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Short-Term Sulfurous Balneotherapy and Self-Reported Sleep Quality: An Exploratory Retrospective Real-World Pre–Post Observational Study at Terme di Saturnia (Italy)

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Abstract

Background: Background: Sleep disturbances are highly prevalent, affecting approximately 21% of the European population, with chronic insomnia disorder estimated at 6%. Non-pharmacological alternatives to pharmacotherapy are needed. Sulfurous balneotherapy represents a potential intervention, yet real-world evidence remains limited. Objective: To explore changes in self-reported sleep quality following sulfurous balneotherapy at Terme di Saturnia (Italy). **Methods:** Retrospective single-arm observational study of 76 participants (mean age 47.3 years, 54% female) undergoing a 7–12-day consecutive balneotherapy cycle with daily sulfurous thermal water immersion sessions (60–90 min/session). The Oviedo Sleep Questionnaire (OSQ) was administered pre- and post-treatment. Participants were stratified by baseline insomnia severity into Group A (OSQ ≥22, n = 47) and Group B (OSQ <22, n = 29). The primary outcome was change in OSQ insomnia score in Group A. Statistical analysis was performed using the Wilcoxon signed-rank test. **Results:** In Group A, insomnia severity decreased significantly from 26.4±8.3 at baseline to 20.1±7.5 post-treatment ($\Delta = -6.3$, 95% CI: −7.9 to −4.7, $p < 0.001$, $r = 0.54$). Sleep satisfaction also improved significantly from 3.2±1.1 to 4.6±1.2 ($\Delta = +1.4$, 95% CI: 1.1–1.7, $p < 0.001$, $r = 0.60$). In Group B, no statistically significant changes were observed, consistent with ceiling effects. However, in an open-ended question, 72.4% (21/29; 95% CI: 54.3–85.3) of Group B participants reported enhanced relaxation during the spa stay. These findings are hypothesis-generating and support further evaluation of balneotherapy as a complementary, patient-centered approach within sleep health pathways. Nevertheless, without control groups, the observed improvements cannot be attributed specifically to sulfurous water properties versus vacation effects, placebo responses, or regression to the mean. **Conclusions:** This exploratory study documents substantial pre-post improvements in sleep quality following balneotherapy. The absence of control groups and unmeasured confounders preclude causal inferences. Future randomized trials with heated non-mineral water controls are needed to isolate specific therapeutic contributions of sulfurous thermal waters.

Keywords: balneotherapy; sulfurous thermal water; insomnia; sleep satisfaction; sleep quality; Oviedo Sleep Questionnaire; real-world evidence; observational study; non-pharmacological intervention; healthcare management

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1. Introduction

Sleep is a complex physiological process fulfilling multiple essential functions, including tissue repair and cellular regeneration, metabolic regulation, and neural plasticity critical for cognitive performance and brain development [1]. Sleep disturbances are highly prevalent, affecting approximately 21% of the European population, with chronic insomnia disorder estimated at 6% [2]. The clinical significance of sleep disturbances extends beyond subjective discomfort, encompassing associations with depression, hypertension, obesity, diabetes, and increased mortality risk [1,3–5]. Pharmacological interventions remain the most commonly prescribed treatment for sleep disorders. However, concerns regarding dependency, tolerance, and residual daytime effects have prompted growing interest in non-pharmacological alternatives with more sustainable benefits [5]. Among non-pharmacological approaches, balneotherapy—involving immersion in mineral or thermal waters—represents a complementary treatment approach that has recently gained interest for improving sleep quality [6]. Balneotherapy should be distinguished from general hydrotherapy (simple heated water immersion) based on the presence of specific mineral compositions that may exert distinct physiological effects beyond thermal stimulation alone [7]. Modern research suggests that balneotherapy may influence sleep through multiple mechanisms, including thermal pathway activation, autonomic nervous system modulation, and reduction of systemic inflammation [6,8,9]. The temperature-regulation hypothesis of sleep initiation posits that body cooling following warm immersion facilitates sleep onset by activating heat loss mechanisms [10,11]. Cutaneous warming promotes vasodilation and subsequent core temperature decline, which aligns with the circadian drop in core temperature that naturally precedes sleep. Cutaneous warming promotes vasodilation and subsequent core temperature decline, which aligns with the circadian drop in core temperature that naturally precedes sleep [10]. Studies using heated water baths have demonstrated accelerated sleep latency and improved sleep efficiency when administered 1-2 hours before bedtime [12]. Sulfurous thermal waters, such as those at Terme di Saturnia (Italy), possess distinctive physicochemical properties beyond temperature alone. These waters contain hydrogen sulfide (H_2S) concentrations of 14-15 mg/L, calcium sulfate, and other dissolved minerals [13]. Hydrogen sulfide exhibits vasodilatory properties through multiple pathways including activation of ATP-sensitive potassium channels, modulation of nitric oxide pathways, and effects on vascular smooth muscle [14]. Whether transdermal absorption of H_2S during brief immersion reaches pharmacologically relevant concentrations remains uncertain, and controlled studies comparing sulfurous versus non-sulfurous heated water are lacking. Previous studies on balneotherapy and sleep have reported improvements in subjective sleep quality [6,9], though methodological limitations including heterogeneous interventions and lack of appropriate control groups constrain interpretation [9]. Critically, randomized controlled trials comparing sulfurous mineral water with heated non-mineral water are notably absent from the literature. The present study aimed to explore changes in self-reported sleep quality following a short-term sulfurous balneotherapy cycle at Terme di Saturnia using the validated Oviedo Sleep Questionnaire in a real-world setting. Given the observational, single-arm design without control group, findings should be interpreted as hypothesis-generating rather than confirmatory.

2. Materials and Methods

2.1. Study Design and Setting

This retrospective, single-arm observational study was conducted at Terme di Saturnia (Tuscany, Italy) between June and September 2024. The thermal spring water at Saturnia is characterized by a stable sulfurous calcium–sulfate composition and high mineralization. The main physicochemical parameters of the spring water are summarized in Table 1, based on published hydrogeochemical analyses of the Saturnia source [15]. This characterization is provided to document the mineral profile of the balneotherapy setting and to support reproducibility and comparability

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with future controlled studies evaluating sulfurous versus non-mineral water immersion. Participants engaged in daily sulfurous thermal water immersion sessions lasting 60–90 min per session, according to routine facility practice and individual tolerance. This study is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for observational studies [16]. Due to the retrospective observational nature and use of anonymized data from routine wellness assessments, formal ethics committee approval was waived in accordance with Italian regulations for non-interventional studies. All participants provided informed consent for data use in aggregate form.

Table 1. Physicochemical profile of Saturnia sulfurous thermal water at source, reported to characterize the mineral composition of the balneotherapy intervention setting.

Parameter	Value (approx.)
Temperature	37.5 °C
Conductivity	~3110 µS/cm
Hydrochemical type	Calcium–sulfate water
Sulfate (SO_4^{2-})	~1540 mg/L
Calcium (Ca^{2+})	~593 mg/L
Boron (B)	~18 mg/L

2.2. Participants

Participants were eligible if they were adults aged 18–75 years who completed a 7–12-day sulfurous balneotherapy cycle and returned both baseline and post-treatment Oviedo Sleep Questionnaire (OSQ) assessments [17]. Individuals were excluded if questionnaires were incomplete or if a known diagnosis of sleep apnea or restless leg syndrome was self-reported. Participants were also excluded when available information indicated acute medical conditions contraindicating immersion or when sleep medication regimens were initiated, discontinued, or modified during the treatment period. Exclusion criteria were based on self-reported information and/or routine facility records available at the time of the wellness assessment. For analysis purposes, participants were stratified according to baseline insomnia severity into two groups: Group A (OSQ insomnia score ≥22) and Group B (OSQ insomnia score <22). The cut-off value of 22 was selected based on validation studies indicating that scores ≥22 correspond to clinically relevant insomnia symptoms [20]. This was a convenience sample comprising all eligible participants who completed balneotherapy cycles during the study period (June–September 2024) and returned complete OSQ assessments. No formal sample size calculation was performed given the exploratory, retrospective nature of the study.

2.3. Study Outcomes

Primary outcome: Change in OSQ insomnia subscale score from baseline to post-treatment in Group A (participants with baseline sleep disturbances). Secondary outcomes: (1) Change in OSQ sleep satisfaction in Group A; (2) Proportion reporting relaxation effects in Group B; (3) Qualitative assessment of perceived benefits via open-ended question.

2.4. Assessment Instrument

The Oviedo Sleep Questionnaire (OSQ) is a validated instrument for assessing sleep quality and insomnia in clinical and research settings [17]. The OSQ comprises three subscales: (1) satisfaction with sleep (scores 1-7, higher scores indicate greater satisfaction); (2) insomnia severity (scores 9-45, higher scores indicate worse insomnia); and (3) hypersomnia (not analyzed in this study).

The OSQ was administered via paper questionnaire at two timepoints: (1) baseline assessment on the first day of balneotherapy (retrospective assessment of sleep quality during the previous

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week); and (2) post-treatment assessment on the final day of the balneotherapy cycle (assessment of sleep quality during the treatment week).

2.5. Balneotherapy Protocol

Participants engaged in daily sulfurous thermal water immersion sessions lasting 60–90 minutes per session, according to routine facility practice and individual tolerance. Immersion occurred in natural thermal pools maintained at 37–38 °C, typically in late afternoon or early evening (15:00–19:00). Participants were free to float, walk slowly, or sit as preferred; no structured exercise protocol was mandated. Participants were advised to maintain adequate hydration and avoid alcohol consumption immediately before or after immersion sessions. No restrictions were placed on other wellness activities available at the facility (e.g., sauna, massage therapy, relaxation areas).

2.6. Potential Confounding Factors

Due to the retrospective real-world design, several lifestyle and contextual factors during the spa stay were not systematically recorded prospectively and could not be controlled for in the analysis. These included concurrent wellness activities (e.g., sauna, massage), changes in daily routines, work stress reduction, dietary modifications, and physical activity levels. Limited retrospective data on some contextual factors were collected via participant recall and are presented descriptively (Table 3), though these data are subject to recall bias and do not permit quantitative adjustment in the analysis.

2.7. Statistical Analysis

Descriptive statistics: mean±SD for continuous variables, frequencies/percentages for categorical variables. Normality was assessed using Shapiro-Wilk test on change scores (Δ = post - pre). Given non-normal distributions in several outcomes (Shapiro-Wilk $p<0.05$) and the ordinal nature of OSQ subscales, non-parametric tests were employed. Primary analysis: Wilcoxon signed-rank test for pre-post comparisons within each group. Effect size r was calculated as $r = Z/\sqrt{N}$ for Wilcoxon tests, with 95% confidence intervals estimated via bootstrap resampling (1000 iterations). Effect size interpretation: small (r=0.10-0.29), medium (r=0.30-0.49), large (r≥0.50) [27]. Between-group comparisons (Group A vs B baseline characteristics): Mann-Whitney U test for continuous variables, Fisher's exact test for categorical variables. Statistical significance: $p<0.05$ (two-tailed). Given the exploratory nature and absence of a priori hypotheses, no corrections for multiple comparisons were applied. All analyses: SPSS version 28.0 (IBM Corp., Armonk, NY). Qualitative data from the open-ended question were analyzed using simple content categorization. Discrepancies were resolved by consensus. Due to resource constraints, formal thematic analysis and inter-rater reliability assessment were not conducted, limiting the rigor of qualitative findings. No sensitivity analyses were performed given the exploratory nature of this initial investigation.

3. Results

3.1. Participant Characteristics

A total of 76 participants met the inclusion criteria and were included in the analysis. The mean age of the sample was 47.3 years (SD = 11.2, range 27–68), and 41 participants (54%) were female. Of the total cohort, 47 participants (62%) were classified as Group A (baseline OSQ insomnia score ≥22), whereas 29 participants (38%) were classified as Group B (OSQ insomnia score <22). Participants completed a mean of 9.4 days of sulfurous balneotherapy (SD = 1.8, range 7–12 days), with daily immersion sessions lasting 60–90 minutes according to routine facility practice. Participant screening, exclusions, and final group allocation are summarized in Figure 1. Baseline demographic and clinical characteristics are presented in Table 2. No significant demographic differences were observed between groups.

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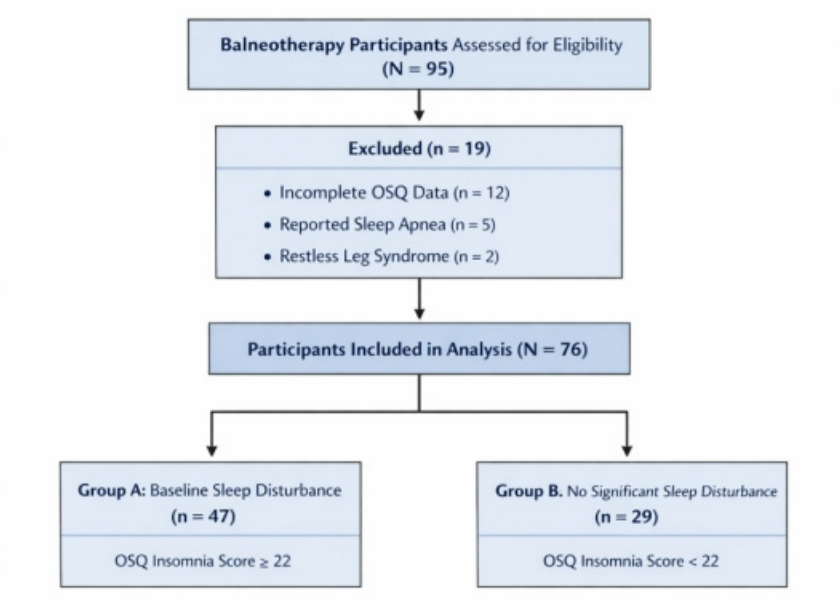

Figure 1. Flow diagram of participant screening, exclusions, and final allocation into Group A (baseline insomnia, OSQ ≥ 22) and Group B (no baseline insomnia, OSQ < 22).

Table 2. Baseline demographic and clinical characteristics of the study participants.

Characteristic	Total (N = 76)	Group A (OSQ ≥ 22) (n = 47)	Group B (OSQ < 22) (n = 29)	p-value
Age, years (mean ± SD)	47.3 ± 11.2	49.1 ± 10.8	44.6 ± 11.5	0.072
Female sex, n (%)	41 (54%)	27 (57%)	14 (48%)	0.442
Treatment duration, days (mean ± SD)	9.4 ± 1.8	9.6 ± 1.7	9.1 ± 1.9	0.054
First-time visitor, n (%)	28 (37%)	15 (32%)	13 (45%)	0.256
Baseline insomnia score (mean ± SD)	21.4 ± 7.9	26.4 ± 8.3	14.2 ± 3.8	<0.001
Baseline sleep satisfaction (mean ± SD)	3.9 ± 1.4	3.2 ± 1.1	5.4 ± 0.8	<0.001

Group A: baseline OSQ insomnia score ≥ 22. **Group B:** baseline OSQ insomnia score < 22. p-values from Mann–Whitney U test (continuous variables) or Fisher's exact test (categorical variables). No participants in the final analyzed sample (n=76) had missing data for any variable presented in this table.

3.2. Primary Outcome: Change in Insomnia Severity (Group A)

After a 7–12-day consecutive sulfurous balneotherapy cycle, participants with baseline sleep disturbances (Group A, n = 47, OSQ ≥ 22) showed a significant reduction in insomnia severity scores, decreasing from 26.4 ± 8.3 at baseline to 20.1 ± 7.5 post-treatment (median change: −6.0 points, mean change: −6.3 points, 95% CI: −7.9 to −4.7; Wilcoxon Z = −5.21, p < 0.001, effect size r = 0.54, 95% CI: 0.38–0.67). The magnitude of change was large by conventional effect size standards. However, no established minimal clinically important difference (MCID) exists for the OSQ insomnia subscale in this population, precluding formal clinical significance determination. Approximately 85% (n=40) of Group A participants demonstrated score reductions ≥3 points.

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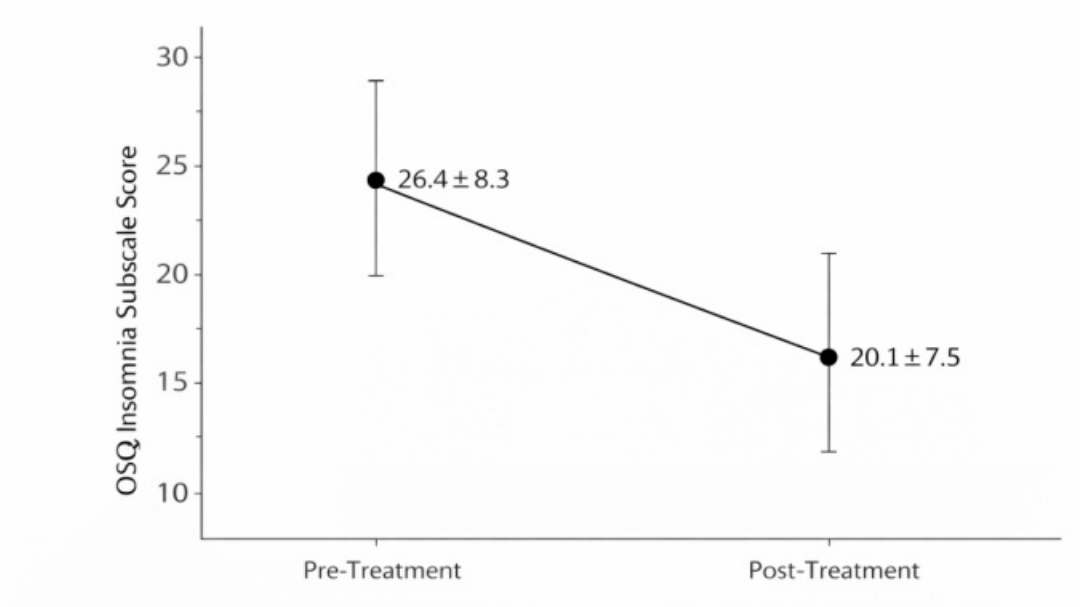

Figure 2. Mean Oviedo Sleep Questionnaire (OSQ) insomnia subscale scores (±SD) at baseline (T0) and post-treatment (T1) in participants with baseline sleep disturbance (Group A, n = 47). Insomnia severity decreased significantly following sulfurous balneotherapy cycle (Wilcoxon signed-rank test, $p < 0.001$).

3.3. Secondary Outcomes

Following the same 7–12-day consecutive sulfurous balneotherapy cycle, sleep satisfaction scores in Group A improved significantly (Figure 3), increasing from 3.2 ± 1.1 at baseline to 4.6 ± 1.2 post-treatment (mean change: +1.4 points, 95% CI: 1.1–1.7; Wilcoxon $Z = -5.84$, $p < 0.001$, $r = 0.60$, 95% CI: 0.45–0.72), representing a shift from "somewhat dissatisfied" to "satisfied." In Group B (no baseline disturbances), neither insomnia scores (14.2 ± 3.8 to 13.5 ± 3.9, $\Delta = -0.7$, 95% CI: −1.8 to 0.4; $Z = -1.12$, $p = 0.26$, $r = 0.21$) nor sleep satisfaction scores (5.4 ± 0.8 to 5.7 ± 0.9, $\Delta = +0.3$, 95% CI: −0.1 to 0.7; $Z = -1.58$, $p = 0.11$, $r = 0.29$) changed significantly. This likely reflects a ceiling effect, as participants without baseline sleep problems had limited room for measurable improvement.

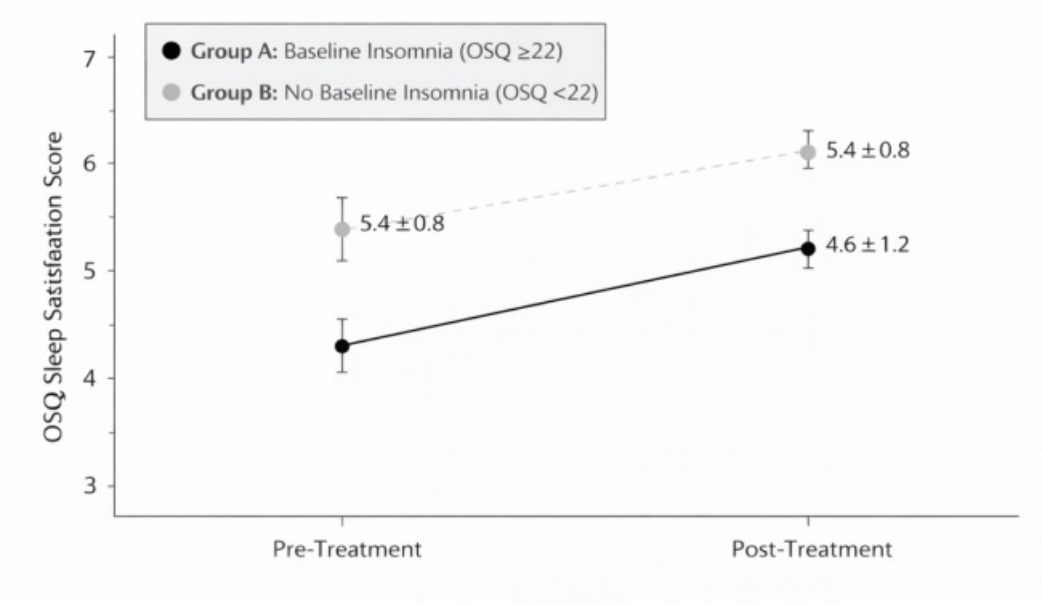

Figure 3. Mean OSQ sleep satisfaction scores (±SD) at baseline (T0) and post-treatment (T1) in Group A (n = 47). Scores improved significantly after sulfurous balneotherapy ($p < 0.001$).

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Qualitatively, 72.4% (21/29; 95% CI: 54.3–85.3) of Group B participants spontaneously reported enhanced relaxation during treatment, despite the absence of statistically significant changes in OSQ scores. All outcomes are summarized in Table 4.

Table 3. Self-reported contextual and lifestyle factors potentially influencing sleep outcomes during the spa stay.

Contextual factor	Total (N = 76)	Group A (n = 47)	Group B (n = 29)
Participants on vacation during treatment, n (%)	68 (89%)	42 (89%)	26 (90%)
Increased outdoor time reported, n (%)	71 (93%)	44 (94%)	27 (93%)
Concurrent wellness activities (sauna/massage), n (%)	42 (55%)	27 (57%)	15 (52%)
Reported reduced work-related stress, n (%)	60 (79%)	38 (81%)	22 (76%)
Increased physical activity (walking/swimming), n (%)	48 (63%)	30 (64%)	18 (62%)
Dietary modifications (reduced caffeine/alcohol), n (%)	39 (51%)	25 (53%)	14 (48%)

Data derived from retrospective participant responses and should be interpreted cautiously due to recall bias and incomplete measurement of confounders.

Table 4. Pre–post changes in OSQ insomnia and sleep satisfaction scores following sulfurous balneotherapy.

Outcome	Baseline (T0) Mean ± SD	Post-treatment (T1) Mean ± SD	Mean Change (Δ)	95% CI	p-value	Effect size r
Group A (OSQ ≥ 22), n = 47						
Insomnia score (9–45)	26.4 ± 8.3	20.1 ± 7.5	−6.3	−7.9 to −4.7	<0.001	0.54
Sleep satisfaction (1–7)	3.2 ± 1.1	4.6 ± 1.2	+1.4	1.1 to 1.7	<0.001	0.60
Group B (OSQ < 22), n = 29						
Insomnia score (9–45)	14.2 ± 3.8	13.5 ± 3.9	−0.7	−1.8 to 0.4	0.26	0.21
Sleep satisfaction (1–7)	5.4 ± 0.8	5.7 ± 0.9	+0.3	−0.1 to 0.7	0.11	0.29

p-values from Wilcoxon signed-rank tests. Effect size r calculated as $r = Z/\sqrt{N}$.

3.4. Qualitative Findings

In response to the open-ended question "What benefits did you experience from the thermal water treatment?", participants most frequently mentioned: improved relaxation (n=68, 89%), better sleep quality (n=51, 67%), reduced muscle tension (n=44, 58%), enhanced mood (n=39, 51%), and improved skin condition (n=27, 36%). These qualitative data should be interpreted cautiously given the lack of systematic coding methodology, absence of inter-rater reliability assessment, and retrospective self-report format. Responses likely reflect a combination of specific treatment effects and non-specific factors including vacation enjoyment, reduced stress, and expectancy effects.

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4. Discussion

This retrospective real-world pre–post observational study explored changes in self-reported sleep quality following a short-term cycle of sulfurous balneotherapy at Terme di Saturnia. Among participants presenting with clinically relevant baseline insomnia symptoms, insomnia severity scores decreased and sleep satisfaction increased after the treatment cycle. Although these findings are consistent with a potential beneficial association between warm thermal immersion and subjective sleep outcomes, the observational single-arm design does not allow causal attribution.

A biologically plausible rationale supports an association between warm water immersion and improved sleep outcomes. Sleep initiation and maintenance are closely linked to thermoregulatory processes, particularly the decline in core body temperature that normally precedes sleep onset. Experimental evidence indicates that passive body heating may facilitate subsequent heat dissipation through peripheral vasodilation, thereby promoting sleep propensity. In a systematic review and meta-analysis, warm water bathing performed approximately 1–2 h before bedtime was associated with shorter sleep onset latency and improved self-reported sleep quality, suggesting that thermal stimulation alone may exert measurable effects on sleep regulation [18].

In older adults, physiological studies further indicate that hot-water bathing before bedtime increases the distal–proximal skin temperature gradient, a marker of enhanced heat loss that correlates with improved sleep initiation [19]. These observations align with established models describing the interrelationship between sleep regulation and thermoregulation [20]. Thus, even in the absence of mineral-specific effects, immersion in warm thermal pools may plausibly contribute to improved sleep through thermophysiological pathways.

Beyond thermal mechanisms, sulfurous waters contain hydrogen sulfide (H_2S), a gaseous signaling molecule with recognized vasodilatory and anti-inflammatory properties in experimental vascular biology. Reviews describe multiple pathways through which H_2S may influence vascular tone, including modulation of ATP-sensitive potassium channels and interactions with nitric oxide signaling [14]. However, it remains uncertain whether transdermal exposure during balneotherapy produces systemic concentrations sufficient to induce clinically meaningful effects. Any mineral-specific therapeutic contribution therefore remains speculative.

Overall, the observed pre–post improvements in this cohort are compatible with known temperature-mediated effects mechanisms and with broader evidence supporting sleep benefits of warm water immersion. Nonetheless, controlled trials are required to determine whether sulfurous mineral content provides incremental benefit beyond temperature- and context-matched non-mineral water exposure.

Following these mechanistic considerations, the present findings are broadly consistent with the limited but growing literature suggesting that spa-based thermal interventions may be associated with improvements in subjective sleep outcomes. A recent systematic review examining hydrotherapy, spa therapy, and balneotherapy concluded that these interventions may improve sleep quality, although the certainty of evidence remains low due to heterogeneity and frequent methodological limitations, including small sample sizes and lack of adequate control groups [9]. Similarly, another systematic review highlighted potential benefits of balneotherapy on sleep parameters, but emphasized that most available studies are observational and do not allow attribution of effects to mineral composition versus non-specific contextual factors [7].

In line with this, Castelli et al. reported that spa stays combining daytime physical activity and balneotherapy were associated with improved sleep and recovery, suggesting that multimodal lifestyle changes during spa exposure may contribute substantially to perceived benefits [6]. Therefore, the improvements observed in the present cohort may reflect not only immersion effects but also broader behavioral and environmental modifications occurring during the treatment period. Importantly, the present design cannot determine whether sulfurous mineral composition provides benefits beyond those expected from passive heating and the spa environment itself. Warm water immersion alone has demonstrated measurable effects on sleep onset and subjective sleep quality and the absence of a heated non-mineral water comparator precludes isolation of any incremental

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sulfur-specific contribution [18]. Thus, any interpretation of hydrogen sulfide–mediated mechanisms must remain hypothetical. The observed changes must also be interpreted in light of substantial non-specific influences. Spa-based interventions occur within a context strongly associated with stress reduction, schedule regularization, increased physical activity, and exposure to restorative natural environments. Such contextual effects are well documented: even short-term holidays have been shown to improve perceived well-being and reduce stress-related symptoms, which may secondarily enhance sleep quality [21]. In addition, placebo and expectancy effects are particularly pronounced in insomnia research, with response rates in placebo arms frequently reaching 30–50% [22]. Regression to the mean may further contribute, especially in participants selected on the basis of elevated baseline symptom scores.

5. Limitations

This study has several important limitations that should be carefully considered when interpreting the findings. First, the retrospective single-arm pre–post design does not allow causal inference. Without a control or comparator group (e.g., heated non-mineral water immersion, wait-list controls, or usual care), the observed improvements cannot be attributed specifically to sulfurous balneotherapy. Non-specific influences such as placebo effects, expectancy, regression to the mean, and the well-described "vacation effect" may have contributed substantially to the changes in self-reported sleep outcomes.

Second, several relevant confounding factors were not systematically measured. Participants were immersed in a complex wellness context that may have included reduced work-related stress, increased outdoor exposure, lifestyle modifications, physical activity, and concurrent spa services (e.g., sauna or massage). Because these factors were not controlled or quantified prospectively, the specific contribution of mineral water properties cannot be isolated. Third, outcomes relied exclusively on subjective self-report measures. Although the Oviedo Sleep Questionnaire is validated, the absence of objective sleep assessments (such as actigraphy or polysomnography) limits the ability to confirm whether perceived improvements corresponded to measurable changes in sleep architecture or efficiency. Fourth, selection bias is likely. Participants were self-selected spa visitors, potentially representing a health-conscious population with positive expectations toward balneotherapy. This limits the generalizability of the findings to broader clinical insomnia populations. Fifth, post-treatment assessments were performed immediately at the end of the balneotherapy cycle, and no longitudinal follow-up was available. Therefore, the durability of the reported sleep improvements beyond the treatment or vacation period remains unknown.

Finally, qualitative findings were derived from open-ended responses without formal thematic analysis or inter-rater reliability procedures. These results should therefore be interpreted as supportive contextual information rather than robust qualitative evidence.

6. Conclusions

This exploratory real-world observational study suggests that a short-term sulfurous balneotherapy cycle lasting at least 7 consecutive days (7–12 days) may be associated with clinically meaningful improvements in self-reported insomnia severity and sleep satisfaction among individuals with baseline sleep disturbance. Participants without baseline sleep disturbance showed stable quantitative OSQ scores, consistent with ceiling effects, but frequently reported enhanced relaxation and sleep-related comfort during the spa stay. However, the absence of a control group and unmeasured confounders preclude causal inference. Future randomized controlled trials comparing sulfurous mineral water with heated non-mineral water immersion are needed to isolate any specific therapeutic contribution of sulfurous thermal waters.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org, Table S1: Complete STROBE Checklist.

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Institutional Review Board Statement: Institutional Review Board Statement: Ethical review and approval were waived for this study due to its retrospective observational nature using anonymized data from routine wellness assessments, in accordance with Italian regulations for non-interventional studies (Decreto Legislativo 211/2003, Article 2). All participants provided informed consent for data use in aggregate form at the time of wellness assessment.

Informed Consent Statement: Written informed consent was obtained from all subjects involved in the study for the use of their anonymized data in aggregate form for research purposes.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy and confidentiality restrictions concerning individual health information collected during wellness assessments at a private healthcare facility.

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Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Brinkman, J.E.; Reddy, V.; Sharma, S. Physiology of Sleep. In StatPearls; StatPearls Publishing: Treasure Island, FL, USA, 2023. Available online: https://www.ncbi.nlm.nih.gov/books/NBK526132/.
2. Chalet, F.X.; Albanese, E.; Egea Santaolalla, C.; Ellis, J.G.; Ferini-Strambi, L.; Heidbreder, A. Epidemiology and burden of chronic insomnia disorder in Europe: an analysis of the 2020 National Health and Wellness Survey. J. Med. Econ. 2024, 27, 1309–1320. https://doi.org/10.1080/13696998.2024.2407631
3. Amagai Y, Ishikawa S, Gotoh T, Doi Y, Kayaba K, Nakamura Y, Kajii E. Sleep duration and mortality in Japan: the Jichi Medical School Cohort Study. J Epidemiol. 2004;14(4):124-8. doi: 10.2188/jea.14.124. PMID: 15369129; PMCID: PMC8702369.
4. Bixler E. Sleep and society: an epidemiological perspective. Sleep Med. 2009;10 Suppl 1:S3-6. doi: 10.1016/j.sleep.2009.07.005.
5. Chan NY, Chan JWY, Li SX, Wing YK. Non-pharmacological Approaches for Management of Insomnia. Neurotherapeutics. 2021;18(1):32-43. doi: 10.1007/s13311-021-01029-2.
6. Castelli L, Ciorciari AM, Galasso L, Mulè A, Fornasini F, Montaruli A, Roveda E, Esposito F. Revitalizing your sleep: the impact of daytime physical activity and balneotherapy during a spa stay. Front Public Health. 2024;8;12:1339689. doi: 10.3389/fpubh.2024.1339689.
7. Reger, M., Kutschan, S., Freuding, M. et al. Water therapies (hydrotherapy, balneotherapy or aqua therapy) for patients with cancer: a systematic review. J Cancer Res Clin Oncol. 2022;148, 1277–1297. https://doi.org/10.1007/s00432-022-03947-w.
8. Ferrara, E.; Scaramuzzino, M.; Murmura, G.; D'Addazio, G.; Sinjari, B. Emerging Evidence on Balneotherapy and Thermal Interventions in Post-COVID-19 Syndrome: A Systematic Review. *Healthcare* 2025, *13*, 96. https://doi.org/10.3390/healthcare13020096
9. Moini Jazani, Arezoo & Azgomi, Hamidreza & Azgomi, Alireza & Ayati, Mohammad & nasimii doost azgomi, Ramin. (2023). Efficacy of hydrotherapy, spa therapy, and balneotherapy on sleep quality: a systematic review. International journal of biometeorology. 67. 10.1007/s00484-023-02471-x.
10. Kräuchi, Kurt & Deboer, Tom. (2010). The Interrelationship between Sleep Regulation and Thermoregulation. Frontiers in bioscience: a journal and virtual library. 15. 604-25. 10.2741/3636.
11. Nakao M, McGinty D, Szymusiak R, Yamamoto M. Thermoregulatory model of sleep control: losing the heat memory. J Biol Rhythms. 1999;14(6):547-56. doi: 10.1177/074873099129000885. PMID: 10643752.

 doi:10.20944/preprints202601.2033.v1

12. Tai, Y.; Obayashi, K.; Yamagami, Y.; Yoshimoto, K.; Kurumatani, N.; Nishio, K.; Saeki, K. Hot-water bathing before bedtime and shorter sleep onset latency are accompanied by a higher distal-proximal skin temperature gradient in older adults. J. Clin. Sleep Med. 2021, 17, 1257–1266. https://doi.org/10.5664/jcsm.9194
13. Vaccarezza, M.; Vitale, M.; Falletta, P.; di Martino, O. Natural Sulfur Compounds in Mineral Waters: Implications for Human Health and Disease. Int. J. Mol. Sci. **2025**, 26, 10807. https://doi.org/10.3390/ijms262110807
14. Munteanu, C.; Popescu, C.; Vlădulescu-Trandafir, A.I.; Onose, G. Signaling Paradigms of H2S-Induced Vasodilation: A Comprehensive Review. Int. J. Mol. Sci. 2024, 25, 11201. https://doi.org/10.3390/ijms252011201
15. Barbagli, Alessio & Fabio, Fabio Nunzio Antonio & Guastaldi, Enrico & Liali, Giovanni & Rezza, Carmela & Trotta, Marilena. (2013). Hydrogeochemical and isotopic characterization of the Saturnia thermal aquifer.
16. von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies.
17. Bobes, Julio & Portilla, PGG & Martinez, PAS & Bascaran, T & Alvarez, CI & Domínguez, J.Ma. Psychometric properties of the Oviedo sleep questionnaire. Psicothema. 2000;12. 107-112.
18. Haghayegh S, Khoshnevis S, Smolensky MH, Diller KR, Castriotta RJ. Before-bedtime passive body heating by warm shower or bath to improve sleep: A systematic review and meta-analysis. Sleep Med Rev. 2019;46:124-135. doi: 10.1016/j.smrv.2019.04.008.
19. Tai Y, Obayashi K, Yamagami Y, Yoshimoto K, Kurumatani N, Nishio K, Saeki K. Hot-water bathing before bedtime and shorter sleep onset latency are accompanied by a higher distal-proximal skin temperature gradient in older adults. J Clin Sleep Med. 2021;1;17(6):1257-1266. doi: 10.5664/jcsm.9180.
20. Krauchi K, Deboer T. The interrelationship between sleep regulation and thermoregulation. Front Biosci (Landmark Ed). 2010;1;15(2):604-25. doi: 10.2741/3636.
21. de Bloom J, Kompier M, Geurts S, de Weerth C, Taris T, Sonnentag S. Do we recover from vacation? Meta-analysis of vacation effects on health and well-being. J Occup Health. 2009;51(1):13-25. doi: 10.1539/joh.k8004.
22. Trauer JM, Qian MY, Doyle JS, Rajaratnam SM, Cunnington D. Cognitive Behavioral Therapy for Chronic Insomnia: A Systematic Review and Meta-analysis. Ann Intern Med. 2015;4;163(3):191-204. doi: 10.7326/M14-2841.