, and mudstones content | Central Lowland and Rakhine Coastal Plain | Thick aquifer, fresh groundwater with high iron content |
| 3. | Pegu Group | Pegu Group Sandstones, siltstones and shales | Central Lowland and Rakhine Coastal Plain | Mostly saline & brackish water, some fresh water in recharged areas |
| 4. | Eocene Aquifer | Sandstones, Siltstones, and Shales | The periphery of Central Lowland | Probably GW Source with reasonable yield |
| 5. | Flysch Aquifer | Interbedded units of sand, siltstones, | Western Ranges | Probable groundwater source area, less yield |

| No | Name of the Aquifer | Major Rock Units | Topographic Region | Occurrence of Groundwater |
|---|---|---|---|---|
| | | shale, and mudstone | | |
| 6. | Cretaceous Aquifer | Flysch units and limestone units | Western Ranges | To study in detail |
| 7. | Kalaw-Pinlaung-Lashio Aquifer reasonable yield | Loi- an Group & Kalaw Red Beds | The western boundary of Eastern Highland and Tanintharyi ranges | To study in detail; some private wells are discharging reasonable yield |
| 8. | Plateau Limestone Aquifer feature such as fractured zones | Limestone & dolomite | Eastern Highland | Groundwater is being extracted in some places where structural feature such as fractured zones |
| 9. | Lebyin-Mergui Aquifer | Graywacke, quartzite, argillite, slate, mudstone, gravel etc; | Western boundary of Eastern Highland and Taninthari ranges | To study in detail; private wells are discharging but proper records; less / moderate yield |
| 10. | Cambrian-Silurian Aquifer | Molohein Group Pindaya Group Mibayataung Group | Eastern Highland | To study in detail |
| 11. | Chaungmagyi Aquifer (Precambrian) | Low grade metamorphic rocks | Low grade metamorphic rocks | To study in detail |

### 3.4 Uses of Groundwater in Karst Areas of Myanmar

Groundwater in the karst regions of Myanmar is a critical resource due to the unique hydrological properties of karst landscapes, which are characterized by soluble limestone, sinkholes, caves, and underground drainage systems (Ford & Williams, 2007). Its uses are diverse, vital for both subsistence and economic development, but also come with significant challenges (Brinkmann & Parise, 2012). Groundwater within Myanmar's karst regions is a vital multi-purpose resource, underpinning human well-being and economic activity. It is the primary domestic water source for countless rural communities and a key component of urban supply systems in towns situated in karst areas (Fig-05) (IGES, 2018; Metcalf & Eddy, 2013; Bender, 2008). For agriculture, it provides essential irrigation during the dry season and water for livestock, directly supporting food security and rural livelihoods (FAO, 2015; Brinkmann & Parise, 2012). Beyond practical uses, many karst springs and caves are considered sacred sites, associated with *nats* (spirits) or Buddhist legends. Water from these sources is used in religious ceremonies and is often believed to have special properties (ICIMOD, 2013). The resource also drives local economies through tourism, as groundwater-fed springs and caves are major attractions (UNWTO, 2020), and supports industry, notably in cement manufacturing and mining (BGR, 2016; Brinkmann & Parise, 2012). Finally, groundwater-fed streams contribute to local food sources by supporting small-scale fisheries (FAO, 2015).

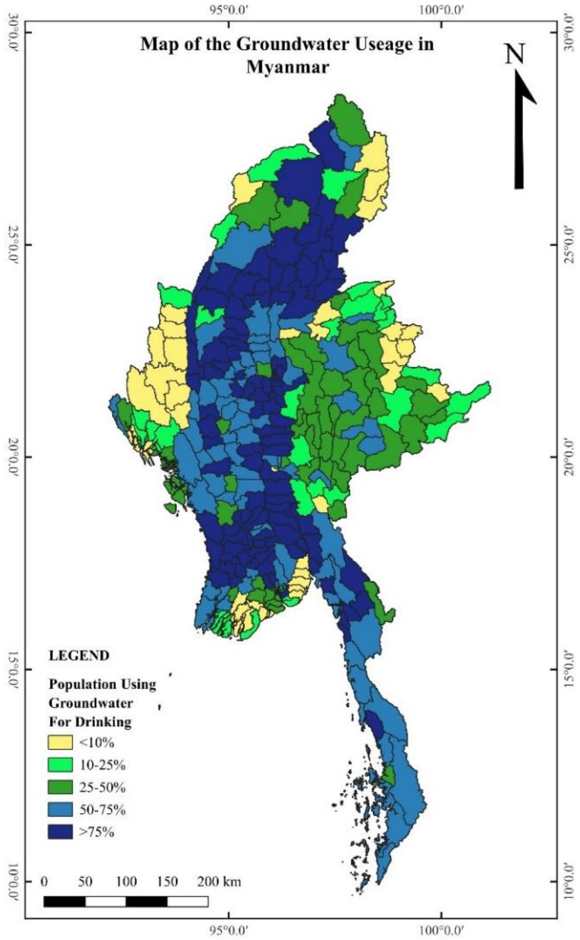


Fig (5) Map of Groundwater usage as drinking water in Myanmar (IWMI-2015)

**3.5 Methodology**

This study employs a national-scale GIS-based vulnerability assessment to evaluate karst groundwater systems in Myanmar using an index-overlay approach, appropriate where long-term groundwater monitoring data are sparse. The methodology integrates lithological karst occurrence, groundwater system characteristics, and groundwater use intensity to derive a Karst Groundwater Vulnerability Index (KGVI). Similar index-based frameworks are widely applied for strategic groundwater assessment in data-limited karst regions (Goldscheider et al., 2000; Daly et al., 2002; Stevanović, 2019).

**3.5.1 Data Sources and Pre-processing**

All the datasets were harmonized to a common coordinate reference system, clipped to the national boundary, topologically validated, and spatially intersected within a GIS environment. Groundwater lithological units were reclassified into vulnerability scores based on their hydrogeological characteristics, with carbonate and karstified formations assigned higher scores than fractured or crystalline units, following established karst hydrogeology principles.

Three national polygon datasets were used:

Table (02) Data Sources

| No | Data Type | Data Source |
|---|---|---|
| 1. | Karst distribution, represented by carbonate lithologies (e.g., Plateau Limestone) | Department of Geological Survey and Mineral Exploration (DGSE-2008) |

| | | |
|---|---|---|
| 2. | Groundwater type, classified into major hydrogeological units (e.g., karstic, fissured, porous, mixed) | Irrigation and Water Utilization Management Department (IWUMD) |
| 3. | Groundwater use intensity, ranked from 1 (very low) to 5 (very high) based on dominant drinking-water abstraction. | International Water Management Institute Report (IWMI-2015) |

### 3.5.2 Spatial Overlay Analysis

Karst polygons were intersected with groundwater type and groundwater use layers to produce composite spatial units (Fig - 6). The analysis focuses on relative vulnerability patterns rather than absolute groundwater quantities, consistent with regional-scale vulnerability mapping principles (Zwahlen, 2004).

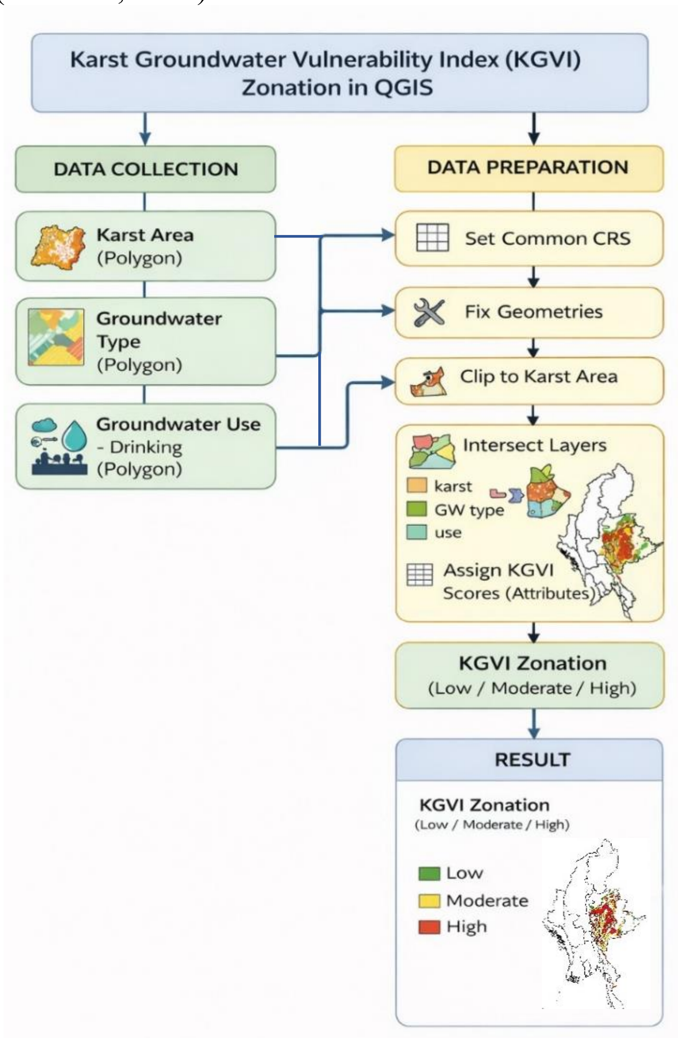


Fig (6) Methodological Flow chart of Spatial Overlay Analysis

### 3.5.3 Karst Groundwater Vulnerability Index (KGVI)

KGVI was calculated using a weighted linear combination (WLC) approach commonly applied in GIS-based multi-criteria decision analysis (Malczewski, 1999; Eastman, 2016):

$$KGVI = \sum_{i=1}^{n} w_i \; r_i$$

where $w_i$is the weight of factor $i$ and $r_i$is its standardized rating (1–5). The WLC method enables the integration of multiple hydrogeological and pressure-related indicators into a single vulnerability index and is widely used in environmental and groundwater vulnerability assessments (Bonham-Carter, 1994; Zwahlen, 2004). Weights were assigned based on established karst hydrogeological principles emphasizing conduit flow, rapid recharge, and low attenuation capacity (Ford & Williams, 2007; Goldscheider & Drew, 2007). KGVI values were classified into low, moderate, and high vulnerability classes using natural breaks to support management prioritization. While constrained by generalized datasets and proxy-based abstraction intensity, the approach provides a robust national baseline suitable for groundwater governance and future site-scale investigations.

Table (03) Scoring and weighting scheme used in the Karst Groundwater Vulnerability Index

| **Indicator** | **Category** | **Description** | **Score** | **Weight** |
|---|---|---|---|---|
| Karst presence (K) | Karst area | Carbonate terrain with conduit flow and rapid recharge | 5 | 0.40 |
| Groundwater type (G) | Plateau Limestone | Well-developed karst aquifer | 5 | 0.35 |
| | Cambrian, Eocene, Cretaceous, Kalaw, Lebyin | Karstified carbonate formations | 4 | |
| | Irrawaddian, Pegu, Aluvial | Porous sedimentary aquifers | 3 | |
| | Flysch, CMG | Fractured and mixed aquifers | 2 | |
| | Igneous, Metamorphic | Crystalline rocks with low porosity | 1 | |
| Groundwater use (U) | Drinking level 5 | Very high drinking-water dependence | 5 | 0.25 |
| | Drinking level 4 | High dependence | 4 | |
| | Drinking level 3 | Moderate dependence | 3 | |
| | Drinking level 2 | Low dependence | 2 | |
| | Drinking level 1 | Very low dependence | 1 | |

## 4. Results

The KGVI map of Myanmar (Fig-07) reveals pronounced spatial variability in karst groundwater vulnerability. High-vulnerability zones (red) dominate central and eastern Myanmar, where extensive carbonate formations coincide with intensive groundwater use for drinking. Moderate vulnerability zones (yellow) occur in transitional hydrogeological settings, while low vulnerability areas (green) are limited and typically associated with lower abstraction intensity or non-karst groundwater systems. High KGVI values spatially correlate with Plateau Limestone and other karstic units, reflecting rapid recharge pathways and minimal natural filtration. Areas underlain by fissured or mixed aquifers generally exhibit moderate KGVI scores, indicating greater attenuation potential but continued sensitivity to over-abstraction. Elevated KGVI values strongly correspond with higher drinking-water use levels (classes 4 - 5), underscoring abstraction pressure as a critical driver of groundwater vulnerability at the national scale. Area statistics derived from the KGVI map indicate that high vulnerability zones account for 80% of the total karst area, followed by moderate (15%) and low (5%) vulnerability classes (Table -05, Fig (8)). High KGVI zones are spatially dominant in central and eastern Myanmar, reflecting the coincidence of karst lithologies and intensive groundwater use.

## 5. Discussion

The KGVI results confirm that Myanmar's karst aquifers are structurally vulnerable systems requiring protection-oriented management rather than yield-maximization strategies (Table -04).

Table (04) Interpretation based on KGVI class

| **KGVI range** | **Vulnerability class** | **Interpretation** |
|---|---|---|
| ≥ 4.15 | High | High vulnerability; priority for protection |
| 3.45 - 4.15 | Moderate | Moderate vulnerability requiring monitoring |
| < 3.45 | Low | Low karst groundwater vulnerability and pressure |

Myanmar's current groundwater governance framework lacks karst-specific protection measures. The KGVI map provides a spatially explicit tool to support national water security planning, climate-resilient rural water supply development, and integration of karst aquifers into Environmental Impact Assessment (EIA) procedures. The spatial patterns and vulnerability drivers identified are consistent with karst vulnerability assessments in Southeast Asia and Europe (Daly et al., 2002; Stevanović, 2019), reinforcing the validity of the adopted framework.

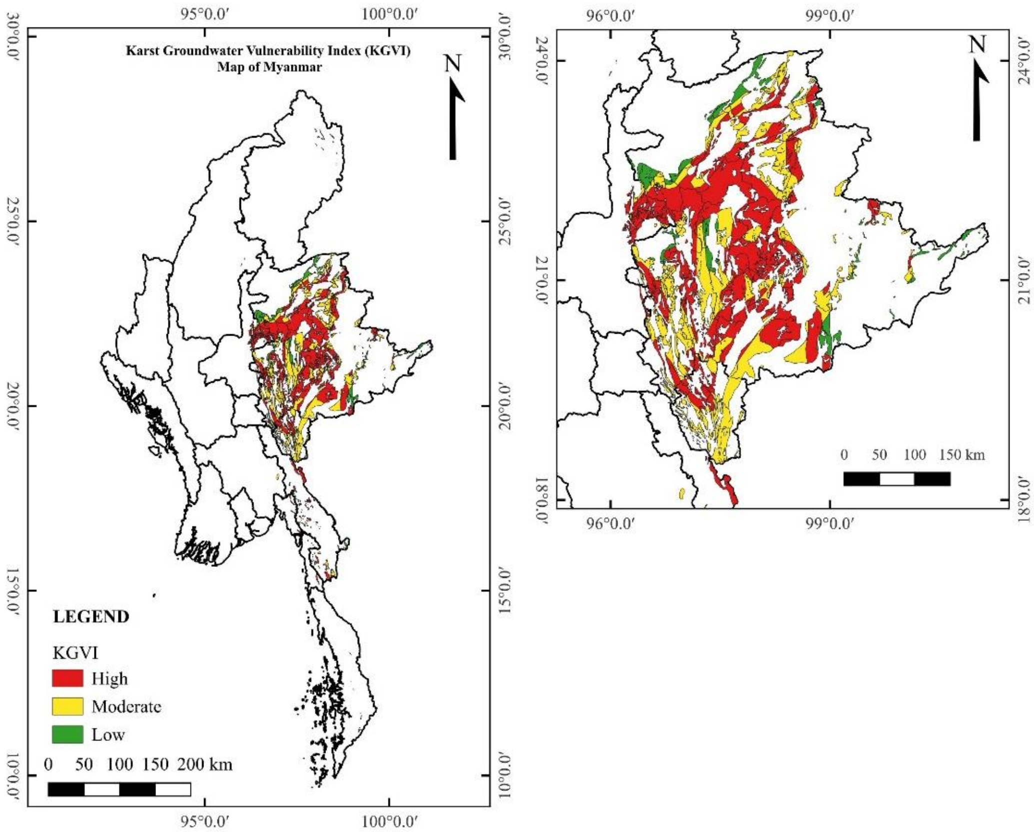


Fig (7) Karst Groundwater Vulnerability Index (KGVI) Map of Myanmar

Table (05) Areal distribution of KGVI classes in Myanmar karst regions

| **KGVI Class** | **KGVI Value** | **Area (km²)** | **Percentage of Karst Area (%)** |
|---|---|---|---|
| High | >4.15 | 52896.22 | 80 |
| Moderate | 3.45-4.15 | 9944.65 | 15 |
| Low | <3.45 | 3548.65 | 5 |
| **Total** | | 66389.51 | 100 |

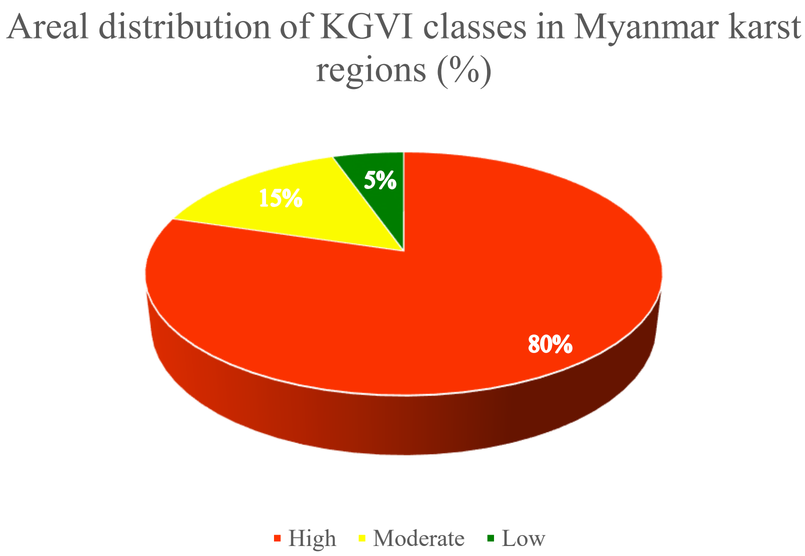


Fig (8) Areal distribution of KGVI classes in Myanmar karst regions

## 6. Conclusion and Recommendations

This study presents the national-scale Karst Groundwater Vulnerability Index (KGVI) assessment for Myanmar using a GIS-based multi-criteria framework integrating karst distribution, groundwater system type, and groundwater use intensity. Despite limitations in quantitative monitoring data, the approach provides a robust strategic-level screening tool for identifying priority areas for groundwater protection in karst terrains. The KGVI map indicates that large areas of central and eastern Myanmar are characterized by high vulnerability, particularly where extensive carbonate formations coincide with intensive abstraction for drinking water. These zones are intrinsically sensitive due to rapid recharge, conduit-dominated flow, and limited natural attenuation in karst systems. Moderate vulnerability dominates transitional hydrogeological settings, whereas low vulnerability is mainly associated with low-use aquifer systems. From a management perspective, high-vulnerability zones should be prioritized for groundwater protection zoning, land-use regulation, and pollution prevention. The KGVI map can be integrated into national and regional water planning frameworks to support risk-informed decision-making, while targeted monitoring should be established in critical karst areas to improve quantitative understanding of recharge, abstraction, and water quality dynamics. Future work should refine the present framework at basin and local scales by incorporating additional hydrogeological and environmental factors to support site-specific vulnerability and risk assessments. Overall, the KGVI provides a scientifically defensible and policy-relevant baseline for strengthening karst groundwater governance and promoting sustainable water resource management in Myanmar.

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