MIKAILALSYS
Journal of Multidisciplinary Sciences

e-ISSN : 2987-2286
p-ISSN : 2987-3924

Index: Harvard, Boston, Sydney, Copernicus, Sinta 4, Scilit, Semantic, Google, etc

https://doi.org/10.58578/mikailalsys.v4i2.10504

Near-Surface Characterization Using Integrated MASW and Seismic Refraction Tomography: A Scoping Review

Syamsuddin Syamsuddin, Kormil Saputra, Olfi Destika,
Winny Anindya Nadi, Zaura Intan Zaraoda
University of Mataram, Mataram, Indonesia
syamsuddin@unram.ac.id; kormil.saputra.fmipa@staff.unram.ac.id

Article Info:

Submitted:	Revised:	Accepted:	Published:
Apr 24, 2026	May 22, 2026	Jun 3, 2026	Jun 8, 2026

Abstract

Subsurface characterization is essential in engineering geology, geotechnical engineering, hydrogeology, and disaster mitigation because subsurface material conditions influence soil stability, seismic response, weak-zone identification, and infrastructure suitability. This study aims to map the development, characteristics, advantages, limitations, and research gaps related to the use of Multichannel Analysis of Surface Waves (MASW) and Seismic Refraction Tomography (SRT) in subsurface analysis. A scoping review approach was employed following PRISMA-ScR guidelines. Literature was obtained from ProQuest, ScienceDirect, and SpringerLink for the 2012–2026 publication period. Of the 852 articles identified, 23 studies met the inclusion criteria and were analyzed further. The findings show that MASW is effective for identifying variations in shear wave velocity (Vs), Vs30, soft layers, soil stiffness, and dynamic site response, whereas SRT is more effective for mapping compression wave velocity (Vp), layer thickness, bedrock boundaries, and lithological contrasts. The integration of MASW and SRT provides more robust subsurface interpretation, particularly in landslide, karst, landfill, sabkha, hydrogeological, and post-earthquake areas. However, several important research gaps remain, including the lack of standardized integration protocols, limited investigation depth, minimal validation with borehole data, ambiguity in integration with Horizontal-to-Vertical Spectral Ratio methods, insufficient systematic modeling of water content, and the limited number of studies in tropical, swamp, and peat environments. This study contributes to near-surface geophysical research by synthesizing current evidence on MASW and SRT integration and identifying methodological priorities for improving subsurface characterization in complex geological settings.

Keywords: MASW; Seismic Refraction Tomography; Subsurface Characterization; Near-Surface Geophysics; Scoping Review.

INTRODUCTION

The Earth's subsurface holds crucial information about geological history, tectonic structure, material composition, and the dynamics of processes occurring within it (Kramer, 1996). An accurate understanding of subsurface conditions is a fundamental prerequisite for various earth science disciplines, including engineering geology, hydrogeology, geotectonics, and geological hazard mitigation (Frei, 2019). Without adequate knowledge of subsurface structures, identifying landslide-prone zones, mapping active fault lines, evaluating liquefaction potential, and characterizing sedimentary basins will be difficult to perform with a high degree of confidence (Perrone et al., 2014; Saadalla et al., 2026).

Direct exploration methods such as drilling and laboratory testing, while providing accurate data at specific points, have fundamental limitations in terms of spatial coverage, cost, and invasiveness (Mayne, 2006). In the last two decades, seismic wave-based geophysical methods have emerged as a reliable alternative for non-destructive imaging of the subsurface with extensive coverage (Mokodenseho et al., 2023; Reynolds, 2011). Among the various techniques available, Multichannel Analysis of Surface Waves (MASW) and Seismic Refraction Tomography (SRT) occupy a central position in shallow to intermediate subsurface characterization (Foti, 2015; Socco et al., 2010). MASW, introduced by Park et al. (1999), exploits the dispersive nature of Rayleigh waves, where the wave propagation velocity is frequency-dependent, to generate a shear wave velocity (Vs) profile with depth (Park et al., 1999). The Vs parameter is a direct indicator of material stiffness and is highly sensitive to variations in lithology, density, and fluid content (Foti et al., 2018). MASW's ability to detect soft layers (low-velocity layers), which are often weak points in stability analysis, makes it the method of choice for identifying potential landslide zones and evaluating the dynamic response of soils (Zhan et al., 2026).

On the other hand, SRT relies on the refraction of compression waves (Vp) at the interface between layers that have a velocity contrast (Marzouk & Tschuchnigg, 2025). This method is very effective for mapping layer geometry vertically, determining the depth of bedrock, and identifying regional geological structures such as faults and folds that cannot be reached by shallow methods (Lankston, 2012; Sheriff & Geldart, 1995). The main advantage of SRT is its ability to penetrate deeper (up to hundreds of meters) than MASW, but at the cost of lower resolution (Gupta & James, 2011). Awareness of the complementary limitations of these two methods has driven the development of an integrative approach. This reflects the global consensus that comprehensive subsurface characterization requires a multi-method approach.

Although various studies have demonstrated the successful application of MASW and SRT methods in various geological conditions, there are still gaps in the literature, particularly regarding systematic comparative synthesis. Several fundamental questions remain unanswered comprehensively, including: (1) what are the fundamental characteristics of each method, including the parameters produced, depth of investigation, resolution, and sensitivity based on empirical evidence from various geological settings; (2) under what geological conditions is MASW superior to SRT, and vice versa; (3) to what extent does the integration of the two methods perform in overcoming their respective limitations; and (4) what are the patterns of findings across studies related to the effectiveness of MASW-SRT integration for various geological targets.

Based on this background, this scoping review aims to: (1) identify and map the literature related to the use of MASW and seismic refraction in subsurface analysis; (2) analyze the technical characteristics of each method based on available empirical evidence; (3) evaluate the synergy and added value of integrating the two methods; and (4) identify patterns of findings and research gaps as a basis for providing direction for future studies.

METHODS

1. Review Design

This study uses a scoping review approach to map the development, characteristics, and scope of application of MASW and SRT methods in subsurface analysis. This approach was chosen because the purpose of the study was not to conduct a meta-analysis or assess the effectiveness of an intervention, but rather to identify the scope of the literature, key concepts, geophysical parameters used, application contexts, and existing research gaps. The preparation and reporting of this study refer to the PRISMA Extension for Scoping Reviews (PRISMA-ScR), so that the processes of identification, screening, eligibility selection, data extraction, and synthesis of results are carried out systematically and transparently. The scope of the review is formulated using the Population–Concept–Context (PCC) framework. Population in this study refers to near-surface seismic geophysical studies using MASW and/or SRT. Concept refers to subsurface characterization based on geophysical parameters such as shear wave velocity (Vs), compression wave velocity (Vp), Vs30, Vp/Vs ratio, attenuation, investigation depth, and elastic modulus.

2. Literature Search Strategy

A systematic literature search was conducted in three scientific databases: ProQuest, ScienceDirect, and SpringerLink. These three databases were selected because they have a broad coverage of publications in the fields of applied geophysics, near-surface seismology, engineering geology, geotechnics, and geological hazard investigation. The search focused on articles discussing the use of MASW and/or SRT for subsurface characterization, either as a single method or as part of an integrated geophysical approach. The search strategy used a combination of primary keywords representing the method, seismic approach, and resulting subsurface parameters. The keywords used were ("MASW" OR "Multichannel Analysis of Surface Waves") AND ("Seismic Refraction" OR "Refraction Tomography") AND ("Shear Wave Velocity" OR "Compression Wave Velocity"). The publication range was limited to 2012–2026 to cover the latest developments in the application of MASW and SRT over the past decade.

3. Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were established before the article selection process. Articles included in this review must be empirical studies that used MASW, SRT, or a combination of both, either as the primary method or as a supporting method in a multi-method approach. Details of the inclusion and exclusion criteria are presented in Table 1.

Table 1. Inclusion and exclusion criteria

Inclusion criteria	**Inclusion criteria**
Original research articles published in peer-reviewed journals or indexed conference proceedings	Review articles, editorials, commentaries, book chapters, or non-empirical documents
Studies using MASW, SRT, or a combination of MASW–SRT with other geophysical methods	Studies that do not use MASW or SRT as the primary or supporting method
Studies are applied to subsurface characterization in geological, geotechnical, hydrogeological, or disaster contexts	Studies that only discuss the engineering aspects of infrastructure without characterizing the subsurface geology
Studies report quantitative parameters such as Vs, Vp, Vs30, Vp/Vs ratio, attenuation, depth of investigation, or elastic modulus.	Studies that do not report quantitative subsurface parameters
The study provides full text that can be analyzed.	Studies not available in full text

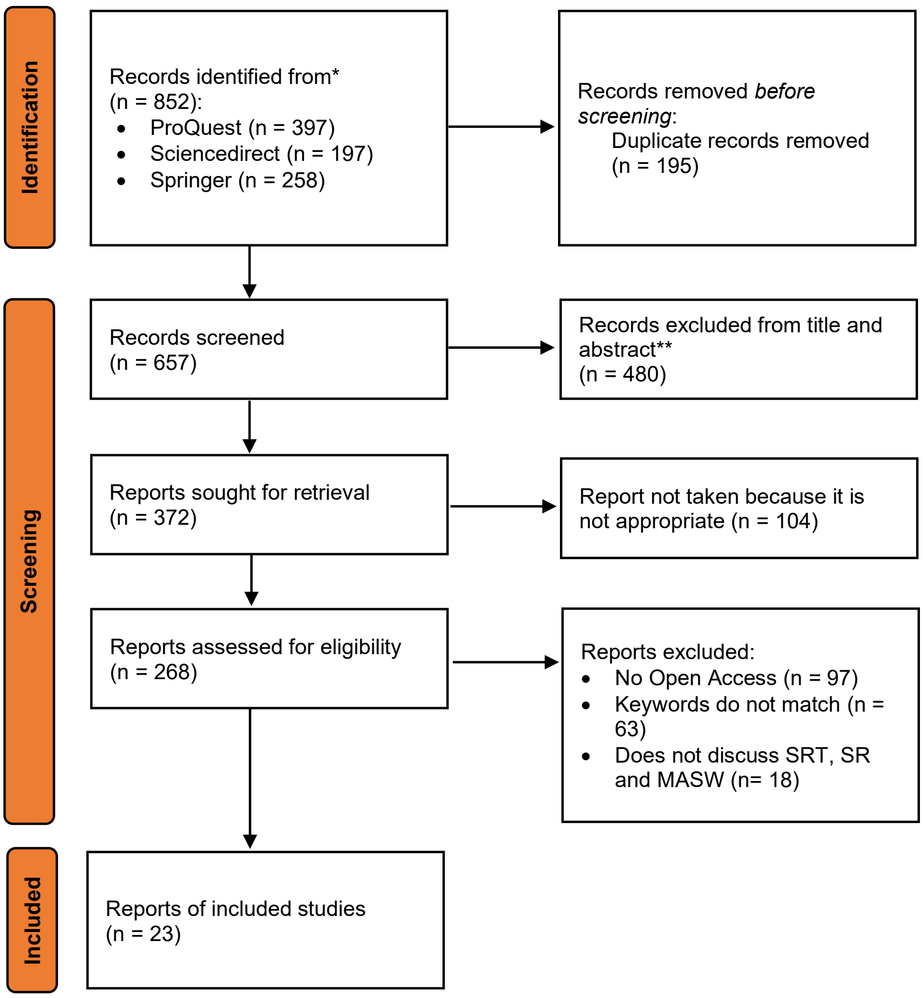

Figure 1. Flow Diagram for Filtering and Selection from Various Databases

4. Study Screening and Selection Process

The article selection process was conducted through four main stages: identification, duplication removal, title and abstract screening, and full-text assessment. During the identification stage, 852 articles were obtained from three databases, consisting of 397 articles from ProQuest, 197 articles from ScienceDirect, and 258 articles from SpringerLink. After removing 195 duplicate articles, 657 articles remained to be screened based on title and abstract. During the title and abstract screening stage, 480 articles were excluded because they did not align with the study focus, resulting in 177 articles proceeding to the full-text assessment stage. Full-text assessment was conducted to ensure the articles met the established inclusion and exclusion criteria. At this stage, articles were excluded if they were not available in full text, were not relevant to the focus of MASW or SRT, did not report quantitative subsurface parameters, or did not substantially discuss shallow subsurface zone characterization. After the entire selection process was completed, 23 studies met the criteria and were included in the final analysis. The article selection flow is presented in the PRISMA diagram in Figure 1.

5. Data Extraction, Synthesis and Data Analysis

Data from each eligible article was extracted using a structured spreadsheet. Information collected included article identity, publication year, study location or country, research objectives, geophysical methods used, measured parameters, subsurface geological targets, investigation depth, key findings, method strengths, and limitations reported by each study. Articles were also classified based on the type of approach used: single MASW, single SRT, a combination of MASW–SRT, or integration of MASW/SRT with other geophysical methods such as ERT, HVSR, GPR, or TEM. The extracted data were analyzed descriptively and narratively. Descriptive analysis was used to map the distribution of articles based on publication year, country or study location, method used, reported geophysical parameters, and application context. Meanwhile, narrative synthesis was used to compare the capabilities of MASW and SRT in identifying subsurface structures, including soft layers, bedrock, weak zones, slip planes, faults, karst, landfills, water-saturated zones, and lithological variations.

RESULTS

1. General Characteristics of the Reviewed Studies

The distribution of articles by publication year range is used to observe trends in research developments related to the application of MASW and seismic refraction/SRT in subsurface characterization. The distribution of the number of articles and the percentage of publications in each year range is shown in Figure 2.

Table 2. Distribution of Main Research Themes

Author, Year	Objective	Country	Method	Location	Findings	Citation
(Alexopoulos et al., 2022)	Estimation of subsurface geotechnical characteristics	Greece	SRT and MASW	Lefkada and Corfu Islands	Vs30 (Eurocode 8) and subsurface structure were identified	6
(Karslı et al., 2024)	Post-earthquake analysis and understanding the relationship between subsurface properties	Turkey	SRT, MASW, and MT	Kahramanmaraş, Hatay, Malatya, and Gaziantep Provinces	Soft layers and subsurface structures were identified at depths of 10–15 m in very loose areas and 15–20 m in highly porous zones	16
(Singh et al., 2024)	Identification of thin sub-vertical fractures	India	ERT, SRT, and MASW	Parwan gravity dam	Fracture zones were identified within the range of 0.25–2.6 ms	2
(Alonso-Pandavenes et al., 2023)	Determination of slip surface and internal landslide structure	Ecuador and Spain	HVSR, SR, and MASW	Pujilí main road	Slip surface identified at depths of 1–7 m and method validated	24
(Centeno-Salas et al., 2015)	Analysis of deformation and subsidence	Mexico	SR, and MASW	Eastern Mexico City	Fractures and deformation identified at depths of 1–3.8 m with clear lithological contrast	5
(Capizzi & Martorana, 2014)	Landslide and subsurface structure analysis	Italy	ERT, SRT, HVSR, and MASW	Agrigento ridge	Complex structural layers, weak zones, and slip surfaces were identified	49
(El-Badrawy et al., 2024)	Karst identification and geotechnical hazard assessment	Egypt	ERT, MASW, and SR	West Cairo–Aswan desert road	Two main units identified (weathered limestone and dolomitic limestone) with	0

Author, Year	Objective	Country	Method	Location	Findings	Citation
					Vs 5–20 m/s, cavities and weak zones detected	
(Alexopoulos et al., 2023)	Geotechnical characterization and site classification	Turkey	ERT, SRT, HVSR, and MASW	Seismological stations and Athenet network	Vs30 and soil classification (Eurocode 8) were defined	17
(Sarkar et al., 2021)	Site characterization and construction feasibility analysis	Himalaya (Bhutan)	MASW and SRT	Phuentsholing region	Vs30, site class D identified, soil layers at 37–81.5 m, imaging depth up to 10 m	24
(Ezersky et al., 2021)	Israel, France, and Jordan	Israel, France, and Jordan	SRFR, SRFL, MASW, and TEM	Ghor Al-Haditha area	Salt layers (37–41 m) identified with high Vs (850–1200 m/s)	8
(Eleslambouly et al., 2025)	Sabkha characterization and hydrological conditions	UAE, Saudi Arabia, and Japan	SR, and MASW	Arabian Gulf	Three zones identified: dry (Vp <428 m/s, Vs <261 m/s), transition (Vp <1900 m/s, Vs <760 m/s), saturated (Vp >1900 m/s, Vs >760 m/s)	2
(Mihai et al., 2017)	Improvement of geotechnical characterization in landslide areas	Romania	MASW, SR, and f-k 2D	Landslide-prone areas (Brebu and Slanic Syncline)	Vs values (66–287 m/s) and low modulus indicating slip surface identified	7
(El-Hussain et al., 2014)	Modeling layer thickness and identifying paleo-channel presence	Oman and Egypt	SR, 2D MASW, and HVSR	Duqm Port	Thick alluvial deposits (4–8 m) and paleo-channel identified	5
(Carrera et al., 2024a)	Assessment of soil structure and compaction effects on physical properties	Italy	SRT dan MASW	Experimental field	Ground amplification of 2.4–4.4 identified, indicating increased seismic impact potential	12
(Mohamed et al., 2013)	Assessment of soil structure and compaction	Egypt and Oman	SR and MASW	Lowland area and hilltop point	Ground amplification of 2.4–4.4 indicating	20

Author, Year	Objective	Country	Method	Location	Findings	Citation
	effects on physical properties				increased seismic impact	
(Kondracka et al., 2021a)	Landfill characterization and waste material distribution	Poland and Norway	ERT, SRT, MASW, and GPR	Landfill site	Layer thickness and resistivity of municipal waste (10–25 Ωm), Vp (300–600 m/s), Vs (100–300 m/s), industrial waste (25–85 Ωm) identified	38
(Salleh et al., 2021)	Geotechnical characterization of industrial areas	Malaysia	ERM, SR, and MASW	USM campus, Paya Terubong, Gelugor	Sandy clay soil (464–1800 Ωm) and silty sand (77–176 Ωm) identified	24
(Innocenti et al., 2026)	Soil condition characterization and three active layers after landslide	Belgium	ERT, SR, and MASW	Eastern HFZ fault boundary	Soft sediments (10–30 m), high amplification, and successful 3D model developed	1
(Frei, 2013)	Development of integrated survey methods for implementation	Switzerland	MASW and SRT	Residential area	Shear wave velocity identified at depths <10–20 m	5
(Schwellenbach et al., 2020)	Subsurface structure and site effect analysis	Germany dan Italy	SR, MASW, and WARAN	Selinunte Archaeological Park, Sicily	Low-velocity layers identified (Vp 655–1525 m/s) with accurate velocity profiles	21
(Onyebueke et al., 2018)	Imaging near-surface sediment architecture for hydrogeological exploration	North Africa	SRT and MASW	Nylsvley Nature Reserve	Bedrock (8–12 m) and groundwater zones identified	31
(Ekinci, 2012)	Determination of soil elastic parameters	Turkey	SR and MASW	Kumluca residential area	Young's modulus, shear modulus, bulk modulus, Vs (186–363 m/s), and Vp (415–1571 m/s) identified	1
(Aranda et al., 2019)	Municipal solid waste (MSW) characterization	Brazil	SR and MASW	Landfill site	Vp (217–252 m/s) and Vs (86–89 m/s) identified	13

Figure 2 shows that publications related to MASW and seismic refraction/SRT experienced the most significant increase in the 2021–2024 period, with 11 articles, or approximately 48% of the total studies analyzed. The 2012–2015 period included 6 articles, or 26%, while the 2016–2020 period showed a decrease to 4 articles, or 17%.

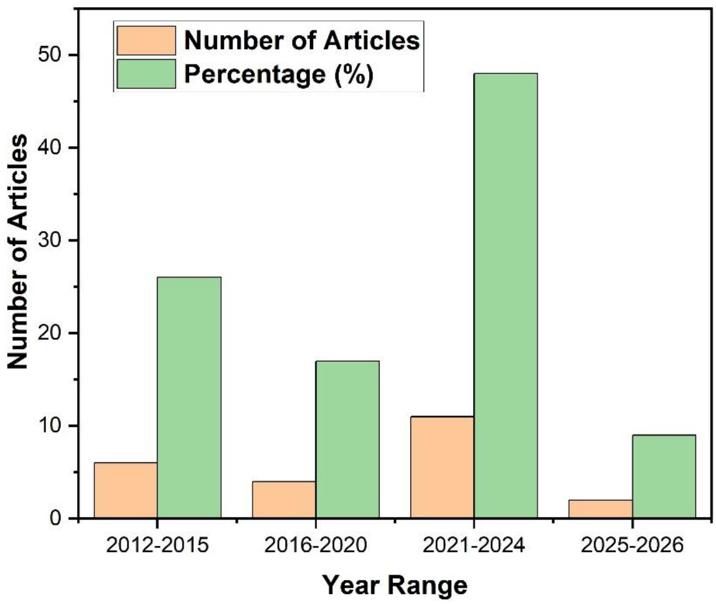

Figure 2. Distribution of Publication Years

Meanwhile, the 2025–2026 period only included 2 articles, or 9%, likely influenced by the shorter span of years compared to the other periods. This pattern indicates that the use of MASW and seismic refraction/SRT has received increasing attention in recent years, particularly for subsurface characterization, geotechnical evaluation, site classification, and geological hazard analysis. Furthermore, a summary of the characteristics of previous studies using the MASW method, seismic refraction/SRT, or their integration with other geophysical methods for subsurface characterization in various geotechnical, disaster, hydrogeological, karst, landfill, and seismic response contexts is shown in Table 2.

Based on Table 2, the reviewed studies show that the MASW and seismic refraction/SRT methods are widely used for subsurface characterization in the context of geotechnics, disasters, hydrogeology, landfills, karst, and seismic response. In geotechnical and site classification studies, (Alexopoulos et al., 2022) used a combination of SRT and MASW in the Lefkada and Corfu Islands, Greece, to estimate subsurface geotechnical characteristics through the identification of Vs30 values and subsurface structures. A similar study was also conducted by (Alexopoulos et al., 2023) on a seismological station network, with the integration of ERT, SRT, HVSR, and MASW to determine Vs30 and soil classification based on Eurocode 8. In a more applicable context, (Sarkar et al., 2021) applied MASW and SRT in the Phuentsholing region, Bhutan Himalaya, for site characterization and construction feasibility, with the results being the determination of Vs30, site class, and soil layer depth. Meanwhile, (Ekinci, 2012) used SR and MASW in Kumluca, Turkey, to determine the elastic parameters of soil, including Young's modulus, shear modulus, bulk modulus, Vs, and Vp.

In geological disaster studies, several studies have placed MASW and seismic refraction as the primary methods for identifying weak zones, slip planes, cracks, deformation, and post-earthquake responses. (Karslı et al., 2024) conducted post-earthquake analyses in several earthquake-affected provinces in Turkey by combining SRT, MASW, and MT to understand the relationship between subsurface properties and surface damage conditions. (Alonso-Pandavenes et al., 2023) applied HVSR, seismic refraction, and MASW to landslide areas in Ecuador and Spain to determine slip planes and the internal structure of landslides. Another study by (Capizzi & Martorana, 2014) in Agrigento, Italy, used an integration of ERT, SRT, HVSR, and MASW to identify complex structures, weak zones, and slip planes in landslide areas. In addition, (Mihai et al., 2017) in Romania showed that low Vs values and small elastic moduli can be used as indicators of the presence of slip surfaces in landslide-prone areas. (Singh et al., 2024) study also demonstrated the ability of a combination of ERT, SRT, and MASW to identify thin subvertical cracks in the Parwan Dam, India.

Table 2 also shows that MASW and SR/SRT are used in studies of specific geological environments, such as karst, sabkha, landfill, and hydrogeology. (El-Badrawy et al., 2024) applied ERT, MASW, and seismic refraction in an Egyptian karst region to identify weathered limestone units, weak zones, and subsurface cavities that could potentially pose geotechnical hazards. (Eleslambouly et al., 2025) used SR and MASW in an Arabian Gulf sabkha environment to distinguish dry, transitional, and saturated zones based on variations in Vp and Vs. In the landfill context, (Kondracka et al., 2021b) integrated ERT, SRT, MASW, and GPR to characterize the distribution of urban and industrial waste materials, while (Aranda et al., 2019) used SR and MASW to determine Vp and Vs values in municipal solid waste. In the field of hydrogeology, (Onyebueke et al., 2018) applied SRT and MASW in Nylsvley Nature Reserve, South Africa, to map near-surface sedimentary architecture, bedrock depth, and groundwater zones.

2. Comparative Analysis of MASW and SRT Methods

The comparison of the technical characteristics of MASW and SRT needs to be presented to clarify differences in key parameters, depth of investigation, resolution, sensitivity to subsurface layers, nd limitations of each method. A comprehensive summary of the comparison between the two methods is presented in Table 3.

Table 3. Comprehensive Comparison of MASW and SRT for Subsurface Analysis

Aspect	MASW	SRT
Key Parameters	Vs	Vp
Effective Depth	5–30 m	10–50 m
Lateral Resolution	Vs: 0.5–5 m, depending on geophone spacing (1–5 m)	Vp: 20–30%, depending on geophone spacing (5–10 m)
Vertical Resolution	Shallow depth accuracy: 1–3 m; greater depth: 5–10 m	Interface accuracy: 5–15 m
Sensitivity to Soft Layers	Capable of detecting layers with Vs ≈ 150 m/s	Difficult to detect soft layers beneath harder layers (hidden layer problem)
Bedrock Detection Capability	Vs 600–800 m/s	Vp 1500–3000 m/s
Fault Identification Capability	Vs reduction of 20–50%	Travel time changes associated with Vp variations of 500–1000 m/s
Noise Dependence	5–50 Hz	Above 5–50 Hz
Advantages	Highly effective for dynamic soil characterization (e.g., seismic response)	Effective for determining subsurface layering and thickness
Limitations	Measures only Vs, non-unique inversion, requires supporting data	Less effective in velocity inversion

Based on Table 3, MASW and SRT have distinct functions but are complementary in subsurface characterization. Studies by (Alexopoulos et al., 2022), (Alexopoulos et al., 2023), (Sarkar et al., 2021), and (Ekinci, 2012) indicate that MASW is widely used to obtain Vs, Vs30, and soil elastic properties, making it particularly relevant for site classification and the evaluation of subsurface material stiffness. In contrast, studies by (El-Hussain et al., 2014), (Onyebueke et al., 2018), (Kondracka et al., 2021b), and (Eleslambouly et al., 2025) demonstrate that SRT is more effective for mapping Vp, layer thickness, bedrock boundaries, and lithological variations. In more complex geological settings, such as landslides, karst, fractures, landfills, and post-earthquake environments, studies by (Capizzi & Martorana, 2014), (Mihai et al., 2017), (Singh et al., 2024), (Karslı et al., 2024), and (El-Badrawy et al., 2024) emphasize that integrating MASW and SRT with other geophysical methods is essential to improve the reliability of subsurface interpretation.

3. Identified Research Gaps

The identified research gaps are presented in Table 4.

Table 4. Identified Research Gaps

No	Research Gap	Evidence from the Literature
1	Lack of standardized protocols for method integration	Each study uses different field parameters (receiver spacing, spread length, seismic source)
2	Limited investigation depth	Most studies are limited to 30–50 m (shallow MASW), with few reaching depths >80 m
3	Limited validation using borehole data	Only about 20% of the studies perform calibration with direct drilling data
4	Ambiguity in joint interpretation with HVSR	HVSR does not directly provide velocity profiles and requires additional inversion
5	Influence of water content and soil conditions not systematically modeled	Some studies mention this limitation, but no standardized correction approach exists
6	Limited studies in tropical and swamp/peat environments	Studies are dominated by arid and rocky regions (e.g., Egypt and Turkey), with very few conducted in Southeast Asia or the Amazon

Table 4 indicates that several gaps remain in studies integrating MASW and SRT. One is the lack of standardized acquisition protocols, resulting in varying parameters across studies and difficult comparisons. In addition, the depth of investigation is still limited, generally reaching only 30–50 m, while validation using borehole data remains scarce, reducing the reliability of interpretation results. Other gaps include the ambiguity in joint interpretation with HVSR, as it requires additional inversion to derive velocity profiles, as well as the absence of systematic models addressing the influence of water content and soil conditions. Furthermore, the spatial distribution of studies is uneven, with a dominance of research conducted in arid regions such as Egypt and Turkey, whereas tropical and swamp/peat environments remain underexplored.

DISCUSSION

Based on the mapping presented in Table 1, tudies on MASW and seismic refraction (SR/SRT) demonstrate substantial development in the context of shallow to intermediate subsurface characterization. The reviewed studies not only utilize seismic methods to generate wave velocity models, but also relate geophysical parameters to the needs of geotechnical, hazard, hydrogeological, landfill, karst, sabkha, and seismic site classification interpretations. This pattern indicates that MASW and SRT have moved from being merely subsurface exploration methods to becoming important interpretative tools for understanding the physical conditions of materials, soil stiffness, lithological contrast, bedrock depth, and wave amplification potential. In the context of this scoping review, this diversity of themes demonstrates that MASW and SRT have broad application flexibility, but remain entwined with one main thread: the conversion of seismic wave responses into subsurface information that can be used in geological and geotechnical decision-making.

One of the dominant themes in Table 1 is site characterization and soil classification based on seismic parameters (Alexopoulos et al., 2022) demonstrated that the combination of MASW and SRT can be used to estimate subsurface geotechnical characteristics, as well as to identify Vs30 values and subsurface structures in island regions with diverse lithological conditions. These findings are reinforced by (Alexopoulos et al., 2023), who integrated SRT, MASW, HVSR, and ERT at seismological stations to obtain important parameters such as Vs, Vs30, fundamental frequency, seismic bedrock depth, soil type, and elastic modulus. Within the framework of engineering seismology, this is crucial because the quality of earthquake recordings and seismic hazard estimates are strongly influenced by local subsurface conditions at the location of sensors or infrastructure. Therefore, Vs30 serves not only as a classification parameter but also as an initial indicator for understanding the potential amplification of ground motion due to impedance contrasts and the thickness of soft sediment layers (Alexopoulos et al., 2022, 2023).

A similar trend is observed in (Sarkar et al., 2021), who applied SRT and MASW for site characterization in Phuentsholing, Bhutan Himalaya. This study is significant as it demonstrates that non-destructive methods can serve as viable alternatives when direct investigations, such as drilling or geotechnical testing, are difficult to conduct due to complex terrain conditions. In this case, SRT was used to image the Vp structure, while MASW was employed to derive the Vs structure, providing different but complementary information. (Carrera et al., 2024b) further extended the relevance of this approach to agricultural soils by showing that SRT and MASW can be used to assess changes in soil structure caused by compaction. This highlights that MASW and SRT are not only relevant for earthquake-prone areas or construction sites, but can also be utilized to understand changes in soil mechanical properties at a broader field scale (Carrera et al., 2024b; Sarkar et al., 2021).

In the context of geological hazards, Table 1 shows that MASW and SRT are widely used to identify slip surfaces, weak zones, fractures, surface deformation, and post-earthquake responses. (Alonso-Pandavenes et al., 2023) used HVSR combined with seismic refraction and MASW to define slip planes and the internal structure of landslides. This approach demonstrates that MASW and SRT can provide physical constraints on zones of moving material and more stable layers, while HVSR helps characterize the dynamic response associated with impedance contrasts. In the post-earthquake context, (Karslı et al., 2024) combined SRT, MASW, and microtremor to understand the relationship between subsurface properties and damage levels in several earthquake-affected provinces in Turkey. This study shows that post-disaster analysis is not sufficient to only observe surface damage, but needs to be linked to subsurface characteristics, especially the presence of soft layers, loose sediments, and Vs30 variations that affect seismic amplification (Alonso-Pandavenes et al., 2023; Carrera et al., 2024b).

In the case of fractures and discontinuous structures, (Singh et al., 2024) demonstrated that the integration of ERT, SRT, and MASW can be used to detect thin subvertical fractures at the Parwan Dam, India. This study is significant because it highlights that narrow and discontinuous subsurface targets are difficult to interpret using a single method. SRT can capture travel time variations caused by velocity contrasts, MASW can indicate reductions in Vs associated with weak zones, while ERT helps distinguish potential fracture zones based on resistivity variations. Therefore, for targets such as fractures, weak zones, and shallow discontinuities, method integration becomes a methodological necessity rather than merely an addition of data. A critical reading of Table 1 suggests that the more complex the subsurface target, the greater the tendency for studies to adopt a multi-method approach.

Table 2 clarifies that the most fundamental difference between MASW and SRT lies in the primary parameters they produce. his distinction has significant interpretative implications. Vs is more sensitive to the stiffness of the soil framework, making it particularly useful for identifying soft layers, assessing amplification potential, and evaluating dynamic soil conditions. In contrast, Vp is more influenced by bulk modulus, density, and the presence of fluids, making it more suitable for interpreting lithological contrasts, bedrock depth, and saturation conditions (Eleslambouly et al., 2025) demonstrated the relevance of this distinction in the characterization of sabkha environments, which are strongly influenced by hydrological conditions and degrees of saturation. In that study, a combination of Vp, Vs, the Vp/Vs ratio, anisotropy, and attenuation was used to differentiate between dry, transitional, and saturated zones. This indicates that interpretations based on a single parameter may be misleading, particularly in subsurface conditions that are strongly affected by pore water and variations in saturation (Eleslambouly et al., 2025).

The comparison in Table 2 also indicates that MASW is relatively more effective in detecting soft layers, as low Vs values can serve as indicators of weak materials, unconsolidated sediments, weathered zones, or slip surfaces. However, this advantage does not imply that MASW is free from ambiguity. MASW inversion is inherently non-unique, meaning that multiple subsurface models can produce similar dispersion curves. Therefore, the interpretation of Vs should be supported by additional information, such as Vp from SRT, resistivity from ERT, dominant frequency from HVSR, or direct geotechnical data. On the other hand, SRT is effective in identifying layer boundaries and bedrock when there is a clear contrast in Vp, but it has limitations under velocity inversion conditions. Low-velocity layers located beneath higher-velocity layers may not be detected as first arrivals and can remain unresolved as hidden layers. This is why Table 2 should not be interpreted as a list of separate advantages, but rather as a basis for understanding the necessity of MASW–SRT integration in complex near-surface interpretations.

Kondracka et al., (2021b) provide a compelling example of the importance of method integration in landfill environments. In their study, ERT, SRT, MASW, and GPR were applied to characterize industrial and municipal waste materials. Landfill settings represent highly heterogeneous targets, as they consist of mixtures of materials with varying density, water content, compaction levels, and composition. Under such conditions, Vp and Vs values may vary not only due to lithological differences, but also as a result of changes in moisture content, voids, material degradation, and the internal structure of the waste. Therefore, the use of MASW and SRT should be understood as part of a multi-parameter interpretation strategy. Seismic data provide insights into the mechanical properties of materials, while electromagnetic or resistivity-based methods can help distinguish saturated zones, conductive materials, and boundaries between different waste units (Kondracka et al., 2021b).

In karst environments, (El-Badrawy et al., 2024) demonstrated that the integration of ERT, MASW, and seismic refraction can effectively support geotechnical hazard assessment. Karst settings are particularly challenging due to the presence of cavities, weathered limestone, weak zones, and variations in saturation, all of which can produce complex geophysical responses. In this context, SRT can help identify Vp contrasts associated with more compact rock or weak zones, while MASW provides Vs information that reflects material stiffness. However, cavities do not always produce straightforward geophysical responses, as their size, depth, infill material, and contrast with surrounding media can significantly influence the measured anomalies. Therefore, the discussion of Table 1 and Table 2 leads to a critical point: method integration is required not because each method is inherently accurate, but because each method exhibits different physical sensitivities to the same subsurface target (El-Badrawy et al., 2024).

Table 3 plays an important role in maintaining the methodological boundaries of this scoping review. The inclusion criteria, which emphasize empirical studies, the use of MASW and or SRT, the reporting of quantitative parameters, and a near-surface context, ensure a clear and focused scope. However, these constraints also shape the nature of the findings. Studies that focus solely on infrastructure aspects without subsurface geological characterization are excluded, leading this review to emphasize the relationship between seismic parameters and geological material interpretation. The exclusion of regional-scale mineral or hydrocarbon exploration studies is also appropriate because their scale, targets, and investigation depths differ significantly from near-surface studies. In the context of a scoping review, such decisions are essential to prevent the synthesis from becoming overly broad. Nevertheless, the consequence is that the findings of this review are more applicable to shallow geotechnical contexts, hazard assessment, site classification, and environmental investigations, rather than to regional seismic interpretation or deep resource exploration.

The research gaps presented in Table 4 indicate that the development of MASW and SRT still faces several methodological challenges. The first gap is the lack of standardized protocols for method integration. The reviewed studies employ variations in geophone spacing, spread length, energy sources, number of survey lines, and inversion approaches. These variations are understandable given the differences in field conditions and investigation targets, but without detailed reporting of acquisition parameters, results across studies become difficult to compare. For example, in the study by (Alexopoulos et al., 2023), the integration of multiple methods provided a comprehensive set of parameters for the characterization of seismological stations. However, replicating this approach in other locations still requires transparent reporting of survey design details. Therefore, the standardization needed is not the uniformity of all field configurations, but rather a minimum reporting standard that includes receiver spacing, spread length, geophone frequency, source type, dispersion frequency range, first-arrival picking, inversion parameters, and model uncertainty estimates (Alexopoulos et al., 2023).

The second gap concerns the limitation of investigation depth. Table 4 indicates that most studies are conducted within an investigation range of approximately 30–50 m, while studies reaching depths greater than 80 m remain limited. This is significant because several geological targets, such as deep slip surfaces, bedrock boundaries, sediment-covered fault zones, or deep aquifers, may lie beyond the capability of standard active MASW. Barone et al. (2026) demonstrated that MASW, SRT, and ERT can be jointly applied to characterize the internal structure of rock glaciers, and showed that MASW can help resolve ice-rich layers under conditions where SRT may face limitations. Such studies suggest that increasing investigation depth does not necessarily require reliance on a single method, but can be achieved through the combination of active and passive configurations, multi-method modeling, and the integration of different physical parameters (Barone et al., 2026). The third gap is the limited validation using borehole data. This represents a critical issue because MASW and SRT produce indirect geophysical models. Low Vs values may indicate soft soils, saturated materials, fractured zones, or organic layers, whereas high Vp values may suggest compact rock but can also increase due to water saturation. Without validation from boreholes, SPT, CPT, lithological logs, or laboratory data, geophysical interpretations risk becoming overly deterministic. (Carrera et al., 2024b) showed that seismic wave responses to soil structure and water content can differ, implying that the interpretation of Vp and Vs must account for both mechanical and hydrological conditions. In this context, direct validation serves not only as a reference, but also as a control to ensure that geophysical models are not interpreted beyond their physical resolution and sensitivity (Carrera et al., 2024b).

Concerning combined interpretation with HVSR, HVSR is widely used because it is cost-effective, rapid, and effective for obtaining dominant frequency and site resonance indicators. However, HVSR does not directly provide velocity profiles with depth. (Alonso-Pandavenes et al., 2023) demonstrated that HVSR can support landslide studies, particularly when combined with MASW and seismic refraction. Nevertheless, HVSR interpretation still requires constraints from other methods, since frequency peaks can be influenced by impedance contrasts, sediment thickness, valley geometry, or lateral heterogeneity that departs from one-dimensional conditions. Therefore, HVSR is more appropriately positioned as a complementary tool in site response interpretation, rather than as a substitute for MASW or SRT in constructing subsurface velocity profiles (Alonso-Pandavenes et al., 2023). Furthermore, there is a lack of systematic modeling of the influence of water content and soil conditions. This is crucial because Vp and Vs have different sensitivities to pore fluids. Vp tends to be more responsive to saturation, while Vs is more related to grain framework stiffness.

(Eleslambouly et al., 2025) demonstrated that the integration of Vp, Vs, the Vp/Vs ratio, anisotropy, and attenuation can effectively distinguish between dry, transitional, and saturated zones in sabkha environments. This finding is particularly relevant for tropical, wetland, coastal, and peat environments, which are characterized by high water content and dynamic groundwater fluctuations. If the effects of water are not explicitly modeled, interpretations of lithology or material strength may become biased. Therefore, future developments in MASW–SRT research should incorporate seismic parameters with water content measurements, hydrogeological data, or saturation correction models to strengthen the physical basis of subsurface interpretation (Carrera et al., 2024b; Eleslambouly et al., 2025). Another gap is the limited number of studies conducted in tropical and swamp or peat environments. This is significant because most studies presented in Table 1 are still concentrated in arid regions, mountainous areas, sabkha, karst, or temperate climates. Tropical environments present specific challenges, including intense weathering, thick residual soils, high moisture content, dense vegetation, young volcanic deposits, and rapid fluctuations in groundwater levels.

In swamp or peat environments, the challenges become more pronounced, as organic materials are characterized by low density, high compressibility, high saturation, and often weak velocity contrasts. (Karslı et al., 2024) highlighted the importance of subsurface characterization in understanding post-earthquake damage, while studies in sabkha and landfill environments demonstrate that heterogeneous settings require multi-parameter approaches. The relevance of these findings to Indonesia is particularly strong, as many regions are exposed to a combination of seismic hazards, soft soils, liquefaction, landslides, coastal wetlands, and young volcanic deposits. However, the limited representation of tropical studies suggests that generalizations derived from non-tropical regions should be made with caution and require validation under local geological conditions.

CONCLUSION

This scoping review demonstrates that MASW and SRT are two near-surface seismic methods that play complementary roles in subsurface characterization. MASW contributes significantly to shear wave velocity (Vs) modeling, Vs30 estimation, identification of soft layers, evaluation of soil stiffness, and analysis of site dynamic response. In contrast, SRT provides essential information on compressional wave velocity (Vp), layer thickness, bedrock boundaries, lithological contrasts, and subsurface structures characterized by clear velocity variations. The difference in physical sensitivity between Vs and Vp indicates that these methods should not be treated as interchangeable approaches, but rather as complementary techniques. Based on the 23 studies analyzed, the integration of MASW and SRT has been widely applied across various contexts, including geotechnical characterization, seismic site classification, landslide analysis, fracture detection, landfill studies, karst identification, hydrogeological mapping, sabkha characterization, and post-earthquake assessment. In complex subsurface conditions, the use of a single method is often insufficient to produce reliable interpretations. MASW can clarify variations in material stiffness through Vs, while SRT strengthens the interpretation of subsurface layering through Vp. Their integration, especially when combined with ERT, HVSR, GPR, TEM, or direct geotechnical data, can reduce interpretational ambiguity and improve the reliability of subsurface models. Nevertheless, this review identifies several important limitations in the existing literature.

The lack of standardized acquisition and reporting protocols makes it difficult to directly compare results across studies. Most studies are still limited to shallow to intermediate investigation depths, while validation using borehole data, SPT, CPT, or lithological logs remains relatively scarce. In addition, the influence of water content, saturation conditions, and tropical soil characteristics has not been systematically modeled, even though these factors can significantly affect Vp and Vs values. The limited number of studies conducted in tropical, swamp, and peat environments also highlights an important research gap, particularly for regions such as Indonesia, where complex interactions exist among high seismic activity, soft soils, young volcanic deposits, coastal environments, and landslide hazards.

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