



Analysis of Important Factors of Groundwater Availability in Narmada District, West Lombok Regency, West Nusa Tenggara Province

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Abstract: Groundwater utilization in Narmada Regency has increased significantly while its availability is decreasing. This requires management to maintain clean water supply. Research on variables that affect groundwater availability and interactions between them therefore needs to be carried out. Firstly, a Focused Group Discussion (FGD) was held to identify the variables considered important in groundwater management. Respondents then filled out a set of questionnaires expressing their perceptions about the importance of these variables. The variables were grouped into four dimensions namely Input, Output, Domestic Output and non-Domestic Output. Next, respondents' responses were analyzed using the MICMAC structural analysis tool to sort out variables regarding their influence and dependence as well as evaluating the interactions that occurred between the variables. The results showed that there are 7 key variables i.e. Central Government Regulations (PPP), Local Government Regulations (PPD), Rainfall (HUJ), Groundwater Basin (CAT), Forest (HUT), Climate (IK), Number of Population (JP) and 1 regulatory variable i.e. Geological variable (GEO) in the groundwater availability system in Narmada District. Also, there exist structured and systematic interactions between dimensions in the system. The results of this study are useful as input in making appropriate regulations for sustainable groundwater in the study area.

Keywords: Groundwater conservation; Groundwater management; Lombok island; MICMAC analysis, Water springs

Introduction

Groundwater is a vital water resource supplying 96% of the world's freshwater (Kheirandish et al., 2020), a source of drinking water for around 2.4 billion people on Earth (Pandey et al., 2023), and has been used 25% for consumptive use worldwide, of which 40% is used for

industrial purposes and 50% for drinking (Akurugu et al., 2022). However, groundwater is also vulnerable to drought and may become a big problem later (Jeelani et al., 2021). This is also happening in Narmada District, West Lombok Regency, Indonesia. The district has abundant groundwater resources distributed in 28 points of water spring locations. The total water discharge from these 28 points is up to 3,629.23

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liters/second (NT-1, 2022). In this region, groundwater has been used for various purposes such as irrigation for agricultural activities, drinking water sources, bottled mineral water industry, and tourism.

The distribution of groundwater use originating from Narmada Regency as a source of drinking water is managed by PTAM Giri Menang. This groundwater use has the potential to increase along with the increase in the number of PTAM Giri Menang customers. Groundwater in Narmada District is also used as a source of raw water for the bottled water industry. The extraction of groundwater as bottled drinking water is carried out by several Bottled Drinking Water Companies (AMDK).

Another factor increasing groundwater needs is the establishment of tourism as a flagship program for the villages in Narmada District (Kecamatan Narmada, 2019), as an implementation of the Regional Regulation (Perda) of West Nusa Tenggara Province Number 7 Year 2013 on the Regional Tourism Development Master Plan (Ripparda) of NTB Province. This, in turn, encourages the Regional Government of West Lombok Regency to commit developing sustainable tourism by enacting of West Lombok Regent Regulation Number 41 of 2016 concerning Tourism Village Areas in West Lombok Regency.

Rapid population growth is also expected to put more pressure on groundwater availability in Narmada sub-district. West Lombok Regency's Bureau of Statistics (BPS) data for 2023 shows that Narmada District is the largest population contributor compared to other districts in West Lombok Regency (BPS Prov. NTB, 2023). Population growth is believed to contribute directly to the increasing demand for water in recent decades in addition to urbanization, industrialization, and agriculture (Di Curzio et al., 2021; Li et al., 2022; Steinman et al., 2022). Further Cook et al. (2022) asserts that global groundwater extraction has increased significantly over the past 50 years, largely due to population growth.

The high utilization of groundwater in Narmada District is a form of high dependence from the people in the region on groundwater. While it is undeniable that groundwater is an important resource for many terrestrial, riparian, aquatic ecosystems and species as well as for human communities (Saito et al., 2021), excessive exploitation of groundwater, without adequate research can trigger problems that threaten the availability of groundwater (Gholami et al., 2023). It is, therefore, critical to preserve and responsibly manage groundwater resources (Ninasafitri et al., 2023).

Previous studies have examined the increase in groundwater utilization in Narmada District. Kemulandana et al. (2021) stated that surplus of

groundwater discharge in Narmada district is expected to decrease from 154 liters/second in 2021 to 113.79 liter/second in 2026. In line with this, Yamin (2021) further elaborated that in 2025 water demand in Narmada district reaches 12.20 liters/second with water availability of 14.44 liters/second. It is clear that while potable water needs in the study area are expected to increase due to the growth of bottled water industries and local population, the discharge of spring water to fulfill these needs has a tendency to decrease mainly as an effect of urbanization.

Past studies have also been conducted in their respective study areas. Dianty et al. (2022), Prayitno et al. (2023) and Safitri et al. (2024), for example, accomplished the studies on the feasibility of groundwater and spring water as sources of potable water. Groundwater potency has been investigated by Angglena et al. (2022) and Daruwati et al. (2023), while those by Waangsir et al. (2023) and Lensoni et al. (2023) were focused on treatment of the quality aspects. Last but not least, Karimah et al. (2022) studied the direction of landslides by utilizing the geoelectrical resistivity data.

Taking into account the research that has been accomplished, little attention has been given to groundwater management in a wider sense. Such management should be based on multiple purposes, spanning for the future, considering quantity and quality. Groundwater availability is one aspect included in groundwater management and it is, therefore, necessary to identify variables that affect the groundwater availability system in Narmada Regency. Identification of these variables is felt urgently because considering the decreasing discharge of spring water, while water needs are expected to increase. The important value of this study lies in identifying important factors in groundwater availability, as well as the relationship between these factors which is believed to contribute to comprehensive groundwater management and support groundwater availability in Narmada District. Once the important variables have been identified, they can be used as a base in developing sustainable groundwater management.

The aim of this research is to identify the important variables affecting groundwater availability in Narmada district. To achieve this aim, the objectives are (1) to identify the variables considered important to groundwater availability in the study area by the stakeholders through a Focused Group Discussion (FGD), (2) to develop a set of questionnaire listing the variables mentioned previously, (3) to collect the respondents' perception about the dominant variables in groundwater availability, (4) to conduct structural

analysis by MICMAC to classify the variables regarding their dependency and influence.

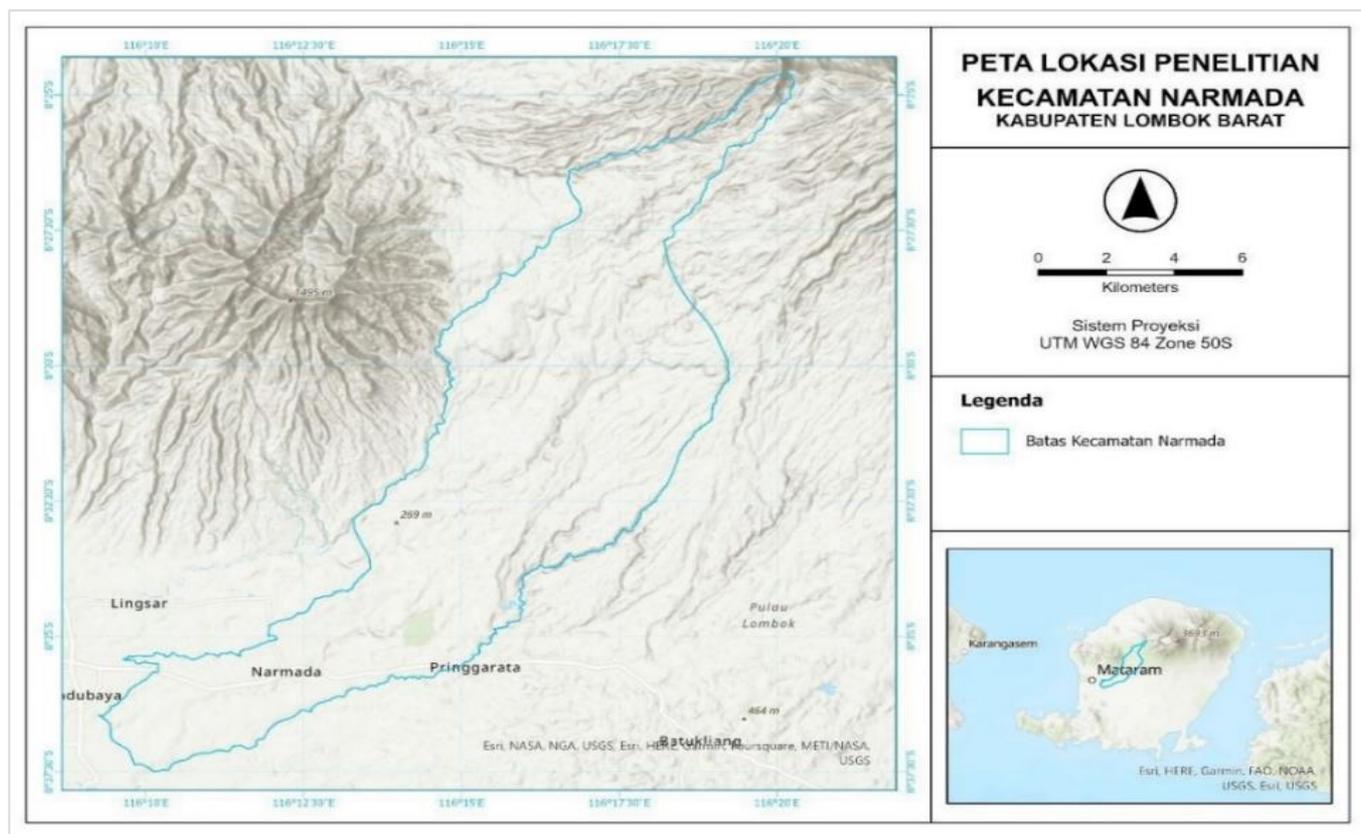


Figure 1. Map of research location

Method

The place of research is carried out in Narmada District, West Lombok Regency, from 01 May to 30 September 2023. The data used are primary and secondary data. Primary data were obtained through questionnaires and Focus Group Discussions (FGDs), which included opinions from government representatives such as Office of Environment and Forestry (DLHK), Governmental Agency of Agriculture, West Lombok Regional Planning Development Agency, staff at Narmada District Office, Narmada local people, academics and researchers teaching and studying water resources at public and private universities in Mataram, West Nusa Tenggara River Basin Office and staff of PTAM Giri Menang. The respondents were firstly gathered in a Focused Group Discussion (FGD) to identify the variables considered important in groundwater availability. They were then individually asked about their perception on the importance and dependence between these variables, by assigning 0 for not important or independent, 1 for weak influence or weak dependence, 2 for moderate importance or weak dependence and 3 for strong influence or strong

dependence. Meanwhile, the secondary data is collected through the elaboration of journals and the results of studies related to research.

The main method used to evaluate the respondents' comprehension is structural analysis by MICMAC which can also be used to analyse mutual interactions between variables (Ahmad et al., 2019; Khan et al., 2022).

Table 1. Variable Groundwater Availability System in Narmada District (Primary Data, 2023)

Dimension	Variable	
	Long Label	Short Label
Input	Forest	HUT
	Rain	HUJ
	Climate	IKL
	Springs	MA
	Geological	GEO
	Groundwater basin	CAT
Domestic output	Population	JP
Non domestic output	Agriculture	PERT
	Tourism	WIS
	Water bottled companies	AMDK
	Water drinking regional companies	PDAM
	Industry	IND

Dimension	Variable	
	Long Label	Short Label
Policy	Central government regulations	PPP
	Local government regulations	PPD

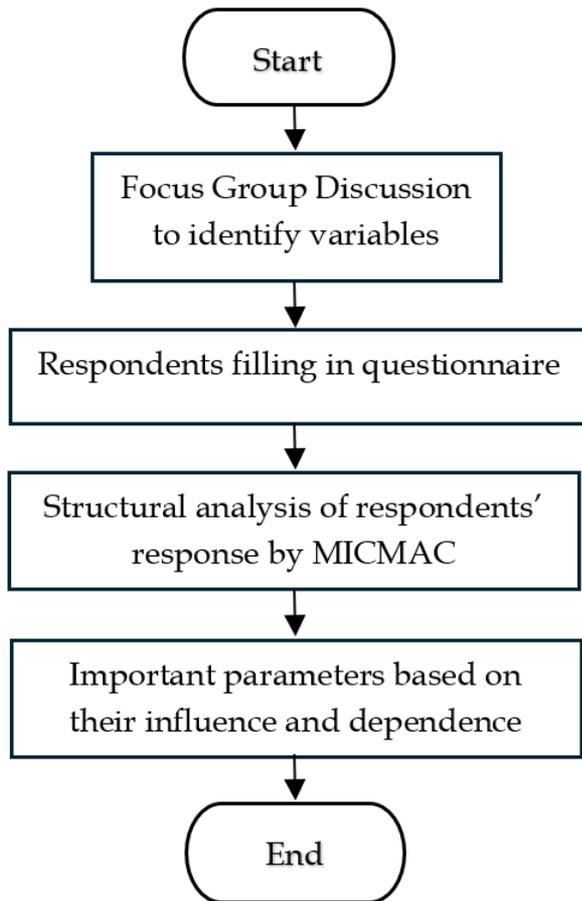


Figure 2. Flow chart of the study

The MICMAC structural analysis technique attempts to find the most important variables in a system and their roles. The three-step MICMAC analysis process includes:

Definition of System Variables

System variables are determined using expert opinion, brainstorming, and literature review. The result is data that hasn't been classified in a dimension.

Identify Relationships between Variables

The second stage is the step of determining the relationship between variables that have been identified.

Identify Key Variables

In the last step, the result of using MICMAC software builds influence-dependencies (Hamidi et al., 2021).

Result and Discussion

The initial stage after determining the variables of the groundwater availability system in Narmada District is to carry out an assessment process using the Matrix of Direct Influence (MDI). The Matrix of Direct Influence is one of the MICMAC software analysis processes that serves as a tabulation of variable mappings that have been assessed by stakeholders.

Table 2. Matrix of Direct Influence (MDI)

VARS	HUT	HUJ	IK	MA	GEO	CAT	JP	PERT	WIS	AMDK	PDAM	PPP	PPD	IND
HUT	0	2	3	2	1	1	2	1	2	2	2	2	2	2
HUJ	3	0	3	3	2	3	1	3	2	3	3	1	1	0
IK	0	3	0	3	1	2	1	3	1	2	2	2	2	0
MA	0	0	0	0	1	2	2	3	3	3	3	2	2	2
GEO	0	0	0	3	0	3	1	1	3	3	2	2	2	1
CAT	3	0	0	3	3	0	3	3	3	3	3	1	1	1
JP	3	0	1	3	3	0	0	3	1	2	3	2	2	2
PERT	2	0	0	3	0	0	0	0	0	0	0	1	1	2
WIS	1	0	0	3	1	0	2	1	0	2	2	1	1	0
AMDK	1	0	0	3	1	1	0	0	1	0	2	1	1	0
PDAM	0	0	0	3	2	1	0	1	0	0	0	1	1	1
PPP	3	0	0	3	3	3	3	3	3	3	3	0	3	3
PPD	3	0	0	3	3	3	3	3	3	3	3	2	0	3
IND	2	0	1	2	0	0	2	2	1	1	1	1	1	0

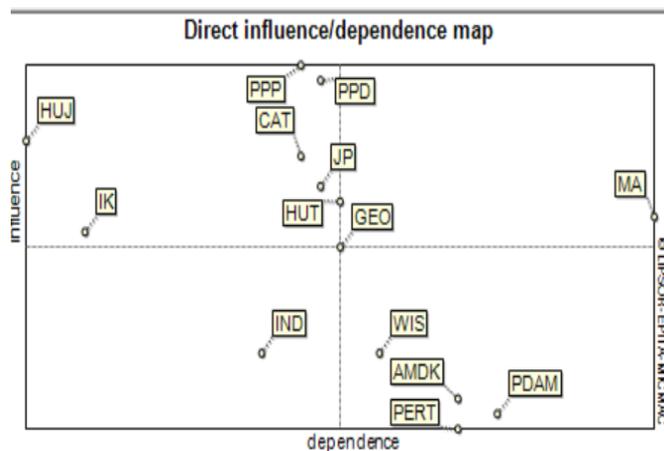


Figure 3. Direct influence/dependence map

The factors' importance is based on variable assessment by MDI. This evaluation would produce a map of variables according to influence and dependence (Direct Influence/Dependence Map). The variables considered as key factors are determined based on the presence or location of each variable indicated in the Direct Influence/Dependence Map. The results of the Direct Influence/Dependence Map of variable groundwater availability in Narmada District are presented in Figure 3.

Quadrant I (Influence Variables / Key Variables)

Also known as "determinant variables" which are very influential and have little dependence on other variables. These variables are crucial elements in the system because it can act as key factors (Fauzi, 2019). According to Sukwika (2021), the category of key factors is an independent factor with a very strong influence power. Figure 3 shows that there are seven variables in Quadrant I from Policy dimension, Input dimension and Domestic Output. Variables in the Policy dimension include Central Government Regulations (PPP) and Local Government Regulations (PPD). Central Government Regulation (PPP) is in the form of Presidential Regulation No. 37 Year 2023 concerning National Water Resources Policy which is a direction or action taken by the central government to achieve water resources management goals. Meanwhile, the Regional Government Regulations (PPD) include Regional Regulation Number 4 of 2007 concerning Environmental Services Management, West Lombok Regent Regulation Number 7 of 2009 concerning the Organizational Structure, Work Procedures, Duties, and Authorities of Multi-Party Institutions, and Regional Regulation of West Nusa Tenggara Province No. 1 of 2023 concerning the Protection and Preservation of Springs. Both Central Government Regulations (PPP) and Local Government Regulations (PPD) are directly or indirectly policy formulations that intersect with water resources management.

Variable Input dimensions include Rain (HUJ), Groundwater Basin (CAT), Forest (HUT), and Climate (IK). These four variables are related to hydrological processes and support the availability of groundwater. Rain (HUJ) is an input which in the next process will be stored under the surface and then will become groundwater (aquifer) (Febriarta et al., 2021). Based on the data from the Bureau of Statistics (BPS) of the West Lombok Regency, in 2019-2021 the average rainfall in Narmada District is 139.92 mm/month (Kabupaten Lombok Barat, 2021). Based on BMKG criteria, the average rainfall condition in Narmada District is categorized as medium.

Narmada District is located above the Mataram-Selong groundwater basin (CAT). The area above the groundwater basin is 2,366 km² which has a free water discharge of up to 662 million m³/year and a depressed water discharge of 8 million m³/year (NT-1, 2022). Groundwater basins (CAT) directly affect and are one of the decisive considerations for making regulations and other legal products, such as determining groundwater conservation zones, determining drilling locations and utilizing groundwater, including in spatial planning. Groundwater basins (CAT) shows the potential of groundwater in an area (Noperissa et al., 2018).

The Sesaot Forest area in accordance with the Decree of the Minister of Forestry Number 445/Menhut/2009 is designated as a protected forest. This affirms the protection of the role of forests in maintaining the groundwater availability system in Narmada District. As is known, one of the functions of protected forests is as a regulator of water and watershed management (Shavira et al., 2020). Freshwater retention is one of the ecosystem services provided by forest areas (Botero-Acosta et al., 2022).

The link between climate change and the availability of groundwater has been widely expressed by hydrologists. In addition to anthropogenic factors including excessive pumping, climate is a factor that affects groundwater depletion (Elshall et al., 2020, Qin et al., 2023). Meanwhile Xia et al (2022) states that climate change causes variations in temperature, rainfall, and other factors that affect hydrological runoff processes. The rise in global temperature as one of the consequences of climate change is a factor in changing rainfall patterns (Karki et al., 2022). This condition shows that as a key variable, climate greatly affects the availability of groundwater directly in the process of the hydrological cycle.

The Variable Number of Population (JP) which is in the Domestic Output Dimension, shows that an increase in population will correlate with an increase in water demand (Kustanto, 2020). According to Islami et al. (2022), the population growth in an area will affect the

needs of the physical condition of settlements and, in turn, will have an impact on the availability of groundwater. The increase in population will increase water needs for daily living needs, followed by the provision of life support infrastructure so that it will lead to land clearing and reduce water catchment. The need for supporting facilities will be followed by land clearing where in the end the conversion of green open land which is a water catchment area will affect the water supply for the community both in the rainy and dry seasons (Anisah et al., 2021).

Quadrant II (Relay Variables)

Variables in Quadrant II are characterized with high influence and dependency and the interrelationship between each other are unstable, reflecting a system's instability. A change in one variable can have significant impact on the others (Fauzi, 2019). Water springs in this study, for instance, is a relay variable indicating its high impact on groundwater availability in the study area while also depends heavily

on other variables such as the climate factor (IK) population growth (JP) and even requires regulations to conserve.

It is an influential but very dependent variable. These variables are described as factors that indicate the instability of a system. Fauzi (2019) states that any change that occurs in this variable has quite serious consequences on other variables. Referring to the results of research with MICMAC software presented in Figure 3. It can be seen that in quadrant II there is one variable, namely the spring variable. This condition shows that the availability or loss of spring water will affect water consumption activities carried out, especially by variables in Quadrant III. This is relevant to the conditions in Narmada District, where the availability of groundwater appears in the form of springs and becomes a source of groundwater that is shared by residents as well as non-domestic activities such as tourism activities, bottled water companies, PDAMs, and agriculture.

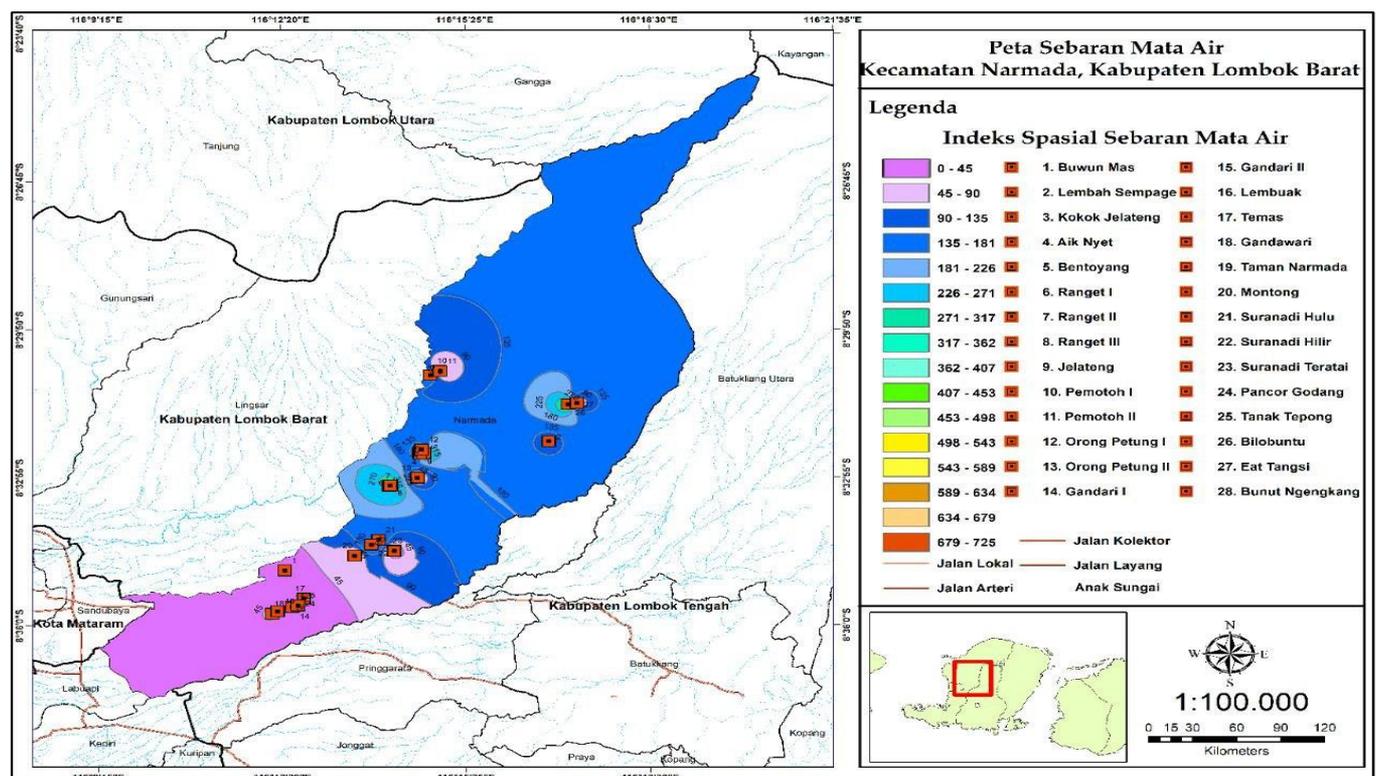


Figure 4. Map of the spread of springs in the Narmada Subdistrict

Figure 4 shows the location of the springs and the water discharge of each spring. The highest spring discharge came from Bunut Ngenggang spring at 745 liters/second, followed by Ranget III spring at 730.98 liters/second and Aik Nyet spring with water discharge reaching 541.90 liters/second. BWS NT-I data for 2022 states that the water discharge in 3 springs, namely

Kokok Jelateng, Jelateng, and Narmada Park is 0.00 liters/second (NT-1, 2022). It is necessary to emphasize the need for spring conservation efforts, both in the form of conservation of spring discharge availability and management of water consumption taken from springs. This is increasingly important because springs are

reliable providers of water flow related to climate change (Lewis et al., 2023).

Quadrant III (Dependent Variables)

The dependent variables are quite sensitive to changes in influence variables and relay variables (Fauzi, 2019). This kind of variables is characterized as having a high dependency *but* only has a small *influence*. The results of the MICMAC software are presented in Figure 3 shows that in quadrant III there are 4 variables, namely Tourism (WIS), Bottled Water Companies (AMDK), Regional Water Supply Companies (PDAM), and Agriculture (PERT). These Non-Domestic Output variables are related to groundwater availability in Narmada District. In accordance with its nature, this Non-Domestic Output variables are affected by *Influence Variables* (e.g., population number variable JP) or *Relay Variables* (e.g., water springs variable MA) *either directly or indirectly*.

Quadrant IV (Excluded Variables/ Autonomous Variables)

This type of variable will not stop the working of a system or utilize the system itself (Fauzi, 2019). This variable is characterized by having little influence and little dependence. The results of data processing using MICMAC software are shown in Figure 3 shows that Quadrant IV consists of one variable, namely industry.

In many cases, industrial activities play a key role in groundwater availability but in this study the results of MICMAC analysis showed the opposite. This is an interesting phenomenon to be explored further, but in this case the industrial activities in the study area can be categorized as Micro, Small and Medium Enterprises (MSMEs) so that their water needs are negligible and do not have significant influence on groundwater availability in the study area.

Regulator Variables

Regulator variable acts as a lever in the system. The characteristic of this variable is that it has a moderate influence and a moderate dependence. However, with certain actions, this variable will provide support that strengthens the groundwater availability system in Narmada District. The direct influence regulator variable contained in the groundwater availability system in Narmada District is the Geological variable (GEO). Groundwater has a close relationship with the geology of an area, where groundwater is a store of water in aquifer rock layers (Daruwati et al., 2023). The same thing was conveyed Zhang et al. (2019) that local hydrological geological conditions affect the existence of water sources.

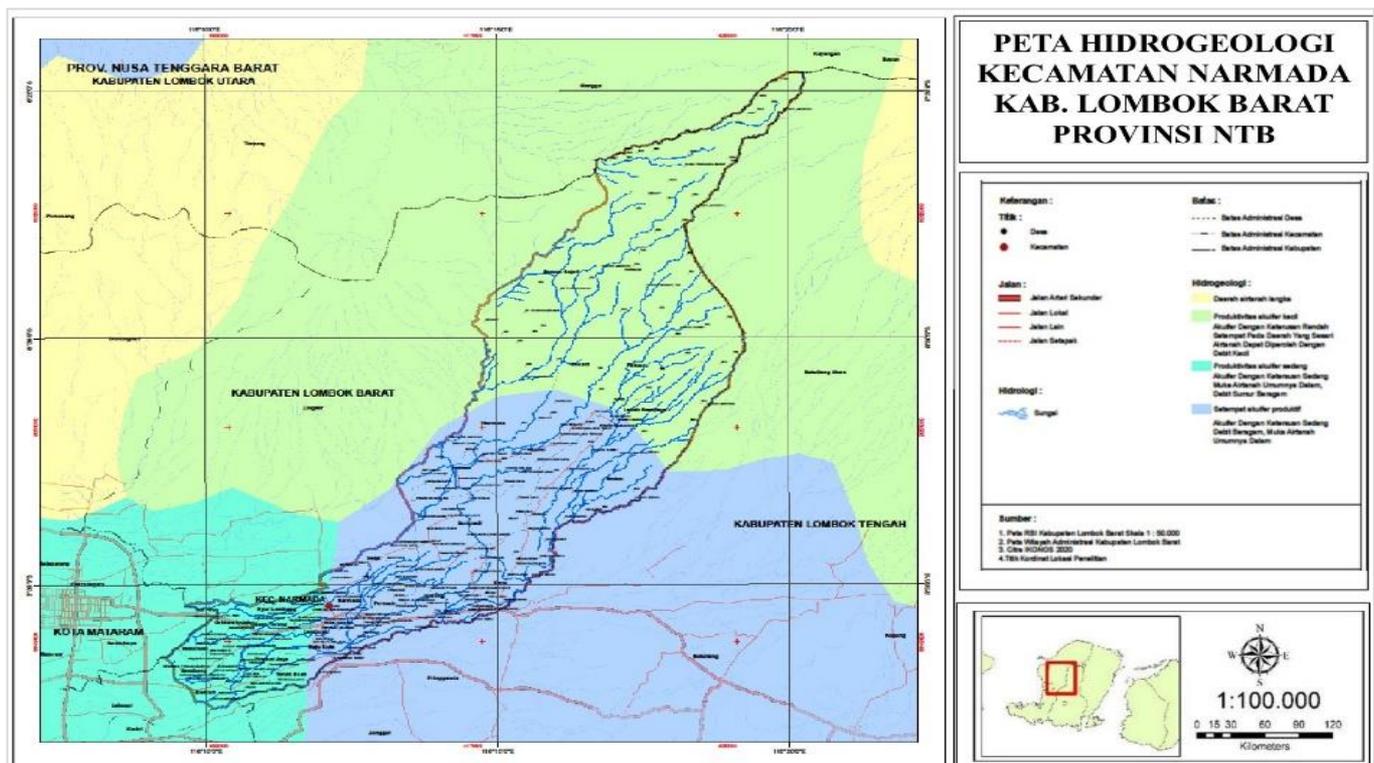


Figure 5. Hydrogeological map of Narmada District

The hydrogeological condition of Narmada District in Figure 5 shows that geologically Narmada District is composed of holocene-aged volcanic material. The characteristics of rocks and deposits in the formation are *unconsolidated-semi-consolidated material*. Aquifers in these formations are in the form of flows through fissures and spaces between grains. Water productivity falls into the category of medium aquifers with shallow well water discharge of less than 5 liters/ second. The groundwater table generally has a depth of more than 3 meters from the ground surface. This geological condition supports the availability of groundwater. This is in accordance with the location of Narmada District which is in the bending area of the slopes of the volcano in the Mount Rinjani complex, which is characterized as a spring emergence area with a fairly high discharge (Oktariadi et al., 2018).

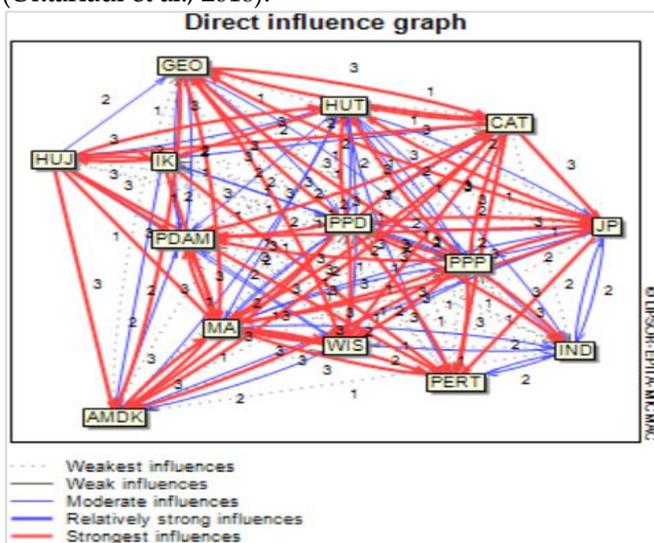


Figure 6. Direct influence relationship between groundwater availability system variables in Narmada District

Matrix Relationships between Important Variables

A matrix of relationships between important variables is depicted in Figure 6. It is clear that policy variables has a strong influence on other variables indicated by a thick red line with an outward arrow. Conversely, Tourism Variables (WIS), Bottled Water Companies (AMDK), Regional Water Supply Companies (PDAM), and Agriculture (PERT) are variables that are strongly influenced by other variables, marked by the direction of the arrow from the thick red line that leads to the variable.

Conclusion

The main factors in the groundwater availability system in Narmada District are three main factors, namely Domestic Policy, Input, and Output. The key variables in the system are variables that occupy

Quadrant I (Influence Variables). There are 7 key variables that are a combination of Domestic Policy, Input, and Output dimensions. This is because the availability of water is inseparable from the influence of the Policy dimension on some variables in the Input dimension, natural mechanisms that produce rain through the hydrological cycle are processes that involve variables in the Input dimension, and Population Number as a variable in the Domestic Output dimension. The influence of the Policy dimension is very high on the system, so it must be a major concern, because it has a high influence power on other dimensions. The relationship between variables occur between the Policy dimension to the Input dimension, the Policy dimension to Domestic Output and Non-Domestic Output, and the Output dimension both domestic and non-domestic to several variables in the Input dimension. The Policy Dimension has a strong influence in an integrated and structured manner to push several Input variables so that the Input process can run well. The policy dimension is a determinant of groundwater availability in Narmada District in its role in controlling the dimensions of Domestic Output and Non-Domestic Output. While the Output Dimension, both Domestic and Non-Domestic, has a strong influence in utilizing water resources that exceed the capabilities of the Input Dimension.

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Author Contributions

Conceptualization: A.D.I., D.N.W. and E.R.A.; Methodology: D.N.W., E.R.A., and E.H.; Validation: E.H., and M.; Analysis: A.D.I., S.H. and N.G.; Investigation: A.D.I. and S.H.; Resources: A.D.I and S.H.; Data curation: A.D.I, S.H. and N.G.; Draft writing: A.D.I.; Draft review and editing: A.D.I, S.H, N.G, D.N.W, E.R.A, E.H., and M.; Visualization: S.H.

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Conflicts of interest

The authors declared that they have no conflict of interest related to this study.

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