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Local Governance of Groundwater Resources through the Lens of Stakeholders in the Context of State-Led Management in the Lower Mekong Region

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Abstract: Local groundwater governance in the Lower Mekong Region (LMR) is often inadequate and ineffective because of policy incoherence and lack of public participation; thus, groundwater exploitation and pollution have been accelerated in many LMR countries. Through a case study in Khon Kaen, Thailand, this study aims to assess the state of local groundwater governance (GWG) through the stakeholders' perception by using Water Governance Framework developed by the Organization for Economic Co-operation and Development (OECD). Although it is useful for the assessment at the national scale, it is still inadequate and has some limitations on the local scale. Hence, the principles were reconsidered and translated to fit the local context. Descriptive statistical analysis was used to explain the state of GWG, while confirmatory factor analysis (CFA) was used to examine the relations between GWG indicators and GWG dimensions. The findings show that clear roles and responsibilities are have the highest performance. However, integrity and transparency are the challenges of GWG. We found that the indicators explained the effectiveness, efficiency, and trust and engagement in the GWG model. Consequently, this study contributes stakeholder involvement in GWG assessment. The findings show to policymakers and policy practitioners the current state of GWG and propose key indicators in groundwater governance assessment at the local context.

Keywords: groundwater governance; policy coherence; role and responsibilities; stakeholder engagement; Khon Kaen; Thailand

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1. Introduction

Groundwater represents a vital resource for local communities, particularly in the arid and semi-arid regions [1,2]. The Lower Mekong Region (LMR) is one of the areas in which people depend on groundwater resources [3–5]. Many countries in the LMR have been facing water insecurity driven by climate change, geopolitical uncertainties, and socioeconomic situations [6]. Thus, groundwater was withdrawn to supply fresh water to many communities in the LMR [7]. However, groundwater policies in this region have not been strengthened [8]. Further, many impacts of groundwater exploitation have been accelerated (i.e., groundwater depletion, low quality, seawater intrusion into the aquifer, etc.) [8].

Groundwater governance is still behind the good water governance framework, and it is partly implemented at the local scale [9,10]. Several studies agreed that GWG should be extended to the local community [1,2]. Additionally, national and local governance needs to be integrated with tasks to cope with the multi-level groundwater issues [11,12]. Local GWG is of increasing interest due to the failures of the central government's regulations [13]. Local GWG is the goal to address the challenges of sustainable groundwater management in local communities [14]. Further, it is also key for local communities to manage groundwater resources closely and co-manage with the local governments as well as other stakeholders [15,16].

Local GWG is the key approach to managing groundwater resources more successfully than solely national management [13,17–21]. Local groundwater governance is the bottom-up approach to the greater stakeholder participation in groundwater management [22,23]. Future groundwater sustainability will rely on local management strategies [24]. It is evident that many countries that depend on groundwater resources (i.e., Brazil, Iran, Yemen, Kenya, Spain, etc.) need local groundwater governance, and many studies have outlined appropriate approaches for invisible resource management of the specific challenges, e.g., [19,23–28]. Further, local governance can reduce groundwater extraction significantly [21].

Local GWG has not been largely studied [19,29]. Even though the supply side management tools are implemented (i.e., aquifer recharge and surface water replacement), local GWG is still the key challenge of good arrangements for sustainable use of groundwater resources [30,31]. Further, there is a lack of studies on local groundwater governance (see [32–35]). Additionally, many types of research solely focused on the state actors, official organizations, and experts, thereby appraising groundwater governance performance at the national level (see, [32–36]) with a lack of stakeholders' engagement in GWG at the local scale [34].

The OECD Water Governance Framework is a widely used framework in many countries. Although the OECD Water Governance Framework is useful on the national scale [37,38], it is still inadequate and has some limitations in application at the local level [39,40]. Some challenges of local water governance include the low capacity of local government, a lack of transparency, fragmented tasks of water authorities, and a lack of willingness of users to understand water policy [41]. Hence, it is necessary for further reconsideration and translation of the principles to fit the local context [39]. This paper aims to address the limitation of the framework by adapting the indicators to relate to the groundwater resources and modifying GWG indicators at the local scale. Additionally, the OECD Water Governance Framework principles are applied in the research with primary data to examine the relationship among the principles [37].

Although several GW policies have been implemented to respond to anthropogenic and climatic pressures on groundwater resources, the GW extraction rate has tended to increase over the last two decades [41]. Consequently, this paper aims to assess the state of groundwater governance at the local scale through the stakeholders' perception of the effectiveness of policies, the efficiency of groundwater institutions, and trust and engagement among multi-stakeholders through a case study in Khon Kaen, Thailand. The significance of the study is to address the actions from the shared global vision of groundwater governance for 2030 initiated by International Groundwater Resources Assessment Centre (IGRAC) and The United Nations Educational, Scientific and Cultural Organization (UNESCO) [1,2]. Therefore, the GWG at the local level needs to be assessed by groundwater governance frameworks to understand the factors indicating good governance principles.

2. Materials and Methods

2.1. Study Area

Khon Kaen is located in the northeastern region of Thailand (15–17° N latitude, 101–103° E longitude), covering an area of 10,886 km^2 (Figure 1). Khon Kaen was selected as the case study because it is one of the urbanizing cities with rapid economic development in the LMR [41–43]. Additionally, it has similar climatic and socioeconomic characteristics, as well as similar groundwater issues, as several cities in this region [3,41,44]. It faces an increase in water demand due to population growth and business expansion (i.e., industries and food processing require more water in their production) [45]. The situation may lead to water shortage and competition among sectors in the study area [41].

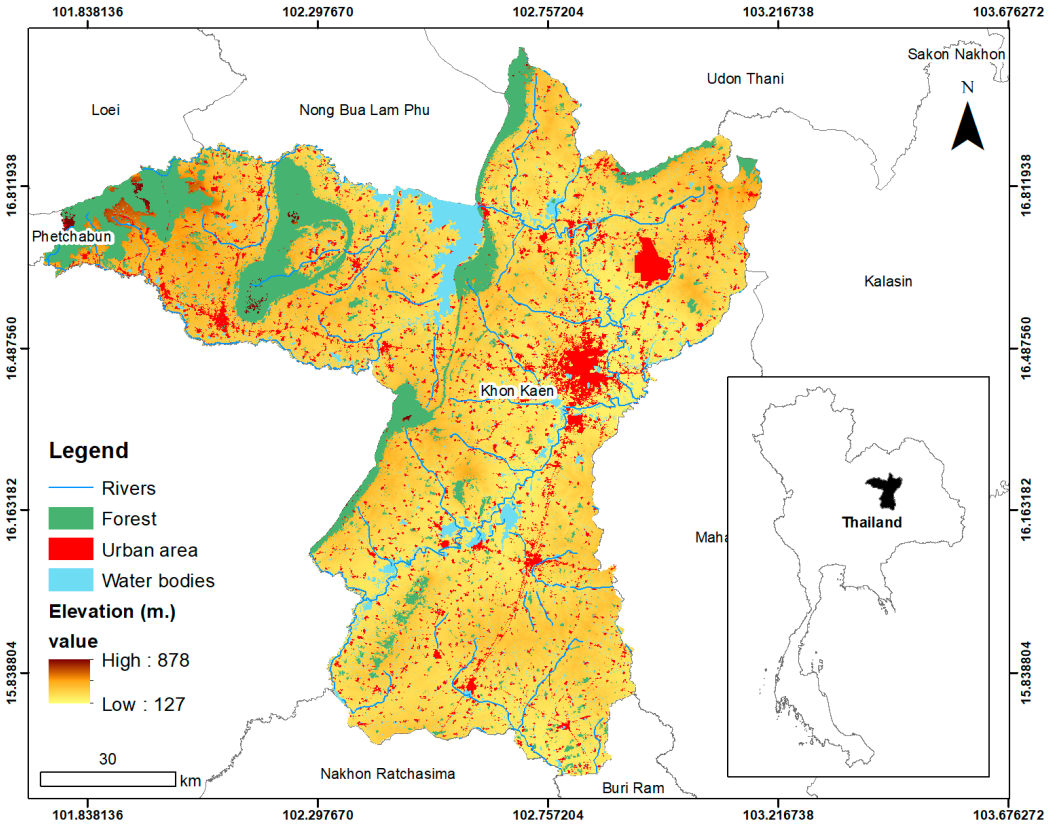

Figure 1. Location of the study area in Khon Kaen, Thailand (data source: Land Development Dept. 2020; SRTM DEM).

Khon Kaen has faced similar challenges of groundwater use and management as Vietnam (Hanoi and Ho Chi Minh City) [3] and Cambodia (Cambodia industrial zones). In the study area, groundwater extractions have been increasing, while GW levels have tended to drop in the last two decades [41]. Further, Khon Kaen was announced to be an emergent drought area by the Royal Thai government [46–48]. The issues have affected several stakeholders, especially agricultural users who have a higher demand for groundwater to mitigate drought risks [49]. Further, business owners have influenced other groups due to business expansion, and they extract large amounts of groundwater to support their economic activities [41].

Through groundwater management in a case study, the Department of Groundwater resources (DGR) reported that 2881 public wells and 2728 private wells were active in 2019. The highest extraction is concentrated in Mueang Khon Kaen [41]. However, shallow aquifer recharge is initiated by DGR and implemented at the subdistrict level [50]. Low institutional capacity and a lack of effective groundwater policies to control groundwater extraction as part of the top-down institutional arrangements are the GWG challenges in the study area [41]. Although a decentralization policy was implemented for GW management at the local scale, the policy is still weak due to a lack of knowledge of groundwater management regarding local governments [41]. Therefore, GWG needs to be strengthened to respond to GW management in the study area.

Data and methods for the adopted methodology are shown in Figure 2.

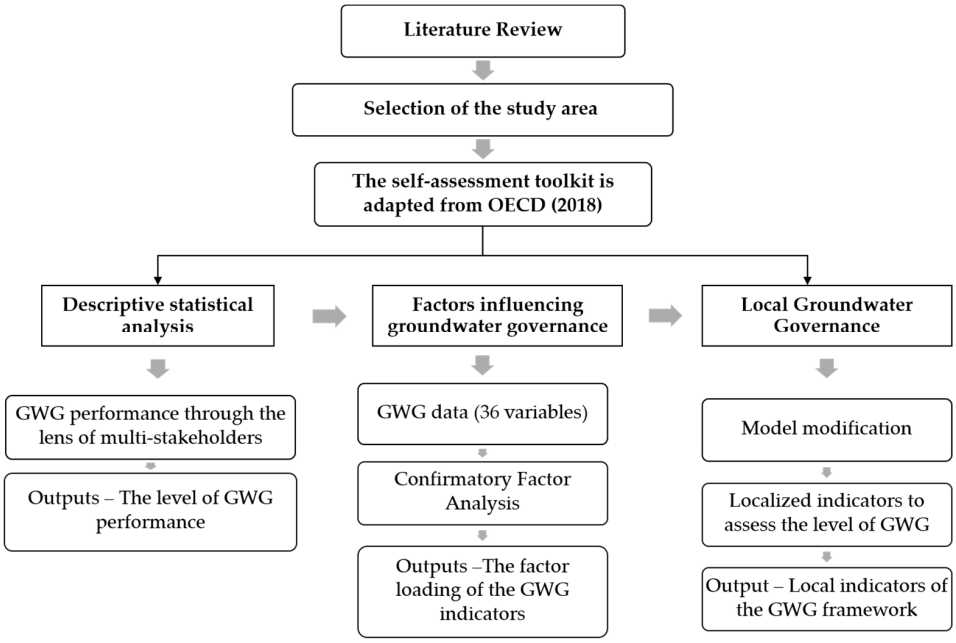

Figure 2. Data and method for the adopted methodology.

2.2. Data Collection

The self-assessment toolkit was adapted from the OECD (2018) [51], and we applied the indicators to assess the performance of groundwater governance at the local scale. The tools were distributed to groundwater stakeholders (i.e., national policymakers, policy practitioners, members of the private sector, local communities, GWG users, etc.) via email to reveal the current state of GWG performance according to the water governance principles. We sent the self-assessment to 150 stakeholders related to groundwater governance in Khon Kaen and received 81 self-assessments back.

2.3. Data Analysis

(1) Descriptive statistical analysis

The average score was calculated to present the level of groundwater governance in each dimension to reveal the key challenges of groundwater governance in Khon Kaen. We presented the 12 key indicators to illustrate the overall state of groundwater governance. We show the results of the assessment in detail of 36 sub-indicators under the dimensions of (i) effectiveness, (ii) efficiency, and (iii) trust and engagement. These findings are discussed through the lens of different stakeholders to understand the state of groundwater governance from extensive perspectives.

(2) Confirmatory Factor Analysis (CFA)

Confirmatory factor analysis (CFA) is a type of Structural Equation Modeling (SEM) used to test the relationships between observed variables which can be directly measured and latent variables which are variables that are a theoretical concept and cannot be directly observed [52]. In the CFA, we examined relations between the GWG indicators and GWG dimensions to understand the power of indicators in GWG.

A total of 36 indicators were added to the CFA model (Appendix A). The results of factors that have a key effect on groundwater governance performance are presented (Appendix B). The standardized factor loadings (β) and standard error (S.E.) are presented (Table 1). Table 1 shows the selected indicators based on the following criteria: if standardized factor loading (β) is higher than 0.7 (rule of thumb), it is low S.E. [53] in the local governance context (model fit index: Root Mean Square Error of Approximation (RMSEA) < 0.08, Comparative Fit Index (CFI) > 0.9, Tucker-Lewis Index (TLI) > 0.9, and Standardized Root Mean Squared Residual (SRMR) < 0.05) [53].

Table 1. Standardized factor loadings (β) and standard error (S.E.) of GWG indicators.

Dimension	Observed Variables	Label	Standardized Factor Loadings (β)	Standard Error (S.E.)
Effectiveness	GW related authorities	GRA	0.78	0.046
	Existing analytical reports about GW management	ERG	0.84	0.032
	Cooperation for GW management	CGM	0.77	0.043
	Institutions facilitated policies across ministries	IFP	0.78	0.041
	Policy coherence	PC	0.83	0.037
	Transparent policies	TP	0.80	0.041
	Institutional capacity	IC	0.82	0.039
Efficiency	GW information systems	GWI	0.82	0.037
	Economic policy instruments	EPI	0.80	0.042
	Legal framework	LF	0.79	0.043
	Public organization	PO	0.80	0.042
	Regulatory instruments	RI	0.80	0.042
	Bottom-up approach	BUA	0.84	0.034
	Science–policy interface	SPI	0.80	0.040
Trust and Engagement	Transparency of decision makers	TDM	0.83	0.039
	Corruption monitoring	CM	0.85	0.032
	Legal frameworks related to stakeholder participation	LSH	0.89	0.025
	Organization related to stakeholder participation	OSH	0.84	0.032
	Review stakeholder engagement challenges, processes, and outcomes	RSH	0.81	0.040
	Legal frameworks related GW user equality	LFU	0.85	0.036
	Trade-off across GW users	TU	0.82	0.042

3. Results

3.1. GWG Performance through the Lens of Different Stakeholders

The stakeholder profiles show 71.6% of stakeholders are in the age group of 18–30 years old. Most of them are female and the highest level of education is undergraduate. Stakeholders are policymakers, policy practitioners, and communities and civil societies.

The result shows the average score of self-assessment to see the whole picture of GWG performance among stakeholders. Overall, clear roles and responsibilities (mean = 3.85) are acknowledged as having the highest performance. However, integrity and transparency (mean = 3.45) have the lowest performance of GWG principles.

The insight of each stakeholder is presented in Figure 3. It is found that policymakers assessed the data and information as the key challenge of groundwater governance in Thailand (mean = 3.28). Policy practitioners acknowledged that trade-offs across users, rural and urban areas, and generations (mean = 3.37) are the low-prioritized principles. Further, communities and civil societies perceived that integrity and transparency (mean = 3.55) have low performance.

We summarized the level of GWG in Figure 4. The weakness of GWG performance is the key point to discuss in groundwater governance principles. Figure 4 shows the lowest average score of GWG principles highlighted by the pink color. The findings are useful and of primary consideration for related groundwater stakeholders, especially policymakers, to understand the weakness of GWG in Khon Kaen, Thailand. Local policies can be considered and developed based on these findings.

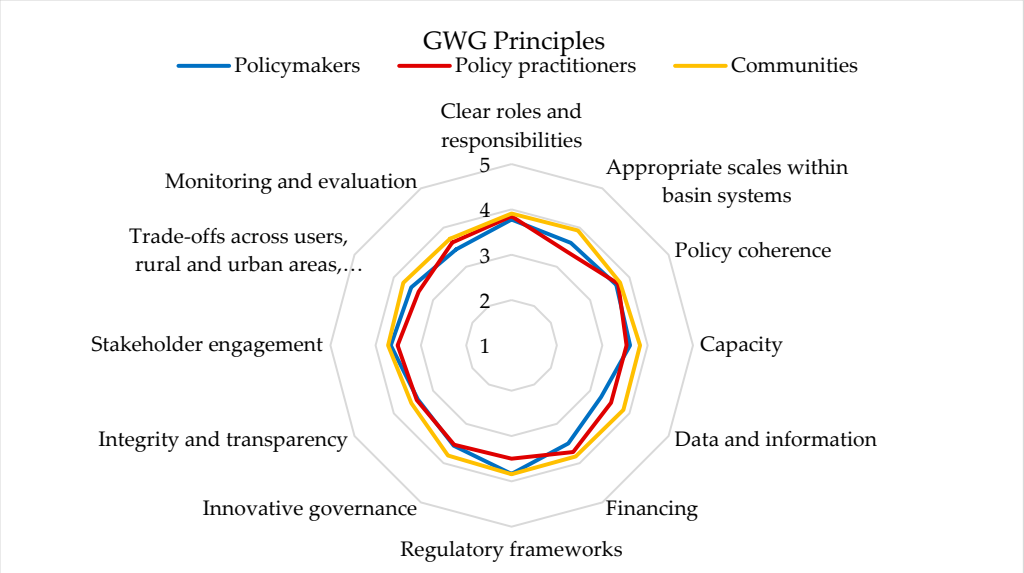

Figure 3. Key principles of the groundwater governance framework in different views.

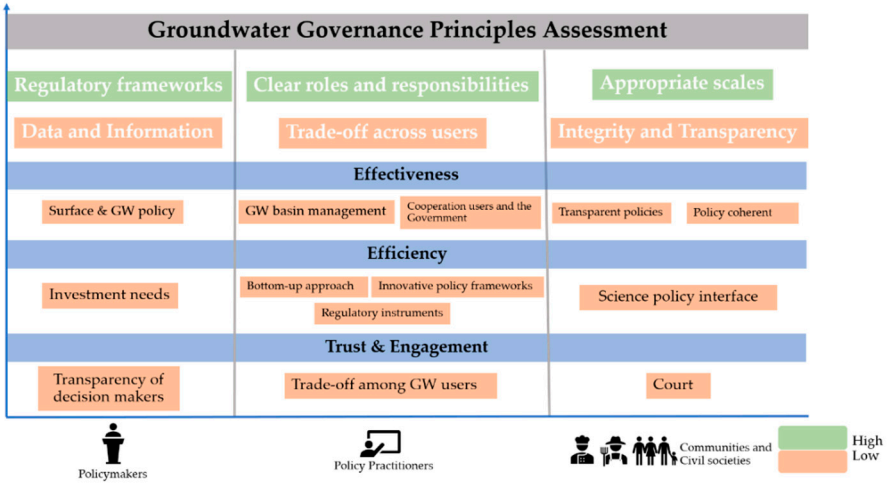

Figure 4. Groundwater Governance Principles Assessment.

Regarding the 12 principles, there are 36 sub-indicators of groundwater governance. These sub-indicators are discussed across three dimensions: (1) effectiveness, (2) efficiency, and (3) trust and engagement.

3.1.1. Effectiveness

Effectiveness refers to sustainable water policy goals and targets at different levels of governance. This dimension indicates whether policy goals implement and meet expected objectives [39]. Figure 5 presents the effectiveness of GWG in Khon Kaen, Thailand.

The scores of the 12 indicators are shown separately regarding stakeholder groups. Policymakers acknowledged that surface and groundwater policies are still at a low–average score (mean = 3.17), while policy practitioners indicated that GW basin management/aquifer management (mean = 3.30) and cooperation for GW management (mean = 3.30) are the challenges of the GWG effectiveness. Further, transparent policies (mean = 3.67) and policy coherence (mean = 3.67) are the key challenges for communities and civil societies in groundwater management at the local scale.

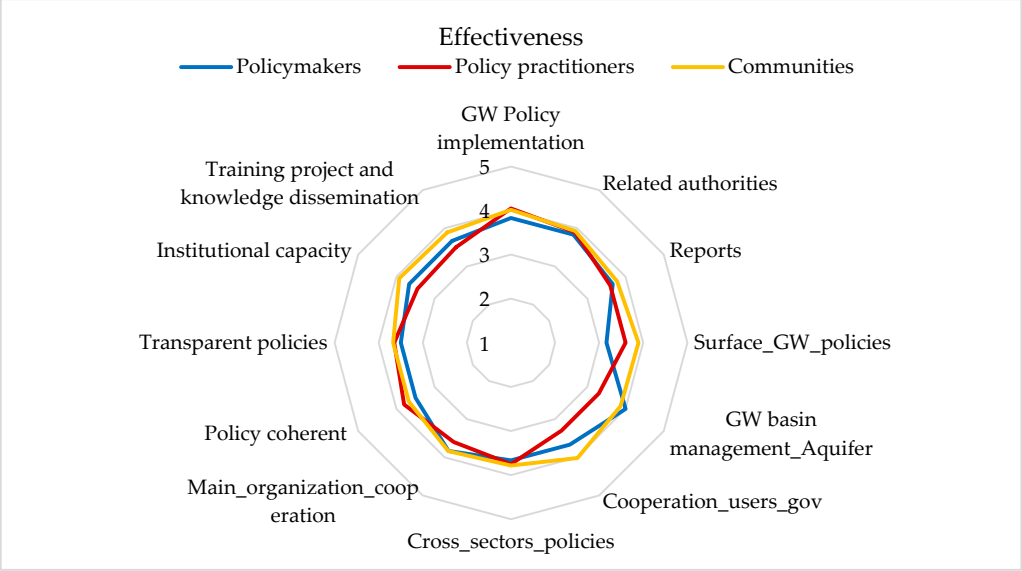

Figure 5. Effectiveness dimension of groundwater governance.

3.1.2. Efficiency

Efficiency indicates the benefits of sustainable water management to society in order to contribute to groundwater governance [39]. Figure 6 presents the efficiency of GWG. The average scores are presented based on 12 indicators. Investment needs (mean = 3) is the key challenge indicator of policymakers. Meanwhile, policy practitioners indicated that the bottom-up approach (mean = 3.45), innovative policy framework (mean = 3.45), and regulatory instruments (mean = 3.45) are the challenges of the efficiency dimension of GWG in Khon Kaen. Lastly, the science and policy interface (mean = 3.65) is the lowest priority of GWG through the lens of communities and civil societies.

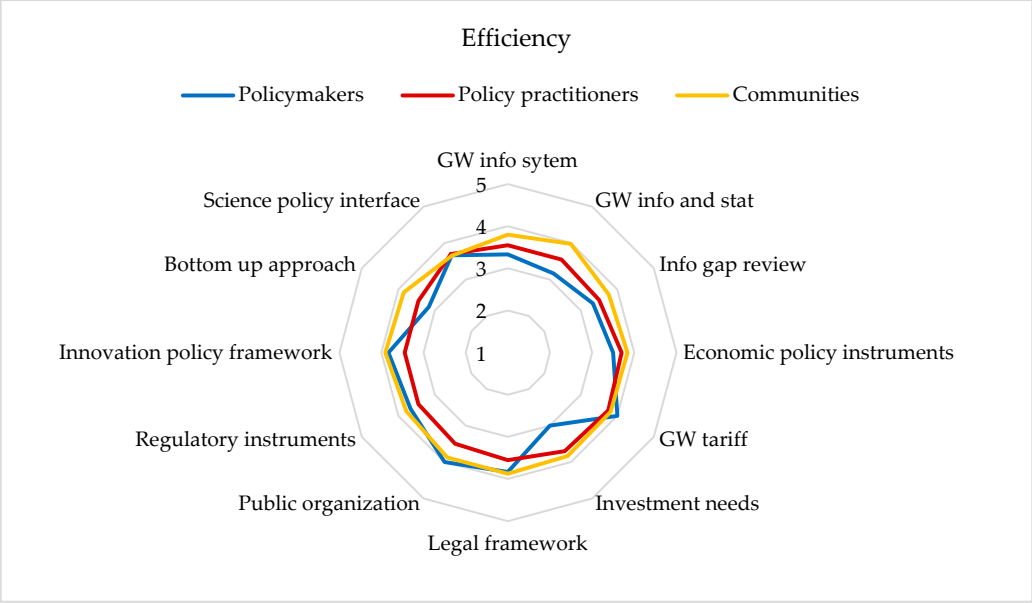

Figure 6. Efficiency dimension of groundwater governance.

3.1.3. Trust and Engagement

Trust and engagement signify the building of public confidence and ensuring inclusiveness of stakeholders through democratic legitimacy and fairness for society [39]. Figure 7

presents the level of the trust and engagement dimension of groundwater governance. It is revealed that the trade-off across groundwater users (mean = 3.10) has the lowest capacity, as assessed by the policy practitioners. Meanwhile, policymakers acknowledged that the transparency of decision makers still has the lowest performance among other indicators of the trust and engagement dimension (mean = 3.17).

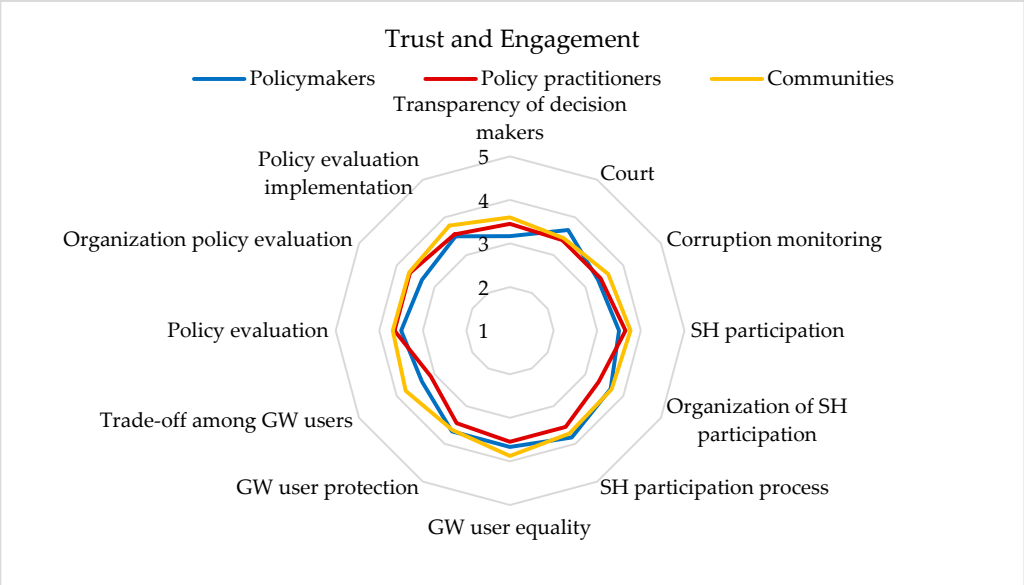

Figure 7. Trust and engagement dimension of groundwater governance.

However, communities and civil societies assessed that there is a lack of independent courts and supreme audit institutions related to GW (mean = 3.45).

3.2. Local GWG Model

Figure 8 presents the local GWG framework model tested by the CFA method. It was found that 21 indicators can strongly explain the 3 dimensions of GWG (Table 1). In this case, we highlighted the indicators which have the highest factor loadings in the model:

- Effectiveness—(i) existing analytical reports about GW management (ERG) (β = 0.85), (ii) policy coherence (PC) (β = 0.83), and (iii) institutional capacity (IC) (β = 0.82).
- Efficiency—(i) bottom-up approach (BUA) (β = 0.84) and (ii) GW information systems (GWI) (β = 0.82) have the highest factor loadings in this dimension. Both indicators can explain the efficiency (EFFI) of GWG in this case.
- Trust and engagement—(i) legal frameworks related to stakeholder participation (LSH) (β = 0.89) and (ii) corruption monitoring (CM) (β = 0.85) and (iii) legal frameworks related GW user equality (LFU) (β = 0.85) have strong explanation to the trust and engagement dimension.

All of the strong indicators can be prioritized in the GWG assessment in the study area to enhance the performance of the institutional capacity in this case.

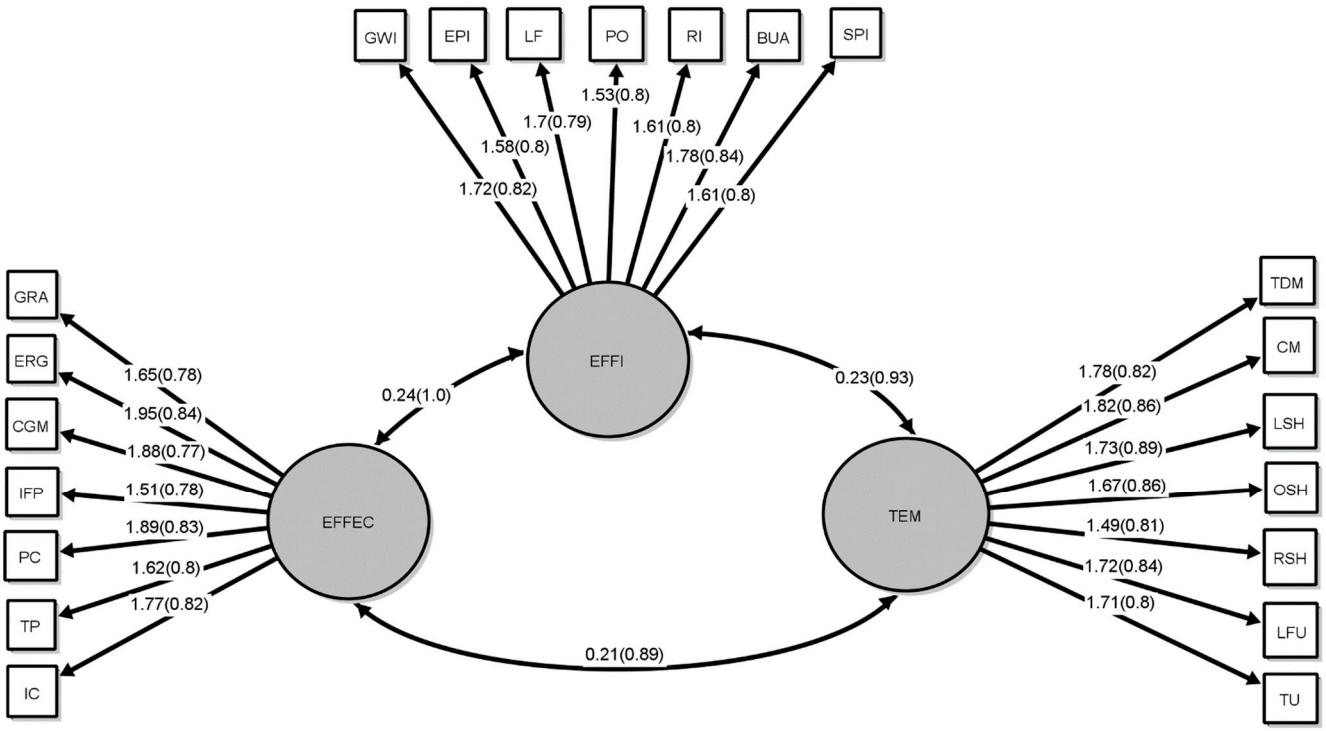

Figure 8. Confirmatory factor analysis of the relationships among GWG governance dimensions of Khon Kaen city from the stakeholders' perspectives.

4. Discussion

Groundwater governance presents the significance of multi-scales, multi-actors, and multi-tools to uncover the issues of groundwater resources. However, the local scale is still behind the national groundwater management [15,16,19], even though groundwater is presented as a local resource [54–56]. These findings are the key tools to overcome the challenges of GWG at the local scale. We analyzed and identified the appropriate sub-indicators through the lens of multi-stakeholders for facilitating policymakers in developing the framework of local groundwater governance in the specific context. Further, these findings can be developed and applied in other urbanizing cities in the LMR.

Water governance principles developed by the OECD [57] are not the panacea for water management worldwide [39]. Hence, appropriate indicators are necessary to modify them based on the specific context for addressing the effective management of groundwater resources [39]. Our findings are significant in addressing the challenges of groundwater at the local scale to propose and extend beyond transboundary aquifer management. Extensive literature has acknowledged that the capacity of the OECD Water Governance Framework is quite effective on a national scale [37,38]. However, groundwater is presented as a local resource, which means it is necessary for close monitoring and appropriate management at the local level [19] due to the invisible characteristics of the resources [1].

Our findings highlight that the clear role and responsibilities of the GW organizations is the strength of GWG. Conversely, integrity and transparency need to be addressed. Integrity and transparency play a key role in good groundwater governance and need to be ensured [58–60]. Thus, they should be prioritized in this case. This finding can be discussed with the GWG indicators corruption monitoring and transparency of decision makers under the integrity and transparency principle, which can strongly explain the trust and engagement dimension. It may imply how important it is to consider these indicators in the study area. However, data and information are the weaknesses of GWG through the lens of policymakers. The finding is in line with Ponok et al. [61]. They found that there is some limitation on water policy information disseminated in communities due to the complexity of water issues, and it is difficult for general people to understand this

information. Thus, data and information need to be digested and disseminated by the public and all stakeholders in groundwater governance to enhance the capacity of data and information in the GWG framework.

Keller and Hartmann [39] argued that the weakness of the OECD Water Governance Framework was revealed by the local governments (i.e., municipalities) in The Netherlands. They indicated that the indicators are quite abstract for implementation at the local scale. Municipalities did not understand the indicators, while water managers were willing to understand the indicators since they manage water closely. The weakness of the OECD Water Governance Framework principles has led to the investigation of the appropriate indicators for groundwater governance assessment at the local scale. In this case, we found strong indicators which explained the effectiveness, efficiency, and trust and engagement of groundwater governance in Khon Kaen, Thailand. The CFA model presents the key indicators which are strong to explain the GWG dimensions and fit in the context of groundwater governance in Khon Kaen. However, these indicators are based on stakeholders' assessment at the local scale, which is the significant purpose of our study to address the gaps of the OECD weaknesses. This approach may not be able to explain the governance at the macro-scale.

In this study, we aimed to address the policy challenges in groundwater management in Thailand. Ponok et al. [61] recommended that local water management should be studied to involve the community in water policy decision making at a higher level. Consequently, this study addressed this challenge through stakeholder involvement in GWG assessment. Additionally, the findings are the key target to ensure good groundwater governance at the local scale. Thus, the findings will be useful for the policymakers and practitioners to understand the key indicators that can explain the dimensions of effectiveness, efficiency, and trust and engagement in groundwater governance. Groundwater authorities can use these indicators to assess the current state of groundwater governance in Khon Kaen immediately, and these indicators can be applied to the LMR urbanizing cities [62] which have similar contexts as Khon Kaen, Thailand.

5. Conclusions

Massive national GW policies and regulations have been enforced in the last two decades; consequently, GW as a local resource in Khon Kaen tended to be highly extracted over time [41]. Therefore, local GWG should be urgently addressed to balance groundwater use in local communities. In our case, the findings highlight that integrity and transparency have the lowest performance of the GWG principles in the study area. Further, policymakers assessed the data and information as the key challenge of groundwater governance in Thailand, while policy practitioners acknowledged that trade-offs across users, rural and urban areas, and generations are indicators which have lacked priority. In another view, communities and civil societies reflected that integrity and transparency need to be strengthened in groundwater management.

Stakeholders agree that a clear role and responsibility are quite well performed in the study area, as communities and civil societies have quite positive perception due to several provisions of GW development projects. However, integrity and transparency regarding groundwater management should be addressed immediately to enhance the trust and engagement dimension in groundwater governance.

The indicators that explained the three dimensions are summarized as follows: (i) Existing analytical reports about GW management, policy coherence, and institutional capacity can strongly explain the effectiveness of GWG. (ii) The bottom-up approach and GW information systems can explain the efficiency of GWG in this case. (iii) Legal frameworks related to stakeholder participation, corruption monitoring, and legal frameworks related to GW user equality have strong explanations for the trust and engagement dimension.

These indicators will be useful for policymakers, policy practitioners, GW organizations, GW decentralized organizations (municipalities, Tambon administrative organizations (T.A.O.)), Non governmental organizations (NGOs), and communities and civil

societies who are interested in groundwater management in Khon Kaen. The indicators fit in the context of the study area; thus, they can use them and develop them further for GWG assessment in Khon Kaen. The findings could be linked from the GW challenges at the local scale to the national groundwater policy decision-making to cope with the dynamics of the invisible resources in Thailand and develop frameworks for transboundary aquifer management in the LMR cities [63,64].

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Research Ethics Committee) of ASIAN INSTITUTE OF TECHNOLOGY (protocol code RERC 2021/006 and 23 February 2021)." for studies involving humans.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

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

Appendix A

Table A1. The GWG indicators.

Dimension/Principles (Latent Variables)	Indicators (Observed Variables)	Label
Effectiveness		
1. Clear roles and responsibilities	1.1 The level of implementation of groundwater laws and regulations (Groundwaters Act 1992).	GPI
	1.2 Ministry of Natural Resources and Environment, Department of Groundwater Resources and Bureau of Groundwater Resources Region 4 (Khon Kaen) approached to manage groundwater resources in Khon Kaen.	GRA
	1.3 The existing of forms of analytical reports, regulatory impact assessments, or regulatory reviews about groundwater management, i.e., open stakeholder consultations.	ERG
2. Appropriate scales within basin systems	2.1 The level of implementation of integrated groundwater resource management policies and strategies, i.e., manage groundwater together with surface water.	IGM
	2.2 The existence and functioning of institutions managing groundwater at the hydrographic scale, i.e., groundwater basin management or aquifer management.	GWB
	2.3 The level of implementation of cooperation mechanisms for the management of water resources across groundwater users and levels of government from local to basin, regional, national and upper scales, i.e., shared data and information system, joint programs, joint projects or contracts, co-financing, or forms of multi-level dialogue.	CGW

Table A1. *Cont.*

Dimension/Principles (Latent Variables)	Indicators (Observed Variables)	Label
3. Policy coherence	3.1 Integrated policies, strategies, fostering coherence across sectors, while minimizing contradictory objectives and negative impacts.	CSP
	3.2 Institutions facilitated policies across ministries, managing trade-offs across water, environment, health, energy, agriculture, industry, spatial planning, and land use and other relevant sectors.	IFP
	3.3 The level of implementation of mechanisms to review barriers to policy coherence, i.e., outdated legislation, distortive subsidies, conflicting interests, competition between ministries, overlapping roles and responsibilities, lack of integrated planning, split incentives, or poor enforcement.	PC
4. Capacity	4.1 The level of implementation of policies, based on transparent professional and recruitment process of groundwater professionals independent from political cycles, i.e., presence of competent staff able to deal with technical and non-technical water-related issues across agencies and responsible ministries.	TP
	4.2 The level of capacity of responsible authorities in carrying out their duties and coping with groundwater challenges.	IC
	4.3 The level of implementation of educational and training programs for groundwater professionals, i.e., educational curricula, executive training, technical assistance, etc., to strengthen the capacity of groundwater institutions as well as stakeholders.	TKD
Efficiency		
5. Data and information	5.1 The existence and functioning of updated, timely shared, consistent, and comparable groundwater information systems, i.e., the status of groundwater resources, groundwater financing, environmental needs, socio-economic features, and institutional mapping.	GWS
	5.2 The existence of independent data and official groundwater-related statistics at regional and provincial level.	IGR
	5.3 The level of implementation of mechanisms to identify and review data gaps, overlaps, and unnecessary data, i.e., reviews, reports, and open consultations.	EPI
6. Financing	6.1 The level of implementation of governance arrangements which help groundwater institutions collect the necessary revenues to meet their mandates and drive sustainable groundwater and efficient behavior (i.e., the polluter pays or conservation pays).	IGT
	6.2 The functioning of groundwater institutions exists, and they are in charge of collecting groundwater revenues (taxes and tariffs) and allocating them in a transparent, efficient, and timely manner.	IN
	6.3 The level of implementation of identifying investment needs and funding gaps in terms of physical infrastructure and governance functions to achieve universal coverage of groundwater services.	LF
7. Regulatory frameworks	7.1 The level of implementation of a groundwater management regulatory framework to foster enforcement and compliance, achieve regulatory objectives in a cost-effective way, and protect the public interest.	PO
	7.2 The functioning of dedicated public institutions responsible for ensuring key regulatory functions for groundwater services and resource management.	RI
	7.3 The level of implementation of regulatory tools, i.e., evaluation and consultation mechanisms, to ensure that rules, institutions, and processes are fit-for-purpose, well-coordinated, cost-effective, transparent, non-discriminatory, participative and easy to understand and to enforce.	IPF

Table A1. *Cont.*

Dimension/Principles (Latent Variables)	Indicators (Observed Variables)	Label
8. Innovative governance	8.1 The level of implementation of policy frameworks and incentives fostering innovation in groundwater management practices and processes (i.e., pilots to draw lessons and share experience prior to generalizing a given reform or process at a larger scale).	BUA
	8.2 The functioning of institutions encouraging bottom-up initiatives, dialogue and social learning, and experimentation in groundwater management at different levels, i.e., promoting innovative ways to cooperate across government and stakeholders, pool resources, and upscale groundwater governance innovation.	SPI
	8.3 The level of implementation of knowledge and experience-sharing mechanisms to bridge between science, policy, and practice, i.e., multi-stakeholder co-creation processes and tools supporting decision-making processes based on scientific evidence, communicated for example through interactive maps, simulation models, etc.	TDM
Trust and Engagement		
9. Integrity and transparency	9.1 The level of implementation of legal and institutional frameworks which hold decision makers and stakeholders accountable on integrity and transparency also apply to groundwater management at large, i.e., the right to information, public procurement, in accordance with best international practice, as well as the transposition of applicable international conventions.	CM
	9.2 The functioning of independent courts and supreme audit institutions that can investigate groundwater-related offenses and safeguard the public interest.	LFSH
	9.3 The level of implementation of mechanisms to identify potential drivers of corruption and risks in all groundwater institutions at different levels, as well as other groundwater integrity and transparency gaps, i.e., multi-stakeholder approaches, social witnesses, or social monitoring.	OSH
10. Stakeholder engagement	10.1 The level of implementation of legal frameworks to engage stakeholders in the design and implementation of groundwater-related decisions, policies, and projects.	RSH
	10.2 The functioning of organizational structures and responsible authorities to engage stakeholders in groundwater-related policies and decisions, i.e., groundwater basin-based authorities, decentralized assemblies, governing boards, national or subnational groundwater councils or committees, as well as informal forms of community-based engagement or groundwater village councils.	LFU
	10.3 The level of implementation of mechanisms to diagnose and review stakeholder engagement challenges, processes, and outcomes, i.e., satisfaction surveys, standards, impact assessment, financial analysis, evaluation reports, or multi-stakeholder workshops/meetings.	OU
11. Trade-offs across users, rural and urban areas, and generations	11.1 The level of implementation of formal provisions or legal frameworks fostering equity across water users, rural and urban areas, vulnerable and marginalized groups, and next generations (i.e., human right to drinking water and sanitation, sustainable development goals, new urban agenda, and other forms of incentives).	TU
	11.2 The functioning of institutions to protect groundwater users, including vulnerable groups, addressing users' complaints and managing trade-offs when need be.	PFM
	11.3 The level of implementation of mechanisms or platforms to manage trade-offs across users, or transparent and evidence-based decision-making on trade-offs needed across people (i.e., public debates, rural–urban cooperation, partnerships, projects, etc.)	ICM

Table A1. *Cont.*

Dimension/Principles (Latent Variables)	Indicators (Observed Variables)	Label
12. Monitoring and evaluation	12.1 The level of implementation of policy frameworks promoting regular monitoring and evaluation of groundwater policy and governance in order to effectively guide decision making.	PME
	12.2 The functioning of institutions in charge of monitoring and evaluation of groundwater policies and practices to produce evidence-based assessment on the performance of groundwater management and governance to support decision making.	GPI
	12.3 The level of implementation of monitoring and evaluation mechanisms to measure to what extent groundwater policy fulfils the intended outcomes and groundwater governance frameworks are suitable (i.e., groundwater governance reviews, national or international assessment).	GRA

Source: Adapted from OECD (2015, 2018).

Appendix B

Table A2. Factor loading and standard error of 36 GWG indicators.

Latent Variables	Label	Observed Variables	Label	Standardized Factor Loadings (β)	Standard Error (S.E.)
Effectiveness	EFFEC	GW policy implementation	GPI	0.67	0.061
		GW related authorities	GRA	0.78	0.045
		Existing analytical reports about GW management	ERG	0.85	0.032
		Integrated groundwater resource management policies	IGM	0.77	0.046
		GW basin management/Aquifer management	GWB	0.55	0.048
		Cooperation for GW management	CGM	0.79	0.043
		Cross-sectoral policies	CSP	0.77	0.046
		Institutions facilitated policies across ministries	IFP	0.80	0.041
		Policy coherence	PC	0.82	0.037
		Transparent policies	TP	0.80	0.041
		Institutional capacity	IC	0.82	0.039
		Training and knowledge dissemination	TKD	0.76	0.048
Efficiency	EFFI	GW information systems	GWI	0.83	0.036
		GW information and statistical data	GWS	0.76	0.047
		Information gap reviews	IGR	0.77	0.046
		Economic policy instruments	EPI	0.81	0.040
		Institution-related GW tariff	IGT	0.75	0.049
		Investment needs	IN	0.74	0.051
		Legal framework	LF	0.79	0.043
		Public organization	PO	0.79	0.043
		Regulatory instruments	RI	0.81	0.040
		Innovation policy framework	IPF	0.72	0.053
		Bottom-up approach	BUA	0.83	0.035
		Science–policy interface	SPI	0.79	0.042
Trust and Engagement	TEM	Transparency of decision makers	TDM	0.83	0.037
		Courts investigate groundwater-related offenses and safeguard the public interest	CGW	0.75	0.050
		Corruption monitoring	CM	0.85	0.033
		Legal frameworks related to stakeholder participation	LFSH	0.89	0.025
		Organization related to stakeholder participation	OSH	0.84	0.034
		Review stakeholder engagement challenges, processes, and outcomes	RSH	0.81	0.040

Table A2. *Cont.*

Latent Variables	Label	Observed Variables	Label	Standardized Factor Loadings (β)	Standard Error (S.E.)
		Legal frameworks related to GW user equality	LFU	0.85	0.033
		Organization related to GW user protection	OU	0.77	0.047
		Trade-off across GW users	TU	0.82	0.038
		Policy frameworks promoting regular monitoring and evaluation of groundwater policy and governance	PFM	0.79	0.042
		Institutions in charge of monitoring and evaluation of groundwater policies	ICM	0.79	0.042
		Policy monitoring and evaluation	PME	0.76	0.047

References

1. IGRAC. Groundwater Overview: Making the Invisible Visible. UN-Water Category III Publication. 2018. Available online: https://www.unwater.org/publications/groundwater-overviewmaking-the-invisible-visible/ (accessed on 6 June 2022).
2. UNESCO. Science for a Water Secure World in a Changing Environment. IHP-IX: The Ninth Phase of the Intergovernmental Hydrological Programme 2022–2029. 2021. Available online: https://en.unesco.org/sites/default/files/draft_of_3rd_order_draft_of_ihp-ix_fra_ger.pdf (accessed on 6 June 2022).
3. Dam, R.A.; Jayakumar, R.; Surinkum, A.; Pavelic, P.; Johnston, R.; Ansems, N. Groundwater resources in the Greater Mekong Sub-region; collaborative resource management to increase resilience. In *Thematic Session "Geoscience for the Society", 52nd CCOP Annual Session Bangkok, Thailand*. 2016. Available online: http://waterlandexperts.nl/wp-content/uploads/2014/12/Groundwater-Lower-Mekong-Basin-Dam-et-al-2016.pdf (accessed on 6 June 2022).
4. Le Meur, M.; Le Phu, V.; Gratiot, N. What Is the Future of the Lower Mekong Basin Struggling against Human Activities? A Review. In *River Deltas-Recent Advances*; IntechOpen: London, UK, 2021.
5. Ngoc, N.T.M.; Lee, E.; Jayakumar, R. *Current Status and Issues of Groundwater in the Mekong River Basin*; Ha, K., Ed.; Korea Institute of Geoscience and Mineral Resources (KIGAM): Bangkok, Thailand, 2015; p. 121.
6. Shrestha, M.; Matheswaran, K.; Polapanich, O.U.; Piman, T.; Krittasudthacheewa, C. A Stakeholder-Centric Tool for Implementing Water Management Strategies and Enhancing Water Cooperation (SDG 6.5) in the Lower Mekong Region. In *Water, Climate Change, and Sustainability*; 2021; pp. 239–256. Available online: https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119564522.ch16 (accessed on 6 June 2022).
7. Xiao, H.; Tang, Y.; Li, H.; Zhang, L.; Ngo-Duc, T.; Chen, D.; Tang, Q. Saltwater intrusion into groundwater systems in the Mekong Delta and links to global change. *Adv. Clim. Chang. Res.* **2021**, *12*, 342–352. [CrossRef]
8. Gupta, A.D.; Shrestha, S.; Nguyen, T.P.L.; KC, S. Towards sustainable groundwater management of transboundary aquifers in the Lower Mekong region. In Proceedings of the THA 2022 International Conference, Online, 26–28 January 2022. Available online: http://project-wre.eng.chula.ac.th/aseanacademicnetwork/files/THA2022/TC/TC-312S.pdf (accessed on 6 June 2022).
9. Conti, K.I. Norms in Multilevel Groundwater Governance and Sustainable Development. Ph.D. Thesis, University of Amsterdam, Amsterdam, The Netherlands, 2017; *Unpublished*.
10. Linton, J.; Brooks, D.B. Governance of transboundary aquifers: New challenges and new opportunities. *Water Int.* **2011**, *36*, 606–618. [CrossRef]
11. Faysse, N.; Hartani, T.; Frija, A.; Tazekrit, I.; Zairi, C.; Challouf, A. Agricultural use of groundwater and management initiatives in the Maghreb: Challenges and opportunities for sustainable aquifer exploitation. In *AFDB Economic Brief*; African Development Bank: Tunis, Tunisia, 2011; pp. 1–24.
12. Jerbi, H.; Massuel, S.; Leduc, C.; Riaux, J.; Tarhouni, J. To What Extent Can Groundwater Uses Affect Long Term Sustainable Exploitation Schemes? Case Study of the Bouhefna-Haffouz Aquifer System (Central Tunisia). In *Recent Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions. EMCEI 2017. Advances in Science, Technology & Innovation (IEREK Interdisciplinary Series for Sustainable Development)*; Springer: Cham, Switzerland, 2018. [CrossRef]
13. Bruns, B. Polycentric Solutions for Groundwater Governance in Sub-Saharan Africa: Encouraging Institutional Artisanship in an Extended Ladder of Participation. *Water* **2021**, *13*, 630. [CrossRef]
14. Raja Omar, R.A.A.; Zainuddin, A.; Yusof, R.; Roslan, N.H.; Mickey, A.C. Enhancing Community Groundwater Governance (CGG) model towards innovation Via Good Governance Actors' Partnership (GGAP). In Proceedings of the 8th International Conference on Public Policy and Social Science (ICoPS) 2021, Lake Tahoe, NV, USA, 12–16 September 2021.
15. De Stefano, L.; Welch, C.; Urquijo, J.; Garrick, D. Groundwater governance in the Rio Grande: Co-evolution of local and intergovernmental management. *Water Altern.* **2018**, *11*, 824–846.
16. Molle, F.; López-Gunn, E.; van Steenbergen, F. The local and national politics of groundwater overexploitation. *Water Altern.* **2018**, *11*, 445.
17. Molle, F.; Closas, A. Why is state-centered groundwater governance largely ineffective? A review. *Wiley Interdiscip. Rev. Water* **2020**, *7*, e1395. [CrossRef]

18. Pietersen, K.; Beekman, H.E.; Holland, M. South African groundwater governance case study. Final report prepared for the World Bank economic and sector analysis "Improving groundwater governance: The political economy of groundwater policy and institutional reforms. In *Partnership with the South African Dept. of Water Affairs and the WRC*; 2011. Available online: https://www.wrc.org.za/wp-content/uploads/mdocs/KV%20273-11.pdf (accessed on 6 June 2022).
19. Taher, T.; Bruns, B.; Bamaga, O.; Al-Weshali, A.; Van Steenbergen, F. Local groundwater governance in Yemen: Building on traditions and enabling communities to craft new rules. *Hydrogeol. J.* **2012**, *20*, 1177–1188. [CrossRef]
20. Zwarteveen, M.; Kuper, M.; Olmos-Herrera, C.; Dajani, M.; Kemerink-Seyoum, J.; Frances, C.; Beckett, L.; Lu, F.; Kulkarni, S.; Kulkarni, H.; et al. Transformations to groundwater sustainability: From individuals and pumps to communities and aquifers. *Curr. Opin. Environ. Sustain.* **2021**, *49*, 88–97. [CrossRef]
21. Zwickle, A.; Feltman, B.C.; Brady, A.J.; Kendall, A.D.; Hyndman, D.W. Sustainable irrigation through local collaborative governance: Evidence for a structural fix in Kansas. *Environ. Sci. Policy* **2021**, *124*, 517–526. [CrossRef]
22. Calliera, M.; Capri, E. Multi-actor approaches and engagement strategies to promote the adoption of best groundwater management practices. *Curr. Opin. Environ. Sci. Health* **2022**, *27*, 100351. [CrossRef]
23. Wijnen, M.; Augeard, B.; Hiller, B.; Ward, C.; Huntjens, P. *Managing the Invisible: Understanding and Improving Groundwater Governance*; World Bank: Washington, DC, USA, 2012.
24. Afruzi, A.; Zare Abyaneh, H.; Abdolabadi, H. Local strategies to manage groundwater depletion under climate change scenarios—A case study: Hamedan-Bahar Plain (Iran). *Arab. J. Geosci.* **2021**, *14*, 1–18. [CrossRef]
25. Dumont, A. *Acting Together for the Sustainable Use of Water in Agriculture: Proposals to Prevent the Deterioration and Overexploitation of Groundwater*; Éditions AFD: Paris, France, 2021.
26. Mechlem, K. Groundwater Governance: The Role of Legal Frameworks at the Local and National Level—Established Practice and Emerging Trends. *Water* **2016**, *8*, 347. [CrossRef]
27. Mumma, A.; Lane, M.; Kairu, E.; Tuinhof, A.; Hirji, R. *Kenya Groundwater Governance Case Study*; Water Papers; World Bank: Washington, DC, USA, 2011. Available online: https://openknowledge.worldbank.org/handle/10986/17227 (accessed on 13 July 2022).
28. Tsuyuguchi, B.B. A Social-Ecological Systems Analysis of the Governance of Alluvial Aquifers in the Brazilian Semi-Arid Region: The Case of Sume. Ph.D. Thesis, Universidade Federal de Campina Grande, Paraíba, Brasil, 2021.
29. Megdal, S.B.; Gerlak, A.K.; Varady, R.G.; Huang, L.Y. Groundwater governance in the United States: Common priorities and challenges. *Groundwater* **2015**, *53*, 677–684. [CrossRef]
30. Closas, A.; Villholth, K.G. Groundwater governance: Addressing core concepts and challenges. *Wiley Interdiscip. Rev. Water* **2020**, *7*, e1392. [CrossRef]
31. Molle, F.; Closas, A. Groundwater metering: Revisiting a ubiquitous 'best practice'. *Hydrogeol. J.* **2021**, *29*, 1857–1870. [CrossRef]
32. Cheyasit, N.; Kamkiew, W.; Phetsatit, P. The Components of Administration in Accordance with Good Governance of the Department of Groundwater Resources. *J. Soc. Dev.* **2019**, *21*, 196–215.
33. Foster, S. Thailand: Strengthening capacity in groundwater resources management. In *World Bank Case Profile Collection*; World Bank: Washington, DC, USA, 2008; Volume 1. Available online: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/521371468308952444/thailand-strengthening-capacity-in-groundwater-resources-management (accessed on 13 July 2022).
34. Piyapong, J.; Thidarat, B.; Jaruwan, C.; Siriphan, N.; Passanan, A. Enhancing citizens' sense of personal responsibility and risk perception for promoting public participation in sustainable groundwater resource management in Rayong Groundwater Basin, Thailand. *Groundw. Sustain. Dev.* **2019**, *9*, 100252. [CrossRef]
35. Tanaka, T. Groundwater governance in Asia: Present state and barriers to implementation of good governance. *Proc. Int. Assoc. Hydrol. Sci.* **2014**, *364*, 470–474. [CrossRef]
36. Sarami Froushani, M.; Balal, H.; Movahedi, R. Evaluation of Groundwater Resources Governance Indicators in Iran's Agricultural Sector: Application of the OECD Governance Framework in the Hamadan-Bahar Plain. *Iran. J. Agric. Econ. Dev. Res.* **2021**, *52*, 591–615. [CrossRef]
37. Jetoo, S. An Assessment of the Baltic Sea action plan (BSAP) using the OECD principles on water governance. *Sustainability* **2019**, *11*, 3405. [CrossRef]
38. Romano, O.; Akhmouch, A. Water governance in cities: Current trends and future challenges. *Water* **2019**, *11*, 500. [CrossRef]
39. Keller, N.; Hartmann, T. OECD water governance principles on the local scale–an exploration in Dutch water management. *Int. J. River Basin Manag.* **2020**, *18*, 439–444. [CrossRef]
40. Johns, C. Water governance indicators in theory and practice: Applying the OECD's water governance indicators in the North American Great Lakes region. *Water Int.* **2021**, *46*, 976–999. [CrossRef]
41. Muenratch, P.; Nguyen TP, L.; Shrestha, S.; Chatterjee, J.S.; Virdis, S.G. Governance and policy responses to anthropogenic and climate pressures on groundwater resources in the Greater Mekong Subregion urbanizing cities. *Groundw. Sustain. Dev.* **2022**, *18*, 100791. [CrossRef]
42. Chantawongso, P. The 1:50,000 Groundwater Map and Hydrogeological Map of Khon Kaen, Thailand. Technical Report of the CCOP-GSJ Groundwater Project Phase III, 2019; pp. 162–170. Available online: https://www.gsj.jp/data/ccop-gsj/CCOP-GSJ_DOC_GW9_2019.pdf (accessed on 2 July 2022).

43. Sudhipongpracha, T.; Dahiya, B. City Profile: Khon Kaen, Thailand. *Environ. Urban. ASIA* **2019**, *10*, 271–289. Available online: https://www.adb.org/sites/default/files/publication/185008/urban-development-gms.pdf (accessed on 1 August 2022). [CrossRef]
44. Thilakarathne, M.; Sridhar, V. Characterization of future drought conditions in the Lower Mekong River Basin. *Weather Clim. Extrem.* **2017**, *17*, 47–58. [CrossRef]
45. Artlert, K.; Chaleeraktrakoon, C. Modelling and analysis of rainfall processes in the context of climate change for Mekong, Chi, and Mun River Basins (Thailand). *J. Hydro-Environ. Res.* **2013**, *7*, 2–17. [CrossRef]
46. DDPM. The Summary of the Drought Situation in the Responsible Areas of Disaster Prevention and Mitigation Regional Center 6 (DPMRC 6, Khon Kaen). 2016. Available online: http://portal.disaster.go.th/portal/public/index.do#dataTable (accessed on 7 June 2021).
47. Sinha, S.; Tripathi, N.K. Assessing the challenges in successful implementation and adoption of crop insurance in Thailand. *Sustainability* **2016**, *8*, 1306. [CrossRef]
48. Van Dau, Q.; Kuntiyawichai, K.; Suryadi, F. Drought severity assessment in the lower Nam Phong River Basin, Thailand. *Songklanakarin J. Sci. Technol.* **2018**, *40*, 985–992.
49. DGR. The Report of the Strategies of 20 Years (2017–2036) Groundwater Management in Thailand. Report. 2017. Available online: http://www.dgr.go.th/th/download/38 (accessed on 18 November 2021).
50. DGR. DGR Annual Report 2021. Report. 2021. Available online: http://www.dgr.go.th/th/download/152 (accessed on 1 September 2022).
51. OECD. *Implementing the OECD Principles on Water Governance: Indicator Framework and Evolving Practices, OECD Studies on Water*; OECD Publishing: Paris, France, 2018. [CrossRef]
52. Rodríguez-Santero, J.; Torres-Gordillo, J.J.; Gil-Flores, J. Confirmatory factor analysis of a questionnaire for evaluating online training in the workplace. *Sustainability* **2020**, *12*, 4629. [CrossRef]
53. Elias, S.; Ismail, N.; Basri, B.S. The Confirmatory Factor Analysis (CFA) of E-Procurement Adoption Model in Malaysian Construction Industry. *Int. J. Acad. Res. Bus. Soc. Sci.* **2022**, *12*, 623–635. [CrossRef]
54. Foster, S.; Chilton, J.; Nijsten, G.J.; Richts, A. Groundwater—A global focus on the 'local resource'. *Curr. Opin. Environ. Sustain.* **2013**, *5*, 685–695. [CrossRef]
55. Foster, S.; Garduño, H. Groundwater-resource governance: Are governments and stakeholders responding to the challenge? *Hydrogeol. J.* **2013**, *21*, 317–320. [CrossRef]
56. Megdal, S.B. Invisible water: The importance of good groundwater governance and management. *NPJ Clean Water* **2018**, *1*, 15. [CrossRef]
57. OECD. *OECD Principles on Water Governance*; OECD Publishing: Paris, France, 2015. Available online: https://www.oecd.org/cfe/regionaldevelopment/OECD-Principles-on-Water-Governance.pdf (accessed on 11 July 2022).
58. Jasechko, S.; Perrone, D. Global groundwater wells are at risk of running dry. *Science* **2021**, *372*, 418–421. [CrossRef]
59. Jiménez, A.; Saikia, P.; Giné, R.; Avello, P.; Leten, J.; Liss Lymer, B.; Schneider, K.; Ward, R. Unpacking water governance: A framework for practitioners. *Water* **2020**, *12*, 827. [CrossRef]
60. Neto, S.; Camkin, J.; Fenemor, A.; Tan, P.L.; Baptista, J.M.; Ribeiro, M.; Schulze, R.; Stuart-Hill, S.; Spray, C.; Elfithri, R. OECD principles on water governance in practice: An assessment of existing frameworks in Europe, Asia-Pacific, Africa and South America. *Water Int.* **2018**, *43*, 60–89. [CrossRef]
61. Ponok, N.; Arunrat, N.; Pumijumnong, N.; Hamasaki, H.; Sereenonchai, S. Challenges of water policy involvement of the community in the East Coast River Basin of Thailand. *Water* **2021**, *13*, 3395. [CrossRef]
62. Ohgaki, S. *Sustainable Groundwater Management in Asian Cities*; Final Report; Institute for Global Environmental Strategies (IGES): Tokyo, Japan, 2007. Available online: https://www.iges.or.jp/en/pub/sustainable-groundwater-management-asian-0/en (accessed on 15 July 2022).
63. Friend, R.; Thinphanga, P. Urban water crises under future uncertainties: The case of institutional and infrastructure complexity in Khon Kaen, Thailand. *Sustainability* **2018**, *10*, 3921. [CrossRef]
64. Nguyen, T.P.L.; Sean, C. Do climate uncertainties trigger farmers' out-migration in the Lower Mekong Region? *Curr. Res. Environ. Sustain.* **2021**, *3*, 100087. [CrossRef]