Application of Principal Component Analysis to Assess Health Systems Capacity Using Cross Sectional Data in Rural Western Kenya

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Abstract **Introduction:** Strong health systems are essential platforms for accessible, quality health services, and population health and attainment of the Sustainable Development Goal (SDGs). Descriptive methods have been used to assess the health systems strength and impact, however, there is inadequate knowledge on methods of analyzing huge number of indices to provide systematic evidence that service readiness is improving or deteriorating over time. **Methods**: We utilized data from a cross section survey of 71 health facilities in Kakamega County of western Kenya. A total of 151 indices of the health system building blocks were reduced using Principal Component Analysis (PCA) model which generated factor weights for the individual indicators. These included indices from human resources, service delivery, infrastructure, finance, health information systems, commodities and governance. Factors weights were then summed and ranked in order of their relative contribution to better performance. These were then summed and average to rank health facilities. Sum of indicators within each health system block was used as explanatory variables in a linear regression model with overall average of all indicators. Coefficients of the regression was used to assess marginal effects and p-value<0.05 were considered statistics significant. **Results:** The top ranked indicators were basic service deliver for testing and diagnosis and the lowest ranked were infrastructure such as availability of public taps, water, toilet or privacy. The department that were highly ranked whose indicators performed better in terms of weighting, were service delivery (p<0.0001), health financing (p<0.0001), health workforce (p=0.005) and medical supplies and commodities (p<0.0001) in relation to overall service provision denoted by overall weighting for all indicators. Health governance was not a significant factor influencing service provision. **Conclusion:** PCA is an essential methodology for assessing health system readiness and preparedness to provide accessible and quality service delivery in resource poor settings.

Keywords: principal component analysis, health systems, devolution

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1. Introduction

Strong health systems are key to access and provision of quality health care and are essential in monitoring progress towards attainment of the Sustainable Development Goal (SDGs). Despite strong consensus on need to strengthen health systems there are inadequate methods to assess the large number of indices which can inform policy makers on priority areas for improvement [1]. A successful health system investment has been partly attributed to reduction in child mortality in Tanzania [1]. In Kenya, since the decentralization of health care provision to the 47 counties in 2013, the sector continues to grapple with numerous health problem and concerns with declining accessible, affordable, quality and equitable health services [2]. The Kenyan provides that essential health service delivery is assigned to county governments while the national government retains health policy, technical assistance, management of national referral health facilities and human resources [3]. As a result inadequacies in the health system continue to be reported with challenges still existing in the centralized government regime despite devolution of health services [4,5] and specifically human resource has faced challenges due to limited information on their discipline, training needs, promotions, and retirement [2].

Descriptive methods have been used to assess the availability and readiness of health system to provide quality essential services [4]. However, with hundreds of health system indicators often generated to monitor performance of the health systems, and with no means of reducing these indicators to a more interpretable indices that can be monitored with time and used to gauge system performance [4,6] and without prospects that its information base can be a tool for health systems

strengthening, descriptive analysis alone is not an option. Principal component analysis technique has been used in the past to assess socioeconomic status of households into wealth quintiles [7-10] but has not been widely used to assess health system capacity and readiness. A recent study in Tanzania applied PCA to estimate indices of health system readiness [11]. However, the study did not rank the indices to indicate what key indicators is driving the performance of health system [11]. The Kenya Health Policy 2014-2030 [12] laid emphasis on resource allocation based on technical and allocative efficiency [13]. However, there is little published methodologies for assessing performance of health indicators using advanced analytical methods. The purpose of this paper is to demonstrate the application of principal component analysis to estimate health system indices and relative performance in performance in developed health governance setting in western Kenya.

2. Materials and Methods

2.1. Study Site and Setting

We utilized data collected from a cross sectional survey of 71 health facilities in a devolved county government of Kakamega County, western Kenya. The County has a population of 1,660,651 (National census 2009) where females were estimated to be 863,539 (52%). The growth rate is at 2.5 %. The county has a high poverty index at 51.3% and high population density at 572 per Km^2. Farming (Maize and Sugarcane) is the main economic activity. The total number of GOK health facilities is 1 County General hospital, 12 sub county hospitals, 36 health centers and 83 dispensaries in 2014.

2.2. Sampling Techniques

A total of 71 health facilities were evaluated. This included one county referral, five sub-county hospitals, seven hospitals, 57 health centers, one nursing home and one mission hospital The study used both purposive and random sampling and in each facility heads and managers in the sampled facilities were interviewed using one tool per facility. A mixture of purposive and stratified sampling techniques were used where each of the levels of health care were sampled. Health mangers were interviewed, one tool was administered per facility

2.3. Data Collection Methods

A structured questionnaire was used to collect data from CHMT members. The study adopted a validated tool used by WHO called Service Availability and Readiness Assessment (SARA) [14]. A subset of 116 of the indicators were selected to represent the six building blocks of health system which comprise of service delivery indicators, health workforce indicators, health financing indicators, information systems, health governance indicators and medical and supplies indicators.

2.4. Statistical Analysis

Principal component analysis (PCA) regression model was used to generate factor weights for each indicator.

The factors weights were coefficients of the regression analysis model (PCA). PCA is a mathematical procedure which transforms a number of correlated variables into a (smaller) number of uncorrelated variables called principal components. PCA is a linear combination of variables such that the coefficients on each variable maximize the variance of that PC [15]. The model as shown below

$$PC_1 = a_{11}x_{1} + a_{12}x_2 + a_{13}x_3 + \ldots\ldots + a_{1n}x_n$$

Where PC_i is principal component i; a_{ik} represents the weight for the kth variable for the ith principal component. Technically, a principal component can be defined as a linear combination of optimally-weighted observed variables. PCs are extracted in decreasing order of importance so that the first PC accounts for as much of the variation as possible hence PC_1 selected. PCA generates. Indicators of individual health system building blocks were weighted independently to measure the amount of contribution an indicator contributes to the respective health system building block. The weights were then aggregated to produce a single health system building block index (health service provision) which were the dependent variable while the averaged weights for each building block were the exploratory variables. The effect of exploratory variables on the services provision was measured at P value <0.05.

3. Results

The study was conducted in 71 health facilities across Kakamega County which included five County referral hospitals (7.04%), seven sub-county Hospitals (9.86%), 57 health centers (80.28%), one nursing home and one mission hospital. Majority of the facilities (6/71, 95.77%) were public facilities and most (88.73%) of them were located in the rural of Kakamega County. A total of 34 health facilities provided outpatient services. The health facilities were distributed across all the 8 sub counties in Kakamega County (Table 1).

Table 1. Background characteristics of Health Facilities

Characteristics	n=71	Percent (%)
Type of facility		
County Referral Hospitals	5	7.04
Sub-County Hospitals	7	9.86
Health Centers	57	80.28
Maternity/Nursing Home	1	1.41
Mission Hospital	1	1.41
Managing Authority		
Government/public	68	95.77
Mission/Faith based	3	4.23
Location		
Rural	63	88.73
Urban	8	11.27
Outpatient services only		
Yes	34	47.89

3.1. Ranking of Health System Indicators

Service delivery indicators including ability of health facility to diagnose, test and provide inpatient care for patients were the highest ranked. Availability of a

functioning microscope had the highest weight (0.1492) reported by 63.38 % (n=45) of the health facilities, provision of routine inpatient care (weight=0.1492) were ranked second reported by 46.48% (n=33) of the facilities (Table 2).

Table 2. To ten Ranked health system performance indicators

Rank	Indicators	Weight
1	Functioning Microscope for malaria smear test	0.1492
2	Routine inpatient care	0.1477
3	Availability of Giesma or field stain	0.1459
4	Providers in the facility diagnose and/or manage diabetes in patients	0.1452
5	Availability of Microscope	0.1448
6	Availability of dipstick or urine protein (with valid expiration date)	0.1441
7	Availability of dipstick or urine glucose (with valid expiration date)	0.1402
8	The facility accept use of NHIF	0.1402
9	Availability of dipstick or urine ketones (with valid expiration date)	0.1380
10	Functioning computer	0.1370

The lowest ranked indicators were those related infrastructure such as rainwater collection as the most commonly used source of water in the facility (weight=-0.1013) reported by 14% (n=10) of facilities (Table 3).

Table 3. Lowest Ranked health system performance indicators

Rank	Indicators	Weight
141	Protected well as the most commonly used source of water in the facility	-0.0219
142	Functioning landline telephone that is available to call outside at all times that client services are offered	-0.0277
143	Unprotected spring as the most commonly used source of water in the facility	-0.0300
144	Unprotected well as the most commonly used source of water in the facility	-0.0303
145	Public tap/standpipe as the most commonly used source of water in the facility	-0.0366
146	This facility has functional community units in all its area of responsibility	-0.0367
147	In the past financial year all community units carry out community dialogue and action days at least once every quarter	-0.0404
148	Received financial support from the national government for health care delivery since devolved system of government	-0.0430
149	Pit latrine with slab as the type of toilet	-0.0456
150	Rooms with both auditory and visual privacy available for patient consultations	-0.0462
151	Auto-disable needle and syringes	-0.0507

3.2. Performance of Health System Building Blocks Using Factor Weights to Rank

Figure 1 shows that among the health system building blocks in this study, service delivery had the highest mean weight (2.68×10^{-08}). Service delivery was the best performing health system building block compared to the rest. Health workforce was second with a mean of 1.77×10^{-08}. Health financing was third with a mean of 1.60×10^{-08} and Medical products vaccines & technologies came in fourth in ranking with a mean of 1.13×10^{-08}.

Service delivery, health workforce, medical supplies and health financing were highest ranked based on their loading weights while Leadership and governance had a negative weight and lowest ranked in in health systems capacity assessment (Figure 1).
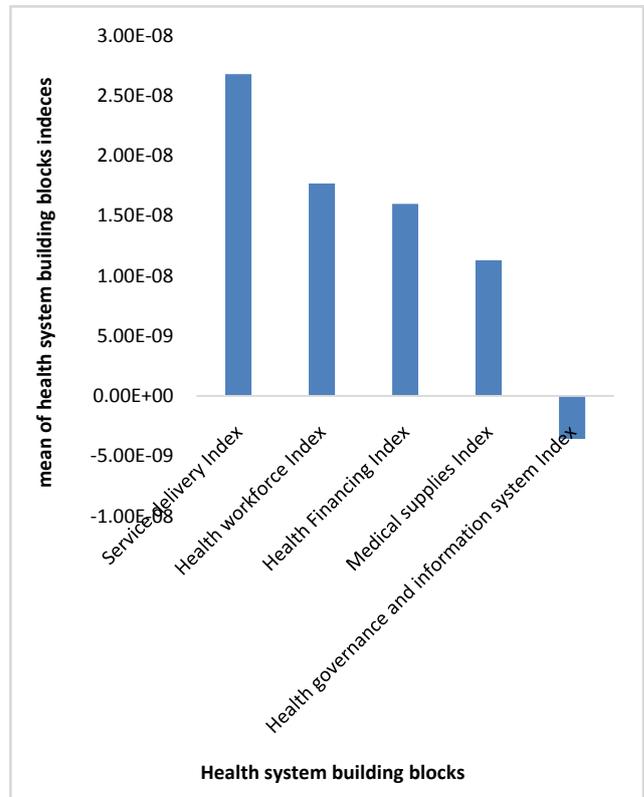
Figure 1. Mean of health system building blocks

3.3. Influence of Health System Building Blocks on Service Provision

Results of the regression analysis shown in Table 4 reveal that Service delivery ($p<0.0001$), health financing ($p<0.0001$), health workforce ($p=0.005$) and medical supplies and commodities ($p<0.0001$) had significant effect on service provision. Health governance was not a significant factor influencing service provision (Table 4).

Table 4. Effect of health system building blocks' indices on health service provision

Indices of Health system building blocks	Regression coefficient	95% Confidence Interval	p value
Service delivery	0.95	0.93-0.97	<0.0001*
Health Governance and information systems	-0.03	-0.08 – 0.02	0.247
Medical supplies and Commodities	0.36	0.33-0.40	<0.0001*
Health Workforce	0.06	0.02-0.11	0.005*
Health Finance	0.06	0.01-0.11	0.017*

The outcome was health service provision index, R^2 =99.62

4. Discussion

This study has applied principal component analysis model, previously only used in assessing household wealth quintiles, to assess health systems indices

using data collected from a cross sectional survey. By application of this model, coefficients of indices of health systems were estimated and used as factor weights to compare them indices individually and later summed or averaged to assess clusters of the indices. The results showed that one average health service delivery indices the best performing health system building block given that indicators in that cluster had the highest positive weights compared to those related to governance and infrastructure. The capacity of the devolved health system to provide essential basic services and primary health care in this setting were positively ranked indicating it's a beneficiary of the devolved health functions. The toped ranked indices of health systems were availability of function microscope, routine in-patient care, Giesmsa or field stain and ability of to test for malaria and diabetes. The least ranked indicators included those related to infrastructure such as availability of tap water, rain water, and telephone. Equally lowly ranked were indicators of governance, leadership issues and quality of data management for health information systems. When we used the average of all indices in the same health system black blocks and applied multivariate linear regression modeling, we established that service delivery influenced health service provision positively. In the multivariate regression analysis assessing the impact of all building blocks of health service provision, servicer delivery has a positive impact index and statistically significant in health service provision. Since the health services were devolved in Kenya in 2013, Kakamega County has intensified investment in health care and service delivery. A recent report comparing performance of various county government, Kakamega County was ranked top in health sector and is refection of a programme called "*Oparanya care*" dubbed "*Afya ya mama na mtoto*" [health of mother and care] which pays or gives a pregnant woman incentive to deliver in an health facility. The programme aimed to reduce the high infant and maternal mortality rate in the county [16]. Women who are financially handicapped are enrolled and enabled to access health care using out-of-pocket payments. As a result there has been progress to deliver efficient, cost effective and equitable health services. This current results may be a reflection of the efforts on service delivery [16].

This study has established that governance was poorly ranked and this is findings is comparable to a qualitative study conducted in a devolved county of Kilifi in Kenya which established that political persuasion influenced the rush to devolve health functions faster than was anticipated by most sector players [5]. The authors concluded that while implementation of the devolved government system in Kenya significantly increased the decision-making space for human resource of health (HRH) and Essential Medicines and Medical Supplies (EMMS) management, county governments lacked capacity to do certain tasks [5]. Management of health information systems and data processing were lowly ranked. Whereas there is a demonstrated fully functional community health units which linked households to the health system, this has not translated in availability of accurate data that can be relied upon to make priority decisions.

In Kenya there has been attempt to improve the functionality of the developed health system since 2013.

For instance, Health Policy Project (HPP) partnered with Kenya ministry of medical Services (MOMS) and the Ministry of Public Health and Sanitation MOPHS on developing a common understanding of the structures, opportunities, and challenges of devolution for health sector actors [17]. The partnership facilitated the ministries of health to understand how devolution would divide authority and responsibility between the national and county governments, as outlined in the 2010 constitution and subsequent relevant legislation. It was from this forum that the health managers recognized the need to prepare better for these significant systemic changes by proposing definitions for national and county-level functions [17].

In this study when were applied multiple regression analysis to assess how the governance, leadership and information system has been affected, the overall regression coefficient was negative but non-significant. This would imply that the health information system has been negatively affected since devolved governance. The lack of significance could also imply that there was no improvement and may reflect lack of progress to provide timely, accurate data for decision making within the county. Human resources indices was second ranked after service delivery indicating that there has been a significant increase in number of workers under devolved governance. This reflects the problem of human resources management since devolution. According to the Kenyan constitution, the national government still control coordination and management of health worker, yet also the county government have increased that number health workers and this would obvious strain the financial resources availed to the county and consequently affect service delivery [5].

The analysis has also established that health financing indices has increased and had an overall positive factor weights from the PCA model. This result contradicts results from a study by Koikai et al which revealed that health care financing deteriorated after devolution in devolved county of Nakuru in Kenya [18]. Similarly, a study on challenges of the devolved health care services in Kenya also revealed that health financing is still a challenge in health care even after decentralization [19]. The findings of this study therefore shows there has been increase in financial resources from the national to devolved units, however the study could not assess the management of these funds although governance was indicated as quite poor. Due to inadequacies of the funds from the national government, the devolved county governments also have found new funding streams to suppliant the national funds hence relative positive coefficient in the PCA model. Among the indicators related to heath financing use of national health insurance fund NHIF had the highest positive factor weight implying that use this facility the facilities has improved.

The other indicator with positive coefficient in the PCA model was the main source of financial support. Where the county government provided the funds, there is direct sufficient effect on service provision in a devolved governance. This finding contrasts a study which found out that there was an overlap of role of national government and county government in delivery of service in health and this has led to conflict in service delivery

which has affected contribution of county government [3]. Moreover, a study on devolution and its effects on health workforce and commodity management in Kilifi county revealed that there was also lack of clarity over specific roles and responsibilities at county and national government, and of key players at each level hence affecting the contribution of the county government in the service provision [5].

In our PCA model, indicator that was least ranked was asking whether or not the county health facilities received financial support from the national government for health care delivery. The results also showed that whether facilities received financial support from the national government or the national government, the financial sector has had the least impact on service provision under decentralization. This may be due to the fact that under the devolved arrangement, national treasury which allocated funds to the county government often delay disbursement and this affect functions of the county. This is merely speculative and may need further research. This finding concurs with a study in Meru county on influence of devolution of government service delivery on provision of health care which revealed that national government was the major source of financing but the finances were not received on time hence contributing least to service delivery after decentralization [20].

The study has several strengths and limitations. The key strength of this paper is that it have applied up to 151 indicators of the health system using a PCA model to reduce the factors to the building blocks and provides the first attempt to provide policy makers and researchers with a tool to assess performance of the health systems. This is the first study to assess performance of the health system indicators using PCA under a devolved governance and demonstrates that the model use can be adopted in assessing capacity and preparedness of health system. The main limitation of this paper are that being a cross sectional study, they was lack of a comparison of data before and after he developed functions. This may have showed which indicators have improved and which one have declined. However, the application of factor weights provides an option in absence of a comparison data. PCA model also requires data to be categorized as binary (presence or absence of an indicator), future research may explore use of multiple correspondence analysis (MCA) which allow continuous variables to be included in the model [21,22].

The findings of this study are only generalizable to Kakamega County and not nationally but the methods can be replicated nationally or other settings. Lastly this was a cross sectional study which lacks ability to monitor effect of time and has several confounding factors the analysis has not address which can be improved in future research.

5. Conclusions

PCA model has been applied to assess the capacity of the devolved health system in health service provision and is a model which can be used to reduce large number of variables into a more used form. By use of the model the study was able to establish that service delivery was positively affected compared to health workforce, health financing, health governance and medical supplies in a devolved government environment. Health workforce was second, health financing was third, medical supplies was fourth and health governance was least performing. The five health system indicators with the highest factor weight were; availability of a functioning microscope for malaria smear test, routine inpatient care, availability of giesma or field stain for malaria smear test, diagnosis and management of diabetes and availability of a microscope for malaria smear test. All these were service delivery indicators.

Among the health system building blocks that performed well were service delivery, health workforce, and health financing and medical supplies. This is the first study to the best of the knowledge of the researcher to apply principal component analysis, an inferential statistical analysis model, to analyze health system capacity in a devolved system. The method provides opportunity for future application in health systems analysis even in absence of comparative data.

6. Recommendations of the Study

PCA provides an opportunity to assess large number of health system indicators and can be applied in any setting. Future studies may explore of MCA buy including the continuous variables such as the number of health workers available etc. The study has established that under a devolved county governance in Kenya, there has been marked improvement in service delivery compared to health workforce, health financing. This implies that the number of health workforce and financing has also increased significantly. The government should strengthen legislation on use on efficient employment policy to avoid blotted works force. The increased availability of funding to counting government should be sustained and bottlenecks removed to ensure counties are in charge of funds. Health governance and data quality performed the poorest and this underscore the low interest the county governance has for health related data. While there was 100% meeting attendance by health committees, such meetings do not seem to address governance challenges including health information management system and data utilizations for policy decision. Revision of policies and by-laws should be enhanced to ensure policies are based on data.

Continuous assessment of impact of components of health systems under devolution is required to the inform enhancement of health service provision in the county. Stakeholder should continuous engage to address the poor performance sectors.

A future study should conduct a quasi-experimentation study to compare data between counties, with a baseline and end line periods. This would improve of cross sectional survey design. Another recommendation.

Ethics Approval

Ethical clearance was obtained from Masinde Muliro University of Science and Technology Ethics Committee (Re: MMU/COR: 403009(50). Consent and approval

was also obtained from Kakamega county director of heath (Ref: CGK/MOH/OCo/1/120) CHMT Chair of the identified health facilities and the local administration in each of the sub counties. The respondents were the health facility mangers who provided informed consent on behalf the health facilities

Competing Interest

The authors declare that they have no competing interests.

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